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MEASURING BUCCOLINGUAL INCLINATION OF MANDIBULAR CANINES AND FIRST MOLARS USING CBCT

by

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

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MEASURING BUCCOLINGUAL INCLINATION OF MANDIBULAR CANINES AND FIRST MOLARS USING CBCT

Abstract

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This study had three objectives: 1. To develop a reliable method to measure buccolingual inclination of mandibular canines and first molars using CBCT. 2. To use this method to determine the mean and standard deviation for buccolingual inclination of the mandibular canines and first molars 3. 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. The sample consisted of 56 male and 52 female patients, with an average age of 13.2 ± 1.0 years. A commercially available software program (Accurex, Cybermed Inc - Seoul, Korea) was used to measure tooth inclination from CBCT images through the long axis of the tooth. A line tangent to the lower border of the mandible was used as a reference. Intercanine and intermolar widths were

measured on the study models using a digital caliper. In addition, Angle molar classification, expander status and crossbite status were collected. For the mandibular canines, the mean inclination was 98.0 ± 4.1° and the mean intercanine width was 26.0 ± 2.2 mm. For the mandibular molars, the mean inclination was 74.6 ± 4.7° and the mean intermolar width was 40.9 ± 2.7 mm. The first molar inclination of subjects with Class II molar was significantly less than Class I subjects (75.7 ± 4.9° VS 73.5 ± 3.7° respectively) ($p \leq 0.05$). The first molar inclination of subjects who underwent palatal expansion was signicantly less than that of subjects who did not have palatal expansion (75.3 ± 4.6° VS 73.3± 4.8° respectively) ($p \leq 0.05$). No differences related to malocclusion were found for canine inclination. In addition, there were no statistically significant age or gender differences in inclination of the mandibular canines or first molars Intra-examiner reliability showed good reproducibility for this method ($r \geq 0.94$). It was concluded that CBCT can be used to reliably measure mandibular buccolingual inclination of canines and first molars. Dental compensations in molar inclination were

seen for Class II subjects and in patients receiving palatal expansion.

DEDICATION

This thesis is dedicated to my father Tawin, mother Jiralak, brother Prapan, sister Lucksikarn, grandparents, aunts, uncles and cousins. I am sincerely grateful for your unconditional love and unending support. I am very fortunate to have you as my family.

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TABLE OF CONTENTS

Page

ABSTRACT ii

DEDICATION v

ACKNOWLEDGEMENTS vii

TABLE OF CONTENTS viii

LIST OF FIGURES x

LIST OF TABLES xi

LITERATURE REVIEW 1

STATEMENT OF THESIS 23

MANUSCRIPT 24

APPENDICES

1. IRB Approval 67

2. Raw Data: All Data 69

3. Raw Data: Paired t-test for Inclination between the Left and Right Mandibular Canines and First molars 79

4. Raw Data: Pearson Correlation for Mandibular Canines and First Molar Inclination, Intercanine and Intermolar Width 81

5. Raw Data: Width and Inclination of Mandibular Canines and First Molars for Caucasoid Subjects excluding Subdivision Malocclusion 84

Page

REFERENCES 86

LIST OF FIGURES

Figure Page

1. Location of the mandibular canine in the axial plane 53

2. Location of the mandibular canine in the sagittal plane 54

3. Location of the mandibular canine in the coronal plane 55

4. Measurement of the mandibular canine inclination through the long axis of the tooth 56

5. Location of the mandibular first molar in the axial plane 57

6. Location of the mandibular first molar in the sagittal plane 58

7. Location of the mandibular first molar in the coronal plane 59

8. Measurement of the mandibular first molar inclination through the long axis of the tooth .. 60

9. Measurements on study models 61

10. Average inclination of the mandibular canine .. . 62

11. Average inclination of the mandibular molar 63

LIST OF TABLES

Table		Page
1.	All Data	70
2.	Reliability Raw Data: Mandibular Canine and First Molar Inclination, Intercanine Width and Intermolar Width	77
3.	Descriptive Statistics for Inclination and width of Mandibular Canines and First Molars for total subjects	78
4.	Paired t-test for Inclination between the Left and the Right Mandibular Canines in Subjects without Subdivision Malocclusion	80
5.	Paired t-test for Inclination between the Left and the Right Mandibular First molars in Subjects without Subdivision Malocclusion	80
6.	Pearson Correlation for Mandibular Right Canine and Others	82
7.	Pearson Correlation for Mandibular Right First Molar and Others	82
8.	Pearson Correlation for Mandibular Left Canine and Others	82
9.	Pearson Correlation for Mandibular Left First Molars and Others	83
10.	Pearson Correlation for Mandibular Intercanine width and Others	83
11.	Pearson Correlation for Mandibular Intermolars Width and Others	83

Page

12. Width and Inclination of Mandibular Canines and First Molars for Class I, II and III Caucasoid Subjects excluding Subdivision Malocclusion 85

LITERATURE REVIEW

Crown inclination is one of the Andrew's "Six Keys of Normal Occlusion," and is often discussed in orthodontic literature. Crown inclination is determined by the angle between a line 90° to the occlusal plane and a line tangent to the middle of the labial or buccal clinical crown (Andrews 1972). Andrews stated that properly inclined teeth contribute to a normal overbite and good posterior occlusion. The American Board of Orthodontics (ABO, 1998) licensure exam includes an assessment of the buccolingual inclinations of posterior teeth in the phase III clinical examination. The board states that "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." It is believed that more ideal crown inclinations may be more stable. Expansion of the mandibular arch may increase arch length for resolution of crowding, however stability of these changes is a concern. Obtaining space by expanding the

mandibular arch width may help treat borderline cases without extracting (Housley et al. 2003).

Crown inclination can be measured using study models (Vardimon et al.1986; Ross et al.1990; Marshall et al.2003; Janson et al.2004, Vardimon et al.1986) evaluated torque data in treated and untreated subjects with normal occlusion. Group 1 was comprised of 34 nonextraction cases treated with removable appliances, with a mean age of 15.9 years post-retention. Group 2 was comprised of 20 untreated cases with a mean age of 24.3 years. The angle of crown inclination was formed by the intersection of a line perpendicular to the occlusal plane and a line tangent to the middle of the labial or buccal long axis of the clinical crown, similar to the angle used in Andrews' study. The result revealed a negative torque of the mandibular buccal segments with a significant increase towards the posterior. In the untreated group, they reported -9° torque and -26° torque in the mandibular canine and first molar respectively. In the treated group, they reported -10° degrees of torque and a -27° of torque in the mandibular canine and first molar respectively. In addition, they found that the facial crown contour was

important in selecting the tangent point used for constructing the torque angle. The facial surface of a tooth is not a uniform curve, and it is difficult to draw a unique tangent at any given point. In addition, the angle between the crown and the root may affect individual torque variation.

Ross et al.(1990) investigated variations in faciolingual tooth inclinations correlated with variations in vertical skeletal growth pattern. Occlusal surface inclinations were obtained from study models of seventy-two Caucasian subjects before orthodontic treatment ranging in age from 9.5 to 41.5 years. Subjects were placed into 4 groups as follows: Group 1 were subjects with ideal dental occlusion based on the standards set by Andrews (1972), irrespective of skeletal pattern (twenty-one subjects). Group 2 were subjects with MP-SN angle $\leq 26^{\circ}$ (sixteen subjects). Group 3 were subjects with MP-SN angle 32° (eighteen subjects). Group 4 were subjects with MP-SN angle 38° (seventeen subjects). The occlusal surface was formed by a line connecting the mesiobuccal and mesiolingual cusps of each molar in transverse view. The inclination of the occlusal surface was reported as the angle formed by a

perpendicular to the occlusal surface line and its intersection with the model base, which was trimmed parallel to the posterior occlusal plane, ±90°. They reported -7° of torque for mandibular first molars in the twenty-one subjects of Group 1 with normal occlusion based on Andrew's six keys (molar relationship, crown angulation, crown inclination, rotations, spacing and occlusal plane). They also found that there was no difference in mean first molar buccolingual occlusal surface inclination between groups of patients with varying vertical facial proportion. However, the number of female subjects was twice more than that of male subjects and there was no reliability test in the measurements. They did not report the MP-SN angle in subjects of Group 1. In addition, this result could be biased due to sample selection.

