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We hereby approve the thesis of

Eleftheria Karamitsou

Candidate for the degree Master of Science

in Dentistry.

Signed: _____ (Chairperson)

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_____ MILTON NTRAVALIS, DDS, MSD

_____

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PRETREATMENT BUCCOLINGUAL INCLINATION OF MAXILLARY CANINES AND FIRST MOLARS

by

ELEFTHERIA K. KARAMITSOU

Submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry

Thesis Advisor: Mark G. Hans, D.D.S., M.S.D.

Department of Orthodontics

School of Dental Medicine

CASE WESTERN RESERVE UNIVERSITY

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DEDICATION

This thesis is dedicated to my family.

A special feeling of love and gratitude to my dear parents, Kosta and Dora, who influenced my life in a profound way and have always been there for me.

To my siblings, Maria and Spyro, who have never left my side and whose words of encouragement over the years have given me strength and confidence.

I am so grateful to have all of you in my life.

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PRETREATMENT BUCCOLINGUAL INCLINATION OF MAXILLARY CANINES AND FIRST MOLARS

Abstract

by

ELEFTHERIA K.KARAMITSOU

This study had three objectives: 1. To develop a reliable and reproducible method to measure the buccolingual inclination of maxillary canines and first molars using CBCT; 2. To determine the range, the mean- or median / mode if not a normal distribution - and the standard deviation of the buccolingual inclination of maxillary canines and first molars before orthodontic treatment; 3. To compare the inclination of the upper canines and first molars before treatment among different age, gender, molar classification and expander status groups. A total of 97 adolescents patients, 47 males and 50 females, aged 12-15 who presented for initial records participated in the present study. Radiographic data were constructed from CBCT dicom files. On Demand 3D software (version 1.0.1.8407, CyberMed, Seoul, Korea) was used to measure the buccolingual Inclination of maxillary canines and 1st molars utilizing the inferior border of nasal

cavity as reference line and the long axis of the tooth. Measurements were taken using the long axis of the teeth. Intra-examiner reliability was acceptable with an, intraclass correlation coefficient greater than or equal to 0.96. The mean inclination for the maxillary left and right canines before orthodontic treatment excluding subdivision malocclusions was 105.9±6.5 and 103±6, respectively. The range was 91.8 to 123.8 for the left side and 89.5 to 123.4 for the right side. The means for the left and right maxillary molars were 101.7±5.4 and 99.2.±5.3, respectively. The range was 88.5 to 117.5 for the left side and 86.6 to 112.8 for the right side. The difference in mean inclination between the left and right sides was statistically significant for both molars and canines. However, no differences related to gender, age, expander status and various molar classifications were noted among the groups. In this sample, it was concluded that Buccolingual inclination of maxillary canines and first molars can be reliably measured using CBCT and the range in angulation is large enough to be clinically significant.

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LITERATURE REVIEW

The American Board of Orthodontics established an objective grading system for dental casts and panoramic radiographs in order to make the phase III clinical examination a meaningful experience for candidates and elevate the quality of orthodontic care. The Board established eight important criteria for the assessment of orthodontic results, one of which is buccolingual inclination. According to the Board "in order to establish proper occlusion in maximum intercuspation and avoid balancing interferences, there should not be a significant difference between heights of the buccal and lingual cusps of the maxillary and mandibular molars and premolars." This specific grading system was developed systematically through a series of four field tests over a period of 5 years (1994 - 1998). At the 1995 ABO Phase III examination 100 cases were evaluated and 15 criteria were measured based on the final models and panoramic radiographs. Seven of fifteen criteria showed 85% of the total inadequacies (marginal ridges, alignment, buccolingual inclination of the posterior teeth, overjet, occlusal relationships, occlusal contacts and root angulation). The Board never determined what were the

inadequacies, the other eight criteria and the initial characteristics of the cases that they were reviewed. In 1996, a second field test was initiated to determine if interexaminer reliability was adequate and verify the results of the previous test. During this field test 300 final models and panoramic radiographs were evaluated by 4 directors, confirming the previous results without adequate interexaminer reliability. Again, it was not given any details as regards the initial characteristics of the cases or the inadequacies in the final results that occurred in the same seven criteria. In 1997, the third field test was performed. 832 dental casts and panoramic radiographs were measured, confirming the same seven criteria. The difference of the other two field tests was the addition of a new instrument to measure the criteria more accurately and the decision of adding interproximal contacts as the eighth category. At the final test, in 1998, the new and improved measuring instrument was used as well as an extensive training and calibration session was performed before the actual examination in order to increase reliability. This test was the most successful since they finally introduced the eight criteria (marginal ridges, alignment, buccolingual

inclination, root angulation, occlusal contacts, interproximal contacts, overjet, occlusal relationship) without giving any further information for the inadequacies on the models, when assessing the above criteria. Based on this grading system the buccolingual inclination of the maxillary and mandibular posterior teeth shall be assessed by using a flat surface that is extended between the occlusal surfaces of the right and left posterior teeth. When positioned in this manner, in the maxillary arch, the straight edge should contact the lingual cusps of the maxillary molars and premolars. The buccal cusps should be within 1mm of the surface of the straight edge. If the maxillary buccal cusps are more than 1mm, but less than 2mm from the straight edge surface, 1 point shall be subtracted for that tooth. (ABO 1998).

According to Andrew's article, "Six Keys of Normal Occlusion", buccolingual inclination of teeth is one of the six significant characteristics for normal occlusion. Andrews studied 120 casts of non-orthodontic patients with normal occlusion which were gathered during a period of four years (1960-1964) with the cooperation of local dentists, orthodontists and a major university. The

selection of casts was based on cases that had never had orthodontic treatment, teeth were straight and pleasing in appearance, they had a bite which looked generally correct, and would not benefit from orthodontic treatment (personal judgement).According to him the six keys for static occlusion were molar relationship, crown angulation, crown inclination, rotations, spaces, and occlusal plane. All of them were established as meaningful to him not solely because all were present in each of the 120 non-orthodontic normals, but also because the lack of even one of the six keys was a defect, predictive of an incomplete final result in treated models. He determined crown inclination, the third key to normal occlusion, as the angle between the long axis of the crown and a line bearing 90 degrees from the occlusal plane. More specifically, he mentioned that the anterior teeth (central and lateral incisors) are inclined toward the buccal or labial surface. Upper posterior teeth have lingual crown inclination which is constant and similar from the canines through the second premolars and slightly more pronounced in the molars. Lower posterior teeth are also inclined lingually, but progressively more from canine to second molars. The best part at his study

in order to validate his results was that he compared the best in nature cases, the 120 non-orthodontic normals with the best 1150 treated cases, which were treated by the masters in orthodontics at that point of time and were submitted to national meetings. Even though Andrew's six keys of occlusion are well-known in the orthodontic society, the limitation of his study was that he relied on his undoubting experience in order to evaluate the casts and establish his 6 keys of static occlusion. (Andrews LF,1972).

A well known method to measure crown inclination is by using study models. Marsall et al. (2003) made a study in order to evaluate longitudinal changes in molar crown torque, as well as changes in arch width, from the time of first permanent molar eruption to early adulthood. The sample for their research project was obtained from the Iowa Facial Growth study. 89 boys and 86 girls of primarily northern European descent and above average socioeconomic status were enrolled. The cases had no facial or skeletal disharmony and normal (class I) molar and canine occlusions. At the end though, after applying the inclusion criteria their sample was limited to 36 subjects (18 women and 18 men). They included subjects

with study models available from ages 7 to 30 years, untreated Class I occlusion, no distortion or abrasion of the tooth portion of the dental casts, no excessive enamel wear or restorations of the dental cusps of measured teeth and no missing or extracted permanent teeth. Four cusp height measurements and two buccolingual intercusp distances were measured in study models. Measurements were made with the dental casts lying flat on the art portion with the occlusal surfaces facing upward. The measurement gauge was then laid transversely across the dental arch to contact the most elevated cusp on the right and the most elevated cusp on the left for paired right and left teeth. Differences in height for mesial cusps and distal cusps were measured separately. Measurements of buccolingual intercuspal distance were obtained with a digital caliper which was calibrated to zero before each measurement. The error of measurement between 2 investigators, or between different occasions for the same investigator, was determined by computing the mean differences between their measurements on casts of 2 subjects. The mean difference between investigator determinations was tested for the significance of its deviation from zero. The statistical method that was used

to test the null hypothesis that the median correlation is zero, regarding the first molars, was the Wilcoxon signed rank test. At this point we can mention that the most appropriate statistical method to test the reliability of the results in-between the same examiner would be intra-class correlation and in case there was any difference in the results between the 2 examiners, inter-class correlation. The conclusions from their research were very clear. According to their study, maxillary molars erupt with buccal crown torque and upright lingually with age, whereas mandibular molars erupt with lingual crown torque and upright buccally with age. The molar uprighting that they found naturally occurring with normal growth supports the board's criteria. In other words their findings justify the goal of achieving upright posterior teeth during orthodontic treatment. Overall, the study was well organized and the only limitations were the small sample size and their statistical analysis as mentioned above.

The study of Ross et al. (1990) had two primary goals. The first was to test the hypothesis - that variations in faciolingual tooth inclinations are correlated with variations in vertical skeletal growth

patterns. The second was to demonstrate the effects of straight-wire appliance therapy on patients with different occlusal plane inclinations. Their subjects included study models and cephalograms from 72 white persons, 20 males and 52 females, (the number of females was more than double the number of males), ranging in age from 9.5 to 41.5 years. At this point is very crucial to report that skeletal growth pattern is not a term that applies to adults and since the age range includes adults, this term should not be used for the specific sample. The subjects were divided into 4 groups. Group 1 (7 males, 14 females) had subjects with ideal occlusion based on Andrews six keys and cephs were not available. In this group, the number of female subjects was twice as much as males and in contrast to the remaining groups, the MP-SN angle was not mentioned. Group 2(8 males, 8 females), had subjects that their cephalograms revealed an MP-SN angle equal or lower to 26 degrees. In Group 3(8 males, 10 females), the MP-SN angle is equal to 32 degrees. In group 4 (4 males, 13 females) the MP-SN angle was 38 degrees. The last two groups are represented only by one absolute value related to MP-SN angle, without determining if 27-31 degrees and 33-37 degrees are

excluded. The faciolingual inclination of the occlusal surface of each maxillary and mandibular first molar was expressed as the angle formed by the occlusal surface of each molar and a total posterior occlusal plane (POP). POP was formed by the three most occlusally located cusps of the two first molars and one or both of the premolars. In practice, the angle formed by the molar occlusal surface and the POP was determined by trimming the heel of each cast perpendicular to its base and parallel to the occlusal line that connects the mesiobuccal and mesiolingual cusp tips through the buccal groove. They photocopied independently the right and left heels of each cast and the angle formed by a perpendicular to the OS line and its intersection with the model base, ± 90 degrees was determining the inclination of the occlusal surface. According to their results the mean maxillary occlusal surface inclination was 8° with a standard deviation of 4.0 and there was no significant difference among the different groups. Unfortunately, this result might be biased since the standard deviation was large, moreover, there were no details regarding the intra-examiner reliability and the inclusion criteria for the sample selection were not specified.

