CHANGES IN BUCCOLINGUAL INCLINATION OF MAXILLARY CANINES AND FIRST MOLARS AFTER ORTHODONTIC TREATMENT

by

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DEDICATION

This thesis is dedicated to my family, especially Sue and Joshua. You have supported me through everything and I wouldn't have been able to fulfill my dream of becoming an orthodontist without you.

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I would like to thank Mark Hans for giving me the opportunity to attend this program and pursue a career in orthodontics. Your guidance, knowledge and support were critical to my success.

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CHANGES IN BUCCOLINGUAL INCLINATION OF MAXILLARY CANINES AND FIRST MOLARS AFTER ORTHODONTIC TREATMENT

Abstract

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Objectives: The aim of this study was to determine the effects of orthodontic treatment on buccolingual inclination of the maxillary canines and first molars. Pre and post-treatment Cone beam CT scans of 70 patients treated at the Case Western Reserve University graduate orthodontic clinic were selected for this retrospective study. Adolescent patients were between the ages of 11 and 16 years of age at the initiation of treatment and were treated with full upper and lower pretorqued/preangulated fixed appliances. Material & Methods: Buccolingual inclination of maxillary first molars and canines, intermolar width, and intercanine width were measured from the cone beam CT DICOM data using the commercially available software program On

Demand 3D software (version 1.0.1.8407, CyberMed, Seoul, Korea). Long axis buccolingual inclinations were measured in the coronal view, using a horizontal reference established by a line tangent the to the internal border of the superior palatal cortical plate. All measurements were made both before and after orthodontic treatment. Results: Buccolingual measurements of all four teeth were judged to be reliable, each with an intraclass correlation coefficient of above 0.93. Mean buccolingual inclinations prior to treatment were 101.9 ± 4.9 and 102.1 ± 4.9 for right and left molars and 106.1 ± 4.8 and 105.9 ± 5.6 for right and left canines respectively. Post treatment inclinations of molars increased to 103.2 ± 4.4 and 102.5 ± 5.1 for right and left; the change in angulation was not statistically significant. Maxillary canine inclinations, on average, decreased to 104.7 ± 5.7 and 105.0 ± 5.7 for right and left, again with the mean change was not significant. Conclusions: Orthodontic treatment tended to increase inclination of maxillary molars and decrease inclination of maxillary canines, although mean changes were not statistically significant. The large range of inclinations was clinically significant and suggests that

evaluation of the transverse dimension has the potential to alter the treatment decisions. Post-treatment changes and final inclinations can also be used to assess the outcome of treated cases.

LITERATURE REVIEW

The field of orthodontics has always relied heavily on quantifiable measurements in making treatment decisions and assessing the success of treated cases. The capability to measure, and thus the ability to use any measurement, however, is innately tied to the technology available at the time. In other words, we measure and use what we can see and essentially ignore the things that we cannot see. Since the use of the cephalometer and cephalometric x-rays in the 1930's, along with other two-dimensional radiography, orthodontists have measured distances, angles and areas to diagnose cases and evaluate treatment outcomes. Lateral cephalometric films are used to measure incisor inclination and provide the orthodontist quantitative data to aid in treatment decisions, such as whether or not to extract teeth.

It seems that some treatment decisions, however, could be affected by the transverse dimension. For example, the decision as to whether a patient is diagnosed with maxillary transverse deficiency and

consequently requires expansion is usually left to the professional judgment of the clinician. This lack of information about the coronal plane of space is due, in part, to a lack of an accurate and accessible method to measure and study the transverse dimension. A reliable method to quantify maxillary transverse deficiency could be of great use to the practicing orthodontist, as it has been estimated that between 8 and 18% of all orthodontic consultations in the deciduous and mixed dentitions have a transverse deficiency in the maxilla (Da Silva Filho, 1991).

According to the available literature, the definition of maxillary transverse deficiency itself is rather ambiguous. It is often diagnosed more on the basis of a collection of different factors such as model analysis, measures of arch shape, height and width, presence of buccal corridors when smiling, principal mode of breathing, presence of crowding, and the existence of crossbites (Suri, 2008).

Cone beam computed tomography (CBCT) was implemented in dentistry in the early 2000's and provides a three dimensional volumetric image of the subject. This technology can record measurements that are impossible to

see on a two-dimensional lateral headfilm. The dental measurements from CBCT volumes have been shown to be accurate to the anatomic structures they represent and can be collected reliably (Baumgartel, 2009). One of these measurements that are now accessible using the CBCT data is the buccolingual inclination of teeth in the transverse dimension.

The inclination of teeth in buccolingual dimension has been of interest to orthodontists for many years. Dr. Lawrence F. Andrews described it in his landmark article *The Six Keys to a Normal Occlusion,* in 1972. Andrews studied 120 sets of models from subjects who had not undergone orthodontic treatment and displayed a proper alignment of teeth and bite. From these models he looked for common patterns and characteristics that made the occlusion "normal". The commonalities he observed in the stone models led him to the conclusion that there were six characteristics in a normal occlusion. His six keys were molar relationship, crown angulation, crown inclination, rotations, spaces and occlusal plane. Andrews proposed that a lack of any one of the six characteristics identified would be predictive of an

incomplete and unsatisfactory outcome in treated orthodontic cases.

Andrews' third key, "crown inclination", is defined as "the angle formed by a line which bears 90 degrees to the occlusal plane and a line that is tangent to the bracket site". Using this reference system he described a normal occlusion as having lingual crown inclination of the upper posterior teeth with increasing lingual crown tip from the canine back to the second molar. Andrews stated that the pattern of increasing lingual crown tip was also consistent in mandibular posterior teeth. Andrews also pointed out that this key to the occlusion was clinically relevant as a variation in buccolingual inclination of the teeth affects the arch size and therefore is an important factor in achieving normal intra and inter-arch relationships (Andrews, 1972).

Andrews was not alone in thinking that crown inclination was an important element in establishing a proper occlusion. The American Board of Orthodontics recognizes buccolingual inclination as one of the criteria that should be used to grade finished orthodontic cases. The board states that buccolingual inclination is important in order to "establish proper

occlusion in maximum intercuspation and avoid balancing interferences”(ABO, 1998). In other words, a finished orthodontic case that meets board standards should not have a “significant difference between the heights of the buccal and lingual cusps of maxillary and mandibular molars and premolars. The measurement is made using the final casts and extending a flat plane across the occlusal surfaces of right and left posterior teeth. An acceptable buccolingual crown position would leave the buccal and lingual crowns with no more than a 1mm height difference when measured in this manner (ABO, 1998).

Similar measurement methods have attempted to describe the changes in buccolingual inclination during eruption and growth. Marshall et al. studied dental casts taken from the Iowa Facial Growth Study. The investigators examined casts from subjects aged 7 to 30, had a Class I occlusion, no extracted permanent teeth, and no excessive enamel wear or restoration of dental cusps. Based on these inclusion and exclusion criteria, the study was limited to 36 subjects (18 women and 18 men). Similar to the ABO methods, a flat plane was placed transversely across the casts and the difference between buccal and lingual cusp heights was recorded at

the different time points. The major findings from this study suggest that maxillary molars erupt with buccal crown torque and upright with lingual crown torque. Mandibular molars were found to erupt with lingual crown torque and upright with buccal crown torque with age. The authors suggest that buccolingual movements in both the maxillary and mandibular arches work towards establishing a flatter occlusal plane in the transverse dimension (Marshall, 2003). These findings seem to support the ABO's guidelines and suggest that uprighting and leveling posterior teeth during orthodontic treatment is justified.

Other studies have looked to find a correlation between buccolingual inclination and facial pattern and vertical growth. Again using dental casts and occlusal plane to determine buccolingual inclination, Ross et al. investigated the claims that people with higher mandibular plane angles had a tendency towards high, narrow palates. They hypothesized that this feature would tend to produce buccally inclined maxillary molars. Conversely, they hypothesized that those subjects with low mandibular plane angles and wider palates would have lingually inclined maxillary molars. The study concluded

that there were no statistical differences in buccolingual inclinations between the different groups of mandibular plane angles. The standard deviations, however, were large, indicating a large variability among individuals (Ross, 1990). In a follow-up study using the same methodology as Ross et al., the author notes that the measurement of the crowns only represents buccolingual inclination as an occlusal surface inclination and cautions that measurements from the crown cannot be extrapolated to the true long axis of the tooth.

Occlusal surface inclination has not been the only method used to attempt to characterize buccolingual inclination. Other studies have tried to characterize ideal buccolingual inclination based on the facial surface (Vardimon, 1986). These studies were used in part to determine the proper angulation prescriptions for the pre-adjusted brackets used in the straight-wire appliance. It was also shown that the relationship between the buccal crown surfaces and the actual long axis of the crowns, however, were subject to biologic variation. Germane et al. reported that standard deviations ranged from 4.3° to 5.2° when comparing the

buccal surface of molars to their long axes (Germane, 1989).

It is apparent that measuring buccolingual inclination using the methods mentioned in the previous studies has some inherent limitations. Buccolingual inclination measurements are inaccurate for any subjects with wear of cusp tips, broken dental casts, abnormal dental anatomy or restorations placed on teeth to be measured. This can limit sample size of a study or leave a clinician unable to evaluate a case properly. Inconsistency in the current methods of measurement suggests that there may be a need for a more accurate and reliable method to evaluate the long axis buccolingual inclination of teeth.

An initial study of the transverse dimension using CT technology by Podesser et al., proposed a method for measurement of maxillary structures and assessed the reliability of this method. The study sample consisted of only 10 individuals who received a CT scan. Two slices in the coronal plane were used for quantitation, one that was defined by transecting the palatal root of the maxillary first molar and one that transected the root of the maxillary canines. Among other measurements,

buccolingual crown inclination was recorded. The reference plane was defined as a horizontal line tangent to the inferior nasal cavity, and for the maxillary molar the angle was measured with a line connecting the apex of the palatal root and the tip of the mesiobuccal cusp. The canine inclination was defined using the same reference plane and a line connecting the canine apex and cusp tip. In order to test the intra-observer reliability of this method, all measurements were repeated 10 days after initial data collection by a different observer. Each observer recorded all points two separate times, and the investigators concluded that although not shown to be statistically significant, there were large inter-observer differences, up to 7.7 degrees for angular measurements. It was determined that this initial variation in reliability suggests that a larger sample should be studied to give significance to the quantitative findings and caution should be used when comparing individual results using this method (Podesser, 2004).

Using a similar method, Karatlian et al., took a step farther and looked at buccolingual inclination in cases of rapid maxillary expansion. Again using the

coronal slice to make quantitative measurements, the authors aimed to compare skeletal and dental dimensional changes of growing adolescent patients treated with palatal expansion to a matched control group who underwent orthodontic therapy without expansion. Three-dimensional volumes of the twenty five subjects from the experimental group and the twenty five matched controls were analyzed using cone beam CT scans and In Vivo 3D software. Buccolingual angulations were measured using the palatal plane as a horizontal reference and a line paralleling the palatal root for the maxillary first molar (Kartalian A, 2010). Interestingly, no differences in dental angulation were seen at the baseline reading, which suggests that there may be a need for more objective measures of transverse deficiency and that there is probably no general consensus on when to expand among orthodontists based on buccolingual inclination.

A limitation in all of these studies was relatively small samples of CBCT images. Studies from Case Western Reserve University have started to establish methods of measuring buccolingual inclination using larger sample sizes. A study by Shewinvanakitkul et al., aimed to create a method to measure the inclination of mandibular

canines and first molars. The subjects in the sample studied were growing adolescent orthodontic patients between the ages of 11 and 14 years old who had fully erupted mandibular first molars and canines with no deciduous teeth present, no previous orthodontic treatment, no extracted or missing mandibular teeth, and no restorations on the cusps of measured teeth.

Buccolingual inclinations of right and left first molars and canines were recorded using the lower border of the mandible in the coronal view as a horizontal reference plane. For first molars, the buccolingual inclination was measured from the apex of the mesial root through the central groove. Canines were measured with the same horizontal reference plane and the angle measured from apex to cusp tip. The reliability of this method, assessed by the intra-class correlation coefficient, was high; $r > 0.94$ for all four teeth measured. The means and standard deviations recorded were 98.0 ± 4.1 degrees for mandibular canines and 74.6 ± 4.7 degrees for mandibular molars with no significant difference between right and left sides. This study established a reliable method to measure buccolingual inclination.

A follow up study by Evagelinakis et al., used the previously described method and investigated the change in buccolingual inclination during orthodontic treatment. Using the same inclusion and exclusion criteria as Shewinvanakitkul et al., this study measured inclination before and after orthodontic treatment on 70 adolescent orthodontic patients. Evangelinakis found a statistically significant change ($P < 0.05$) in buccolingual inclination from before to after orthodontic treatment, as well as a significant change in intercanine width. The initial mandibular canine inclinations reported were 97.8 ± 4.6 for the left canine and 96.8 ± 3.9 degrees for the right canine.

After orthodontic treatment the mandibular canines were positioned with more lingual crown torque than initially with final values of 94.7 ± 4.8 degrees for the left and 93.9 ± 4.1 degrees for the right. Change in intercanine width was also statistically significant, increasing during treatment an average of 1.8 mm. It was suggested by the authors that the root apex of the mandibular canines was moving buccally more than the incisal tip and had the potential to contact the buccal cortical plate. To avoid any potential periodontal

problems associated with this type of movement, it was recommended that lower canine brackets have a positive torque value (Evangelinakis, 2010).