Marshall et al. (2003) looked at thirty-six subjects ranging in age from 7 to 30 years. Longitudinal changes in molar crown torque and arch width were evaluated from the time of first permanent molar eruption to early adulthood. Four cusp height measurements and two buccolingual intermolar cusp distances were measured in study models. The custom measurement gauge was laid

transversely across the dental arch to contact the most elevated cusp on the right and left. Differences in height for mesial cusps and distal cusps were measured separately. If the lingual and buccal cusps were in simultaneous contact with the measuring gauge, the height difference was recorded as zero (zero torque value). The occlusal plane was used as the reference plane. The study showed that mandibular first and second molars decreased lingual crown torque with time and increase in intermolar width over time. However, these results were based on a small sample size.

Janson et al. (2004) compared the buccolingual inclinations of the posterior teeth in subjects with a horizontal growth pattern (short lower anterior face height) with those in subjects with a vertical growth pattern (long lower anterior face height). They looked at the pretreatment study models of seventy subjects. All subjects were evaluated using frontal and profile facial photographs, and a lateral cephalometric radiograph. The cephalograms were traced on acetate and the ratio between upper and lower anterior face height was evaluated. They devided subjects into two groups. Group I was comprised of thirty-five subjets with a

horizontal facial growth pattern (sixteen male, nineteen female, aged 14.08 ± 3.10 years). Group II was comprised of thirty-five subjects with a vertical facial growth pattern (fifteen male, twenty female, aged 13.95 ± 2.41 years). Their measurement method was similar to the one used by Ross et al. (1990). They assessed the inclination of maxillary first molars and second premolars, and mandibular first molars and second premolars. They found the maxillary posterior teeth in subjects with vertical growth patterns had a significantly greater buccal inclination as compared with those with horizontal growth patterns. They reported -7° torque for mandibular first molar inclination in subjects with a horizontal growth pattern and -8° torque for mandibular molar inclination in subjects with a vertical growth pattern. This difference between mandibular first molar inclinations was not statistically different between these two groups. They also reported that the measured angle does not conform to the actual long axis inclination of the tooth but only to the occlusal surface inclination. Therefore, extrapolation of the results of the occlusal surface inclination to the long axis inclination between different tooth types cannot be

achieved, because of the different dental crown anatomies. In other words, the use of the occlusal surface inclination is only a proxy measure of the true three dimensioned tooth inclination.

Further studies attempted to use a new reference plane besides the occlusal plane in order to reduce this bias. The reference plane should be stable so that dental modifications during treatment can be assessed. Ferrario et al. measured the three dimensional inclination of the facial axis of the clinical crown and the size of the clinical crowns in one hundred Caucasians of Italian descent. The subjects consisted of twenty-two female and twenty-one male subjects aged 13-15 years, and thirty-one female and twenty-six male subjects aged 16-26 years. All subjects had full permanent teeth with bilateral Angle Class I molar and canine relationships, normal overjet, no crossbite, no cast restorations or cuspal coverage, no previous orthodontic treatments, no history of craniofacial trauma or surgery, and no temporomandibular disorders. Landmarks were identified on the dental casts and included the gingival and the occlusal limits of the facial axis of the clinical crown (the most prominent and centermost vertical portion of

the labial surface), intersections of the palatal or lingual sulci of the first permanent molars with the gingival margin, and maxillary and mandibular incisive papillae. The three dimensional coordinates of the landmarks were obtained with a three dimensional electromagnetic digitizer (3Draw, Polhemus Inc-Colchester, VT) interfaced with a computer. This system provided actual metric data independent from external reference systems. They reported an error of 2.3-2.5° from ten randomly selected casts. They found that the facial axis of the clinical crown was -12.5° for mandibular canines in girls, -10° for mandibular canines in boys, -36.3° for mandibular first molars in girls and -35.8° for mandibular first molars in boys. They concluded that the facial axis of the clinical crown changed from adolescence to young adulthood, with an age-related decrease in dental inclination. In addition, the suggested that this process could be the effect of a buccal and mesial dental drift.

The use of computed tomography (CT) has been shown to be useful for the measurement of transverse dimensions in any area as well as in axial changes in the inclination of teeth (Podesser et al.2004; Garib et al.

2006). Podesser et al.(2004) aimed to develop a simple technique for a reproducible evaluation of maxillary structures based on a series of frontal CT scans using ten adult subjects. Eighteen registration points were made on the maxillary canine, the first molar and the nasal cavity in an axial view. Linear measurements and angulation were made among these points. The measurements were repeated a minimum of ten days later to determine the intra-observer and inter-observer variation. They found a difference between the first and second reading, a maximum linear value of 1.4 mm and 3.05° for intra-observer error, but it was not statistically significant. The correlation between the first and second reading ranged from 0.48 to 0.98. For inter-observer error, with the exception of maxillary alveolar width, there were no significant statistical differences between the readings of two observers. However, while there was no statistical difference between the readings from the two observers, single difference in linear variables of up to 5 mm and angular variables of 7.7° could be seen. They suggested that CT scans represent a reasonable method by which the transverse morphology of the maxillary structures can be

described. However, in this study, the wide variation in individual measures that were found may be due to a small sample size. In addition, the methods were not clear enough to repeat.

In the study by Garib et al. (2006), computed tomography was used to evaluate the effect of rapid maxillary expansion on the periodontal tissue, in eight subjects. Bone plate thickness and buccal alveolar crest level were measured, and then remeasured one month later by the same examiner. However, they evaluated intra-examiner reliability using questionable methodology and did not report a typical intraclass correlation.

Tsunori et al. (1998) used CT to evaluate the relationship between mandibular structures and facial type. Seven measurements including height, width, buccal, lingual and basal cortical bone thickness, tooth and bone inclination were made on thirty-nine dry skulls of male Asiatic Indians. The skulls were divided into three groups according to facial pattern: short (nine subjects), average (twenty-three subjects), and long (seven subjects) facial types. The measurements were repeated on twenty skulls two months later to assess the significance of error. They found a small number of

significant mean differences between the first and second measurements of some variables including tooth axis. The errors ranged from 2.4-7.2%. Regarding the inclination, they measured the angle from the tooth long axis and lower border of cortical bone of mandible. They reported statistically significant differences in first molar inclination of 75.8°, 80.2° and 82.8° in short, average and long facial type respectively. They stated that there was a significant but complex relationship between structures of mandible and facial type. However, there were some limits in this study including a male only sample. The measurements were made indirectly from the radiographs so there may be an increase the error of the reference points. The reference points were also not clearly defined enough to repeat. There were not sufficient details presented on how measurements were obtained which may explain the larger error. In addition, the error was not accounted for in the results.

Cone-beam computed tomography (CBCT) scanners have lower radiation doses and lower costs. They are useful for three dimensional dental imaging and craniofacial applications (Cevidanes et al.2007; Mah et al.2004; Mozzo et al.1998; Nakajima et al.2005). Three dimensional

imaging allows for quantification of vertical, transverse and anteroposterior dimensions of the maxilla and the mandible. Nevertheless, the reliability of measurements has not been reported in these studies.

It is not possible to measure the long axis of the teeth in three dimensions using study models as used in many studies. The previous methods were limited to the coronal inclination of the teeth, using only the occlusal surface of the tooth and the cusp height. The advent of CBCT allows the analysis of buccolingual tooth inclination through the long axis of the tooth in three dimensions. Buccolingual tooth inclination is of clinical importance and is a determinant of static and functional occlusion; so the knowledge of three dimensional tooth inclination is important.