McNamara et al. (2003) wanted to evaluate the molar angulations' changes as well as the short- and long-term changes in dental arch dimensions in patients treated with rapid maxillary expansion (RME) followed by fixed edgewise appliances compared with the arch changes observed in a control group of untreated individuals. The reason of doing that study was due to the fact that there were few well-designed long term studies that addressed the stability of RME and it was reported in the literature that there is a range of relapse after retention from 0 to 45% (Stockfish, 1969; Spillane et al. 1995; Linder-Aronson et al.1979; Haas et al. 1980;).The treated sample analyzed in this study consisted of 112 subjects (61 females and 51 males). It was part of a long term prospective study on consecutively treated patients who had undergone Haas-type RME and nonextraction edgewise appliance therapy in a single orthodontic practice. All patients presented with a variable degree of crowding associated with narrow dental arches but without posterior crossbites. The patients underwent a standardized protocol of Haas type RME with two turns a day (0.25mm per turn) until the expansion screw reached 10.5mm (about 21 days). Haas expander was kept on the

teeth as a passive retainer for an average of 65 days. After expansion, all patients received full fixed edgewise appliances. The retention after active orthodontic treatment consisted of a fixed lower retainer, except for 24 patients. Dental casts were obtained at three observation times: Pre-treatment (T1), after expansion and fixed appliance therapy (T2), and at long-term recall (T3). The mean age for treated group (TG) at T1 was approximately 12 years 2 months, approximately 14 years 6 months at T2 and approximately 20 years 5 months at T3. The mean duration of the T1-T2 and T2-T3 periods for the TG group was 3 years 2 months ± 5 months and 6 years 1 month ±1 year 2months, respectively. Regarding the Control group, dental casts of 41 untreated subjects (24 males and 17 females) were evaluated. The records were derived from both the University of Michigan Elementary and Secondary School Growth Study and the University of Groningen Growth Study. The control sample with normal occlusion matched the treated sample as to mean age at T1, T2, and T3, sex distribution, mean duration of observation periods. The dental casts were measured with a digital imaging system (Bioscan OPTIMAS Imaging System, Seattle, Wash). The

angulation of the maxillary and mandibular first molars was determined by measuring the angle of intersection of lines passing through the buccal and lingual cusps. Angulation of less than 180° indicated that the molars were tipped buccally, values above 180° implied that they were tipped lingually. According to their findings, the maxillary molars had a significantly greater buccal angulation in TG when compared with controls. Evaluation of post-treatment changes (T3-T2 changes in TG vs. T3-T2 changes in CG) showed significantly greater decreases in intercanine width in TG compared to CG and maxillary molars in TG showed a significant tendency to a less buccal angulation than in CG. Comparison only of final forms (TG at T3 vs. CG at T3) showed significantly more buccal inclination of maxillary molars and more lingual inclination of mandibular molars. As limitation of this study we could mention the way that they measured the angulation of first molars. For instance, the angle of maxillary first molars could be less than 180° and therefore their conclusion would be that the molars were tipped buccally, even though one molar could have tipped a little bit lingually and the other buccally.

Another study related to the buccolingual inclination of posterior teeth in subjects with different facial patterns was that of Janson et al. (2004).The purpose of that project was to compare the buccolingual inclinations of the posterior teeth in subjects with a definite horizontal growth pattern (proportionally short lower anterior facial height) with subjects with a definite vertical growth pattern (proportionally long lower anterior facial height). The initial sample consisted of 120 cases with permanent dentition who voluntarily sought orthodontic treatment at the Department of Orthodontics at Bauru Dental School, University of Sao Paulo, Brazil. All subjects were evaluated using frontal and profile facial color photographs, and a lateral cephalometric radiograph. The cephalograms were traced on acetate by a single investigator, and the ratio between upper and lower anterior facial height was determined. The final sample included the pretreatment dental study models of 70 cases with the more extreme values for this ratio, divided into 2 groups. Group I was comprised of 35 subjects with a horizontal facial growth pattern (16 male, 19 female, aged 14.08 ± 3.10 years). Group II was comprised of 35

subjects with a vertical facial growth pattern (15 male, 20 female, aged 13.95 ± 2.41 years). The base of the models was trimmed parallel to the occlusal plane, and the method which was used for the measurements was the same to the one used by Ross et al (1990). According to their findings, the maxillary posterior teeth of subjects with a vertical growth pattern had a significantly greater buccal inclination compared with subjects with horizontal growth pattern. More specifically, they reported 5.13 ° torque for maxillary molar inclination in subjects with a horizontal growth pattern and 7.74 ° torque for maxillary molar inclination in subjects with a vertical growth pattern. The limitation, as regards the statistical part of that study was that they used Dahlberg's formula in order to calculate the intra-examiner reliability, instead of using the most appropriate intra-class correlation coefficient. Furthermore, it would be efficient to test the intra-examiner reliability regarding the tracings, since they were done by a single investigator. In contrast to Ross et al. (1990), the strength of this study was that the term growth pattern was properly used since the subjects were in a growing age. In addition, they reported that

the measured angle does not correspond to the actual long axis inclination of the tooth but only to the occlusal surface inclination. Thus, extrapolation of the results of the occlusal surface inclination to the long axis inclination between different tooth types cannot be performed, because of the different dental crown anatomies. However, in each category, it is possible to extrapolate the results of the occlusal surface inclination to the long axis inclination between the groups.

In the past years, measurements of the inclination were done on the models. That gives us the crown inclination which is a proxy measurement and not the tooth's root actual inclination, determined by the long axis of the tooth. For that reason the new technology of the 3-dimensional craniofacial imaging can be considered as revolution in the aspect of dentistry. Computed tomography (CT) has provided 3D reconstruction of the entire craniofacial skeleton from axial slices allowing methods to evaluate all internal structures (Vannier et al., 1984; Maki et al., 1997).CT also provides digital 3D data, a source of information for morphometric analysis. An increase of the application of 3D data is expected

soon with the use of new tools in order to redesign cephalometrics and might finally replace the conventional orthodontic records that are used so far.(Halazonetis, 2005).Cone-beam computed tomography (CBCT), allows quantification of vertical, transverse and anteroposterior dimension of mandible as well as maxilla after surgery (Cevidanes et al., 2007). In a recent prospective study, they compared the 2D and 3D images of impacted maxillary canines and they concluded that the clinician's confidence in terms of the accuracy of diagnosis and treatment planning was much higher in 3D images (Haney E. et al., 2010).

Podesser et al. (2004) wanted to develop and evaluate a simple non-invasive technique for accurate and reproducible evaluation of maxillary structures based on a series of frontal CT scans. The study was based on CT registration of 10 adults (3 males, 7 females), with average age of 26 years 3 months. The subjects were chosen irrespective of occlusion, facial morphology and exclusion criteria were dental restorations. The study was approved by the Ethical Committee of the Medical faculty, University of Vienna and each subject signed an informed consent form. Eighteen registration points were

used on the maxillary canine, the first molar and the nasal cavity in an axial view. Linear measurements and angulation were made among these points. To determine the intra-observer and inter-observer variation, the measurements were repeated a minimum of ten days later. According to the tables they reported that the intra-observer correlation between the first and second readings ranged from 0.88 to 0.99, which was high but unfortunately there were many inaccuracies at their tables and at what they reported in the result section. For inter-observer error, with the exception of maxillary alveolar width, there were no significantly statistical differences between the readings of the two observers. However, while there was no statistically significant difference between the readings from the two observers, single difference in linear variables of up to 5mm and angular variables of 11° could be seen. Finally, they suggested that CT scans represent a reasonable method by which the transverse morphology of the maxillary structures can be described. Generally speaking, the strength of their study was the new information obtained from CT scan, as well as the ability to see structures similar to PA cephs with better precision though due to

clearer view. Looking at the limitations in their study, first of all the sample size was very small, 10 patients with the females more than double of the males. Many mistakes were also noticed in the tables regarding the means, maximum, minimum values when calculating numbers and a lot of errors in the text when they were referring to the tables. Furthermore, they did not explain in details the measurements they did.Also, they did not take into consideration potential explanatory factors such as gender, molar classification, expander status, crossbite status. Last but not least, they used student's paired t-test to compare the differences between the 2 readings for both intra-and inter- observer, instead of using correlation coefficient, intra-class for the intra-reliability and inter-class for the inter-reliability.

The most recent studies that have been conducted so far, regarding the buccolingual inclination of mandibular first molars and canines using CBCT is that of Shewinvanakitkul et al (2008)and the follow up from Evangelinakis et al (2009). These projects focused on mandibular teeth measurements using the mandibular plane as their reference line. The goals of Shewinvanakitkul et al study were to develop a reliable method to measure

buccolingual inclination of mandibular canines and first molars using CBCT, to use this method to determine the mean and standard deviation for buccolingual inclination of the mandibular canines and first molars and to compare inclination of the mandibular canines and first molars among Angle classification groups as well as between patients treatment planned with and without palatal expansion. In addition, they measured and reported mean and ranges of the intercanine and intermolar width using study models. Data were derived from pretreatment Cone Beam Computed Tomography (CBCT) scans, taken in the Craniofacial Imaging Center at Case School of Dental Medicine in 2006, with age ranging from 11 to 14 years old. There were approximately 200 pretreatment patient records consisting of CBCT scans, study models, photographs and medical history forms. 108 subjects met the selection criteria which were very specific and finally the sample consisted of 56 males and 52 females, which was still sufficient. Intra-class correlation was used to test intra-examiner reliability which was high. It was equal or more than .94, showing that their method was reliable and their measurements were repeatable. According to their results, the mean inclination for the

mandibular canines was 98.0 ° ± 4.1° and for the mandibular molars, the mean inclination was 74.6 ° ± 4.7°. Mandibular first molar inclination was decreased in Class II (molar) cases and in patients receiving expander and there was no statistical significant difference between the age and gender groups. In addition, dental compensations in molar inclination were seen for Class II subjects and in patients receiving palatal expansion. Finally they concluded that CBCT can be used to reliably measure mandibular buccolingual inclination of canines and first molars.

The buccolingual inclination of the teeth plays a significant role in the establishment of esthetic and functional harmony of the dentition (Jeffrey D. Bert, 1981).In addition, the appropriate inclination of both posterior and anterior teeth is considered essential for providing stability and proper occlusal relationship in orthodontics. Taking everything into consideration it would be beneficial to find a reliable method to measure the inclination of maxillary first molars and canines by using CBCT, which diagnostically appears to be very interesting in the field of orthodontics. As stated previously, most of the studies so far, were focusing on

the crown inclination. The reason for this was the use of the study models as the main available diagnostic tool which give us a proxy measurement and not the tooth's root actual inclination, determined by the long axis of the tooth. Therefore, the use of cone beam computed tomography (CBCT) has been introduced to allow measurement of transverse dimensions as stated by Podesser et al. (2004) as well as changes in actual inclination of teeth as studied by Evangelinakis et al. (2010). After establishing a method for the measurements of the maxillary teeth and reporting the means it would be interesting to find if there are any differences in inclination before treatment among different age, gender, molar classification and expander status groups.