The initial buccolingual inclination of mandibular molars was 74.7 ± 5.1 for the left molar and 76.4 ± 4.5 for the right molar. Both left and right molars were uprighted during treatment with post-treatment values of 77.0 ± 4.9 for the left molar and 77.4 ± 5.0 for the right molar. The change in intermolar width was not found to be statistically significant. Overall, there was a weak correlation between the change in intermolar and intercanine widths and changes in buccolingual inclination, suggesting that these are independent variables (Evangelinakis, 2010).

Karamitsou et al. attempted to create a reliable method to measure the buccolingual inclination of molars and canines in the maxilla using CBCT. The investigators used many of the same inclusion and exclusion criteria as Shewinvanakitkul et al. and Evangelinakis et al. Ninety seven adolescent orthodontic patients with fully erupted maxillary canines and first molars were included in the sample group. Molar inclination was measured in the coronal plane as the angle connecting a horizontal

reference plane tangent to the inferior border of the superior palatal cortical plate and a line through the palatal root apex and mesiopalatal cusp tip. Canine inclination was measured using the same horizontal reference plane. The coronal plane, however, was rotated to measure the maxillary canine from a mesial to distal view, accounting for the fact that the canine lies on the curvature of the dental arc and the maximum angulation measurable will be at this orientation. Thirty five subjects were then re-measured by the same single operator three weeks later to assess reliability.

Results showed a mean inclination of maxillary left and right canines as 105.9 ± 6.5 and 103 ± 6 degrees respectively. Buccolingual inclination of maxillary first molars, the mean inclination was 101.7 ± 5.4 degrees for the left and 99.2 ± 5.3 degrees for the right side. Intraclass correlation values for all four teeth measured were found to be greater than 0.96, indicating a high degree of reliability.

Interestingly, the mean differences in buccolingual inclination between right and left sides were found to be statistically significant. The two sides were reported separately. No differences were found between the group

slated to receive rapid maxillary expansion and the group whe were not going to receive expansion as a part of their treatment plans. Similarly, no differences in angulation were found for patients starting with different molar classifications (Karamitsou, 2010).

Clearly, CBCT offers an advantageous method to measure in the transverse dimension. Changes in the transverse dimension during orthodontic treatment have been shown to be significant and measuring buccolingual inclination may become a useful tool to aid in orthodontic treatment decisions. This is especially important in the maxilla, where, in a growing patient, the transverse dimension can be altered by the orthodontist using rapid palatal expansion. Even in adults once the midpalatal suture has fused, in cases of severe transverse deficiency, surgery is used to increase transverse width. Accurate measurement of the buccolingual inclination allows for a more accurate distinction between dental crossbites and true skeletal maxillary transverse deficiency (Suri, 2008). The purpose of this study was to investigate the change in buccolingual inclination of maxillary molars and canines that occurs as a result of orthodontic treatment.

LITERATURE REVIEW REFERENCES

American Board of Orthodontics. Objective grading system for dental casts and panoramic radiographs. Am J Orthod Dentofacial Orthop 1998; 114:296-309.

Andrews LF. The six keys to normal occlusion. Am J Orthod 1944; 30:196-205.

Baumgartel S. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009; 136: 19-25.

Bjork A, Skieller V. Growth of the Maxilla in three dimensions as revealed radiographically by the implant method. British journal of orthodontics 4: 1977: 53-64.

Da Silva Filho OG, Boas MC, Capelozza Filho L. Rapid maxillary expansion in the primary and mixed dentitions: a cephalometric evaluation. Am J Orthod Dentofacial Orthop 1991;100:171-9.

Evangelinakis NE. Hans MG. Changes in buccolingual inclination of mandibular canines and first molars after orthodontic treatment using CBCT. Masters thesis, Case Western Reserve University, 2010.

Germane N, Bentley BE, Isaacson RJ. Three biological variables modifying faciolingual tooth position by straight wire appliances. Am J Orthod Dentofacial Orthop 1989; 96: 312-9.

Janson G. Buccolingual inclinations of posterior teeth in subjects with different facial patterns. Am J Orthod Dentofacial Orthop 2004;125:316-22.

Karamitsou E. Hans MG. Pretreatment Buccal Inclination of Maxillary First Molars and Canines. Masters thesis, Case Western Reserve University, 2010.

Kartalian A. Cone-beam computerized tomography evaluation of the maxillary dentoskeletal complex after rapid palatal expansion. Am J Orthod Dentofaical Orthop 2010; 138: 486-492.

Marshall S. Transverse molar movements during growth. Am J Orthod Dentofacial Orthop 2003; 124:615-24.

Podesser B. Quantitation of transverse maxillary dimensions using computed tomography: a methodological and reproducibility study. Eur J Orthod. 2004 Apr;26(2):209-15.

Ross VA. Influence of vertical growth pattern on faciolingual inclinations and treatment mechanics. Am J Orthod Dentofacial Orthop 1990; 98:422-9.

Shewinvanakitkul W. Hans MG. Measuring buccolingual inclination of mandibular canines and first molars using CBCT. Masters thesis, Case Western Resreve Unviersity, 2009.

Suri L. Surgically assisted rapid palatal expansion: A literature review. Am J Orthod Dentofacial Orthop 2008; 133: 290-302.

Vardimon AD. Statistical evaluation of torque angles in reference to straight-wire appliance (SWA) theories. Am J Orthod Dentofacial Orthop 1986: 56-66.

STATEMENT OF THESIS

The purpose of this study was to determine the range, mean and standard deviation for the buccolingual inclination of maxillary first molars and canines in adolescent patients before and after orthodontic treatment. Specific aims of this study were to: 1) measure and report descriptive statistics of buccolingual inclination of maxillary first molars and canines before and after orthodontic treatment, 2) measure and report descriptive statistics of the intermolar and intercanine width before and after orthodontic treatment, 3) evaluate any changes in buccolingual inclination, intermolar with and intercanine width from before to after orthodontic treatment, and 4)describe any changes in buccolingual inclination, intermolar with and intercanine width in relation to the explanatory variables tested.

Null hypotheses: 1) There is no difference in the buccolingual inclination of maxillary first molars before and after orthodontic treatment, 2) There is no difference in the intermolar width of maxillary first molars before and after orthodontic treatment, 3) There

is no difference in the buccolingual inclination of maxillary canines before and after orthodontic treatment, 4) There is no difference in the intercanine width of maxillary canines before and after orthodontic treatment, 5) There is no relationship between post-treatment changes in intermolar width and buccolingual inclination of maxillary first molars, 6) There is no relationship between post-treatment changes in intercanine width and buccolingual inclination of maxillary canines.

Changes in buccolingual inclination of maxillary canines and first molars after orthodontic treatment

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Objectives: To determine the effects of orthodontic treatment on buccolingual inclination of the maxillary canines and first molars.

Setting and Sample Population: Pre and post-treatment cone beam CT scans of 70 adolescent patients were selected for this retrospective study. Patients were treated with full upper and lower pretorqued/preangulated fixed appliances in the graduate orthodontic clinic at Case Western Reserve University.

Material & Methods: Long axis buccolingual inclination of maxillary first molars and canines, intermolar width, and intercanine width were measured in the coronal view from cone beam CT DICOM data, using the commercially available software program On Demand 3D software.

Results: Mean pre-treatment buccolingual inclinations were 101.9 ± 4.9 and 102.1 ± 4.9 for right and left molars and 106.1 ± 4.8 and 105.9 ± 5.6 for right and left canines respectively. Post-treatment molar inclination increased to 103.2 ± 4.4 and 102.5 ± 5.1 for right and left. Maxillary canine inclinations, on average, decreased to 104.7 ± 5.7 and 105.0 ± 5.7 for right and left. Mean changes were not statistically significant.

Conclusions: Orthodontic treatment tended to increase inclination of maxillary molars and decrease inclination of maxillary canines, although mean changes were not statistically significant. The large range of inclinations is likely clinically significant and suggests that evaluation of the transverse dimension has the potential to alter treatment decisions. Post-treatment changes and final inclinations may also be useful for post-treatment outcome assessment.

Keywords: Buccolingual inclination, Cone beam computed tomography (CBCT)

Clinical Relevance:

Cone beam CT (CBCT) technology offers orthodontists access to information beyond that of two-dimensional radiographs. It is now both possible and practical to make measurements in the transverse plane of space, including the buccolingual angulations of teeth. Measuring the inclination of the molars and canines gives the orthodontist information that may be useful in both diagnosis and outcome assessment. Even in the absence of crossbites, orthodontists may use an increased buccolingual inclination, in conjunction with clinical findings, to determine that a patient is maxillary transverse deficient and would benefit from rapid maxillary expansion to correct the discrepancy.

Introduction:

The profession of orthodontics has always relied heavily on quantitative measurements in making treatment decisions and assessing the success of treated cases. The capability to measure, and thus the ability to use any measurement is innately tied to the technology available at the time. Since the use of the cephalometer and cephalometric x-rays in the 1930's, along with other two-dimensional radiography, orthodontists have measured distances, angles and proportions to diagnose cases and evaluate treatment outcomes. Measurements and angulations from traced lateral headfilms have routinely given the orthodontist confidence to decide whether to extract teeth or to move the dentition in an anteroposterior or vertical direction.

The treatment decisions that affect the transverse dimension, however, are usually based primarily on the professional judgment of the clinician. A diagnosis of maxillary transverse deficiency (MTD), and thus a need for rapid maxillary expansion (RME), is often identified by a collection of factors such as model analysis, measures of arch shape, height and width, presence of buccal corridors when smiling, principal mode of breathing, presence of crowding, and the existence of crossbites[(1)]. This inconsistency in diagnosis is due, in part, to a lack of an accurate and accessible method to assess the transverse dimension. A reliable method to quantify maxillary transverse dimensions could be of great use to the practicing orthodontist, as it has been estimated that 8-18% of all orthodontic consultations in the deciduous and mixed dentition have a transverse deficiency in the maxilla[(2)].

Cone beam computed tomography (CBCT) was implemented in dentistry in the early 2000's and provides a three dimensional volumetric image of the subject[3]. Using this technology, it is possible to accurately record measurements[4] that are difficult to assess from a two dimensional film, including transverse measurements taken from a coronal view such as buccolingual tooth inclination.

The inclination of teeth in the buccolingual dimension was described in 1972 by Dr. Lawrence F. Andrews in 'The Six Keys to a Normal Occlusion' in which he identified six characteristics of an ideal occlusion. Andrews' third key, the "crown inclination", was described as being clinically relevant as a variation in buccolingual inclination affects the arch size and therefore is an important factor in achieving normal intra and inter-arch relationships[5]. In agreement with Andrews, the American Board of Orthodontics (ABO) recognizes buccolingual inclination as one of the criteria that should be used to grade finished orthodontic cases. The ABO states that buccolingual inclination is important to "establish proper occlusion in maximum intercuspation and avoid balancing interferences" [6].

Similar measurements have been used describe buccolingual inclination during eruption and growth[7], its correlation to facial pattern and vertical growth[8], and to determine the proper torque angulations for the pre-adjusted appliance[9]. These studies relied on crown inclination only, and did not measure the long axis of the tooth represented by the crown and roots together.

Recently, studies from Case Western Reserve University (CWRU) have attempted to establish methods of measuring buccolingual inclination using CBCT

data. One study by Shewinvanakitkul et al. [10], tried to establish a method to measure the inclination of mandibular canines and first molars. Long axis buccolingual inclination of right and left first molars and canines was recorded using the lower border of the mandible in the coronal view as a horizontal reference plane. This study established a reliable method to measure buccolingual inclination. A follow up study by Evagelinakis[11], used the previously described method and investigated the change in buccolingual inclination during orthodontic treatment. The initial mandibular canine inclinations reported were 97.8 ± 4.6 for the left canine and 96.8 ± 3.9 for the right canine. After orthodontic treatment the mandibular canines were positioned with more lingual crown torque than initially with final values of 94.7 ± 4.8 degrees for the left and 93.9 ± 4.1 degrees for the right. The initial buccolingual inclination of mandibular molars was reported as 74.7 ± 5.1 for the left molar and 76.4 ± 4.5 for the right molar. Both left and right molars were uprighted during treatment with post-treatment values of 77.0 ± 4.9 for the left molar and 77.4 ± 5.0 for the right molar.

Karamitsou[12] attempted to create a reliable method to measure the buccolingual inclination of molars and canines in the maxilla also using CBCT. Molar and canine inclinations were measured in the coronal plane as the angle connecting a horizontal reference plane tangent to the inferior border of the superior palatal cortical plate and a line through long axis of the tooth. For the molars the palatal root apex and mesiopalatal cusp tip represented the long axis measured. Results showed a mean inclination of maxillary left and right canines as 105.9 ± 6.5 and 103 ± 6 degrees respectively. Buccolingual inclination of maxillary first molars,

the mean inclination was 101.7 ± 5.4 degrees for the left and 99.2 ± 5.3 degrees for the right side. Intraclass correlation values for all four teeth measured were found to be greater than 0.96, indicating a high degree of reliability in this method.

CBCT allows the clinician to view individual slices in the volume image giving the clinician an unobstructed view of the transverse dimension. Changes in the transverse dimension during orthodontic treatment have been shown to be significant and measuring buccolingual inclination may become a useful tool to aid in orthodontic treatment decisions. This holds especially true in the maxilla, where, in a growing patient, the transverse dimension can be changed by the orthodontist using rapid palatal expansion. Accurate measures of the buccolingual inclination allows for a more accurate distinction between dental crossbites and true skeletal maxillary transverse deficiency[(1)]. The aim of the present study is to use the method developed by Karamitsou et al. to investigate the change in buccolingual inclination of maxillary molars and canines that occurs as a result of orthodontic treatment.