Arch width and arch form have implications in orthodontic diagnosis and treatment planning. Edward Angle opposed extractions in orthodontic treatment and substantial controversy on this topic still continues today (Dewel, 1981). Several approaches, such as conservation of leeway space, interproximal tooth reduction, rapid palatal expansion and functional appliances have allowed non extraction treatment. Rapid

maxillary expansion (RME) increases the transverse dimension of maxillary arch by separating the suture (Haas 1961; Bishara 1987) and has been used successfully to gain maxillary arch width and length partially by tipping teeth. However, gaining space in the mandibular arch has been limited to tooth movement, due to lack of a suture. Consequently, the mandibular expansion effect is localized to the alveolar bone and tooth inclination (Haas 1961). This factor leads to the consideration that expansion in the mandibular arch is not stable.

There are many factors affecting orthodontic posttreatment stability: posttreatment tooth positioning and establishment of functional occlusion, alteration of arch form, periodontal and gingival tissues, mandibular incisor dimensions, influence of environmental factors and neuromusculature, continuing growth and influence of the elements of the original malocclusion (Blake et al, 1998).

One important factor relevant to stability is arch width. Harris (1997) assessed longitudinal changes in size and form of the dental arches in a series of adults. Subjects had been participants as children in the Bolton-Brush longitudinal growth studies. Subjects were

Caucasian, healthy, and from an above-average socioeconomic segment of the population. None had been treated orthodontically. Molar classification, presence of crossbite, and non-response subjects were not mentioned. Dental casts of sixty adults at an average age of 20 years and at an average of 55 years of age were examined. Arch width at canines, first premolars and first molars, and arch length from canines to first molars were measured. Arch width was measured as the maximum distance of the buccal surfaces of the teeth. They reported that arch widths increased with age, with little change across the canines (mean = 0.5 mm), but more in the more distal regions of each arch (mean at intermolar width = 2.4 mm). In contrast, arch lengths decreases with time were statistically significant. However, there were twice as many male subjects as female subjects. Therefore, the finding might be mainly contributed by males.

Erdinc et al. (2006) investigated associations between cephalometric and dental cast parameters that may be predictors of post-treatment alignment of incisors. Dental casts from ninety-eight patients were measured using intercanine and intermolar widths. Intercanine

width was defined as the distance between cusp tips of the right and left canines. Intermolar width was defined as the distance between the central fossae of the left and right first molars. Dental casts and cephalometric records were evaluated before treatment, at the end of active treatment and at two years postretention. The subjects were equally divided into nonextraction and extraction groups. In the nonextraction group, there were nineteen male and thirty female subjects, with a mean pretreatment age of 14 years, 1 month. In the extraction group, there were nineteen male and thirty female subjects with mean pretreatment age of 12 years, 11 months. The study showed a pretreatment mean mandibular intercanine width of 26.03 mm and a mean mandibular intermolar width of 39.63 mm in the extraction group. In the nonextraction group, they reported a mean mandibular intercanine width of 25.71 mm and a mean mandibular intermolar width of 40.21 mm. The intercanine width was shown to increase with treatment. During the postretention period, there was relapse in both groups, however intermolar width was stable in both groups. They found no statistically significant correlation between any variables and mandibular incisor

irregularity. However, this study did not mention inclusion and exclusion criteria of sample selection.

Herby et al. (2006) determined the relationship between transverse skeletal changes and transverse molar movements during growth. Subjects were selected based on the following criteria: 1) longitudinal records available from ages seven to thirty years, 2) untreated Class I occlusion, 3) lack of distortion of the dental casts, 4) lack of excessive enamel wear or restorations of the dental cusps of the measured teeth, 5) lack of missing of extracted permanent teeth, and 6) lack of gingival recession with time in the first molar regions. Thirty-six subjects met the criteria which included subjects grouped into five stages of dentition development: early, middle, and late mixed dentition; adolescent dentition; and adult dentition. Posteroanterior radiographs and dental casts were used to measure transverse maxillary and mandibular dentoalveolar and skeletal widths. The results showed that transverse molar movements during growth mirror transverse basal bone width increases and alveolar process width increases. They showed that the posterior teeth are uprighting and expanding during

growth and spontaneous mandibular molar uprighting could be seen after rapid maxillary expansion.

Buccal expansion in the mandibular arch may help gain arch width. Housley et al. (2003) evaluated the effects of an expansion appliance in the mandibular arch and the stability of the expansion obtained. The sample consisted of twenty-nine Caucasian patients who had received nonextraction orthodontic treatment. These patients were selected based on the availability of their records and no missing permanent teeth. The effects of mandibular dental arch expansion were studied by measuring dental casts and cephalometric radiographs at pretreatment, posttreatment and postretention. The mean pretreatment age was 12 years, 5 months. The mean treatment time was 2 years, 6 months, and the mean post retention period was 6 years, 3 months. Arch width at the permanent canines (distance between cusp tips), first premolars, second premolars and first molars (distance between central grooves) were measured in millimeters. The data revealed that transverse expansion was more stable in the posterior region of the mandibular arch than in the anterior region. However, in this study there may have been selection bias since the patients

were selected based on the availability of records. There were no measurements after the appliance phase, but at the end of full treatment. Therefore, the findings included changes from both the expansion appliance and the fixed edgewise appliances. In addition, the values in the table of distribution for direction of treatment change and postretention change in dental cast measurements did not add up to total sample of twenty-nine patients. Therefore, the conclusions may not be valid because they were not based on all the data. In addition, there was no explanation for the exclusion.

There were the studies that investigated mandibular arch width in an untreated normal occlusion. Sinclair and Little (1983) looked at sixty-five children with dental and skeletal Angle class I relationships who had undergone no orthodontic treatment. The records were collected in three periods of time: mixed dentition (9-10 years), early permanent dentition (12-13 years) and early adulthood (19-20 years). Mandibular intercanine and intermolar widths were measured on the study models. Mandibular intercanine width was the distance between cusp tips, and mandibular intermolar width was the distance between mesiobuccal cusp tips. They found

statistically significant decreases of intercanine width from the mixed dentition to early adulthood. For mandibular intermolar width, male subjects showed insignificant increases in intermolar width over time while female subjects showed statistically significant decreases in intermolar width. They supported the concept that the intercanine width should remain unchanged during orthodontic treatment. Ferrario et al. (1999) used a three-dimensional electromagnetic digitizer to measure arch width in the mandibular arch. They had twenty adolescent subjects aged 12-14 years with full permanent dentition. Subjects had normal overjet and overbite, bilateral Angle class I molar and canine, and the absence of a crossbite. Arch width was measured on study models. Digitized landmarks were the midpoints of canine cusps, and buccal and lingual cusps of first molars. They reported 25.96 ± 2.39 mm and 42.97 ± 2.45 mm of mandibular intercanine width and intermolar width respectively. However, there was no reliability test of the measurement method in this study. They mentioned that the reliability of the measurements had been performed in their previous studies.

Contemporary practice has considered the mandibular arch as a limiting factor. In the situation where there is not sufficient space to accommodate the mandibular teeth, a decision will be make between extraction and expansion of the arch. Schulhof et al. (1978) examined the possiblility of buccal expansion in the mandibular arch as an alternative to extraction. They looked at buccal expansion of molars and cuspids using the frontal headfilm. There were thirty-four male and thirty-eight female subjects, however, they did not mention the ages of subjects or the inclusion criteria of the sample. The fifty measurements of the Rocky Mountain Data Systems were made for each subject. Norms were calculated based on the Ricketts analysis, then expressed in standard deviation from the norm before treatment, after treatment and postretention. They found that the canines were the greatest limiting factor for arch expansion and that the first premolars allowed the greatest opportunity for expansion. They observed that the cases expanded more than 1 mm exceeding the norm showed a greater tendency toward relapse.

Motoyoshi et al.(2002) performed the experiment to estimate the increase in arch perimeter associated with

mandibular lateral expansion. A three-dimensional finite element method and a computer graphics technique were used to simulated the mandibular expansion. The geometry of the model was determined using the mandibular bone of an East Indian skeletal specimen, and 1 mm computer tomogram (CT) slices were digitized with a microcomputer and a special software program. The three-dimensional computer graphics were used to construct a three-dimensional set-up instead of using a lower plaster model. Rotational movement was produced in the buccal segment from the first premolar to the second molar around the center of rotation. The center of rotation was determined as the convergence point of perpendicular lines to the displacement vectors at nodal points making up the first molar which was about 4.5 mm below the root apex of the first molar. Lateral expansion was produced by uprighting the buccal segment ten degrees around the center of rotation. The result showed that 1 mm of intermolar expansion increased the perimeter by 0.37 mm, and a 1 mm increase in unilateral arch width resulted in a change in tooth axis of 2.6°. However, this result was based on one skull and there was no reliability test in the measurement method.