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STATEMENT OF THESIS

The objectives of the study are: 1. To develop a reliable and reproducible method to measure the buccolingual inclination of maxillary canines and first molars using CBCT; 2. To determine the range, the mean- or median / mode if not a normal distribution - and the standard deviation of the buccolingual inclination of maxillary canines and first molars before orthodontic treatment; 3. To compare the inclination of the upper canines and first molars before treatment among different age, gender, molar classification and expander status groups.

It is hypothesized that:

There is no difference in the buccolingual inclination, in maxillary arch between males and females, adolescents 12-13 and 14-15 years old, adolescents with class I, II and III molar classification, patients treatment planned with and without RPE.

Pretreatment Buccal Inclination of Maxillary First Molars and Canines

Authors: Eleftheria Karamitsou D.D.S. [1]

Manish Valiathan D.D.S., M.S.D. [2]

J. Martin Palomo D.D.S., M.S.D. [3]

Milton Ntragatakis D.M.D., M.S.D. [4]

Mark G. Hans D.D.S., M.S.D. [5]

1. Resident, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH
2. Associate Professor, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH
3. Associate Professor and Program Director, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH
4. Assistant Professor, Department of Pediatric Dentistry at Case School of Dental Medicine in Cleveland, OH
5. Professor and Chairman, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH

Corresponding Author:

Mark G. Hans, D.D.S., M.S.D.
Case Western Reserve University
School of Dental Medicine
Department of Orthodontics
10900 Euclid Ave. Cleveland, OH 44106

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Objectives: 1. To develop a reliable and reproducible method to measure the buccolingual inclination of maxillary canines and first molars using conebeam computed tomography (CBCT) 2.To determine the range, mean and standard deviation for the buccolingual inclination of the maxillary first molars and canines, and 3.To compare the inclination of the upper canines and first molars before treatment among different age, gender, molar classification and expander status groups.
Methods: A total of 97 adolescents patients, 47 males and 50 females, aged 12-15 who presented for initial records participated in the present study. Radiographic data were constructed from CBCT dicom files. On Demand 3D software (version 1.0.1.8407, CyberMed, Seoul, Korea) was used to measure the buccolingual Inclination of maxillary canines and 1st molars utilizing the inferior border of nasal cavity as reference line and the long axis of the tooth. Measurements were taken using the long axis of the teeth. **Results:** Intra-examiner reliability was acceptable with an, intraclass correlation coefficient greater than or equal to 0.96. The mean inclination for the maxillary left and right canines before orthodontic treatment excluding subdivision malocclusions was 105.9±6.5 and 103±6, respectively. The range was 91.8 to 123.8 for the left side and 89.5 to 123.4 for the right side. The means for the left and right maxillary molars were 101.7±5.4 and 99.2.±5.3, respectively. The range was 88.5 to 117.5 for the left side and 86.6 to 112.8 for the right side. The difference in mean inclination between the left and right sides was statistically significant for both molars and canines. However, no differences related to gender, age, expander status and various molar classifications were noted among the groups. **Conclusions:** Buccolingual inclination of maxillary canines and first molars can be reliably measured using CBCT and the range in angulation is large enough to be clinically significant.

INTRODUCTION

The American Board of Orthodontics[1] established eight important criteria for the assessment of orthodontic results, one of which was buccolingual inclination. As stated by the Board "in order to establish proper occlusion in maximum intercuspation and avoid balancing interferences, there should not be a significant difference between heights of the buccal and lingual cusps of the maxillary and mandibular molars and premolars." This specific grading system was developed systematically through a series of four field tests over a period of 5 years (1994-1998). In addition, according to Andrew's article[2], "Six Keys of Normal Occlusion", buccolingual inclination of teeth is one the six significant characteristics for normal occlusion. He determined crown inclination (third key to normal occlusion), as the angle between the long axis of the crown and a line drawn perpendicular to the occlusal plane. More specifically, he mentioned that the anterior teeth (central and lateral incisors) are inclined toward the buccal or labial surface. Upper posterior teeth have lingual crown inclination which is constant and similar from the canines through the second premolars and slightly more pronounced in the molars. Reviewing the studies that have been carried out so far, it is obvious that buccolingual inclination has long been an area of interest in orthodontics; however, the most well known method to measure it is by using study models. Ross et al.[3] investigated if variations in faciolingual tooth inclinations are correlated with variations in vertical skeletal growth patterns. According to their findings, the mean maxillary occlusal surface inclination was

8° with a standard deviation of 4.0 and there was no significant difference among the different groups. Marshal et al.[4] evaluated longitudinal changes in molar crown torque, as well as changes in arch width, from the time of first permanent molar eruption to early adulthood. They reported that maxillary molars erupt with buccal crown torque and upright lingually with age, whereas mandibular molars erupt with lingual crown torque and upright buccally with age. Another study related to the buccolingual inclination of posterior teeth in subjects with different facial patterns was that of Janson et al.[5]. They compared the buccolingual inclination of the posterior teeth in subjects with a definite horizontal growth pattern, with those in subjects with a definite vertical growth pattern. They found that the maxillary posterior teeth of subjects with a vertical growth pattern had a significantly greater buccal inclination (7.74° torque for maxillary molar inclination) compared with subjects with horizontal growth pattern (5.13° torque for maxillary molar inclination).

As previously mentioned, the studies that have been published regarding the inclination of maxillary teeth are based on study models; nevertheless, things in the real world tend to be quite different. So, measurement of the inclination on the models, gives us the crown inclination which is a proxy measurement and not the tooth's root actual inclination which should ideally be measured using the long axis of the tooth. Three dimensional craniofacial imaging provides new information and can be considered revolutionary in the profession of dentistry. Computed tomography (CT) is a 3D reconstruction of the entire craniofacial

skeleton from axial slices allowing the evaluation of all internal structures [6,7]. CT also provides digital 3D data, a source of information for morphometric analysis[8]. CT scans overcome the limitations of 2D images and have proven to be a significant invention for diagnosing the positions and complications of ectopically positioned teeth[9,10,11].Cone-beam computed tomography (CBCT), allows quantification of vertical, transverse and anteroposterior dimensions of the maxilla and mandible[12]. The availability of 3D data will allow orthodontists to redesign traditional cephalometrics and may eventually replace the conventional orthodontic records that are today[8].

Podesser et al.[12] wanted to develop a simple non-invasive technique for accurate and reproducible evaluation of maxillary structures based on a series of frontal CT scans. Eighteen registration points were used on the maxillary canine, the first molar and the nasal cavity in an axial view. Linear measurements and angulation were made among these points. Finally, they suggested that CT scans represent a reasonable method by which the transverse morphology of the maxillary structures can be described. A recent study by Shewinvanakitkul used CBCT to measure the buccolingual inclination of mandibular first molars and canines.[13]. She developed a reliable method for measuring the inclination of mandibular canines and first molars and reported the mean, standard deviation and range of varitation of these teeth. However, her study was limited to the mandible. The present study will focus on the inclination of maxillary canines and first molars.

The objectives of this study are to: 1) develop a reliable and reproducible method to measure the buccolingual inclination of maxillary canines and first molars; 2) to determine the range, the mean – or median / mode if not a normal distribution- and the standard deviation of the buccolingual inclination using CBCT, and 3) To compare the inclination of the upper canines and first molars before treatment among different age, gender, molar classification and expander status groups.

MATERIALS AND METHODS

The experimental protocol was approved by Case Western Reserve University Institutional Review Board (IRB). Data were derived from existing pre-treatment Cone Beam Computed Tomography scans (CB MercuRay, Hitachi Medical Systems America Co. – Twinsburg, OH). All scans were obtained in the Craniofacial Imaging Center at Case School of Dental Medicine during scheduled appointments for initial records of patients, who sought voluntarily orthodontic treatment at the Department of Orthodontics in 2006 and 2007. A total of 450 pretreatment patient records for both years were available. Patient records included medical and dental history forms, intraoral and extraoral photographs, study models and large volume 2mA CBCT scans. Sample size calculations done using an estimated standard deviation of 5 degrees and a confidence interval of 95% suggested that a minimum of 62 subjects would be needed. Eventually, a total of 97 subjects participated in this study.

The following inclusion criteria were used:

1. Adolescent orthodontic patients, aged 12-15 at the time of initial records.
2. Maxillary first molars and canines present and fully erupted into occlusion determined from study models.
3. Landmarks (cusps tips and root apices) of measured teeth can be seen clearly on the CBCT radiograph.
4. No previous orthodontic treatment, based on dental history form.
5. No severe rotations (>=90 degrees) of maxillary first molars and canines determined from study models and CBCT
6. No maxillary deciduous teeth present determined from study models
7. No extracted permanent maxillary teeth.
8. No supernumerary or congenitally missing teeth in the maxillary arch determined from the CBCT.
9. No previous restorations of the measured dental cusps of maxillary first molars and canines determined from the CBCT.
10. No patients with craniofacial anomalies and syndromes.

From the CBCT scans taken in 2006, 42 subjects of the 200 met the inclusion criteria and 158 did not. Fifty-one subjects were excluded because of the age, 36 subjects had unerupted maxillary canines, 18 had maxillary deciduous teeth, eight subjects had missing maxillary teeth, nine subjects had a history of previous orthodontic treatment, 28 subjects had restorations of maxillary first molars, and eight subjects had poor images. The remaining 55 subjects in our sample were

selected from the 250 patients who had records in 2007. The ones who met the inclusion criteria were selected by alphabetical order. The final sample was composed of 97 patients, 47 females and 50 males with an average age of 13.34 ± 1.14 years.

Data were collected by a single operator (EK). Radiographic data were constructed from CBCT dicom files. OnDemand3D software (version 1.0.1.8407, CyberMed, Seoul, Korea) was used to measure the buccolingual Inclination of maxillary 1st molars and canines. Measurements were made separately for the right and left maxillary canines and the right and left first molars, through the long axes of the teeth. Each slice was saved as a jpeg image, and was labelled using a patient identifier. Slice thickness was set by default to 0.28mm (as a function of the standard voxel height). Measurements were made on slices of the left canine, right canine, left first molar and right first molar and repeated after a 3 week interval on 35 subjects randomly selected. Patient demographic data, molar classification, expander status and crossbite status were abstracted from the dental chart.

Method of canine inclination measurement

1. Locate the canine in axial view and place the line that represents the sagittal plane tangent to the buccal cortical plate of the canine (most buccal point). The same line should then be moved parallel (buccolingually) until we see the longest root length in the sagittal slice view. (See Figure 1)

2. In sagittal view, position the line representing the coronal slice along the long axis of the tooth. (See Figure 2)

3. In coronal view, draw the reference line as tangent to the inferior border of the nasal cavity (reference point) (See Figure 3)

4. Measure the inclination through the long axis of the canine. (See Figure 4)

5. Repeat 1-4 for the controlateral canine.

Method of Molar inclination measurement

Maxillary first molar is the largest tooth in volume and the most complex in root and canal anatomy[14]. The palatal root is the longest, has the largest diameter, and offers the easiest access[14]. Therefore the long axis of the palatal root was used to meaure molar inclination.