Materials and Methods:

Data were collected retrospectively from the records of patients treated in the graduate orthodontic clinic at Case Western Reserve University School of Dental Medicine. Records include initial and final intraoral/extraoral photographs, self-reported demographic data, clinical treatment notes, and Cone Beam Computed Tomography (CBCT) scans from the Craniofacial Imaging Center at CWRU. Cone beam CT (CB MercuRay^{TM}, Hitachi Medical Systems America Co. – Twinsburg, OH) scans were collected at a large field of view, at the 2mA setting and with a voxel

size of 0.38 mm. All patients signed a consent form allowing for the use of records for research, and no patients were contacted during the course of the research project. The study was approved by the Internal Review Board (IRB) at CWRU.

Subjects were selected based on the following criteria: 1) age of 11 and 16 years old at the time of initial records, 2) complete orthodontic records, including pre and post treatment photographs, CBCT scans, dental and medical history, and treatment notes, 3) no previous orthodontic treatment based on dental history form, 4) fully erupted maxillary first molars and canines at the time of initial records, 5) no deciduous maxillary teeth present, 6) no missing or extracted permanent teeth in the maxillary arch, 7) no severe rotations (> 90°) of maxillary first molars or canines, 8) no patients with craniofacial anomalies or syndromes, and 9) landmarks (cusp tips and root apices) clearly visible on CBCT scans.

Sample size was calculated with an estimated effect size (E) of 3 degrees and standard deviation of 6 degrees. 3.0 ± 6.0 Two-tailed alpha was set at 0.05 and beta at 0.20. Using the table for sample size calculation for paired-sample t-test to compare means of continuous variables, the estimated sample size for this study was 63 subjects. After identifying all eligible subjects based on the inclusion and exclusion criteria, 70 subjects were selected using a table of random numbers.

Radiographic data were constructed from CBCT images using the commercially available software OnDemand 3D (version 1.0.1.8407, CyberMed Inc., Seoul, Korea). Patient demographic and treatment data were collected from patient charts and treatment records. The method for measuring buccolingual inclination was

based on the work of Karamitsou[11]. Images were oriented prior to measurement by aligning the axial plane along anterior nasal spine (ANS) to posterior nasal spine (PNS), the sagittal plane along the midline of the palate. All angulation measurements were made in the coronal view to a horizontal reference line tangent to the inferior border of the superior cortical plate of the palate. Right and left first molar and canine buccolingual inclinations were measured both pre- and post-treatment.

Measurement of molar inclination was accomplished by establishing a line connecting the palatal root apex to the mesiolingual cusp tip, representing the long axis of the maxillary first molar. If incisal wear was present, the cusp tip location was assigned to be at the middle of the wear facet. The internal angle of the intersection of the long axis line and the horizontal reference line was measured to determine buccolingual inclination (Figure 1).

The long axis for measurement of maxillary canines was defined as a line connecting the middle of the root apex and the cusp tip. Maxillary canines, unlike first molars, are located along the curvature of the dental arch. Prior to measurement, the coronal plane was rotated accordingly so that it ran through the canine in a straight buccolingual direction along the curvature of the arch. The buccolingual inclination was measured as the internal angle of the long axis of the canine and the horizontal reference plane (Figure 2).

Intermolar and intercanine widths were measured by manipulating the coronal plane so that it passed through the central fossa of the maxillary molars and

the incisal tips for the maxillary canines. The distance between the central grooves and incisal tips was recorded both pre and post-treatment.

All measurements were made by a single operator (MM). Two weeks after data collection, buccolingual inclination was measured on 15 randomly selected subjects, and intraclass correlation coefficient was used to assess reliability. Data were analyzed using Statistical Package for the Social Sciences (SPSS; 19.0.0, Inc. – Chicago, IL). An initial paired sample t-test determined whether there was a statistical difference between right and left sides. Paired sample t-test investgated pre- to post-treatment changes in buccolingual inclinations and intermolar/intercanine widths. Categorical data including gender, race, expander type, initial and final molar classification, bracket prescription, slot size and extraction pattern were stratified and inclinations were compared using independent samples t-test and analysis of variance (ANOVA) (Table 1). Pearson correlation coefficient (r) evaluated the relationship between changes in buccolingual inclination and changes in intermolar and intercanine widths. To reduce the chances of a type-I error, the significance level, alpha, was set at less than or equal to 0.01.

Results:

The study sample (N=70) was primarily Caucasian (81%) and consisted of 43 females and 27 males with an average age at the start of treatment of 13.7 ± 1.2 years old, ranging from 11 to 16 years of age. Average treatment time was 24.4 ± 5.3 months ranging from 9 to 38 months. The study sample was generally non-

extraction (94%) and non-expansion (84%), reflecting the inclusion and exclusion criteria used to select cases.

Intraclass correlation coefficient (r^2) of buccolingual inclination was greater than 0.93 for both molars and canines. Variables tested were distributed normally, as determined by the Shapiro-Wilk test. Paired sample t-test showed that there was a statistically significant mean change for intercanine and intermolar widths from before to after orthodontic treatment, but not for buccolingual inclination for any of the four teeth measured.

Maxillary molars had a tendency to increase in buccolingual inclination going from 101.9 ± 4.9 (85.7 - 112.5) degrees to 103.2 ± 4.4 (95.6 - 115.6) degrees on the right and 102.1 ± 4.9 (89.7 - 112.7) degrees to 102.5 ± 5.1 (84.4 - 112.5) degrees on the left. When right and left were combined, 59% of molars increased in inclination after treatment (buccal crown torque) while 41% decreased in inclination (lingual crown torque). Maxillary canines tended to decrease in inclination going from 106.1 ± 4.8 (97.0 - 119.3) degrees to 104.7 ± 5.7 (88.6 - 115.8) degrees on the right and 105.9 ± 5.6 (90.8 - 119.6) to 105.0 ± 5.7 (88.8 - 121.1) on the left. When right and left sides were combined, 56% decreased in buccolingual inclination and 44% increased. The pre- to post-treatment change in angulation ranged 24 degrees (-9.60 - 14.4) for molars and 25.9 degrees (-17.2 – 8.7) for canines (Table 2).

On average, intermolar width increased from 45.3 ± 2.6 mm (38.1 - 50.6) to 46.5± 2.6 mm (39.9 - 52.9) and intercanine width increased from 33.9 ± 2.7 mm (27.5 – 39.8) to 34.9 ± 2.1 mm (30.3 - 39.1). Out of the 70 subjects, 59 increased in

intermolar width from pre to post-treatment, three had no change and 8 decreased. Of those who decreased in width, only two of the eight patients had extractions in the maxillary arch. When intercanine width was analyzed, 48 subjects increased in width, and 22 decreased.

There was no statistical difference between right and left sides. Males (47.5mm) had a significantly larger final intermolar width than females (45.8mm). Males also had a smaller final inclination of right and left canines than females. No differences between slot sizes (.022 and .018). Comparison of expansion and non-expansion groups showed a statistically significant change in intermolar and intercanine widths, which were larger for the expansion group. No statistical difference in angulation was observed when expansion was performed. No differences were observed between extraction and non-extraction groups with the exception of change in intermolar width, which decreased in the group receiving extractions and increased in the non-extraction group.

There was no difference in angulations among the different ethnic groups, but intermolar widths were significantly wider for the African American and Asian groups when compared to the Caucasian group. When stratified by initial and final molar classification, no differences were found. Although bracket torques for molars and canines varied for each prescription, no significant differences in angulation or widths were observed among groups.

The correlation between change in buccolingual inclination and change in intermolar and intercanine widths resulted in a 0.372 coefficient for both maxillary

right and left first molars, 0.272 for the right canine, and 0.471 for the left canine. This weak, positive association was statistically significant and indicated that, in general, as the width increased, the angulation also increased.

Discussion:

Although it was not the primary goal of this study, the high intraclass correlation coefficient was in agreement with the previous study by Karamitsou where it was shown that this method of measuring long axis buccolingual inclination could be repeated reliably. Mean initial inclination values of the two separate samples varied by less than 2 degrees for both first molars and canines when right and left sides were averaged.

Pretreatment data showed no significant difference between patients receiving rapid maxillary expansion and those treated without expansion, suggesting that either clinicians were unable to judge the buccolingual inclination of the teeth with the existing protocols for diagnosis and treatment planning or that they used criteria other than buccolingual inclination to make the decision to expand. In the presence of posterior crossbites it is an easily justifiable decision by the orthodontist to use RME. It is not as clear of a decision to use RME when no dental crossbites are present.

It seems reasonable that in the absence of crossbites, increased buccolingual molar and canine inclinations could be interpreted as dental compensations for a skeletal maxillary transverse deficiency. This parallels the way that maxillary and mandibular incisor dental compensations are seen from a lateral cephalogram for an anteroposterior skeletal discrepancy. Although in many of these cases, the dental

compensations are adequate to avoid crossbites, when the dentition is viewed from the transverse dimension, and buccolingual inclinations are measured, it becomes evident that if the curve of Wilson in each arch was leveled and the molars were decompensated that the patient would likely have a posterior dental crossbites as a result of maxillary transverse deficiency. In this way, buccolingual inclination may be useful as an objective measurement that helps to justify an orthodontist's decision to use RME prior to orthodontic treatment and a way to evaluate the transverse leveling of the arch post-treatment.

Using the mean and standard deviation of the buccolingual inclinations from this study, it is suggested that any patients with a pretreatment buccolingual inclination of more than 107 degrees for the molars and 111 degrees for the canines (greater than one standard deviation from the mean) be evaluated, along with other clinical features, for maxillary expansion to correct a skeletal transverse discrepancy. A pretreatment buccolingual inclination of less than these means may suggest that transverse deficiency could be resolved by dental tipping and may be less likely to be a skeletal deficiency. In this case, archwire expansion may be a reasonable option to resolve a crossbite.

In addition to the added diagnostic value, the significance of buccolingual inclination may also be in analyzing the physiologic boundaries of dental movements. It would seem a reasonable goal of the orthodontist to keep the root of the tooth within the alveolar process. In some cases, however, the root a tooth is tipped to an extreme, leading to a perforation of the cortical plate. This then leads to bony

dehiscence and fenestrations and may eventually cause attachment loss and gingival recession[13, 14]. This may be especially true in those individuals who have been described as having a thin gingival biotype, an inherent predisposition to recession and attachment loss following inflammation[15, 16].

The aim of the study was to examine the treatment effects of orthodontics on buccolingual inclination. On average, maxillary molar buccolingual inclination increased about one degree during the course of treatment and maxillary canines showed a decrease of one degree. The direction of movement of the canines is in agreement with previous studies of the inclination change during eruption of untreated subjects where maxillary teeth erupt buccally and then move lingually to their final positions, but the molars in this study moved in the opposite direction. Mean changes were not found to be statistically significant, nor would one degree of change be considered to be clinically significant.

It may easily be argued that the mean change of a few degrees over the course of a 2-year treatment does not constitute a clinically significant change, but nonetheless there are some clinically relevant conclusions that may be drawn from these findings. For example, there were no differences in the final inclinations of the expansion and non-expansion groups although intermolar and intercanine widths both increased significantly. This suggests that during active maxillary expansion if there was concurrent dental tipping, it was corrected prior to removing fixed appliances. Also of interest was a significant difference in initial intermolar width among the different racial groups. This suggests that diagnosing a transverse deficiency based

on any single "standard" width measurement may not be applicable to the entire population.

Mean changes during treatment were relatively small and could be argued to be clinically insignificant. However, what is of great clinical interest were the large range of pre- and post-treatment inclinations and change in inclinations observed in this study. Although mean changes were small, we must always remember as clinicians we are treating individual patients, not average values. It would be difficult to argue that the degree of variation and change among patients is clinically insignificant.

When observing the individuals in the study sample who were at the extreme buccolingual angulations, it was observed that buccolingual inclinations might be dependent on anteroposterior skeletal position. Individuals with a class III relationship between maxilla and mandible tended to have increased buccolingual inclinations of maxillary molars and canines when compared to the mean values. In contrast, skeletal class II patterns seemed to have decreased inclinations. This seems to be a result of the dental compensations attempting to maintain proper intra-arch relationships.

If achieving an ideal occlusion is the goal of orthodontic treatment and buccolingual inclination contributes to intra- and inter-arch relationships, the management of inclination in the transverse dimension should be a part of the treatment plan and paid attention during active treatment. As evidenced by the lack of difference in buccolingual inclination among certain variables tested in this study,

it seems likely that angulation is not strongly influenced by any single variable. Every subject's treatment was unique, and there were numerous factors that could affect tooth movement including bracket prescription, archform, treatment mechanics, and anatomical variation. The final buccolingual inclination achieved is likely a multifactorial outcome, influenced by a combination of many different variables.

CBCT offers a practical way to evaluate the position of teeth in the transverse dimension, which may compel orthodontists to begin to evaluate cases in all dimensions. In addition to enhancing case diagnosis and outcome assessment, this new information may aid orthodontists in keeping the teeth in a more physiologically healthy position, reducing the possibility of fenestration and dehiscence of the root and consequent periodontal problems. Proper angulations could also contribute to increased long axis directed chewing forces resulting in more efficient function and possibly more stable results. Further research is needed to investigate the role of buccolingual inclination in the stability of results and its effect on the long-term health of the dentition and surrounding periodontium.

Conclusions:

The results of this study indicate that: 1) Change in buccolingual inclinations of maxillary molars and canines can be measured reliably using CBCT, 2) There was a general tendency for molars to increase in buccolingual inclinations and a tendency for canines to decrease inclination during orthodontic treatment for adolescent patients, 3) Ranges of buccolingual inclination in this study sample pretreatment, post treatment and change during treatment were large and those with more than one

standard deviation from the mean could have clinical significance, and 4) Changes in buccolingual inclination were not strongly associated with changes in intermolar and intercanine widths.