The majority of past studies pertaining to mandibular arch width focused on changes with time and orthodontic treatment. Changes in arch width have also been a focus in retention studies (McCauley 1944; Riedel 1966; Kahl-Nieke et al.1995; Glynn et al.1987). The range and variation of mandibular arch width and tooth inclination in the general population have rarely been reported in spite of being a determinant in treatment planning.

STATEMENT OF THESIS

This study has three objectives: 1) to develop a reliable method to measure buccolingual inclination of mandibular canines and first molars using CBCT; 2) to measure and report mean buccolingual inclination using CBCT, and intercanine and intermolar widths using study models; 3) to compare inclination, intercanine and intermolar width between patients treatment planned with and without palatal expansion. It is hypothesized that there is no difference in mandibular canine and molar inclination, intercanine and intermolar width between patients treatment planned with and without expansion. If rejected, there would be a difference in the mandibular canine and first molar inclination, intercanine and intermolar between patients receiving palatal expansion and those of subjects without expansion.

MEASURING BUCCOLINGUAL INCLINATION OF MANDIBULAR CANINES AND FIRST MOLARS USING CBCT

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Objectives: 1. To develop a reliable method to measure buccolingual inclination of mandibular canines and first molars using CBCT. 2. To use this method to determine the mean and standard deviation for buccolingual inclination of the mandibular canines and first molars 3. 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. **Methods:** The sample consisted of 56 male and 52 female patients, with an average age of 13.2 ± 1.0 years. A commercially available software program (Accurex, Cybermed Inc – Seoul, Korea) was used to measure tooth inclination from CBCT images through the long axis of the tooth. A line tangent to the lower border of the mandible was used as a reference. Intercanine and intermolar widths were measured on the study models using a digital caliper. In addition, Angle molar classification, expander status and crossbite status were collected. **Results:** For the mandibular canines, the mean inclination was 98.0 ± 4.1° and the mean intercanine width was 26.0 ± 2.2 mm. For the mandibular molars, the mean inclination was 74.6 ± 4.7° and the mean intermolar width was 40.9 ± 2.7 mm. The first molar inclination of subjects with Class II molar was significantly less than Class I subjects (75.7 ± 4.9° VS 73.5 ± 3.7° respectively) ($p \leq 0.05$). The first molar inclination of subjects who underwent palatal expansion was signicantly less than that of subjects who did not have palatal expansion (75.3 ± 4.6° VS 73.3± 4.8 ° respectively) ($p \leq 0.05$). No differences related to malocclusion were found for canine inclination. In addition, there were no statistically significant age or gender differences in inclination of the mandibular canines or first molars Intra-examiner reliability showed good reproducibility for this method ($r \geq 0.94$). **Conclusions:** CBCT can be used to reliably measure mandibular buccolingual inclination of canines and first molars. Dental compensations in molar inclination were seen for Class II subjects and in patients receiving palatal expansion.

INTRODUCTION

Orthodontists have historically been interested in the buccolingual angulation of the teeth. Most clinicians believe that properly inclined teeth contribute to normal overbite and good posterior occlusion[1]. The American Board of Orthodontics[2] (ABO) licensure exam includes an assessment of the buccolingual inclination of posterior teeth in the phase III clinical examination. The ABO states that "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". Tooth angulation is also one of Andrew's "Six Keys to Normal Occlusion."[1] It is also believed that normal crown inclinations may be more stable.

By necessity, crown inclination of the posterior teeth has traditionally been measured using the occlusal plane[1, 3-5] and a line tangent to the middle of the labial or buccal clinical crown.[1,5] Vardimon et al.[5] evaluated certain aspects of third-order angulations in the normal dentition. The crown inclination measurement method was similar to that of Andrew's study[1]. They reported a minus nine degrees of torque and a minus 26 degrees of torque in the mandibular canine and first molar respectively. However, they found that the facial crown contour was important in selecting the tangent point used for constructing the torque angle. Since the facial surface of a tooth is not a uniform curve, it is difficult to draw a unique tangent at any given point. In addition, the angle

between the crown and the root may affect individual torque expression. For these reasons, the use of tangents to estimate tooth inclination is problematic.

Ross et al.[3] investigated variations in faciolingual tooth inclinations correlated with variations in vertical skeletal growth patterns. The inclination of the occlusal surfaces was obtained from study models. They reported a mean of minus seven degrees of torque for mandibular first molars in a group of 21 subjects with Class I occlusion. They found that no difference in the mean first molar buccolingual occlusal surface inclination between groups of patients with varying vertical facial proportions. Janson et al.[4] reported a mean of minus seven degrees torque for mandibular first molars in subjects with a horizontal growth pattern and a minus eight degrees torque for mandibular first molars in subjects with a vertical growth pattern. However, this difference between mandibular first molar inclinations was not statistically different between these two groups. Their measurement method was similar to the one used by Ross et al.[3] They reported that the measured angle does not conform to the actual long axis inclination of the tooth but only to the occlusal surface inclination. Therefore, extrapolation of the results of the occlusal surface inclination to the long axis inclination between different tooth types cannot be gained, because of the different dental crown anatomies[4]. In other words, the use of the occlusal surface inclination is only a proxy measure of the true three dimensional tooth inclination.

The use of computed tomography (CT) has been shown to be useful for the measurement of transverse dimensions in any area as well as in axial changes

in the inclination of teeth[6-7]. Tsunori et al.[8] used CT scans to evaluate the relationship between mandibular first molar angulation and facial type in 39 dry skulls of male Asiatic Indians. Although, they reported statistically significant differences in the inclination of first molars of 75.8° in short facial types, 80.2° in average facial types and 82.8° in long facial types. However, the sample size was small and the measurement error substantial making the values reported in this study of little clinical use.

The advent of the edgewise orthodontic appliance allowed orthodontist to modify the inclination of the teeth. Since inclination is under operator control, it is important for clinicians to have some guidelines for the range of normal inclination of the teeth. Cephalometrics allowed operators to determine the inclination of the lower incisors from the lateral view and to a lesser extent to measure the inclination of the molars on the front view. Cone beam computed tomography now allows clinicians to determine the inclination of any tooth in the mouth. Since clinicians often expand the dental arches to increase arch length, the degree two which changes in inclination contribute to arch expansion is of some interest.

Therapeutically induced changes in tooth inclination may be important factors for post treatment orthodontic stability. For example, increasing mandibular intercanine width has been implicated in post treatment relapse. Housley et al.[9] evaluated the effects of an expansion appliance in the mandibular arch and the stability of the expansion obtained. The data revealed that transverse expansion was more stable in the posterior region of the mandibular arch than in the anterior region.

The majority of past studies pertaining to mandibular arch width focused on changes over time and with orthodontic treatment. Changes in arch width have also been a focus in retention studies[10-13]. The range and variation of mandibular arch width and tooth inclination in the general population have rarely been reported in spite of the reported relationship between arch expansion and stability. In an attempt to determine the range of variation in arch width, a few studies have used untreated individuals.[14-15] These studies have found 25.14 ± 1.43 mm and 25.96 ± 2.39 mm of mandibular intercanine width, and 43.69 ± 2.77 mm and 42.97 ± 2.45 mm of mandibular intermolar width in adolescent subjects. They reported statistically significant decreases of intercanine width from mixed dentition to early adulthood.[15]

With the introduction of CBCT into clinical orthodontics, it is now possible to determine the mean, standard deviation and range of pretreatment variation in buccolingual tooth inclination for any tooth in the mouth. Given the amount of clinical interest in measuring the angulation of the lower incisor on the lateral cephalogram it is likely that a better understanding of the inclination of other teeth may have clinical importance. Ultimately, clinicians are interested in the role of tooth inclination in malocclusion.