Orientation of the subject:

In the sagittal view orient the line which represents the axial view so that it passes through anerior nasal spine (ANS). (See Figure 5.)

Locate ANS In the axial view (point where coronal and sagittal plane meet). (See Figure 6.)

In the sagittal view move the line which represents the axial view downwards so that it passes through the center of the atlas. (See Figure 7.)

Go back to the axial view rotate the line that illustrates the sagittal plane around ANS so that it passes through the center of the odontoid process. (Figure 8.)

When orientation is complete,

1. Locate molar in axial view, the point at which the palatal root length is the longest in the sagittal view. (See Figure 9.)
2. In sagittal view, position the line representing the coronal slice along the mesiopalatal cusp tip and the palatal root apex. (See Figure 10.)
3. In coronal view, draw the reference line tangent to the inferior border of the nasal cavity. (See Figure 11.)
4. Measure the inclination through the long axis of the molar (represented by the line coming through the apex of the palatal root and the cusp tip) in the coronal view. (See Figure 12.)
5. Repeat 1-4 for the contra-lateral molar

Measurements were recorded and saved in a Microsoft® Excel 2003 spreadsheet for statistical analysis.

Buccolingual inclination measurements

Maxillary canine inclination (degrees) was specified as the angle between a line passing through the long axis of maxillary canine (cusp tip to root apex), and a line tangent to the inferior border of the nasal cavity. Maxillary first molar inclination (degrees) was defined as the angle between a line passing through the long axis of maxillary molar (apex of the palatal root to the mesio-palatal cusp tip of the molar) and another line tangent to the inferior border of the nasal cavity.

Statistical analysis

The skewness and kyrtosis statistics showed that all the variables were distributed normally. Descriptive statistics (means and standard deviations) were calculated

for each independent variable. Data were transferred to SPSS software (Statistical Package for the Social Sciences, SPSS 17.0, Inc. – Chicago, IL) for further analysis. Paired sample t-tests were applied to compare mean differences in inclination between the right and left sides for the maxillary first molars and canines. A p-value of less than or equal to 0.01 was used to assign statistical significance. Additionally, (ANOVA- among group comparsions) (Independent sample t-tests between group comparisons) were used to analyze potential variations in buccolingual inclination of maxillary first molars and canines among gender, age, expander status groups, and molar classification group. A reliability study was carried out after a 3-week interval on 34 randomly selected subjects. The square of the intraclass correlation coefficient (r^2) was used to estimate reliability.

RESULTS

Demographics

The resulting study included 50 males and 47 females for a total of 97 subjects. The mean age was 13.34 ± 1.14 years, with a range from 11.6 to 15.4 years. Caucasians (n=85) were the majority among the subjects with nine African-Americans, and three Asians. A descriptive summary of race, gender, age, molar classification, expander status, and crossbite status is shown in Table 1.

Buccolingual Inclination for maxillary canines and first molars

Twenty five subjects with subdivision malocclusions were excluded when the mean and the standard deviation for class I, II, and III molar classifications were calculated. (Table 3a.) The mean and the standard deviation for the 64 caucasian subjects without subdivision malocclusion was also calculated. However, due to the small number of Asians (n=3) and African Americans (n=9) means were not calculated for these groups (Table 3b.). Data for right and left sides were collected separately. After applying a paired-T test for right and left canines and first molars, a statistically significant difference was found between the right and left sides (Table 3a.).

In this study, the mean inclination for the maxillary left and right canines was 105.9 ± 6.5 and 103 ± 6 degrees respectively. For the 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. (Table 3a.). The above means and standard deviations are for the 72 subjects without subdivision malocclusion and include 44 class I subjects as well as 20 class II and 8 class III subjects. There were no significant differences betweeen angle classes, gender, or subdivisions.

Looking at table 4, we could have a better idea of the subjects with class I, II and III molar relationship including also the non crossbite cases. In Class I, non-crossbite cases, the mean maxillary left canine inclination was 105.1 ± 5.7 degrees and the right canine inclination was 103 ± 4.5 degrees. As regards the maxillary left and right first molar inclination, the mean was 101.8±5.5 degrees and 99.8

±4.3 degrees respectively. Descriptive summary of maxillary canine and first molar inclination by subdivision malocclusion, expander and crossbite status is shown in Table 5.

Differences between left – right side and among age, gender, expander status and molar classification groups

Comparisons between left and right side by using paired t-tests revealed that there was a statistically significant difference in terms of the inclination for the canines (left and right) and first molars (left and right) (Table 3a.). Applied independent t-tests showed that there were no statistically significant differences in the buccolingual inclinations of the maxillary canines and molars between males and females and the 12–13 year olds and the 14–15 year olds. Additionally, no significant differences were noticed in inclinations between the expander status and various molar classification groups.

Reliability

The Intraexaminer reproducibility of the measurements was tested by the same operator (EK). More specifically, measurements were repeated 3 weeks later on 30 randomly selected subjects and reliability was estimated using intraclass correlation coefficient (r^2). The intraclass correlation values for the left canine, the right canine, the left molar and the right molar were all greater than 0.96 (see Table 2).

DISCUSSION

One of the primary goals of this study was to develop a reliable and reproducible method for measuring the actual inclination of maxillary canines and first molars using cone beam computed tomography. The intraclass correlation coefficient confirmed that this method was highly repeatable. The reason for using the palatal root to measure the long axis of the first molar has already been mentioned in the materials and method section. Although any of the three roots could be used it was decided that the palatal root best represented the angulation of the maxillary first molars. In addition to the reasons previously cited in the materials and methods section, the orthodontic literature often cites the rotation of the first molar around the palatal root as a way to correct a class II molar relationship.[15] Podesser et al.[12] and Kimberly et al. [16] also used the palatal root as a marker for maxillary first molar inclination. Specifically, for their measurements in the coronal view, they draw a reference line passing through the lateral walls of the nasal cavity and another one connecting the apex of the 1st molar palatal root with the mesiobuccal cusp. Our study did not use the mesial buccal cusp because it was felt that using a different cusp tip and root would overestimate the tooth angulalation. Therefore, the long axis of the maxillary molar was represented by a line passing through the apex of the palatal root and the large palatal cusp tip. Moreover, the subjects were oriented on ANS and the odontoid process of the axis and two slices (axial and sagittal) were used to make the necessary adjustments before starting the measurements in coronal view in

order to assure for their precision. The same slices were repeated separately for right and left side. The reference line of our study was defined in the coronal view, as a tangent to the inferior border of the nasal cavity. Podesser et al.[12] showed that this reference line was reproducible which is in accordance with our reliability test and makes the present method useful for evaluating also post treatment changes in tooth inclination.

This study found significant differences between the left and right sides for both canines and molars. Specifically, it was found that on the left side the measurements were 2.9° and 2.5° higher for the canines and the molars respectively. While interesting this finding is probably not clinically significant. Nevertheless, it is informative to consider several factors that could potentially explain this finding. The first is a preference for unilateral mastication resulting in differences in occlusal forces per side and increased muscular activity on one side. A second reason might be preferences for sleeping on one side. Honma et al.[17] showed that unilateral chewing requires a greater number of chewing strokes, higher occlusal forces and contact points of the involved posterior teeth, which might result in morphologic differences between the sides as noted in our study. Gormis et al.[18] studied one hundred and seventeen subjects and they noted that fifty-nine were chewing on the right, fifteen on the left and forty-three both sides. According to their findings, chewing side preference in a dentate population is related to lateral asymmetry of bite force and asymmetry of occlusal contact area at the intercuspal position but not on to handedness. Furthermore, Kimoto et al.

[19] reported that activities of both the anterior temporalis and masseter on the working side were significantly greater than those of the non working side and the asymmetry of the elevators muscles during mastication was a common finding in normal subjects. Analyzing these studies and thinking a little further we could possibly explain why a difference between left and right side in terms of the inclination could occur. Moreover, De Koninck et al.[20] found that with age individuals are significantly more likely to adopt the right lateral position for sleep due to overtime related alterations in cardiovascular function. Similarly, Gordon et al.[21] denoted that the majority of people whether left or right handed prefer to sleep on their right side. These studies could probably explain our findings, since extrinsic forces from the cheeks (as they are compressed during sleep) could possibly affect the inclination of the teeth in the right side in a palatal direction, so as not to be the same with the left. In addition, another recent study of mandibular molars by Evangelinakis reported a statistically significant difference between the left and right first molars[22] before orthodontic treatment.

According to our reported means the molars are less buccally inclined compared to the canines which is in agreement with Andrews'[2] findings. On the other hand he reported that maxillary posterior teeth are lingually inclined. In our study we showed that maxillary teeth are buccally inclined. A possible reason for that could be that Andrews measured the inclination on the casts using the crown of the teeth. It is unlikely that the buccal surface of the maxillary first molars is exactly parallel to the long axis of the palatal root. The important finding in this

study is that most clinicians are under the impression that the maxillary cuspids are almost vertical in their angulation (i.e. 90 degrees, when in reality the maxillary cuspids are inclined a minimum of ten degrees to the buccal (i.e. 100 degrees or more).

Although Marshal et al [4] stated that maxillary molars erupt with buccal crown torque and upright lingually with age we did not find any age variation in tooth angulations. This is probably because once teeth erupt into occlusion there is little change in the angulation of the teeth in the absence of orthodontic tooth movement. For example, the stability of the angulation of the upper and lower incisors in the absence of treatment has been well documented by numerous cephalometric studies over the last 75 years. Natural dentitions, with no doubt are in equilibrium and the major factors for this situation appear to be resting pressures of tonque, lips and forces created within the periodontium, analogous to forces of eruption.[23]

The clinical importance of this study lies in the potential to use molar and cuspid inclination for diagnosis and treatment planning of the orthodontic cases. It's been 75 years since Downs came up with the first cephalometric analysis. Since that time there were many additional analyses, most of which were reporting norms for the inclination of the incisors. Downs Analysis was an important diagnostic tool for the clinician in order to evaluate the position of the incisors and consequently determine the appropriate treatment plan for the patient. Now in the CBCT era we are able to make any 2D slices from 3D. Most clinicians

who are using CBCT today are constructing 2D cephalometric radiographs and using them for diagnosis and treatment planning[24]. True 3D treatment planning is still lacking. By measuring the inclination of the maxillary first molars and canines through the coronal slices, it's the first time that such measurements for the maxillary teeth can be reported. Knowledge of the norms and range of inclination of the maxillary canines and molars can be used to evaluate the degree to which a given patient deviates from these norms. This could be helpful to clinicians deciding on the need for palatal expansion with RPE or dental expansion with archwires only. There are many cases that appear borderline for using or not using rapid palatal expansion. Since RPE is not a pleasant experience for the patient avoiding unnecessary expansion would be a positive outcome for patients. Looking at the norms from this study the orthodontist might be able to determine if there is a buccolingual dental compensation present in their patient or if their patient has a true maxillary transverse deficiency. In cases with buccally inclined teeth and maxillary transverse deficiency, a treatment plan with wire expansion and not RPE would not correct the problem because it is skeletal. On the other hand a posterior crossbite due to lingually inclined molars without any maxillary transverse deficiency component should be also identified and the use of RPE avoided.