References:

(1) Suri L, Taneja P. Surgically assisted rapid palatal expansion: A literature review. Am J Orthod Dentofacial Orthop 2008; 133: 290-302.

(2) Da Silva Filho OG, Boas MC, Capelozza Filho L. Rapid maxillary expansion in the primary and mixed dentitions: a cephalometric evaluation. Am J Orthod Dentofacial Orthop 1991;100:171-9.

(3) Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac Radiol 199928: 245-248.

(4) Baumgartel S. Reliability and accuracy of cone-beam computed tomography dental measurements. Am J Orthod Dentofacial Orthop 2009; 136: 19-25.

(5) Andrews LF. The six keys to normal occlusion. Am J Orthod 1944; 30:196-205.

(6) American Board of Orthodontics. Objective grading system for dental casts and panoramic radiographs. Am J Orthod Dentofacial Orthop 1998; 114:296-309.

(7) Marshall S, Dawson D, Southard KA, Adam NL, Casko JS, Southard TE. Transverse molar movements during growth. Am J Orthod Dentofacial Orthop 2003; 124:615-24.

(8) Ross VA, Isaacson RJ, Germane N, Rubenstein LK. Influence of vertical growth pattern on faciolingual inclinations and treatment mechanics. Am J Orthod Dentofacial Orthop 1990; 98:422-9.

(9) Vardimon AD, Lambertz W. Statistical evaluation of torque angles in reference to straight-wire appliance (SWA) theories. Am J Orthod Dentofacial Orthop 1986: 56-66.

(10) Shewinvanakitkul W, Hans MG, Palomo JM, Narendran S. Measuring buccolingual inclination of mandibular canines and first molars using CBCT. Masters thesis, Case Western Resreve Unviersity, 2009.

(11) Evangelinakis NE. Changes in buccolingual inclination of mandibular canines and first molars after orthodontic treatment using CBCT. Masters thesis, Case Western Reserve University, 2010.

(12) Karamitsou E. Pretreatment Buccal Inclination of Maxillary First Molars and Canines. Masters thesis, Case Western Reserve University, 2010.

(13) Steiner GG, Pearson JK, Ainamo J. Changes of the marginal periodontium as a result of labial tooth movement in monkeys. J Periodontol 1981;52:314-20.

(14)WennstromJL, Lindhe J, Sinclair F. Some periodontal tissue reactions to orthodontic tooth movement in monkeys. J Clin Periodontol 1987;14:121-9.

(15) Müller HP, Eger T. Gingival phenotypes in young male adults. J Clin Periodontol 1997;24:65-71.

(16) Müller HP, Schaller N, Eger T. Ultrasonic determination of thickness of masticatory mucosa: a methodologic study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1999;88:248-53.

Tables:

Table 1: Descriptive summary of demographics, expander status, Angle classification, bracket prescription, bracket slot size, and extraction pattern

Variable	Group	Total (N=70)	Percent
Gender	Male	27	38.6
	Female	43	61.4
Race	Caucasian	57	81.4
	African American	7	10
	Asian/Other	6	8.6
Expander	None	59	84.2
	Expansion	11	15.8
Initial Molar classification	Class I	39	55.7
	Class II	25	35.7
	Class III	6	8.6
Bracket prescription	MBT	29 (U3 0; U6 -14)	41.4
	Roth	13 (U3 -3; U6 -10)	18.6
	Damon	6 (U3 0; U6 -18)	8.6
	Tip Edge	7 (U3 -4; U6 -10)	10
	Alexander	4 (U3 -3; U6 -10)	5.7
	Mixed Prescription	11	15.7
Bracket slot size	.018	13	18.6
	.022	55	78.6
	Bidimensional	2	2.9
Extraction pattern	Non-extraction	66	94.3
	Extraction	4	5.7

Table 2: Means, Standard Deviations and Range of Maxillary Canine and First Molar Inclination and Arch Width before and after treatment (N=70)

Variable (N=70)	**Initial**		**Final**		**Change**	
	Mean±SD	Range	Mean±SD	Range	Mean±SD	Range
Right molar inclination (°)	101.9 ± 4.9	85.7 - 112.5	103.2 ± 4.4	95.6 - 115.6	1.3 ± 4.2	-6.0 - 14.4
Left molar inclination (°)	102.1 ± 4.9	89.7 - 112.7	102.5 ± 5.1	84.4 - 112.5	0.4 ± 3.9	-9.6 - 7.7
Right canine inclination (°)	106.1 ± 4.8	97.0 - 119.3	104.7 ± 5.7	88.6 - 115.8	-1.4 ± 4.8	-17.2 - 8.7
Left canine inclination (°)	105.9 ± 5.6	90.8 - 119.6	105.0 ± 5.7	88.8 - 121.1	-0.9 ± 4.4	-12.4 - 8.3
Intermolar width (mm)	45.3 ± 2.6	38.1 - 50.6	46.5 ± 2.6	39.9 - 52.9	1.2 ± 1.4*	-3.1 - 4.3
Intercanine width (mm)	33.9 ± 2.7	27.5 – 39.8	34.9 ± 2.1	30.3 - 39.1	1.0 ± 1.8*	-3.7 – 5.1

*P≤.01

Figures:

Orientation (Figures 1, 2, 3): Orient the volume along ANS/PNS in the sagittal and axial plane and set a horizontal reference plane tangent to the inferior border of the superior palatal cortical plate.

Figure 1:

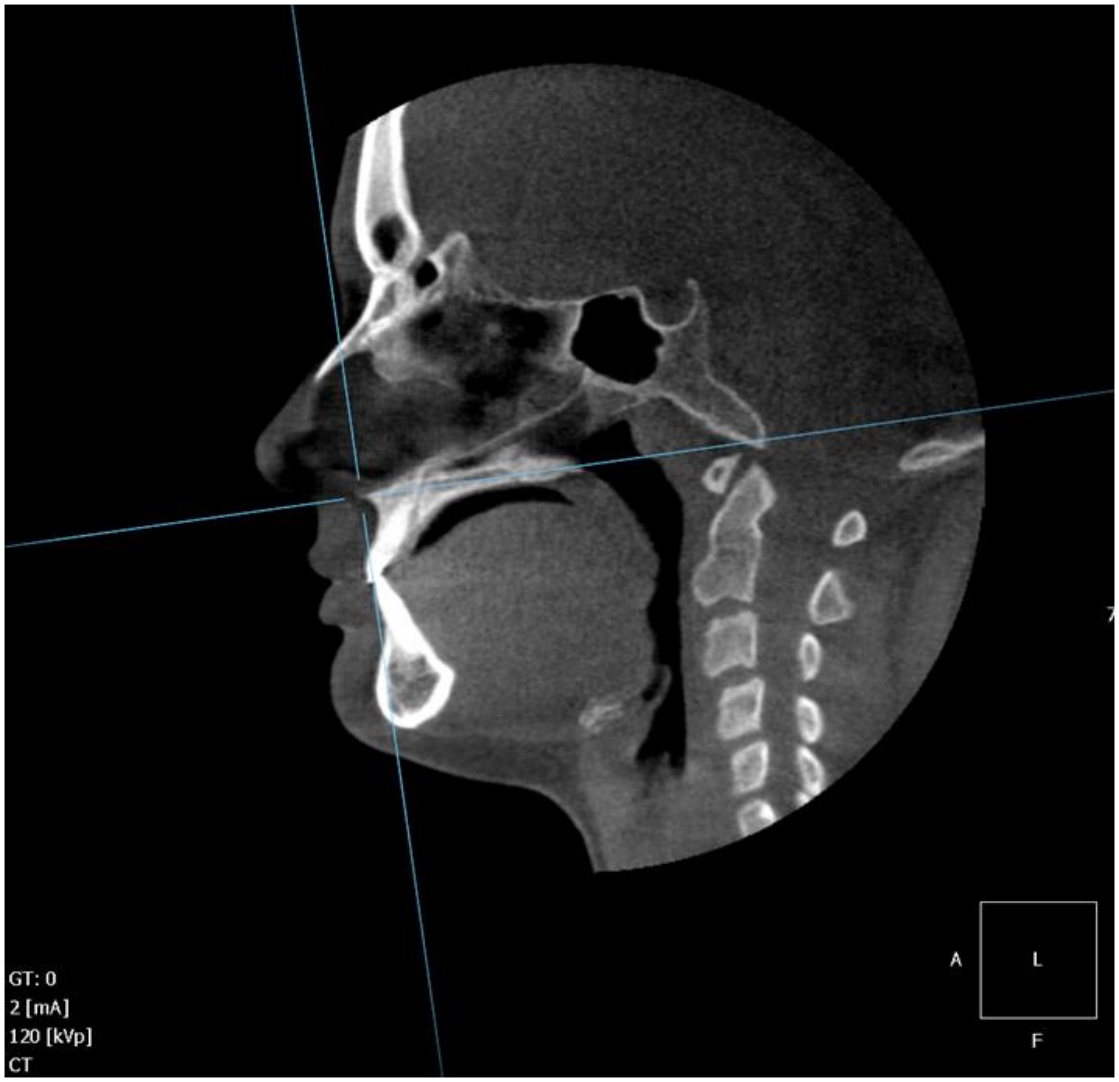


Figure 2:

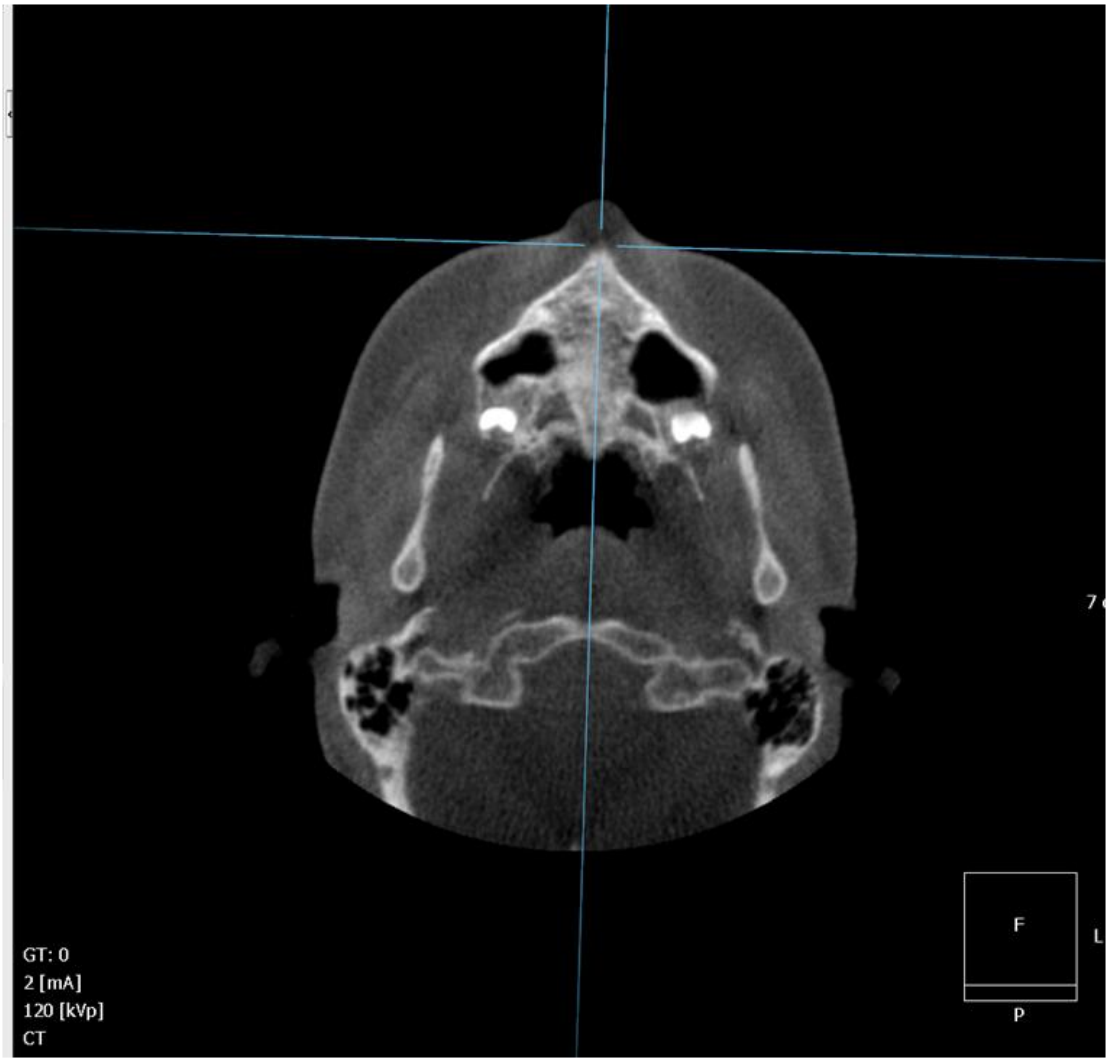


Figure 3:



First molar measurement (Figures 4, 5, 6): Locate the palatal root in the axial view, align the coronal plane along the palatal root and mesial buccal cusp tip, measure the buccolingual inclination in the coronal view.