This study has three specific aims: 1) to develop a reliable method to measure buccolingual inclination of mandibular canines and first molars using CBCT; 2) to determine the mean and standard deviation for buccolingual inclination of mandibular canines and first molars using CBCT, and 3) to compare inclination with intercanine

and intermolar width between patients treatment planned with and without palatal expansion.

MATERIALS AND METHODS

The Case Western Reserve University Institutional Review Board (IRB) approved the experimental protocol. Data were derived from pretreatment Cone Beam Computed Tomography scans (CB MercuRay^{TM}, Hitachi Medical Systems America Co. – Twinsburg, OH). All scans were taken in the Craniofacial Imaging Center at Case School of Dental Medicine during routine pretreatment records appointments in 2006. There were 200 pretreatment patient records consisting of CBCT scans, study models, photographs and medical history forms. Subjects presented to the dental school for comprehensive orthodontic treatment in the graduate orthodontic clinic.

Subjects were selected based on the following criteria. (All eligible subjects were included in the study.)

1. Age between 11 and 14 years old at the time of the records
2. Fully erupted mandibular canines and first molars, determined using study models
3. No previous orthodontic treatment, based on medical history form
4. No deciduous mandibular teeth present
5. No missing or extracted permanent teeth in mandibular arch
6. No restoration of the dental cusps of measured teeth
7. No severe rotations ($\geq 90°$) of the mandibular canines or first molars

8. No buccal crossbites
9. Landmarks (cusp tips and root apices) of measured teeth were clearly visible on the CBCT scan
10. Agreed to orthodontic treatment in the Department of Orthodontics at Case Western Reserve University

One hundred eight subjects met the selection criteria. Of the 92 patients excluded, 37 subjects were excluded based on age. Nine subjects had a history of previous orthodontic treatment, five subjects had missing or supernumerary mandibular teeth, 12 subjects had unerupted or severe rotated mandibular canines, second premolars or first molars, 10 subjects had mandibular deciduous teeth. Six subjects had poor images and 13 subjects receiving no treatment or transferred to other clinics/offices. The sample consisted of 56 male and 52 female patients, with an average age of 13.2 ± 1.0 years. A commercially available software program (Accurex by Cybermed Inc – Seoul, Korea) was used to reconstruct and analyze the CBCT data. Data were collected by a single operator (WS). Measurements were made of the right and left mandibular canines and first molars. Buccolingual inclination was measured through the long axes of the teeth. Each slice was stored as a jpeg image, and was labeled using a patient identifier. Measurements were repeated after a three week interval on 30 subjects. Patient demographic information, molar classification, expander status and crossbite status were also collected from the dental chart. Digital calipers (Central Tools Inc - Cranston, RI) were used to measure mandibular intercanine and intermolar width on the dental models accurate to 0.01 mm.

Method of inclination measurement

Slice thickness was fixed at 0.28 mm as a standard voxel height. Measurements were based on slices of the left and right canines, and the left and right first molars.

Canine inclination technique (see Figure 1-4)

Location of the long axis of the canine: line between cusp tip and root apex.

1. Locate the canine in the axial view, the point at which the root is longest in sagittal view.
2. In the sagittal view, position the line representing the coronal slice along the long axis of the tooth.
3. In the coronal view, draw the reference line as the tangent at the base of mandible.
4. Measure the inclination through the long axis of the tooth.
5. Repeat 1 - 4 for the contralateral canine.

Molar inclination technique (see Figure 5-8)

Location of the long axis of the molar (in coronal view): line between the central groove and root apex. If two roots are shown in the coronal view, use the line between the central groove and the way half between the two apices.

1. Locate molar in the axial view, the point at which the root is longest in the sagittal view.
2. In the sagittal view, position the line representing the coronal slice along the plane of the mesial cusp tip and the mesial root apex.
3. In the coronal view, draw the reference line tangent to the base of mandible.

4. Measure the inclination through the long axis of the molar.
5. Repeat 1 – 4 for the contralateral first molar.

Measurements on CBCT (modification of Tsunori et al. 1998)

- Mandibular canine inclination (degrees) = the angle between one line passing through the long axis of mandibular canine (cusp tip to root apex), and one tangent line at the inferior border of the mandible

- Mandibular first molar inclination (degrees) = the angle between one line passing through the long axis of molar (central groove to root apices), and one tangent line at the inferior border of the mandible.

Measurements on study models using digital calipers (see Figure 9)

- Mandibular intercanine width (mm) = distance between incisal tips of mandibular canines.

If incisal wear was present, the cusp tip was defined as the middle point of the wear.

- Mandibular intermolar width (mm) = distance between central pits of mandibular first molars.

If any restorations were present, the central pit was defined as the mid point between the mesiobuccal and mesiolingual cusp tips. If occlusal wear was present, the cusp tip was defined as the mid point of the wear.

Statistical analysis

Measurements were repeated after a three week interval on 30 subjects randomly selected using a random number computer program. The intraclass correlation coefficient was used to assess reliability of all continuous measurements.

Means and standard deviations for each variable were calculated. An independent sample t-test was used to compare measurements between two groups and a p-value $\leq$ 0.05 was used to assign statistical significance. A Pearson correlation was used to evaluate the relationship between tooth inclination and arch width. All statistics were calculated using the Statistical Package for the Social Sciences (SPSS 13.0, Inc. – Chicago, IL).

RESULTS

Demographics

The final sample consisted of 56 male subjects and 52 female subjects for a total of 108 subjects. The average age was 13.2 ± 1.0 years, with a range from 11.1 – 14.9 years. The overwhelming majority of subjects were Caucasoid (n=95) with nine Negroid, and four Mongoloid subjects. A descriptive summary of demographics, molar classification, expander status and crossbite status is shown in Table 1.

Normal inclination and width of mandibular canines and first molars

All subdivision malocclusions were excluded when comparing the inclination and width in order to investigate the averages by that Angle molar classification. There were a total of 78 subjects excluding 30 subjects with a subdivision malocclusion (Table 3).

Data for right and left sides were collected separately. A preliminary t-test showed no difference between right and left sides, and therefore data were pooled together for subsequent analyses. For the mandibular canines, the mean inclination was 98.0 ± 4.1 degrees and the mean intercanine width was 26.0 ± 2.2 mm. For the mandibular molars, the mean inclination was 74.6 ± 4.7 degrees and the mean

intermolar width was 40.9 ± 2.7 mm. In terms of molar classification, there were 41 subjects with Class I, 33 subjects with Class II and four subjects with Class III molar relationships.

The mean mandibular canine inclination was 97.5 ± 3.6 degrees in subjects with Class I molar occlusion, 98.7 ± 4.4 degrees in subjects with Class II molar occlusion and 97.3 ± 4.6 degrees in subjects with a Class III molar occlusion and the mean mandibular first molar inclination was 75.6 ± 4.9 degrees in subjects with Class I molar occlusion, 73.7 ± 4.2 degrees in subjects with Class II molar occlusion and 70.8 ± 1.3 degrees in subjects with Class III molar occlusion.

The mean and standard deviation for mandibular canine and molar inclination, intercanine width and intermolar width in subjects excluding subdivision malocclusion is shown in Table 4. Subjects with Class I molar and without crossbite had an average canine inclination of 97.6± 3.6° , a first molar inclination 75.7 ±4.9° , an average intercanine width of 26.1± 2.4 mm and average intermolar width of 40.9± 2.4 mm in the mandibular arch. Descriptive analyses of width and inclination of mandibular canines and first molars by subdivision malocclusion, expander and crossbite status are shown in Table 5.

Age, gender, molar classification and expander status differences

The subjects with subdivision malocclusion were excluded when comparing the measurements regarding molar classification. There were no statistically significant differences in the inclinations of the mandibular canines and molars and arch width between the 11–12 year olds and the 13–14 year olds, or between male

and female subjects (see Table 6 and 7). The first molar inclination in subjects with a Class II molar relationship was statistically less than that found for subjects with a Class I molar (see Table 8). In addition, the first molar inclination in subjects with palatal expansion was statistically less than that of subjects without palatal expansion (see Table 9). There were low correlations between canine and first molar inclinations, and between intercanine and intermolar width ($r \leq 0.5$).