This study represents a first step in the study of the inclination of maxillary canines and molars. The means and the standard deviations reported are only useful if the measurement method is the same as described herein. Further

research needs to be conducted to evaluate the degree to which orthodontic treatment changes the buccolingual inclination of these teeth. Additionally, it would be beneficial to identify differences in inclination among racial groups. The era of 3D cephalometrics is just beginning, as is the hope for better and more stable orthodontic treatment interventions in the future.

CONCLUSION

The results of the present study indicate that: 1) CBCT can be reliably used to measure the buccolingual inclination of maxillary canines and first molars. 2) The newly developed method using the inferior border of the nasal cavity and the long axis of the tooth is highly repeatable as shown by the high intraclass correlation coefficients. 3) Differences in inclination between left and right side exist and may be due to unilateral mastication, sleep side preferences, and/or asymmetric musculature. 4) Clinicians are now able to use the means and range values for inclination of the maxillary molars and cuspids as a reference for orthodontic treatment planning.

TABLE 1.—Descriptive Summary of Demographics, Molar Classification, Expander Status and Crossbite Status of Maxillary Canines and Molars (N=97)

Variables	Group	Total	Percent	Male	Female
Age	12-13 yr	51	52.6	27	24
	14-15 yr	46	47.4	23	23
Race	Caucasians	85	87.6	44	41
	Others (African	12	8.3	5	4
	Americans–		3.1	1	2
	Asians)				
Gender	Male	50	51.5	50	0
	Female	47	48.5	0	47
Molar	Class I	44	45.4	20	24
Classification	Class II	20	20.6	10	10
	Class III	8	8.2	4	4
	Class II subdiv right	15	15.5	8	7
	Class II subdiv left	6	6.2	5	1
	Class III subdiv right	2	2.1	1	1
	Class III subdiv left	2	2.1	2	0
Expander status	No expander	78	80.4	42	36
	Expander	19	19.6	8	11
Crossbite status	No crossbite	75	77.3	39	37
	Crossbite of canines	4	4.1	10	7
	Crossbite of posterior teeth	18	18.5	1	2

TABLE 2. — Intra-examiner Reliability of Maxillary Canines and Molars

Variables	Intraclass correlation (r)
Left canine	0.98
Right canine	0.97
Left molar	0.97
Right molar	0.96

TABLE 3a. — Inclination of Maxillary Canines and First Molars for Class I, II and III Subjects Excluding Subjects with Subdivision Malocclusion (N=72)

Variables(N=72)	Minimum	Maximum	Mean±SD
Upper Left Canine (N=72) (degrees)	91.8	123.8	105.9 $\pm$ 6.5*
Upper Right Canine (N=72) (degrees)	89.5	123.4	103 $\pm$ 6*
Upper Left 1st Molar (N=72) (degrees)	88.5	117.5	101.7 $\pm$ 5.4**
Upper Right 1st Molar (N=72) (degrees)	86.6	112.8	99.2 $\pm$ 5.3**

*Denote statistical significant difference a at $P \leq 0.01$
**Denote statistical significant difference a at $P \leq 0.02$

TABLE 3b — Inclination of Maxillary Canines and First Molars for Class I, II and III Subjects Excluding Subjects with Subdivision Malocclusion, African Americans and Asians(N=64)

Variables(N=64)	Minimum	Maximum	Mean±SD
Upper Left Canine (N=64) (degrees)	91.8	123.8	105.4 ± 6.6
Upper Right Canine (N=64) (degrees)	89.5	123.4	103 ± 6.3
Upper Left 1st Molar (N=64) (degrees)	88.5	117.5	101.5 ± 5.5
Upper Right 1st Molar (N=64) (degrees)	86.6	112.8	99.2 ± 5.5

TABLE 4 — Canine and Molar Inclination by Molar Classification and Crossbite Status, excluding Subdivision (N=72)

Molar classification	Upper Left Canine inclination (°)	Upper Right Canine inclination (°)	Upper Left 1st Molar inclination (°)	Upper Right 1st Molar inclination (°)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Class I (n=44)	105.8 ± 6.5	103.1 ± 5.7	101.9± 5.2	99.4 ± 4.5
Class I without crossbite (n=38)	105.1 ± 5.7	103 ± 4.5	101.8± 5.5	99.8 ± 4.3
Class II (n=20)	104.5 ± 6.3	101.5 ± 6.8	100.7± 5.4	97.5 ± 5.5
Class II without crossbite (n=15)	104.2 ± 6.1	101 ± 6.3	101.1± 5.3	98.8 ± 5.1
Class III (n=8)	109.3± 6.2	106.2± 5.5	103± 6.3	101.8± 8
Class III without crossbite (n=6)	108.8±5.8	107.7 ± 5.1	101.4 ±2.6	102.5± 5.7

TABLE 5 — Canine and First Molar Inclination by Subdivision, Expander Status and Crossbite Status (N=97)

	Left canine (°)	Right canine (°)	Left Molar (°)	Right Molar (°)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Subdivision (N=25)				
Class II				
Subdiv right (n=15)	107.3 ± 6.6	103.7± 6.4	103.1 ±4.7	98.2 ± 5.3
Subdiv left (n=6)	104 ± 9.1	101.8± 7.7	103.1± 4.0	100.7± 1.3
Class III				
Subdiv right (n=2)	111.6± 3.8	102.4 ±0.9	105.5± 1.0	100.3± 1.6
Subdiv left (n=2)	110.0± 7.7	109.1± 9.4	105.2± 2.3	103.9± 4.3
Expander status (N=97)				
No expander (n=78)	106.2± 6.9	103.1± 5.8	102.6± 5.0	99.6 ±5.0
Expander (n=19)	106.3± 5.8	103.5± 7.9	100.6 ± 5.5	98.1 ± 5.7
Crossbite status (N=97)				
No crossbite (n=75)	105.6± 6.2	103.2.±5.7	101.8± 4.9	99.8 ± 4.5
Crossbite of canines (n=4)	114.3	103.7	105.0	101.7
Crossbite of posterior teeth (n=18)	107.2± 8.1	103.1.±7.7	103.6.±6.2	96.2±6.9

Figure 1. Location of the canine in axial view

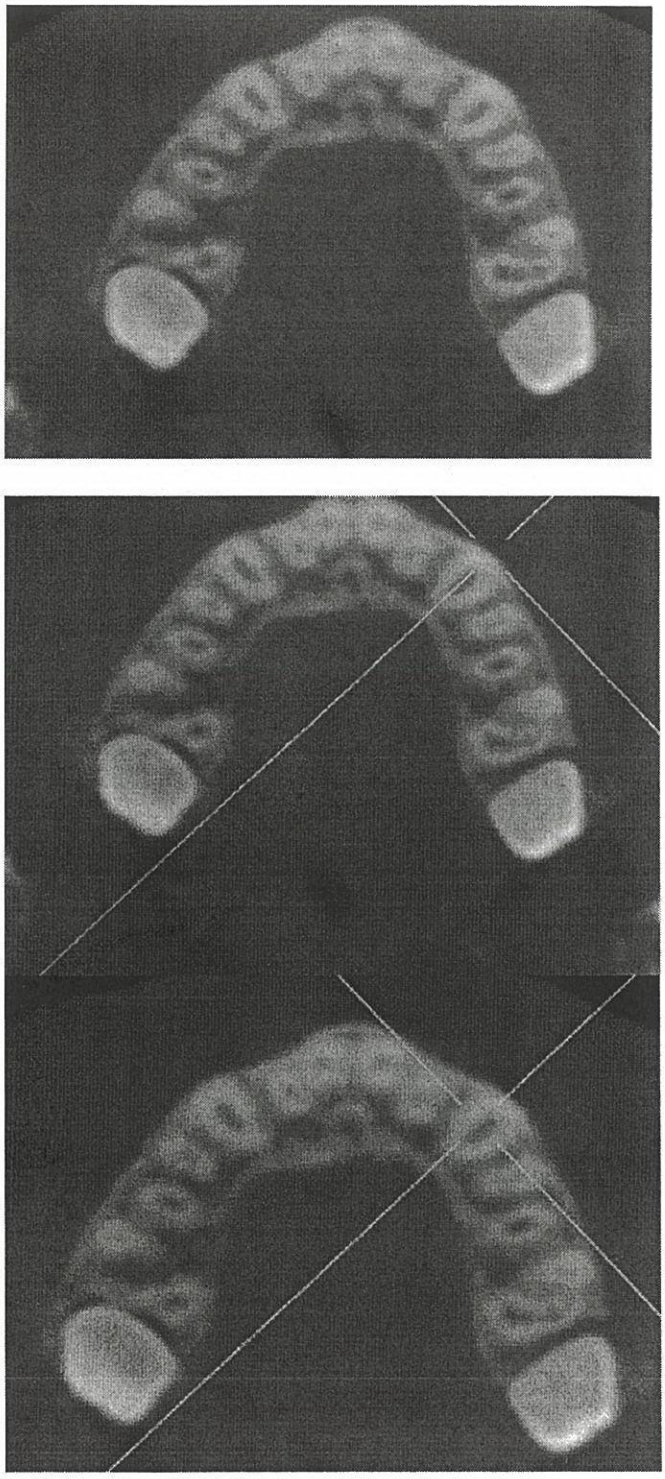
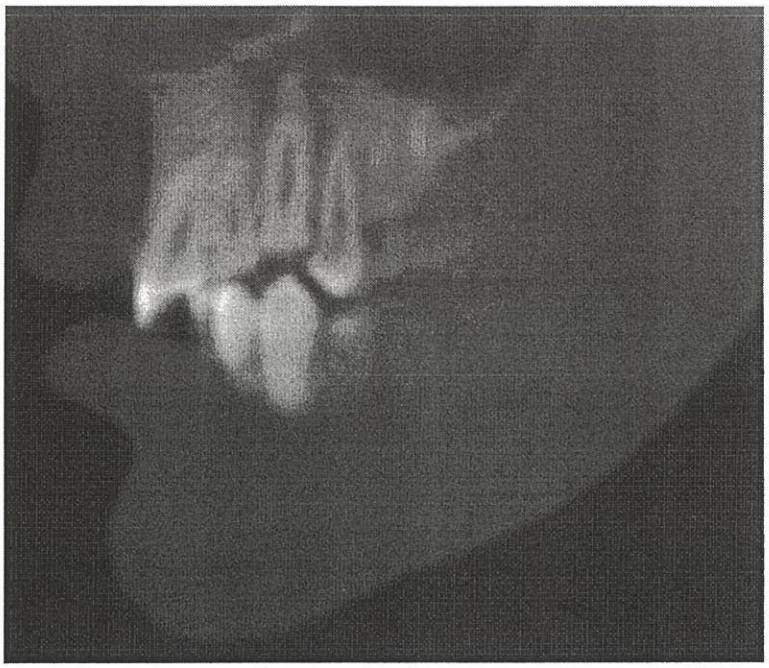