Figure 4:

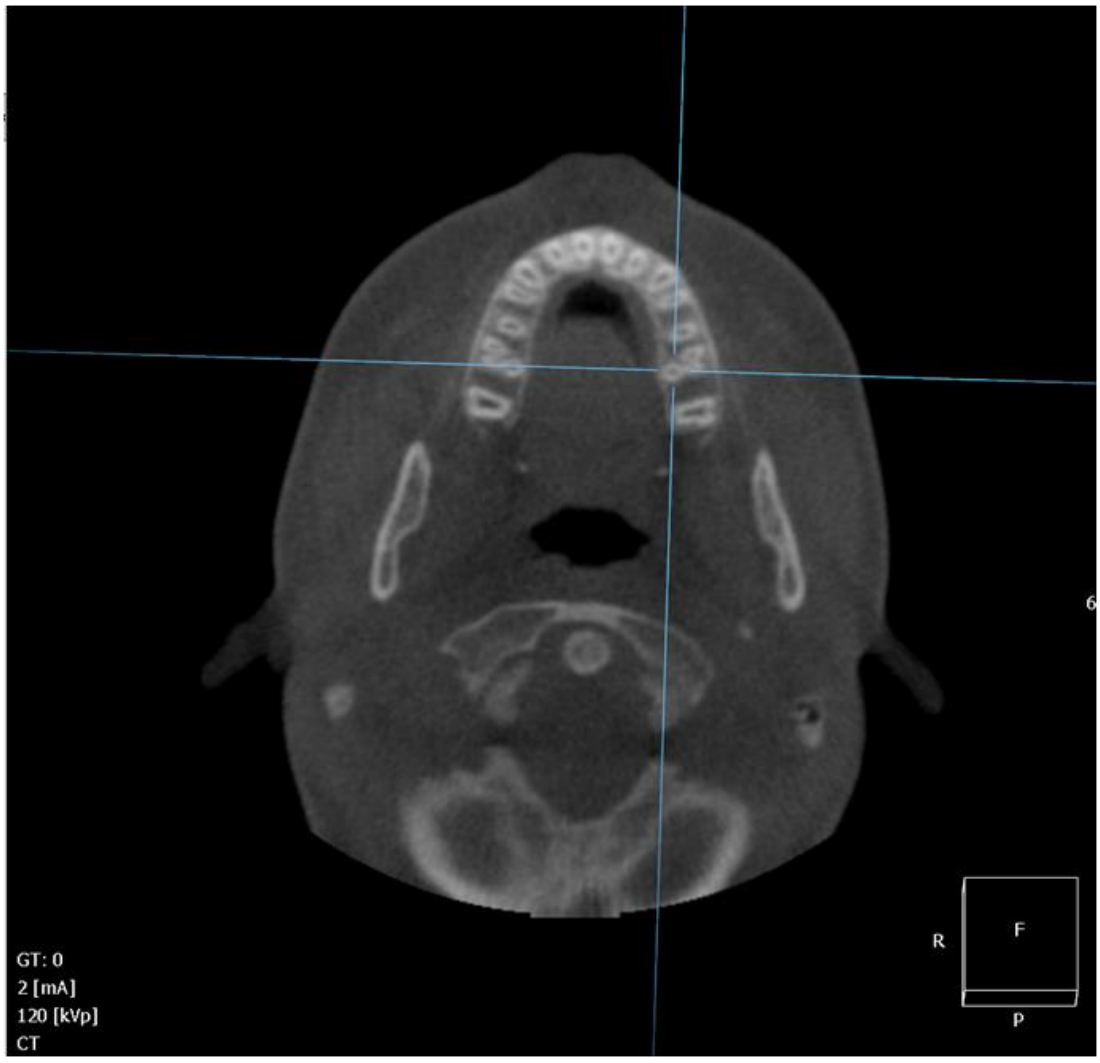


Figure 5:

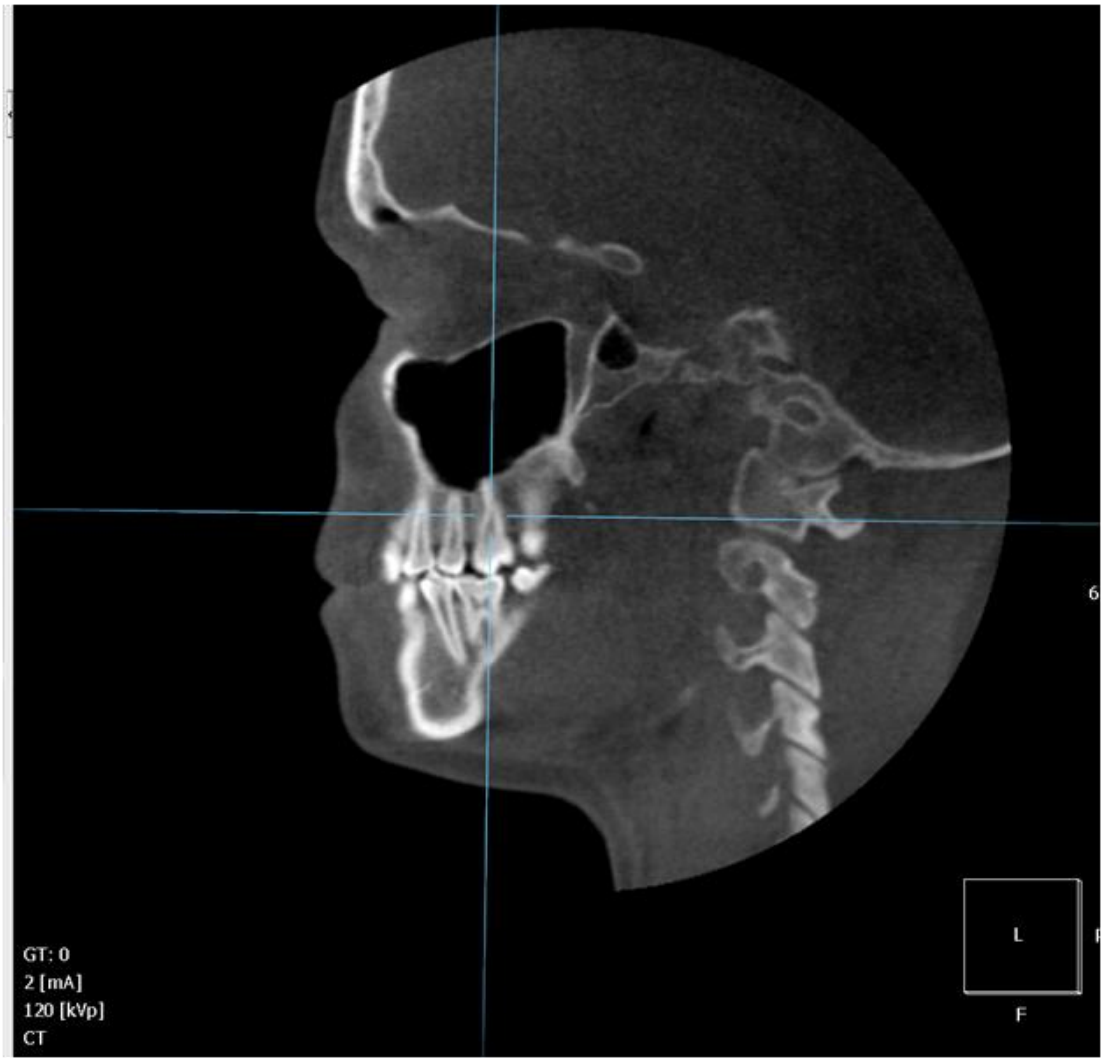
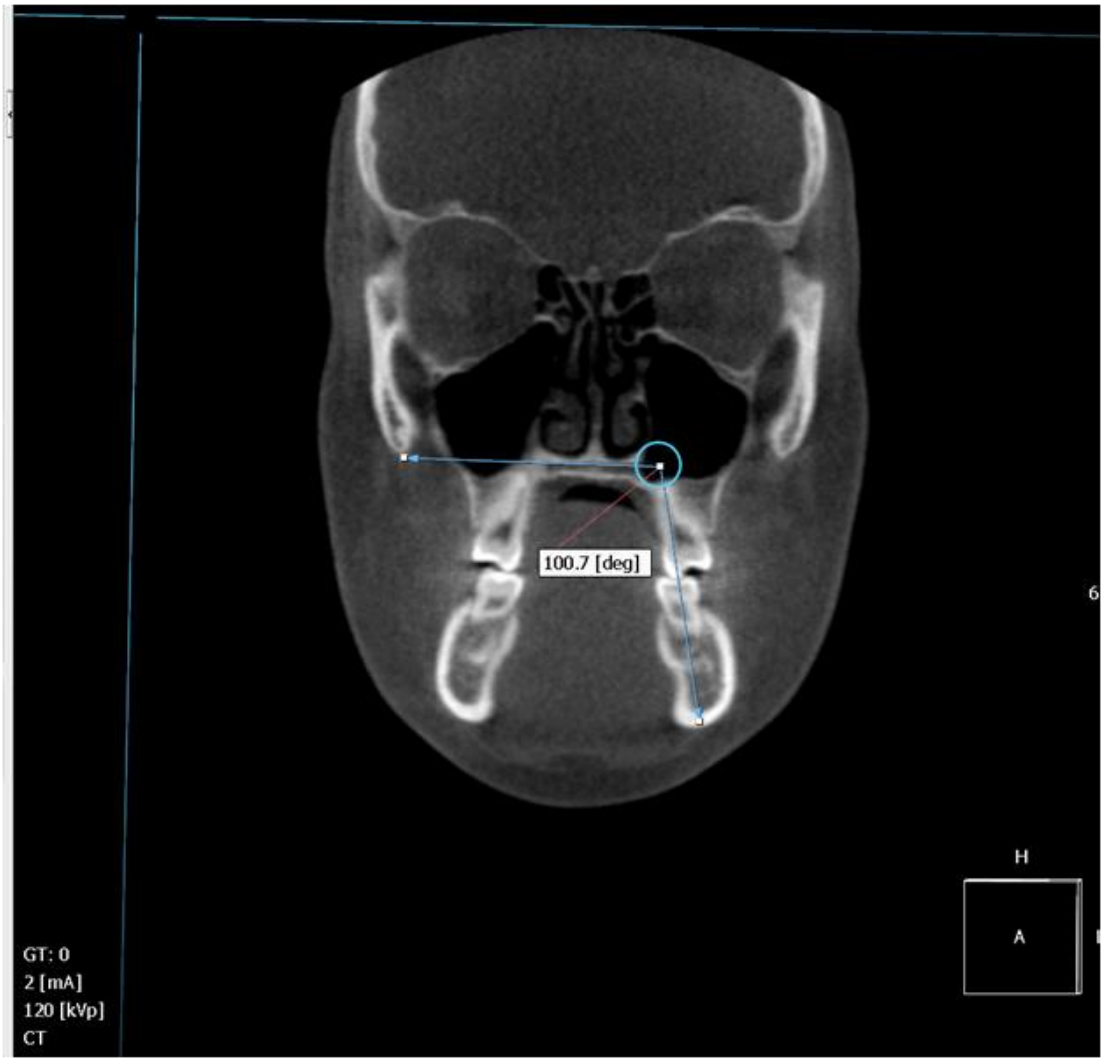


Figure 6:



Canine measurement (Figures 7, 8, 9): Rotate the coronal plane so that it passes through the canine in a direct buccolingual direction, align along the long axis, measure inclination in the coronal plane.

Figure 7:

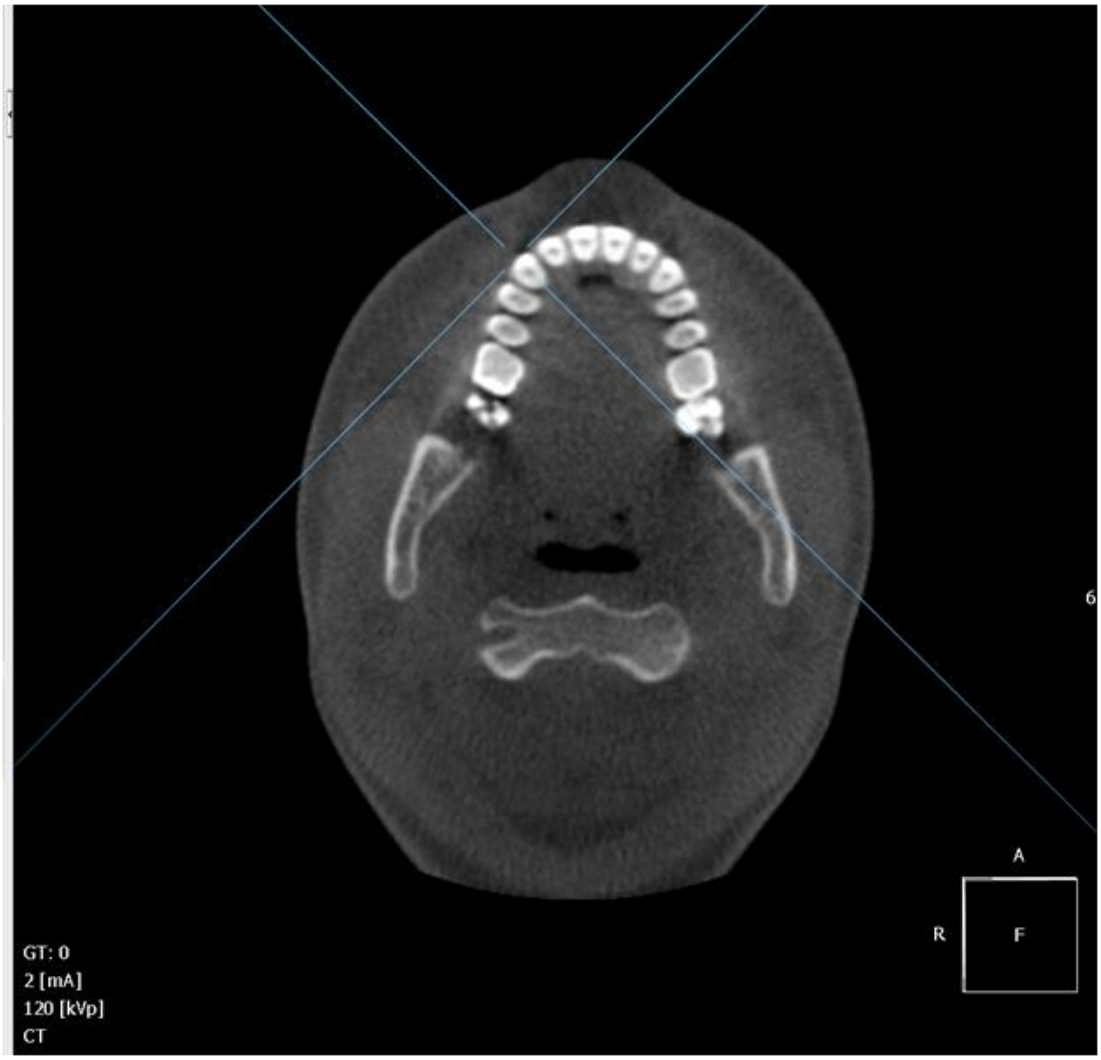


Figure 8:

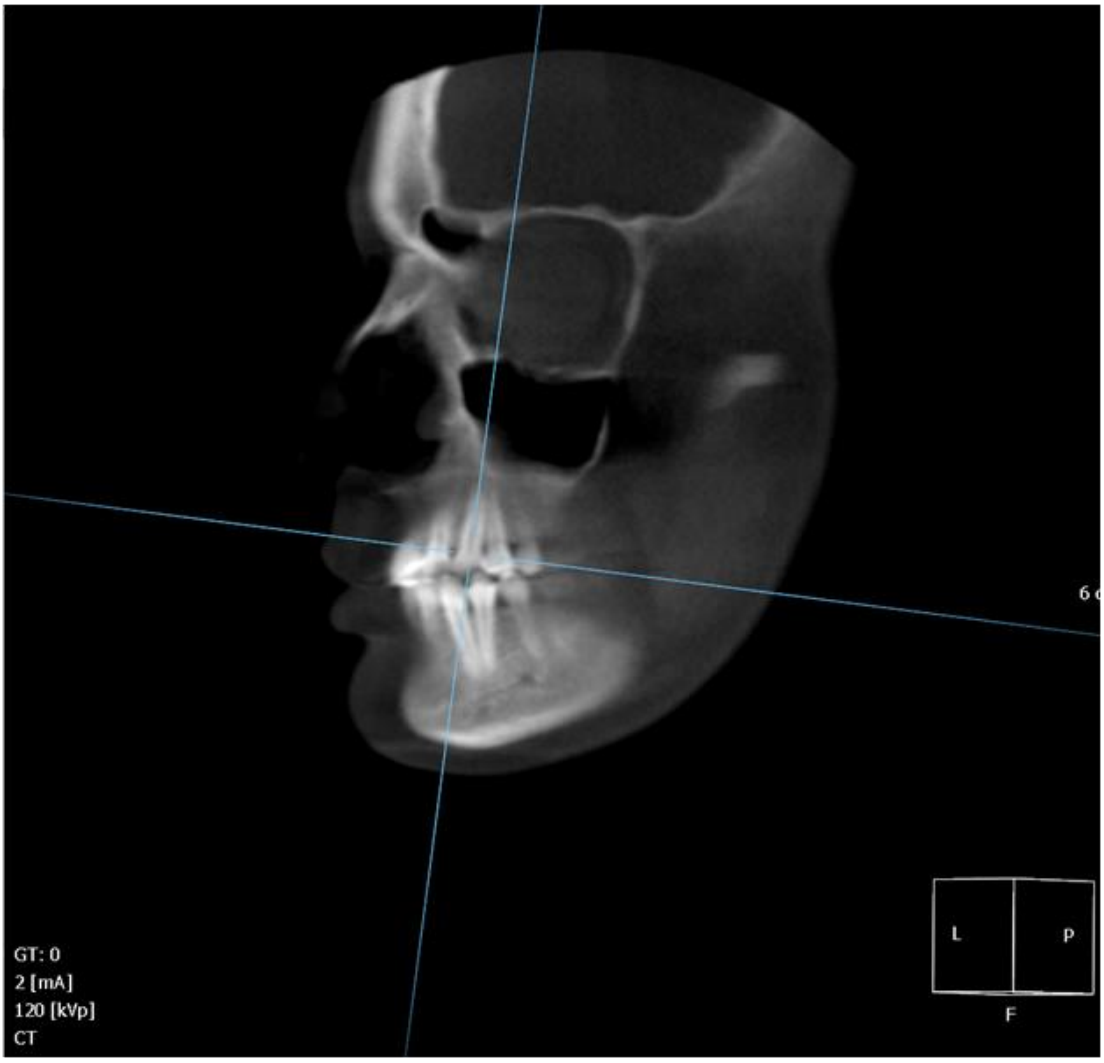
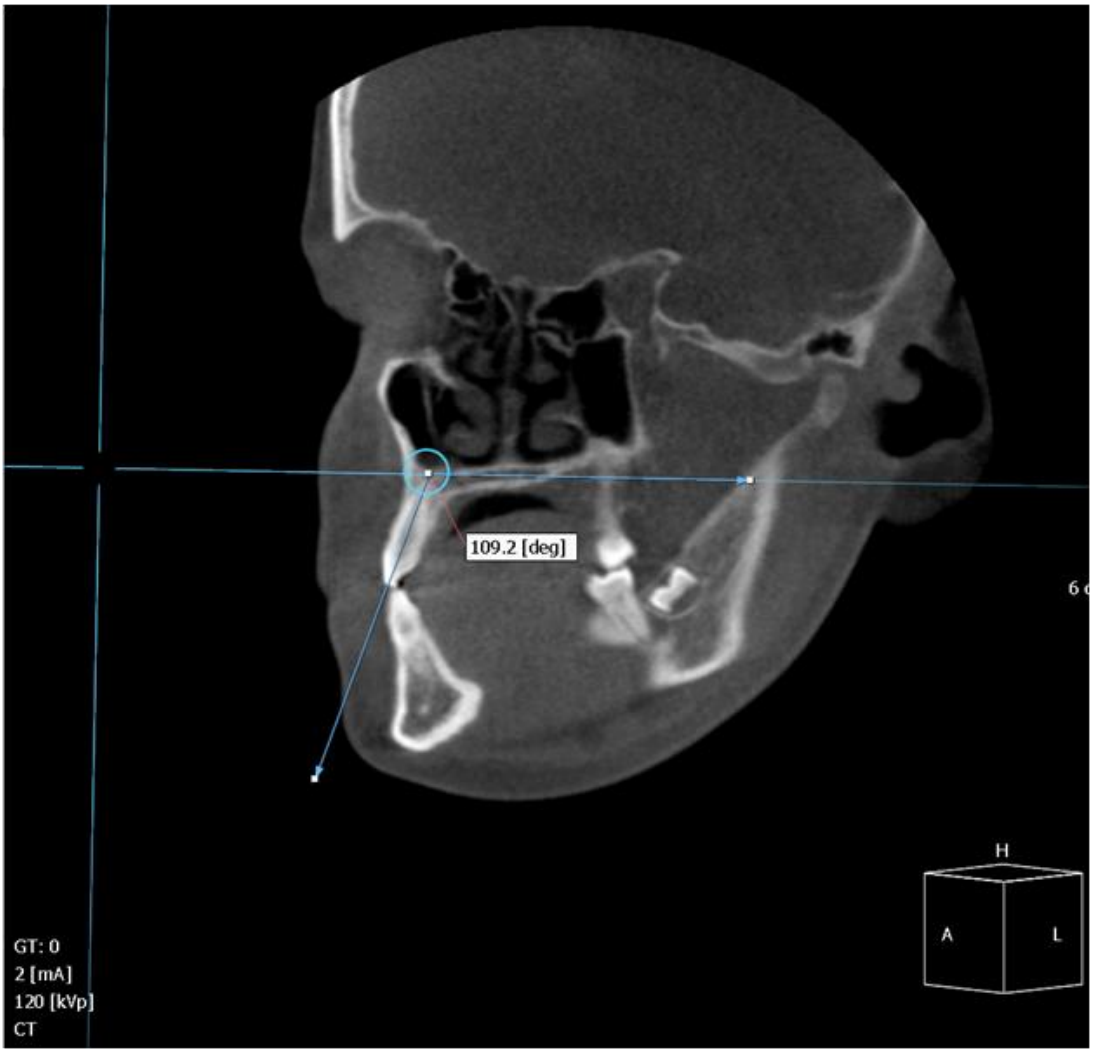


Figure 9:



APPENDIX A

IRB Approval

Case Western Reserve University
Institutional Review Board

NOTICE OF EXEMPTION (#4)

Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

This protocol is exempt under the #4 category because this involves existing retrospective de-identified data. Please note that this only applies to existing data.

Prospective data is NOT included in this exemption – i.e., De-identified pre-existing data to be collected on 04/22/2011 and after are NOT covered by this exemption.

Responsible Investigator: **J. Martin Palomo**
Department: **Dental Orthodontics**
IRB Protocol Number: **20110405**
Title: ***Changes in Buccolingual Inclination of Maxillary First Molars and Canines After Orthodontic Treatment***
Co-Investigator: **Michael Miyamoto**

Exemption Date: **April 21, 2011**

The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(4). The IRB will not conduct subsequent reviews of this protocol.

Any changes to the protocol that put it under the purview of the IRB would require a formal application to, and approval of, the IRB prior to implementation of the change IRB applications are available at the CWRU IRB Pages, or from the Office of Research Compliance (ORC) at Sears Library Building, #657.

APPENDIX B

RAW DATA

Patient	IM	IC	R6	L6	R3	L3	FIM	FIC	FR6	FL6	FR3	FL3
1	46.1	36.9	94.8	101.3	109.2	110.3	48.2	35.1	98.9	108.1	109.6	106
2	45.3	35.1	97.3	89.7	109.8	103.1	47.4	36.1	99.8	84.4	109.2	104.9
3	47	38.1	100.1	105.1	105.2	109.4	48.5	36.3	102.7	106	101.1	104.1
4	45.5	36.9	99.2	106.5	102.2	105.8	47.8	36.5	96.9	102.7	104.4	104.5
5	46.4	39.8	103.4	98.4	112.2	113.2	48.4	36.1	97.6	99.9	104.5	106.6
6	38.1	31.9	94.3	92.1	107.9	109.1	39.9	33.57	95.8	93.4	107.7	114.2
7	46.5	32.4	101.1	91.7	102.6	99.1	48.1	36.5	108.3	96.9	110.4	102.6
8	41.3	31	97.1	102	104.8	106.5	43.8	31.7	104.8	103	106.3	109.8
9	40.5	27.7	99	102.3	102.5	98.3	42.4	31.2	103.1	102.5	98.9	99.4
10	44.5	32.9	97.3	101.2	97.9	101.3	47.1	34.9	100.8	104.2	97.7	105.9
11	46.4	32.9	96.9	107.1	102.1	108.1	47.4	36.5	102.9	108.9	105.3	106.4
12	48.3	35.2	104.2	101.4	101	97.4	45.2	35.4	98.2	96	93.5	88.8
13	45.3	35.2	103.6	108.7	101.4	104.7	45.7	35.6	105.7	107.3	100.7	99.3
14	47.8	33.8	106.5	100.3	105.1	99.6	47.6	36	101.6	95	104	99
15	47.8	31.4	111.3	106.8	102.7	104.4	48.2	35.2	105.6	102.5	105.5	105
16	47.6	36.8	102	99.9	109.8	101.9	48.6	36.5	99.8	92.7	115.5	97.6
17	45.4	34.8	100	100.6	99.6	100.2	45.6	36.8	99.7	103.6	101.1	104.5
18	42.6	33.3	100.3	102.9	105.7	109.7	42.8	35.9	99.8	102.6	106.7	110.9
19	47.3	35.6	111.9	112.7	110.7	119.6	46.2	36.4	107.1	109.9	114.7	121.1
20	45.2	35.5	101.7	96.8	107.9	105.2	46.4	35	105.3	103.2	107.8	105.5
21	47	35.5	102.5	106.5	116.5	115.1	47.4	36.4	103.3	100.3	110.7	115.3
22	45.2	33.7	100.8	101.3	106.1	107.6	45.7	34.7	99.9	103.1	104.4	104.5
23	49.4	33.9	100.4	98.3	108.2	101.3	50.3	33.2	102.7	98.8	100.7	98.1
24	49.1	35.7	112.2	99.9	112.6	103.8	50.1	39.1	108	105.7	105.1	104.8
25	47.8	36.9	96.6	98.7	107.2	107.1	49.5	37.5	104.2	101.7	104.1	109.2
26	46	34.5	104.8	105.8	113.7	113.3	45	35.1	101.1	102.5	105.1	108.5
27	45.3	32.5	107.1	105.2	119.3	113.5	42.6	33.1	103.1	95.6	109.7	104.2
28	44.6	33.7	100.1	98.3	99.6	100.8	46.7	32.3	99.9	94.7	98.5	94.8
29	49.4	36	103.2	108.7	100.1	104	49.4	35.4	101	108	101.1	102.2
30	44.1	27.5	105.3	102.9	97	95.7	44.5	31.1	105.4	98.1	97.4	100
31	42.3	28.7	99.3	96.2	103.6	100.6	44.3	31.2	104.9	102.5	107.5	105.2
32	43.2	34.8	106.8	106.7	109.3	108.8	45.1	34.7	112.3	109.5	112.6	109.4
33	42.8	29	101	102.3	108.2	110.7	47.1	31.6	98.3	101.1	105.1	106.4
34	42.1	29.6	100.8	99.1	106.5	103.6	42.7	31.3	106.6	103.3	105.4	109.5