Reliability

All measurements were collected by a single operator (WS). Three weeks after the initial measurements, thirty subjects were randomly selected for repeat measurements. The intraclass correlation values for the left canines, the right canines, the left molar, the right molar, intercanine width and intermolar width were all greater than 0.94 (see Table 2).

DISCUSSION

One purpose of this study was to develop a reliable method to measure tooth inclination using cone beam computed tomographic images. Our method showed high reproducibility as evidenced by the high intraclass correlation coefficients. Although the occlusal plane has been used to be the reference plane in the past studies, this study showed that the inferior border of the mandible could also be used as a reproducible reference plane. It is likely that the mandibular plane and the occlusal plane are parallel in most non-syndromic patients. And, unlike the occlusal plane, the mandibular plane is less likely to be influenced by orthodontic tooth movement. This makes our method useful for studying post treatment changes in tooth inclination.

Although we studied only the canines and molars it is likely that the inclination of any tooth that can be visualized on a CBCT image could be measured using this method.

We measured intercanine and intermolar width to see if the inclination of the teeth was related to the absolute width of the arches or whether tooth inclination was independent of width measures. Intercanine and intermolar width in this study are consistent with Housley[9] and Erdinc.[16] However, the correlation between arch width and angulataion was low suggesting that tooth inclination is independent of width. This is interesting because most clinicians believe that arch contriction is at least in part due to lingual inclination of the molars and cuspids. Our results do not support this hypothesis.

Only a few other attempts have been made to quantify mandibular molar inclination.[3,5,8] Tsunori et al[8] found 80.2 ± 4.6° torque for mandibular first molar inclination in an average facial type. They investigated 23 dry skulls of male Asiatic Indians subjects of unknown age. The method used in this study was a modification of Tsunori's method. Our results show a different average inclination. This is likely due to several factors. First, Tsunori's study only included male subjects of Asian descent while the majority of our subjects were Caucasians. Second, they did not exclude the subdivision malocclusion nor report the inclination by Angle molar classification. And finally, the sample size in their study was so small that the descriptive statistics calculated are likely to be in error. Therefore, we would suggest

that the values found in the present study more closely reflect the average values found in an orthodontic age population.

Another reason for clinical interest in tooth inclination is that the torque in preadjusted brackets has been built-in based on previous research findings that used the clinical crown to measure buccolingual inclination (the Andrews Method[1]). The manufacturer used the point of tangency according to the method of Andrews, that is, the most prominent portion in the central area of the labial or buccal surface and only reflects an average torque for each tooth. However, the factor that might affect torque variation is the angle between crown long axis and root long axis (column angle). Carlsson and Ronnerman[17] found the column angle of the central incisor to vary in a range of 17.5 ± 4.2°. However, their study was restricted to the central incisor only. Torque of the mandibular canine bracket is minus seven degrees in the Alexander prescription, minus 11 degrees in Roth prescription and minus six degrees in the MBT prescription.[18] Ricketts[19], however, recommended a positive torque in canines to drag their roots away from the buccal cortical plate. His prescription has a plus seven degree torque for the mandibular canine and minus 24 degrees for the mandibular first molar.[20] Torque is minus 20 degrees in Alexander and MBT prescriptions, and minus 25 degrees in Roth prescription for the mandibular first molars.[18] In our study, we found that plus eight degrees of torque would be the ideal average for the mandibular canine in this sample based on a 98° buccal inclination (see Figure 10). For the mandibular first molar a minus 14° torque would be the average based on a 76° buccal inclination (see Figure 11). The plus torque in

mandibular canine would be beneficial in terms of maintaining the root in the alveolar bone and would not expand the canine as might occur with negative torque. For the torque of mandibular first molars, our results suggest that commercially available bracket prescriptions have more torque than the average. If clinicians do not use a full size rectangular wire this difference might not be clinically important. However, it is worth considering if a clinician wants a torque value that is based on actual patient data.

One issue that has created much debate is the change of the mandibular arch form during orthodontic treatment. Many clinicians believe in maintaining the mandibular intercanine width during treatment.[21] Many clinical studies on postretention results reflect the validity of maintaining intercanine width based on statistical findings.[22-23] Because of the negative torque in the mandibular canine bracket, some clinicians may believe that a canine in the alveolar bone normally leans lingually, however our findings showed that almost all mandibular canines, regardless of molar classification, actually lean buccally. This may explain why expansion of the intercanine width is unstable. During orthodontic treatment, some clinicians may assume that the changes in mandibular canine width are all bodily movement. However, our results suggest that the mandibular canines are already buccally inclined and therefore expansion of the canines can only result in greater buccal after treatment.

Blake et al.[21] reviewed the literature pertaining to retention and stability. They reported that original mandibular intercanine width should be maintained

because collapse of mandibular intercanine width is the most predictable of all orthodontic relapse.[10-12, 24-26] Lip and cheek pressure may also be related to canine relapse. Proffit and Fields stated that "intercanine dimensions typically decrease as patients mature because of lip pressures at the corners of the mouth. Expansion across the premolars and molars is much more likely to be maintained, presumably because of the relatively low cheek pressures".[27] Our findings support the concept that the intercanine width should be maintained during orthodontic treatment. Tooth inclination may be a considerable factor in the stability of the dentition, and in regard to the mandibular expansion, the clinician must be aware of the pre-existing inclination of the canines. In contrast to the mandibular canines that are already inclined buccally in the pre-treatment state, mandibular molars tend to be lingually inclined which could make uprighting more stable.

Previous studies did not separate subdivision malocclusion from bilateral Class I or Class II patients, therefore differences between Class I and Class II were not seen to the degree observed in this study. All subdivision malocclusions were excluded before calculating the averages by Angle Class. This was done to allow the valued to be used as a "norm" for that malocclusion type. This is especially true for the Class I patients without existing crossbite. These norms might be useful in the future for diagnosis and treatment planning using CBCT data.

Interestingly, our results showed that mandibular first molar inclination in subjects with class II molar was significantly less than those with class I molar. This may be a dental compensation to maxillary transverse deficiency which is typical in

Class II malocclusion. McNamara[28] has suggested that the position of the lower teeth may depend more on maxillary morphology than by the mandibular morphology. He found the lower posterior teeth often have erupted into occlusion more lingually because of the constricted maxilla.[28] In mixed-dentition, in the patients with class II malocclusions, the malocclusion is often associated with maxillary constriction. Many Class II malocclusions, when evaluated clinically, appear to have no obvious maxillary transverse constriction. However, when the study models articulated into a Class I relationship, a unilateral or bilateral crossbite is often produced.[28] In addition, Tollaro et al.[29] showed that Class II patients who appear to have a normal buccolingual relationship of the posterior teeth usually have a 3 to 5 mm transverse discrepancy between the maxilla and mandible. In contrast to molar inclination, in the present study, the canine inclination in class II subjects was greater than that in Class I molar subjects although it was not statistically significant ($P \leq 0.08$). This suggests there may also be a dental compensation of the cuspid teeth in the retrognathic mandible of Class II patients.

Similarly, Nie and Lin[30] investigated arch form differences between subjects with an untreated Class II, division 1 malocclusion and Class I occlusion. They reported significantly narrower maxillary posterior arch width in Class II, division 1 subjects and suggested that this was an important arch form difference compared with Class I occlusion. However, there was no difference in lower arch width between the two groups. In the present study, the correlation between canine and molar inclination, and intercanine and intermolar width was weak ($r \leq 0.5$) as was the

correlation between intercanine width and intermolar width ($r \leq 0.6$). These low correlations suggest that tooth inclination is probably not related to arch width and that cuspid width and molar width are likely independent variables. Therefore, clinicians should not assume that the narrow arches can always be expanded. This is especially true for the cuspid teeth where the angulalation is already buccal. One possible use of pretreatment CBCT images is to assess tooth inclination and then use this assessment to make the decision on uprighting the teeth. In patients with narrow mandibular arches with normal tooth inclinations, uprighting the teeth may not be the proper treatment and may not be stable. In contrast, patients with a narrow mandibular arch and more lingually inclined molars might be good candidates for expansion by uprighting the molar teeth. Tooth inclination seems to be a dental adaptation or compensation for anteroposterior skeletal discrepancy and should be evaluated by clinicians planning treatments to correct these A-P problems.