Figure 2. Location of the canine in sagittal view



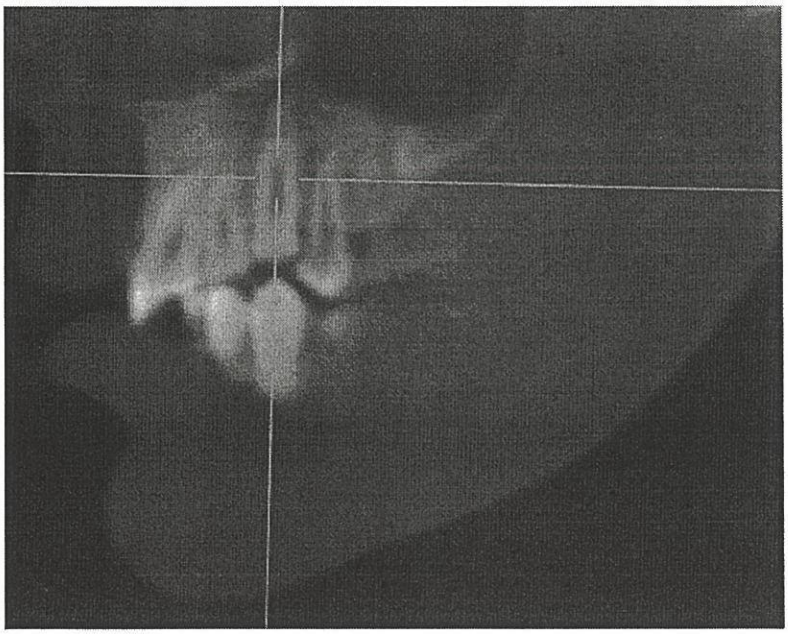


Figure 3. Location of the canine in coronal view

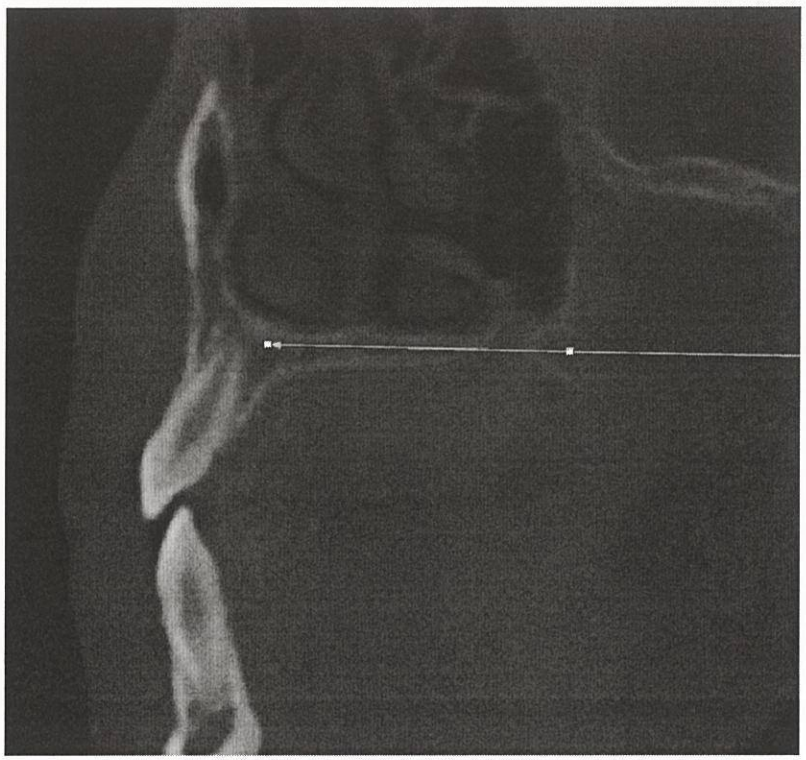


Figure 4. Measurment in coronal view

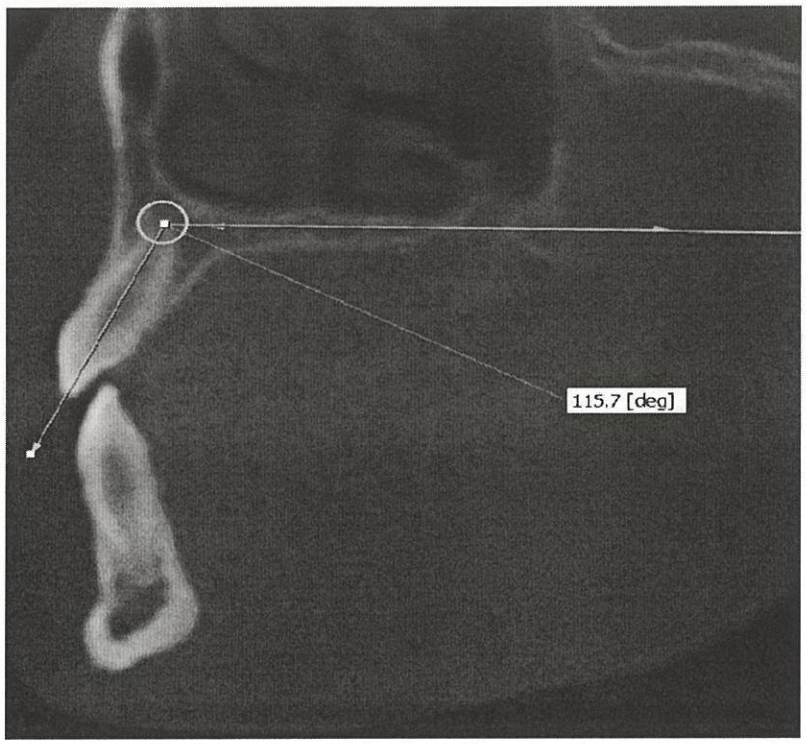


Figure 5. Orientation: In the sagittal view orient the line which represents the axial view so that it passes through ANS.



Figure 6. In the axial view locate the ANS (point where coronal and sagittal plane meet).

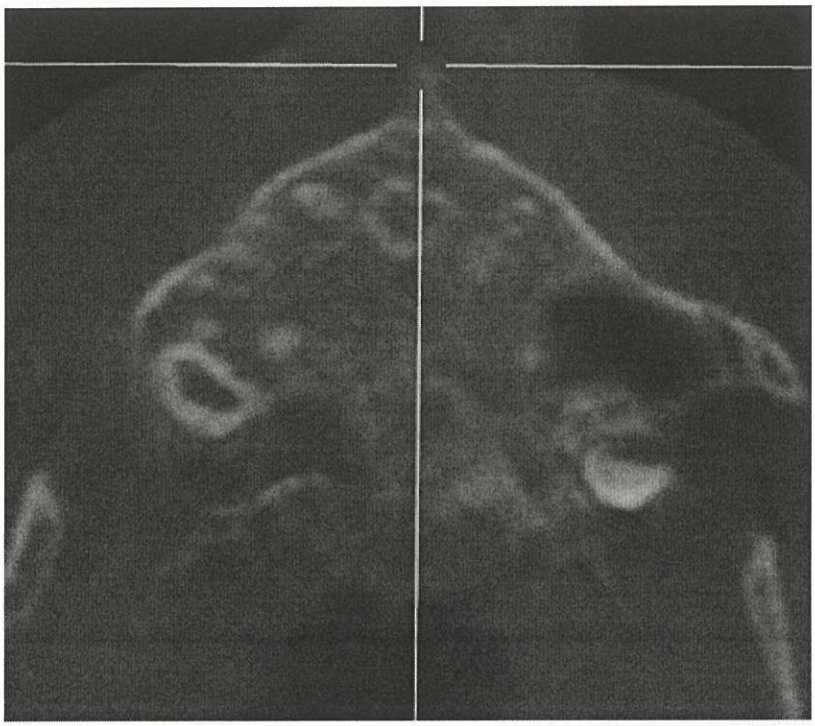


Figure 7. In the sagittal view move the line which represents the axial view downwards so that it passes through the center of the atlas.

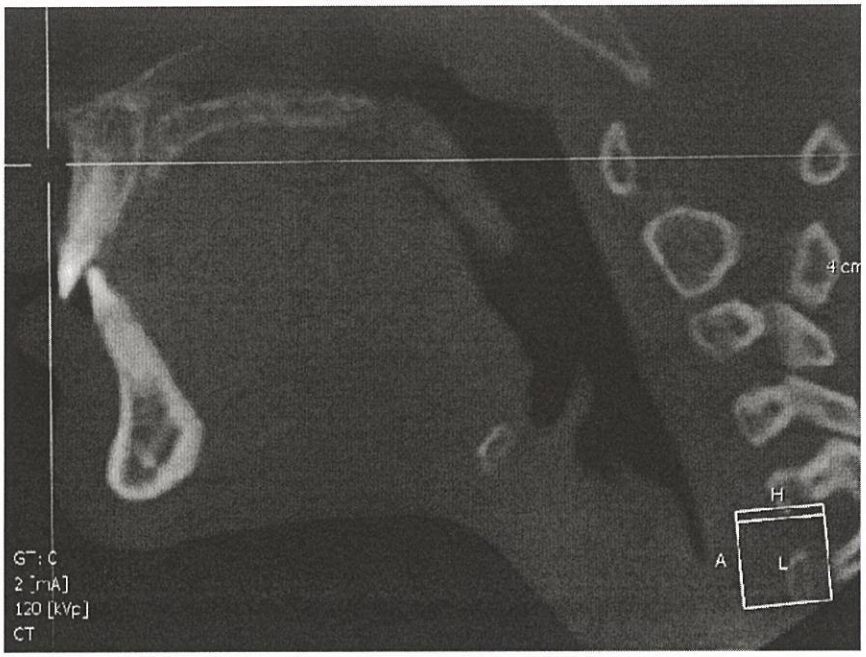


Figure 8. Go back to the axial view rotate the line that represents the sagittal plane around the ANS so that it passes through the center of the odontoid process.