35	42.4	33.3	85.7	94.4	101.5	100	45.6	34.1	95.6	97	98.4	95.7
36	44.9	35.7	106.1	102.6	108.9	111.3	48.5	36.7	103.1	103.1	102.2	106.3
37	42.7	31.3	98.8	91	97.1	90.8	45.3	30.3	104.5	93.9	96.1	91.9
38	46.7	35.2	96	101.7	109.8	113	46.8	35.5	100.8	104.8	112.3	113.5
39	42.4	31.7	100.1	108	106.4	109.4	42.4	34.5	102.5	110.1	106	111.2
40	39.3	28.8	98	107.2	101.6	104.5	40.5	33.4	98	99.8	102.4	102.5
41	47	35.7	111.4	111.5	114.9	113.2	47.9	37.9	110.1	106.5	115.8	113.5
42	44.3	33.5	102.1	102.2	105.6	104.5	44.3	33.2	103.6	103.1	107	108.5
43	46.5	35.6	98.2	95.6	102.3	102.2	49.3	38.5	95.7	98	101.1	102.5
44	47.5	36.1	99.6	108	106.8	105.8	46.3	35.3	95.6	107.4	100.7	105.2
45	49.5	37.2	108.1	107.4	114.5	114.3	50.4	38.8	108.1	103.3	115.6	108.6
46	44.9	33.2	103.2	102.2	99.9	103.7	45.1	32.3	104	102.9	100.8	105.8
47	49.1	36.1	99.9	99.2	115.8	107.8	50.1	39	101.7	103.4	111	107.3
48	45	35	100.4	96.5	108.8	107.8	46.4	33.9	99.5	97.4	101.2	102.3
49	43.1	33.7	101.6	103.9	106.2	113.4	43.2	33.5	104.3	97.3	100.6	101
50	43.5	31.1	96.2	101.2	105.5	94.6	47.2	33.4	101.9	104.4	93.9	102.9
51	50.2	38.6	106.5	108.4	106.3	106.5	51.1	37.1	105.7	108.8	106.5	104.9
52	46.5	33.6	108.2	108	105.8	102.7	50.2	31.7	104.8	109.8	88.6	91.7
53	42.2	31.8	98.6	100.1	104.6	108.1	42.9	33.2	102.4	101.3	112	110.4
54	42.3	34.8	99	97.8	107.7	103.2	43.2	36.3	106.7	103.1	109.9	104.4
55	45.7	32.8	112.5	104.3	105.7	103.5	46.8	35	110.7	100.4	101.1	102
56	47.8	33.8	100.9	99.9	101.2	111.9	47.5	33.7	98.1	97	104.5	111.7
57	41.9	32.3	99	101.8	102.3	105.4	44.2	34.5	113.4	109.5	107.2	104.2
58	50.6	38.6	108.9	106.3	106.9	105.7	52.9	38.9	115.6	109.9	103.6	103.6
59	44.2	34.6	93.9	107.6	103.5	105.1	46.2	36	99.8	106.8	102.5	108.5
60	46.3	35.9	103.1	96	109	109.4	46.4	35.1	102.3	101.6	107.3	106.7
61	41	28.8	110.8	101.9	103.1	95.4	41.6	33.9	110	103.4	103.9	103.7
62	45.5	37.6	102.5	108.3	108.7	105.5	47.6	37.2	103.8	107	103.8	104.9
63	46.5	36.8	103	100.8	103.2	107.4	49.4	36	98.6	103.1	97	104.4
64	45.6	34.3	99.7	100.7	106.3	114.3	45.7	35	103.8	103.5	102.8	110.2
65	44.4	32.6	100.3	100.4	103.6	104.8	44.8	33.4	102.2	102.3	112.3	109.7
66	45.9	31.8	100.4	103.9	114.1	110.2	46.9	36.3	105.7	104.8	113.7	112.6
67	45.4	34.2	108.8	109.3	110.7	110.2	47.9	34.6	112.9	112.5	111.6	107.6
68	44.9	30.7	100.5	103.8	101.8	107.2	47.3	32.9	107.8	107.8	93.2	95.6
69	48.9	36.2	103.6	99.3	109.5	114	48.5	36.5	103	103.5	106.8	109.1
70	44.5	32.6	103.2	102.4	99.7	95.9	45.6	34.7	103.2	99.5	106.7	99.8

Patient	Initial Age (Mo)	Tx Time (Mos)	Gender	Race	Expander	In Mol Class	Fin Molar Cl	Slot size	Prescrip	Extraction
1	135.4	24.6	2	1	1	7	1	2	2	1
2	152.4	24	2	3	1	5	1	2	1	1
3	168	28.7	2	2	1	7	7	2	4	1
4	170.2	23.9	1	1	1	1	1	1	2	1
5	164.7	27.1	1	1	1	3	1	2	6	1
6	155.9	20.8	2	1	1	3	1	2	4	1
7	156.8	25.3	2	1	1	1	1	1	2	1
8	136.5	26.9	2	1	1	1	1	2	1	1
9	143.6	26.1	1	1	1	1	1	2	4	1
10	180.3	27.8	1	1	1	2	1	2	1	1
11	188.9	16.7	2	1	1	1	1	2	6	1
12	164.7	24.1	1	1	1	1	1	2	4	4
13	166.8	23	1	1	1	1	1	2	1	1
14	174.8	14.4	1	1	1	6	6	2	3	1
15	165.8	21.6	2	3	3	1	1	2	6	1
16	143.7	25.5	1	1	1	1	1	2	2	1
17	196.8	17.7	2	2	1	1	1	2	2	1
18	153.3	23	2	1	1	1	1	2	3	1
19	166.1	25.2	2	1	1	1	1	2	6	1
20	138.2	19.3	2	1	1	2	1	1	5	1
21	155.6	24.6	2	1	4	8	8	2	6	1
22	172.6	21.1	2	2	1	1	1	2	6	1
23	172.5	27.7	1	3	1	1	1	2	1	1
24	145.5	27.4	1	1	1	1	1	1	5	1
25	143.8	23	2	3	1	1	1	2	1	1
26	161	28.5	2	1	1	1	7	2	4	3
27	187.8	23.9	2	2	1	1	1	2	4	1
28	161.1	25	2	3	1	6	1	2	6	1
29	189.3	16.5	1	1	1	1	1	2	1	1
30	174.2	24.6	2	1	4	1	1	1	5	1

31	173.7	25.6	2	1	1	5	1	2	3	1
32	148.2	14.7	2	1	1	1	1	2	1	1
33	162.3	19.6	2	1	3	1	1	2	1	1
34	193.1	9.9	1	1	1	1	1	2	1	1
35	182.1	37	1	1	3	3	1	2	6	1
36	168.7	24.8	1	1	3	2	1	2	6	1
37	151.3	24.6	1	1	1	3	1	1	2	1
38	182.2	9.4	2	1	1	1	1	2	6	1
39	159.2	27.1	2	1	1	1	1	2	1	2
40	168.4	26.5	2	1	3	2	2	2	1	6
41	150.4	26.2	2	1	1	1	1	2	1	1
42	168.2	24.1	2	1	1	1	1	2	1	1
43	154	26.4	1	1	3	2	1	1	5	1
44	181.3	25.8	1	1	1	1	1	2	6	1
45	156.6	25.8	1	3	1	4	4	2	6	1
46	182.4	26.7	1	1	1	1	1	2	1	1
47	171.6	23.7	2	2	1	5	1	2	6	1
48	151.2	35.6	2	1	1	2	1	2	6	1
49	180.1	22.5	2	1	1	2	1	2	6	1
50	160.9	30.4	1	1	3	5	1	2	1	1
51	161.8	21.8	2	2	1	4	1	2	3	1
52	161.7	29	1	1	1	2	1	1	2	1
53	153.9	17.2	2	1	1	1	1	1	2	1
54	172.6	26.6	2	1	1	4	1	2	3	1
55	158.4	30.4	1	1	1	2	1	2	1	1
56	139.3	19.3	2	1	1	6	1	1	2	1
57	179.9	23.9	2	1	1	6	1	1	2	1
58	159.4	25.8	1	2	1	1	1	1	2	1

59	151.5	23.3	1	1	1	3	1	2	4	1
60	179.6	36.8	2	1	1	1	1	2	6	1
61	171.6	26.9	2	1	1	1	1	2	1	1
62	166.6	32.6	1	1	1	5	1	2	1	1
63	174.5	23.9	1	1	2	5	1	2	2	1
64	164.4	24.6	2	1	1	1	1	2	6	1
65	175.7	17.3	2	1	1	1	1	2	1	1
66	156.3	24.2	1	1	2	2	1	2	1	1
67	159.5	24.2	2	1	1	1	1	2	3	1
68	133.2	38.2	2	1	1	2	1	2	1	1
69	183.4	25.7	2	1	1	1	1	2	6	1
70	135.5	22.3	2	1	1	1	1	1	2	1

RAW DATA: RELIABILTIY

Patient	R6	L6	R3	L3	FR6	FL6	FR3	FL3
4	100.4	107.4	102.1	105.6	100.1	105.3	104.4	104.4
11	97.9	107.2	100.6	108	102.6	109.5	103.9	105.2
17	99	101.8	99	100.4	102.7	104.1	102.2	102.2
18	99.2	106.2	106.6	100.6	101.8	106	104.8	111.7
20	101.5	96.9	108.2	105.7	103.7	103.8	107.1	104.8
24	110.6	100.3	103.3	106	109.2	102.2	103.6	104.4
26	106.1	105.8	111.2	108.1	99.9	99.9	107.1	107.9
27	105.1	107.1	117.9	115.2	103.8	97.5	111.1	102.9
30	101.9	101.9	99.1	95.3	106.7	99.6	99.1	101.2
31	101.1	95.4	102.5	104.5	107.3	102.2	104.6	104.9
32	102.9	107.3	111.2	109.2	114.1	109.9	110.8	111.4
39	99.7	102.9	106.7	107.8	101.2	109.2	104.3	114.2
52	106.7	110.1	105.8	103.7	102.9	111.4	90.1	90.5
60	104.4	94.7	107.7	111.1	101.3	101.5	108.3	106.1
63	104.3	99.3	101.1	104.1	99.6	102.5	99.8	106.3

KEY FOR CATEGORICAL DATA COLLECTION

Gender
1 - male
2 - female

Race
1 - Caucasian
2 - Black
3 - Asian/other

Expander
1 - None
2 - Haas
3 - Hyrax
4 - Bonded

Initial/Final Molar Classification
1 - Class I
2 - Class II/Div I
3 - Class II/Div II
4 - Class III
5 - Class II Subdivision R
6 - Class II Subdivision L
7 - Class III Subdivision R
8 - Class III Subdivision L
9 - Undetermined/other

Bracket Slot
1 - 0.018
2 - 0.022

Bracket Prescription
1 - MBT
2 - Roth
3 - Damon
4 - Tip edge
5 - Alexander
6 - Mixed

Extraction Pattern
1 - None
2 - U/L 4's
3 - U4/L5
4 - U/L 5's
5 - U5/L4
6 - U 4's only
7 - U 5's o

APPENDIX C

Descriptive summary of demographics; gender and anthropological group

Variable	**Group**	**Total**	**Percent**
Gender	Male	27	38.6
	Female	43	61.4
Anthropological Group	Caucasian	57	81.4
	Black	7	10
	Other	6	8.6

Age at start of treatment and total treatment time

Variable	Mean & SD	Range
Age (years)	13.7 ± 1.2	11.1-16.4
Treatment Time (months)	24.4 ± 5.3	9.4-38.2

Descriptive summary of expander status, initial molar classification, final molar classification, bracket slot size, bracket prescription, extraction pattern (N=70)

Variable	Group	Total	Percent
Expander	None	59	84.2
	Haas	2	2.9
	Hyrax	7	10
	Bonded	2	2.9
Initial Molar classification	Class I	39	55.7
	Class II Div I	10	14.3
	Class II Div II	5	7.1
	Class III	3	4.3
	Class II Sub R	6	8.6
	Class II Sub L	4	5.7
	Class III sub R	2	2.9
	Class III Sub L	1	1.4
	Undetermined	0	0
Final Molar classification	Class I	64	91.4
	Class II Div I	1	1.4
	Class II Div II	0	0
	Class III	1	1.4
	Class II Sub R	0	0
	Class II Sub L	1	1.4
	Class III sub R	2	2.9
	Class III Sub L	1	1.4
	Undetermined	0	0
Bracket prescription	MBT	29 (U3 0; U6 -14)	41.4
	Roth	13 (U3 -3; U6 -10)	18.6
	Damon	6 (U3 0; U6 -18)	8.6
	Tip Edge	7 (U3 -4; U6 -10)	10
	Alexander	4 (U3 -3; U6 -10)	5.7
	Mixed	3 (U3 -7; U6 -10)	4.3
	Mixed	5 (U3 0; U6 -14)	7.1
	Mixed	3 (U3 0; U6 -10)	4.3
Bracket slot size	.018	13	18.6
	.022	55	78.6
	Bidimensional	2	2.9
Extraction pattern	None	66	94.3
	U4 / L4	1	1.4
	U4 / L5	1	1.4
	U5/L5	1	1.4
	U5/L4	0	0
	U4 only	1	1.4
	U5 only	0	0

APPENDIX D

Intraclass correlation to calculate intra-examiner reliability for inclination of maxillary molars and canines (N=30)

Variable	**Intraexaminer reliability (r^2)**
Right molar inclination (°)	0.93
Left molar inclination (°)	0.96
Right canine inclination (°)	0.97
Left canine inclination (°)	0.97

Gender Differences in Maxillary Canine and First Molar Inclination, Intercanine Width and Intermolar Width (N=70)