It is interesting to note that 82 percent of our subjects with bilateral Class II molar relationship did not have a crossbite. This could be related to the fact that these subjects had more lingually inclined mandibular first molars and therefore would be less likely to be in posterior crossbite because of the existing dental compensation. This is interesting because clinicians have long known that the absence of a posterior crossbite does not necessarily mean that the maxilla is of normal width. Our data suggest that one explanation for this clinical finding is that mandibular first molars are lingually compensated. This is one possible explanation for the clinical finding of maxillary transverse deficiency in the absence of posterior crossbite.

An interesting clinical question is "How much arch width could we gain from uprighting the mandibular teeth?" Assuming a mandibular canine length of 27 mm[31], a 1° bilateral increase in the mandibular canine inclination results in a 1 mm increase in intercanine width. This one millimeter increase would be clinically significant in a borderline extraction case. Likewise, assuming a mandibular first molar length of 21.5 mm[31] , a 1° bilateral increase in inclination results in a 0.8 mm increase in intermolar width. These value could be useful as guides when estimating the effects of mandibular molar and canine uprighting on arch width.

CONCLUSION

CBCT can be used to measure the buccolingual tooth inclination in the mandibular canines and first molars. Using the inferior border of the mandible may be a better reference plane than the occlusal plane which can change during orthodontic treatment. However, further studies are required to establish the reliability of this reference plane over time. Patients with a Class II molar relationships and those treatment planned for palatal expansion showed decreased inclination of their mandibular first molars suggesting that molar inclination may occur in response to skeletal discrepancies.

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TABLE 1.—Descriptive Summary of Demographics, Molar Classification, Expander Status and Crossbite Status of Mandibular Canines and Molars (N=108)

Variables	Group	Total	Percent	Male	Female
Age	11-12 yr	45	41.7	21	24
	13-14 yr	63	58.3	35	28
Anthropological group	Caucasoid	95	88.0	48	47
	Negroid	9	8.3	7	2
	Mongoloid	4	3.7	1	3
Gender	Male	56	51.9	56	0
	Female	52	48.1	0	52
Molar Classification	Class I	41	38.0	19	22
	Class II div 1	25	23.1	11	14
	Class II div 2	8	7.4	3	5
	Class III	4	3.7	4	0
	Class II subdiv right	11	10.2	8	3
	Class II subdiv left	8	7.4	6	2
	Class III subdiv right	5	4.6	3	2
	Class III subdiv left	4	3.7	2	2
	Others	2	1.9	0	2
Expander status	No expander	84	77.8	46	38
	Expander	24	22.2	10	14
Crossbite status	No crossbite	81	75.0	43	38
	Crossbite of canines	12	11.1	6	6
	Crossbite of posterior teeth	15	13.9	7	8

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

Variables	Intraclass correlation (r)
Left canine	0.96
Right canine	0.94
Left molar	0.98
Right molar	0.97
Intercanine width	0.99
Intermolar width	0.99

TABLE 3. — Width and Inclination of Mandibular Canines and First Molars for Class I, II and III Subjects Excluding Subjects with Subdivision Malocclusion*

Variables	Minimum	Maximum	Mean±SD
Canines (N=156) (degrees)	88.6	110.4	98.0±4.1
First molars (N=156) (degrees)	64.4	90.0	74.6±4.7
Intercanine width (N=78) (mm)	21.2	31.1	26.0±2.2
Intermolar width (N=78) (mm)	33.2	46.0	40.9±2.7

*Right and left canines and first molars were combined because these were no statistically significant differences between the left and the right sides.

TABLE 4. — Canine and Molar Inclination and Width by Molar Classification and Crossbite Status, excluding Subdivision (N=78)

Molar classification	Canine inclination (°)	Molar inclination (°)	Intercanine width (mm)	Intermolar width (mm)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Class I (n=41)	97.5 ± 3.6	75.6 ± 4.9	26.1 ± 2.3	41.1 ± 2.4
Class I without crossbite (n=33)	97.6 ± 3.6	75.7 ± 4.9	26.1 ± 2.4	40.9 ± 2.4
Class II (n=33)	98.7 ± 4.4	73.7 ± 4.2	25.9 ± 2.0	40.8 ± 3.1
Class II without crossbite (n=27)	98.9 ± 4.5	73.5 ± 3.7	26.0 ± 2.1	40.9 ± 3.0
Class III (n=4)	97.3 ± 4.6	70.8 ± 1.3	25.4 ± 3.1	39.3 ± 3.1

TABLE 5. — Canine and First Molar Inclination and width by Subdivision, Expander Status and Crossbite Status (N=108)

	Left canine (°)	Right canine (°)	Left Molar (°)	Right Molar (°)	IC width (mm)	IM width (mm)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean± SD	Mean ± SD
Subdivision (N=28)						
Class II						
Subdiv right (n=11)	100.3 ± 5.4	96.8 ± 3.6	76.7 ± 4.9	75.1 ± 4.8	25.0 ± 1.4	41.7 ± 1.8
Subdiv left (n=8)	98.4 ± 2.8	97.0 ± 2.4	75.1 ± 3.8	76.6 ± 2.4	26.6 ± 1.5	42.1 ± 2.3
Class III						
Subdiv right (n=5)	97.1 ± 4.9	98.6 ± 3.9	72.0 ± 2.3	76.5 ± 3.4	26.6 ± 0.6	41.1 ± 1.5
Subdiv left (n=4)	98.0 ± 6.5	96.1 ± 9.3	78.9 ± 5.5	78.8 ± 7.4	25.5 ± 2.4	41.5 ± 2.5
Expander status (N=108)						
No expander (n=84)	98.4 ± 4.4	97.3 ± 4.1	75.0 ± 4.8	75.6 ± 4.5	26.0 ± 2.0	41.2 ± 2.4
Expander (n=24)	99.1 ± 3.4	98.5 ± 4.1	73.7 ± 4.8	73.0 ± 4.8	25.5 ± 1.9	40.5 ± 2.9
Crossbite status (N=108)						
No crossbite (n=81)	98.4 ± 4.4	97.5 ± 4.1	74.8 ± 4.5	75.0 ± 4.4	26.0 ± 2.1	41.1 ± 2.5
Crossbite of canines (n=12)	99.0 ± 3.0	99.2 ± 4.6	73.3 ± 4.5	74.8 ± 6.9	26.6 ± 1.2	39.9 ± 3.0
Crossbite of posterior teeth (n=15)	99.2 ± 3.8	96.7 ± 3.8	75.5 ± 6.3	75.2 ± 4.2	25.3 ± 1.9	41.8 ± 2.3

TABLE 6. —Age Differences in Mandibular Canine and First Molar Inclination*, Intercanine Width and Intermolar Width (N=78)**

Variables	Age 11-12 yr (n=34)	Age 13-14 yr (n=44)	P-value
	Mean ± SD	Mean ± SD	
Canine inclination (°)	98.1 ± 3.8	97.9 ± 4.3	0.7
First molar inclination (°)	74.7 ± 5.1	74.5 ± 4.3	0.7
Intercanine width (mm)	26.4 ±1.8	25.6 ± 2.4	0.1
Intermolar width (mm)	41.0 ± 2.9	40.7 ± 2.6	0.6

*Left and right teeth were combined.
**Subjects with Class I, II and III molar relationship excluding subjects with subdivision malocclusion

TABLE 7. —Gender Differences in Mandibular Canine and First Molar Inclination*, Intercanine Width and Intermolar Width (N=78)**