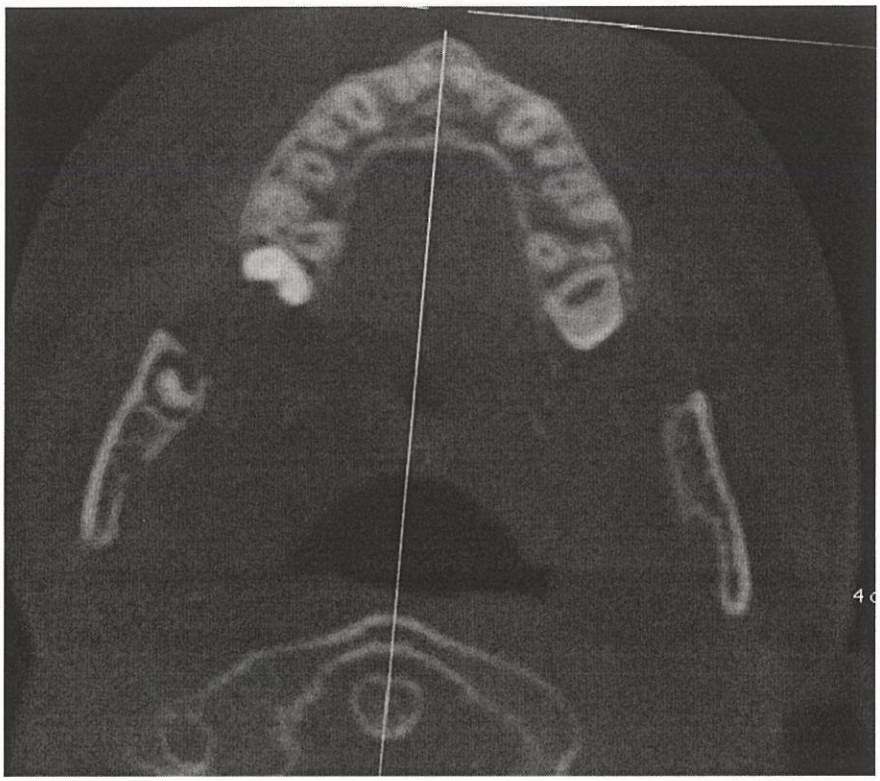


Figure 9. Locate molar in axial view, the point at which the palatal root length is the longest in the sagittal view.

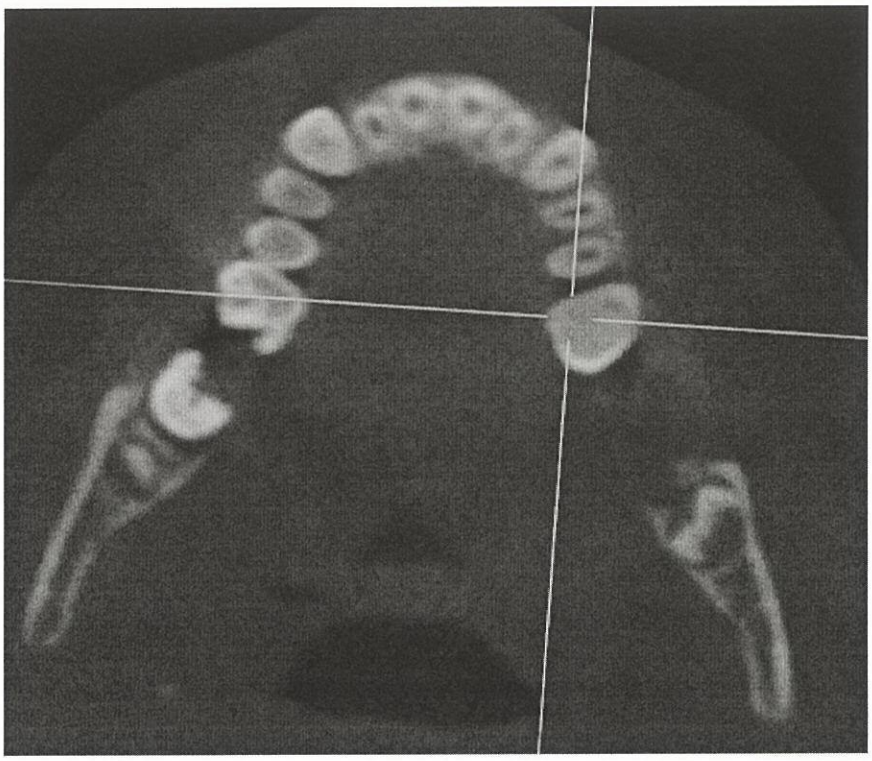


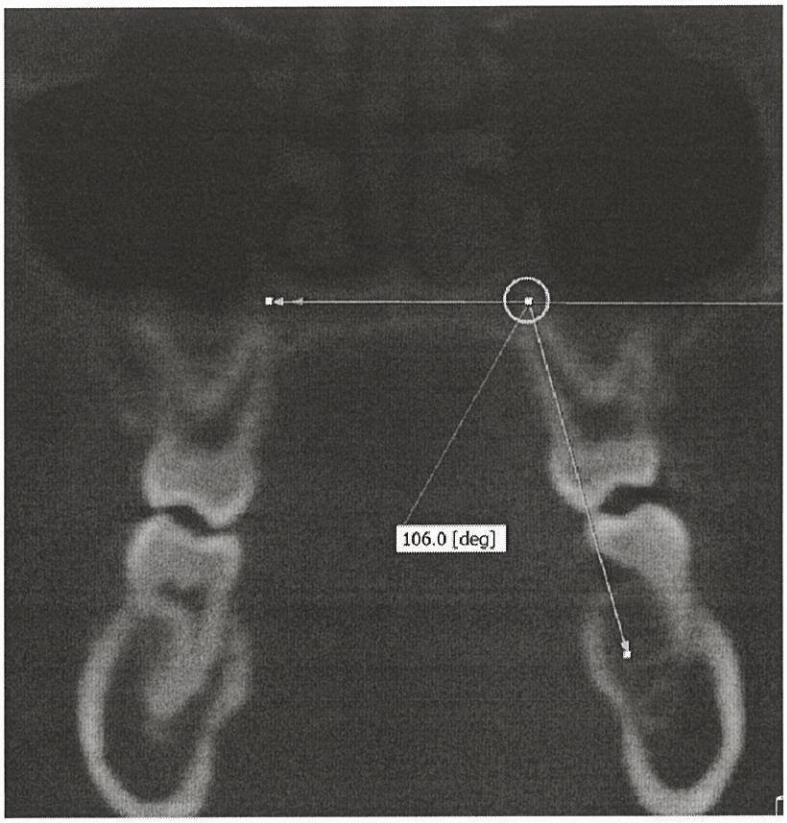
Figure 10. In sagittal view, position the line representing the coronal slice along the mesiopalatal cusp tip and the palatal root apex.



Figure 11. In coronal view, draw the reference line tangent to the inferior border of Nasal cavity



Figure 12. Measure the inclination through the long axis of the molar (represented by the line coming through the apex of the palatal root and the cusp tip) in the coronal view.



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APPENDIX 1

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.

Prospective data are NOT included in this exemption. De-identified pre-existing data to be collected on

09/12/2009 and after are NOT covered by this exemption.

Responsible Investigator: **Mark Hans**
Department: **Dental Orthodontics**
IRB Protocol Number: **20090901**
Title: ***Method to measure the buccolingual inclination of maxillary canines and first molars using CBCT***
Co-Investigator: **Eleftheria Karamitsou**

Exemption Date: September 11, 2009

APPENDIX 2

Raw Data: Left Canine and Right Canine Inclination, Left and Right First Molar Inclination, Age, Race, Gender, Molar Classification, Expander Status, Crossbite Status.

TABLE 1.--All data

No	NL3	NR3	NL6	NR6	age	race	gender	molar	xbite	rpe
1	96.3	94.3	99.9	99.3	2	1	2	1	1	1
2	114.6	108.9	98.9	112.8	2	1	2	5	1	1
3	89.8	90.5	104.5	99.3	2	1	1	4	1	1
4	111.7	102.8	103.6	100.3	2	1	2	3	1	1
5	106.3	99.7	100.8	101.9	2	1	2	4	2	2
6	102.9	97	97	98.9	1	1	2	1	4	2
7	108.5	102.7	99.7	99.9	1	1	2	1	1	1
8	120.2	123.4	105.3	98.3	1	1	2	1	2	2
9	97.3	99.3	102.5	101.2	1	1	1	4	2	1
10	93.6	95.8	102.1	100.3	2	1	1	1	1	1
11	103.4	107.2	101.4	105.7	1	1	1	1	1	1
12	111.7	94.8	108	92.8	1	1	2	3	1	1
13	103.6	98	98.2	87.9	2	1	1	5	2	2
14	111.0	115.2	93.6	91.3	1	1	2	2	2	2
15	111.2	106.8	97.5	97.6	1	3	2	1	1	1
16	106.4	106.8	105.8	105.3	1	2	2	1	1	1
17	104.4	108.5	102.2	101.8	2	1	2	1	1	1
18	107.4	104	96.8	99	1	1	1	4	1	1
19	107.7	107.8	99.6	98.6	2	1	2	1	1	1
20	112.9	94.5	109.4	87	2	2	1	3	2	1
21	111.5	104.3	100.9	106.1	1	1	1	3	1	1
22	115.7	114.4	105.5	100.9	1	1	1	4	3	1
23	101.0	111.2	91.2	109.9	2	1	2	1	1	2
24	100.5	102.5	101.2	98.2	2	1	1	1	1	1
25	91.8	103.4	103.5	109.7	1	1	1	2	1	1
26	100.6	99.6	95.3	99.3	1	1	1	2	1	2
27	107.9	105.2	98.7	93.8	1	1	1	1	1	1
28	99.0	96.3	109.5	96.6	1	1	1	2	2	2

29	108.2	105.6	94.1	94.5	2	1	2	1	1	1
30	105.4	98.3	101.1	92.3	2	1	1	3	1	1
31	113.3	108.1	102.8	95.3	2	1	2	2	1	1
32	98.0	97.5	98.1	93.6	2	1	2	1	1	1
33	108.5	104.3	88.5	88.5	1	1	2	2	1	1
34	103.7	95.4	99.8	102.4	2	1	1	1	1	1
35	103.4	97.1	104.3	97.5	2	1	2	1	1	2
36	116.4	116.5	104.2	102.1	1	1	1	2	1	1
37	103.3	104	100.2	100.1	1	1	2	5	1	1
38	101.9	101.7	99.2	103.2	1	1	2	5	1	1
39	107.5	102.6	114.2	100.4	2	1	2	1	1	1
40	100.6	104.2	100.7	103.5	2	1	1	1	1	1
41	113.6	93.8	107.6	102.9	1	1	2	1	3	1
42	103.3	97.7	103	93.5	2	1	1	2	1	1
43	104.6	102.5	103.6	100.8	1	1	1	7	1	1
44	123.8	110.4	101.2	99.5	2	1	1	1	2	1
45	102.0	101.2	103.1	97.2	2	1	2	1	1	1
46	113.6	103.1	102.1	101.5	2	1	2	2	3	2
47	101.8	95.5	103.7	87	1	1	1	1	2	1
48	116.2	104.9	110.4	97.5	1	2	1	1	1	1
49	113.3	113	103.8	102.7	1	1	1	3	1	1
50	109.2	105.6	101.2	102.4	1	1	2	1	1	2
51	114.4	101.7	104.8	101.5	2	1	1	6	1	1
52	114.8	106.2	113.9	95.7	1	1	1	1	1	1
53	111.1	103.4	101.5	94.7	2	2	2	1	1	1
54	114.4	108	100.9	96.2	2	2	1	5	1	1
55	111.5	113.7	97	99.7	1	1	1	3	1	2
56	107.3	101.8	109.2	97.4	2	1	2	3	2	1
57	91.8	93.6	95.5	98.9	2	1	1	1	1	1