Variable	Group (N=70)	Mean	Std. Deviation	Sig (P-value)
Initial intermolar width(mm)	M (27)	46.0259	2.51864	.071
	F (43)	44.8744	2.57849	
Initial intercanine width (mm)	M (27)	34.5481	2.75644	.124
	F (43)	33.5349	2.57616	
Initial inclination R6 (°)	M (27)	102.1148	5.64533	.755
	F (43)	101.7349	4.44034	
Initial inclination L6 (°)	M (27)	102.4556	4.69896	.687
	F (43)	101.9698	5.00345	
Initial inclination R3 (°)	M (27)	105.3296	4.73659	.287
	F (43)	106.5953	4.84208	
Initial inclination L3 (°)	M (27)	103.6185	5.19571	.005*
	F (43)	107.3907	5.44705	
Final Intermolar Width (mm)	M (27)	47.5185	2.39439	.006*
	F (43)	45.7837	2.51793	
Final Intercanine Width (mm)	M (27)	35.2481	2.40966	.338
	F (43)	34.7574	1.82910	
Final inclination R6 (°)	M (27)	102.5741	4.81589	.342
	F (43)	103.6070	4.10762	
Final inclination L6 (°)	M (27)	102.5148	4.77241	.995
	F (43)	102.5070	5.27737	
Final inclination R3 (°)	M (27)	101.8741	6.12112	.001*
	F (43)	106.5465	4.66718	
Final inclination L3 (°)	M (27)	102.3074	5.69405	.001*
	F (43)	106.7512	5.03537	
Change in intermolar width (mm)	M (27)	1.4926	1.57234	.084
	F (43)	.9093	1.19877	
Change in intercanine width (mm)	M (27)	.7000	1.85223	.235
	F (43)	1.2226	1.72826	
Change in inclination R6 (°)	M (27)	.4593	4.52125	.177
	F (43)	1.8721	4.02666	
Change in inclination L6 (°)	M (27)	.0593	3.26770	.620
	F (43)	.5372	4.25978	
Change in inclination R3 (°)	M (27)	-3.4556	4.73167	.003*
	F (43)	-.0488	4.38093	
Change in inclination L3 (°)	M (27)	-1.3111	4.37540	.540
	F (43)	-.6395	4.47518	

*P≤.01

Differences in Maxillary Canine and First Molar Inclination, Intercanine Width and Intermolar Width in patients receiving rapid maxillary expansion (N=70)

Variable	Group (N=70)	Mean	Std. Deviation	Sig (P-value)
Initial intermolar width(mm)	Non-expansion (59)	45.4508	2.61615	.328
	Expansion (11)	44.6091	2.50258	
Initial intercanine width (mm)	Non-expansion (59)	34.2085	2.49415	.040
	Expansion (11)	32.4091	3.20139	
Initial inclination R6 (°)	Non-expansion (59)	102.1017	4.56884	.388
	Expansion (11)	100.7000	6.55881	
Initial inclination L6 (°)	Non-expansion (59)	102.1492	5.00666	.975
	Expansion (11)	102.2000	4.18999	
Initial inclination R3 (°)	Non-expansion (59)	106.2034	4.64346	.701
	Expansion (11)	105.5909	5.83566	
Initial inclination L3 (°)	Non-expansion (59)	106.0915	5.47714	.595
	Expansion (11)	105.1000	6.59530	
Final Intermolar Width (mm)	Non-expansion (59)	46.3915	2.62267	.651
	Expansion (11)	46.7818	2.54748	
Final Intercanine Width (mm)	Non-expansion (59)	34.9758	2.04733	.788
	Expansion (11)	34.7909	2.28143	
Final inclination R6 (°)	Non-expansion (59)	103.6169	4.38320	.071
	Expansion (11)	101.0182	3.90405	
Final inclination L6 (°)	Non-expansion (59)	102.7712	5.35627	.320
	Expansion (11)	101.1091	2.68866	
Final inclination R3 (°)	Non-expansion (59)	105.1644	5.61300	.156
	Expansion (11)	102.4909	5.97937	
Final inclination L3 (°)	Non-expansion (59)	105.0678	5.78191	.918
	Expansion (11)	104.8727	5.44134	
Change in intermolar width (mm)	Non-expansion (59)	.9407	1.27023	.005*
	Expansion (11)	2.1727	1.50406	
Change in intercanine width (mm)	Non-expansion (59)	.7673	1.68694	.005*
	Expansion (11)	2.3818	1.73079	
Change in inclination R6 (°)	Non-expansion (59)	1.5153	4.15181	.395
	Expansion (11)	.3182	4.82200	
Change in inclination L6 (°)	Non-expansion (59)	.6220	3.85992	.182
	Expansion (11)	-1.0909	3.90114	
Change in inclination R3 (°)	Non-expansion (59)	-1.0390	4.85305	.192
	Expansion (11)	-3.1000	4.18665	
Change in inclination L3 (°)	Non-expansion (59)	-1.0237	4.49606	.587
	Expansion (11)	-.2273	4.09929	

*P≤.01

Slot size differences in maxillary canine and first molar inclination, intercanine width and intermolar width (N=70)

Variable	Group (N=70)	Mean	Std. Deviation	Sig (P-value)
Initial intermolar width(mm)	.018 (13)	45.6231	2.61092	.643
	.022 (57)	45.2491	2.61480	
Initial intercanine width (mm)	.018 (13)	33.6615	2.85439	.696
	.022 (57)	33.9860	2.65393	
Initial inclination R6 (°)	.018 (13)	102.7154	4.57308	.501
	.022 (57)	101.6912	4.99472	
Initial inclination L6 (°)	.018 (13)	100.2231	5.34028	.112
	.022 (57)	102.5982	4.68186	
Initial inclination R3 (°)	.018 (13)	103.2462	4.35615	.016
	.022 (57)	106.7596	4.69844	
Initial inclination L3 (°)	.018 (13)	102.4846	5.74904	.013
	.022 (57)	106.7228	5.34068	
Final Intermolar Width (mm)	.018 (13)	47.2923	2.84384	.199
	.022 (57)	46.2614	2.52472	
Final Intercanine Width (mm)	.018 (13)	34.9000	2.91690	.929
	.022 (57)	34.9574	1.85810	
Final inclination R6 (°)	.018 (13)	104.7385	5.86068	.165
	.022 (57)	102.8596	3.96371	
Final inclination L6 (°)	.018 (13)	101.9615	5.39808	.668
	.022 (57)	102.6351	5.01325	
Final inclination R3 (°)	.018 (13)	103.4538	6.36640	.371
	.022 (57)	105.0386	5.57125	
Final inclination L3 (°)	.018 (13)	102.5538	5.85913	.081
	.022 (57)	105.6035	5.55010	
Change in intermolar width (mm)	.018 (13)	1.6692	1.11384	.121
	.022 (57)	1.0123	1.40675	
Change in intercanine width (mm)	.018 (13)	1.2385	1.96067	.629
	.022 (57)	.9714	1.75404	
Change in inclination R6 (°)	.018 (13)	2.0231	5.47238	.517
	.022 (57)	1.1684	3.96071	
Change in inclination L6 (°)	.018 (13)	1.7385	4.16084	.156
	.022 (57)	.0368	3.79175	
Change in inclination R3 (°)	.018 (13)	.2077	6.88821	.192
	.022 (57)	-1.7211	4.16605	
Change in inclination L3 (°)	.018 (13)	.0692	3.89602	.385
	.022 (57)	-1.1193	4.53019	

*P≤.01

One way ANOVA comparing intermolar with, intercanine width and buccolingual inclination by race

Variable	Group 1 **Caucasian n=57** (Mean±SD)	Group 2 **Black n=7** (Mean±SD)	Group 3 **Asian/Other n=6** (Mean±SD)	**P Value**
Initial intermolar width(mm)	44.8±2.5	47.5±2.4	47.4±2.0	.003* a,b
Initial intercanine width (mm	33.5±2.6	36.1±2.5	34.7±2.1	.050*
Initial inclination R6 (°)	101.7±4.9	103.3±4.0	102.1±6.0	.687
Initial inclination L6 (°)	102.2±4.8	103.7±3.4	99.9±6.5	.360
Initial inclination R3 (°)	105.7±4.5	108.4±6.7	107.0±5.3	.331
Initial inclination L3 (°)	105.8±5.9	107.2±4.0	105.1±5.0	.783
Final Intermolar Width (mm)	46.0±2.3	48.0±3.6	48.7±1.6	.009* b
Final Intercanine Width (mm)	34.7±2.0	36.6±2.1	35.5±2.5	.059
Final inclination R6 (°)	103.0±4.4	104.0±5.6	103.3±3.3	.858
Final inclination L6 (°)	102.8±4.6	104.3±4.7	97.6±7.2	.030
Final inclination R3 (°)	104.6±5.9	105.3±3.9	105.6±6.2	.882
Final inclination L3 (°)	105.2±6.0	104.7±1.2	103.4±5.8	.757
Change in intermolar width (mm)	1.2±1.4	0.5±1.6	1.4±0.7	.458
Change in intercanine width (mm)	1.1±1.8	0.5±1.7	0.8±1.8	.674
Change in inclination R6 (°)	1.4±4.4	0.7±3.4	1.1±4.4	.912
Change in inclination L6 (°)	0.6±3.8	0.6±4.7	-2.3±3.3	.219
Change in inclination R3 (°)	-1.1±5.0	-3.1±3.7	-1.4±3.6	.596
Change in inclination L3 (°)	-0.6±4.5	-2.5±4.2	-1.7±3.7	.506

*P≤.01
a = significant difference between group 1 and 2
b = significant difference between groups 1 and 3
c = significant difference between groups 2 and 3

One way ANOVA comparing intermolar with, intercanine width and buccolingual inclination by bracket prescription

Variable	Group 1 **MBT n=22** (Mean±SD)	Group 2 **Roth n=13** (Mean±SD)	Group 3 **Damon n=6** (Mean±SD)	Group 4 **TipEdge n=7** (Mean±SD)	Group 5 **Alexander n=4** (Mean±SD)	Group 6 **Mixed n=18** (Mean±SD)	**P Value**
Initial intermolar width(mm)	44.5±2.5	45.7±2.4	45.1±3.3	44.2±3.7	46.2±2.1	46.3±1.9	.245
Initial intercanine width (mm)	32.9±2.6	34.5±2.4	33.9±3.2	33.5±3.3	33.6±4.1	35.1±1.9	.169
Initial inclination R6 (°)	101.9±4.7	101.4±3.9	103.4±4.3	100.4±5.2	104.4±6.0	101.7±5.9	.814
Initial inclination L6 (°)	103.2±4.8	100.8±5.0	102.5±5.4	102.8±5.2	98.8±3.3	102.3±5.0	.549
Initial inclination R3 (°)	105.7±4.4	103.4±3.8	106.5±2.5	107.6±6.7	105.0±6.8	108.2±4.8	.123
Initial inclination L3 (°)	104.9±4.4	103.5±5.9	105.0±4.5	106.6±6.6	101.7±4.2	110.0±5.2	.006**
Final Intermolar Width (mm)	45.9±2.6	47.4±2.7	46.1±3.3	44.3±2.8	47.6±2.6	47.1±1.7	.080
Final Intercanine Width (mm)	34.3±1.9	34.9±2.3	35.2±2.1	34.4±1.8	35.9±3.7	35.6±1.7	.392
Final inclination R6 (°)	104.4±4.0	103.4±5.9	105.3±4.6	100.5±2.8	103.6±5.4	101.9±3.5	.208
Final inclination L6 (°)	103.4±5.2	102.2±6.0	104.1±6.0	100.4±5.4	101.3±3.8	102.3±4.1	.751
Final inclination R3 (°)	104.4±5.9	104.4±7.3	107.7±2.7	102.6±5.5	102.9±4.6	105.7±5.3	.617
Final inclination L3 (°)	105.8±4.7	102.5±6.0	105.3±3.9	103.9±8.1	103.2±2.5	106.6±6.3	.420
Change in intermolar width (mm)	1.4±1.2	1.7±1.1	1.1±1.0	0.1±2.3	1.4±1.0	0.8±1.3	.113
Change in intercanine width (mm)	1.5±1.8	0.4±1.8	1.3±1.6	0.9±1.6	2.4±1.9	0.5±1.8	.257
Change in inclination R6 (°)	2.5±3.2	2.0±5.5	1.9±4.7	0.1±4.6	-0.8±3.4	0.2±4.2	.433
Change in inclination L6 (°)	0.2±3.2	1.4±4.4	1.6±4.3	-2.4±4.0	2.4±5.1	0.1±3.8	.282
Change in inclination R3 (°)	-1.3±4.3	1.0±6.9	1.2±1.7	-4.9±3.7	-2.1±3.7	-2.5±3.9	.076
Change in inclination L3 (°)	0.9±4.6	-0.9±4.2	0.4±2.6	-2.6±5.8	1.5±1.9	-3.4±3.4	.029

*P≤.01

a = significant difference between group 1 and 6

b = significant difference between groups 2 and 6

Pearson correlation comparing change in intermolar/intercanine width with change in buccolingual inclination of molars/canines

N=70	Change in R6 inclination
Change in intermolar width	Correlation = 0.372 Sig (2-tailed) = 0.002**

*P≤.01

N=70	Change in L6 inclination
Change in intermolar width	Correlation = 0.372 Sig (2-tailed) = 0.002**

*P≤.01

N=70	Change in R3 inclination
Change in intercanine width	Correlation = 0.272 Sig (2-tailed) = 0.023

*P≤.01

N=70	Change in L3 inclination
Change in intercanine width	Correlation = 0.461 Sig (2-tailed) = 0.000**

*P≤.01