58	106.0	58	102.7	102.4	1	1	2	3	1	2
59	104.8	98	106.6	99.6	2	2	1	1	1	1
60	109.6	114.9	107.2	102.9	1	1	1	3	1	1
61	101.6	102.3	109.8	101.5	1	1	1	2	1	1
62	90.4	101.3	100.2	97.8	2	1	1	3	1	1
63	111.1	107.4	106.8	96.8	1	1	2	1	1	1
64	93.2	101.7	92.7	103.8	2	1	1	1	1	1
65	109.9	106.8	99.2	93.4	2	2	1	3	1	1
66	98.9	89.5	97.1	93.3	1	1	1	2	1	1
67	106.4	106.6	97	93.7	2	1	1	2	2	2
68	107.8	101.3	104	98.1	1	1	1	2	1	1
69	109.4	107.8	94.2	97.8	2	1	2	1	1	1
70	108.3	97.2	106	93.8	2	1	1	1	1	2
71	105.7	105.8	96.4	99.9	1	1	1	1	1	2
72	102.4	95.3	107.4	105.6	1	2	2	2	1	2
73	105.6	106	98.6	98.9	1	1	2	1	1	1
74	109.3	102	108	95.4	1	1	1	1	1	1
75	103.4	96.6	98.3	99.2	1	1	2	2	1	1
76	107.8	102.9	108.5	102.4	1	1	1	4	1	1
77	97.7	96.1	96.4	96.5	2	1	2	3	1	1
78	105.5	103.1	101.5	100	2	1	1	1	1	1
79	96.1	93.7	95.5	86.6	2	1	1	2	2	2
80	113.4	103.8	99.5	94.6	2	1	2	1	1	1
81	113.3	116.7	104.6	99.3	1	1	1	5	1	1
82	115.5	115.8	106.9	107	1	3	1	7	1	1
83	101.0	101.4	101.6	99	1	1	2	2	1	1
84	117.6	105.4	117.5	111.6	2	1	1	5	2	1
85	108.9	103.1	106.3	99.1	2	2	2	6	2	1
86	99.1	105.2	98.2	105.3	2	1	2	3	2	1
87	106.7	109.7	111	99.8	1	1	1	1	1	1

87	106.7	109.7	111	99.8	1	1	1	1	1	1
88	100.5	102.2	103.4	95.2	1	1	1	1	2	1
89	105.8	107	105	103.8	1	1	2	5	1	1
90	104.7	93.7	104.6	97.2	1	1	2	2	1	1
91	104.7	101.1	106	105.6	2	1	1	1	1	1
92	110.0	104.5	96.1	99.7	2	3	2	2	1	1
93	105.1	97.1	103.6	101.7	1	1	2	1	1	1
94	100.5	106.7	95	109.7	2	1	2	1	1	1
95	103.4	102.9	106.2	108.3	1	1	2	1	1	1
96	100.6	101.5	100.5	100	1	1	2	2	1	1
97	111.8	102.9	110.5	97.2	1	1	2	3	2	2

What follows are the definitions for the column headings used in Table 1.

Age

1 = 12-13 years old

2 = 14-15 years old

Race

1 = Caucasians

2 = African -American

3 = Asian

Gender

1 = Male

2 = Female

Molar Cl = Molar Classification

1 = Class I

2 = Class II

3 = Class III

4 = Class II subdivision right

5 = Class II subdivision left

6 = Class III subdivision right

7 = Class III subdivision left

Rpe = Expander status

1 = none

2 = Haas, Hyrax, Bonded

X-bite = Crossbite status

1 = none

2 = Crossbite of posterior teeth

3 = Crossbite of canines

Left canine = Inclination of left maxilalry canine (°)

Right canine = Inclination of right maxillary canine (°)

Left molar = Inclinaiton of left maxillary first molar (°)

Right molar = Inclinaiton of right maxillary first molar (°)

TABLE 2.-- Reliability Raw Data: Maxillary canine and first molar inclination, of thirty randomly selected subjects

22	115.7	115.4	105.4	101.1
68	107.9	102.1	103.6	97.1
71	104.7	105	95.4	99.6
64	93.2	103.3	91	103.8
93	105.6	96.1	103.1	101.2
69	108.6	108.3	94.3	98
95	103.8	103.1	105.9	107.9
97	111.9	103.2	108	96.8
94	99.6	106.8	105.9	95.9
59	104.9	99	105.8	100.5
61	102.4	102.9	110.4	100.8
66	99.4	90.4	97.6	92.9
58	105.6	105.5	102.9	103.4
62	91.1	102.3	101	98.2
76	107.9	102.6	109	101.6
12	112.4	95.2	108.2	92.4
79	95.8	93.5	93.5	85.8
63	111.8	106.8	107.1	96.5
27	107.0	105	99.4	94.2
67	105.5	105.9	96.6	92.9
78	105.7	103.6	101.5	100.2
74	110.6	101.4	108.8	95.4
92	111.2	105.6	95.8	100
96	101.7	101.1	99.8	99.6
74	110.6	107	105.4	102.1
65	110.4	105.8	100	92.3
91	105.4	102	105.4	106.2
72	102.5	94.6	108.2	104.9
75	106.4	94.8	97	100.4
18	105.5	106.2	96.8	103.4

TABLE 3.-- Descriptive Statistics for Inclination of Maxillary Canines and First Molars For Total Subjects

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Left canine (°)	97	89.8	123.8	106.2	6.70
Right canine (°)	97	89.5	123.4	103.18	6.20
Left molar (°)	97	88.5	117.5	102.19	5.17
Right molar (°)	97	86.6	112.8	99.27	5.13

APPENDIX 3

Paired t-test for Inclination between the Left and Right Maxillary Canines and First Molars in Subjects without Subdivision Malocclusion

TABLE 4.-- Left and Right Maxillary Canines

Left canine (n=72)	Right canine (n=72)	P-Value
Mean ± SD	Mean ± SD	
105.9 ± 6.5	103 ± 6	0.00

TABLE 5.-- Left and Right Maxillary First Molars

Left first molar (n=72)	Right first molar (n=72)	P-Value
Mean ± SD	Mean ± SD	
101.7 ± 5.4	99.2 ± 5.3	0.02

APPENDIX 4

Differences in Inclination of Maxillary Canines and First Molars between males and females, adolescents 12-13 and 14-15 years old, adolescents with class I, II and III molar classification, patients treatment planned with and without RPE. (excluding subjects with subdivision malocclusion N=72)

TABLE 7 – Gender Differences in Maxillary Canine and First Molar Inclination, excluding subjects with subdivision malocclusion. (N=72)

Variables	Male (n=34)	Female (n=38)	P-value
	Mean ± SD	Mean ± SD	
ULCanine inclination (°)	104.9 ± 7.7	106.7 ± 5.2	0.08 (NS)
URCanine inclination (°)	102.3 ± 6.1	103.7 ± 6.0	0.7 (NS)
UL 1st Molar inclination (°)	103.0 ± 5.7	100.7 ± 5.0	0.5 (NS)
UR 1st Molar inclination (°)	98.4 ± 5.6	99.9 ± 5.0	0.2 (NS)

TABLE 9 – Age Differences in Maxillary Canine and First Molar Inclination, excluding subjects with subdivision malocclusion. (N=72)

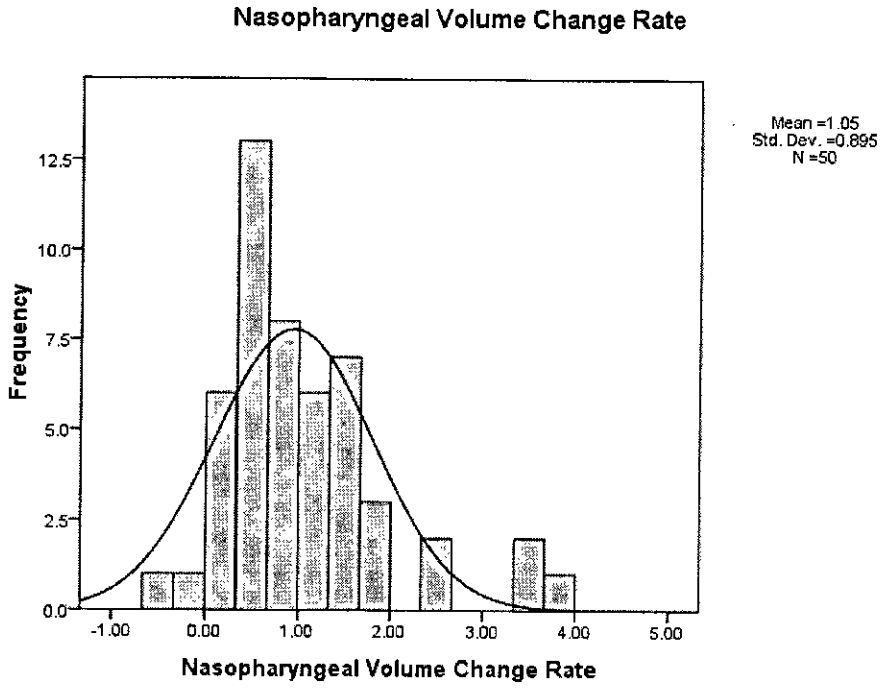
Variables	Age 12-13 yr (n=38)	Age 14-15 yr (n=34)	P-value
	Mean ± SD	Mean ± SD	
ULCanine inclination (°)	106.2 ± 5.8	105.5 ± 7.3	0.2 (NS)
URCanine inclination (°)	103.6 ± 6.9	102.5 ± 5.1	0.4 (NS)
UL 1st Molar inclination (°)	102.7 ± 5.3	100.7 ± 5.4	0.6 (NS)
UR 1st Molar inclination (°)	99.2 ± 4.8	99.2 ± 6.0	0.2 (NS)

TABLE 10 – Expander Status Differences in Maxillary Canine and First Molar Inclination, excluding subjects with subdivision malocclusion. (N=72)

Variables	No expander (n=78)	Expander(n=19)	P-value
	Mean ± SD	Mean ± SD	
ULCanine inclination (°)	106.2 ± 6.9	106.3 ± 5.8	0.3(NS)
URCanine inclination (°)	103.1 ± 5.8	103.5 ± 7.9	0.07(NS)
UL 1st Molar inclination(°)	102.6 ± 5.0	100.6 ± 5.5	0.4(NS)
UR 1st Molar inclination(°)	99.6 ± 5.0	98.1 ± 5.7	0.5(NS)

37 5 CW TH 4505
01/11 00-104-07 OHIO
Group

Figure 15. Nasopharyngeal Volume Rate of Change (CC/Yr)



65 52 CW 5227
02/10 00-104-07 Ohio
TH
Group

premolars and maxillary lateral incisors to properly evaluate the potential for increased risk in relatives.