Variables	Male (n=37)	Female (n=41)	P-value
	Mean ± SD	Mean ± SD	
Canine inclination (°)	97.7 ± 4.2	98.3 ± 3.9	0.3
First molar inclination (°)	74.7 ± 4.6	74.4 ± 4.7	0.7
Intercanine width (mm)	26.0 ± 2.3	25.9 ± 2.1	0.9
Intermolar width (mm)	41.4 ± 2.3	40.4 ± 3.0	0.1

*Left and right teeth were combined.
**Subjects with Class I, II and III molar relationship excluding subjects with subdivision malocclusion

TABLE 8. —Molar Classification Differences in Mandibular Canine and First Molar Inclination*, Intercanine Width and Intermolar Width (N=60)**

Variables	Class I (n=33)	Class II (n=27)	P-value
	Mean ± SD	Mean ± SD	
Canine inclination (°)	97.6 ± 3.6	98.9 ± 4.5	0.08
First molar inclination (°)	75.7 ± 4.9	73.5 ± 3.7	0.01
Intercanine width (mm)	26.1 ± 2.4	26.0 ± 2.1	0.86
Intermolar width (mm)	40.9 ± 2.4	40.9 ± 3.0	0.98

*Left and right teeth were combined.
**Subjects without crossbite and subdivision malocclusion

TABLE 9. —Expander Status Differences in Mandibular Canine and First Molar Inclination*, Intercanine Width and Intermolar Width (N=108)**

Variables	No Expander (n=84)	Expander (n=24)	P-value
	Mean ± SD	Mean ± SD	
Canine inclination (°)	97.8 ± 4.3	98.8 ± 3.8	0.1
First molar inclination (°)	75.3 ± 4.6	73.3 ± 4.8	0.01
Intercanine width (mm)	26.0 ± 2.0	25.5 ± 1.9	0.2
Intermolar width (mm)	41.2 ± 2.4	40.5 ± 2.9	0.2

Figure 1. Location of the mandibular canine in the axial plane

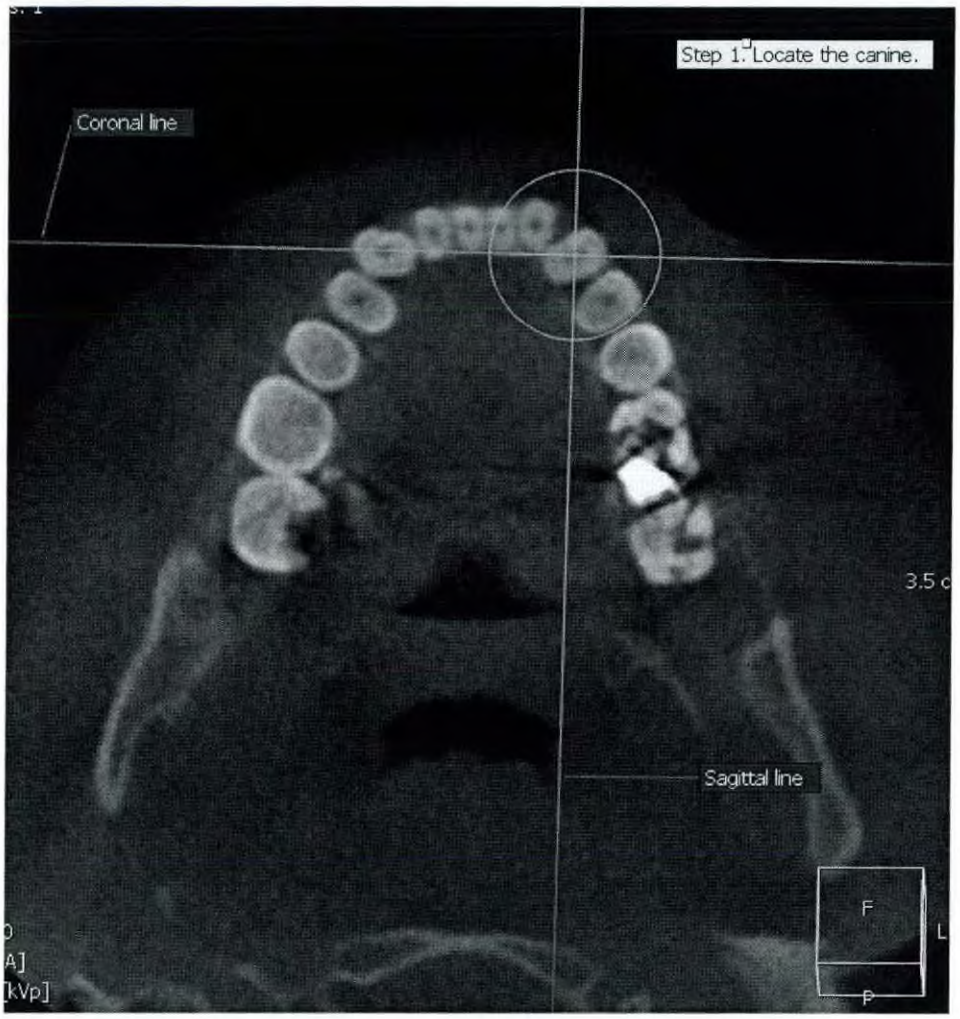


Figure 2. Location of the mandibular canine in the sagittal plane



Figure 3. Location of the mandibular canine in the coronal plane

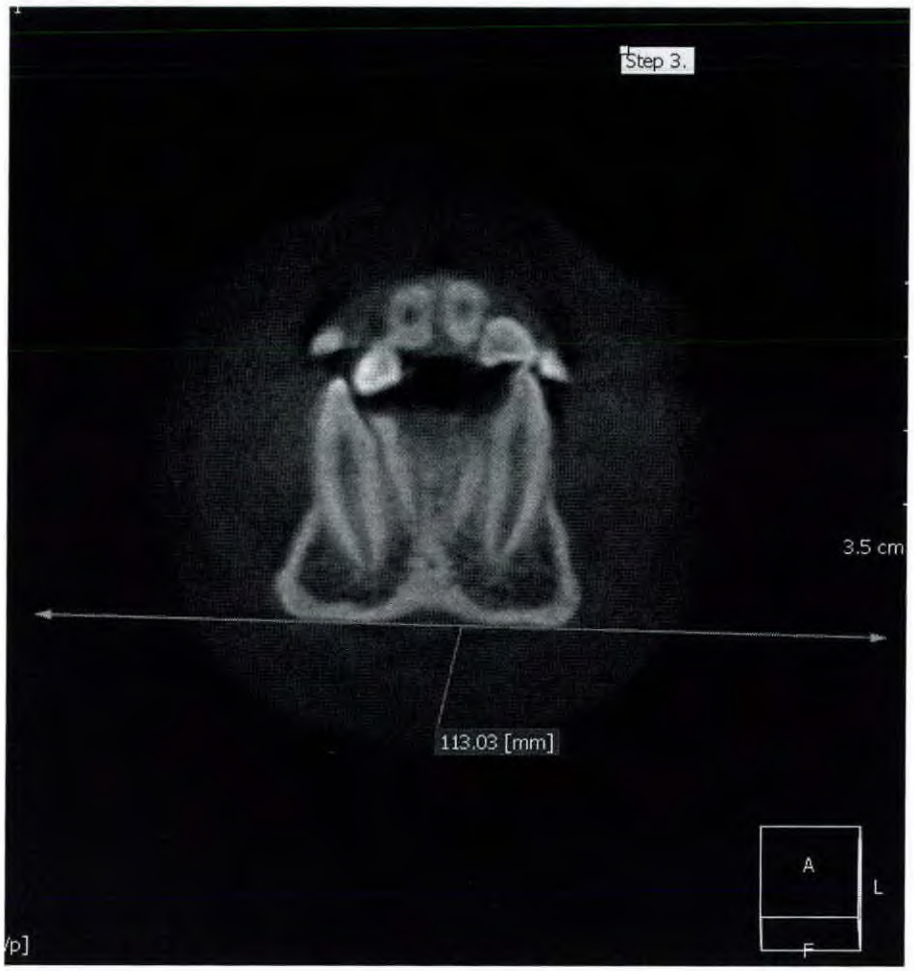


Figure 4. Measurement of the mandibular canine inclination through the long axis of the tooth

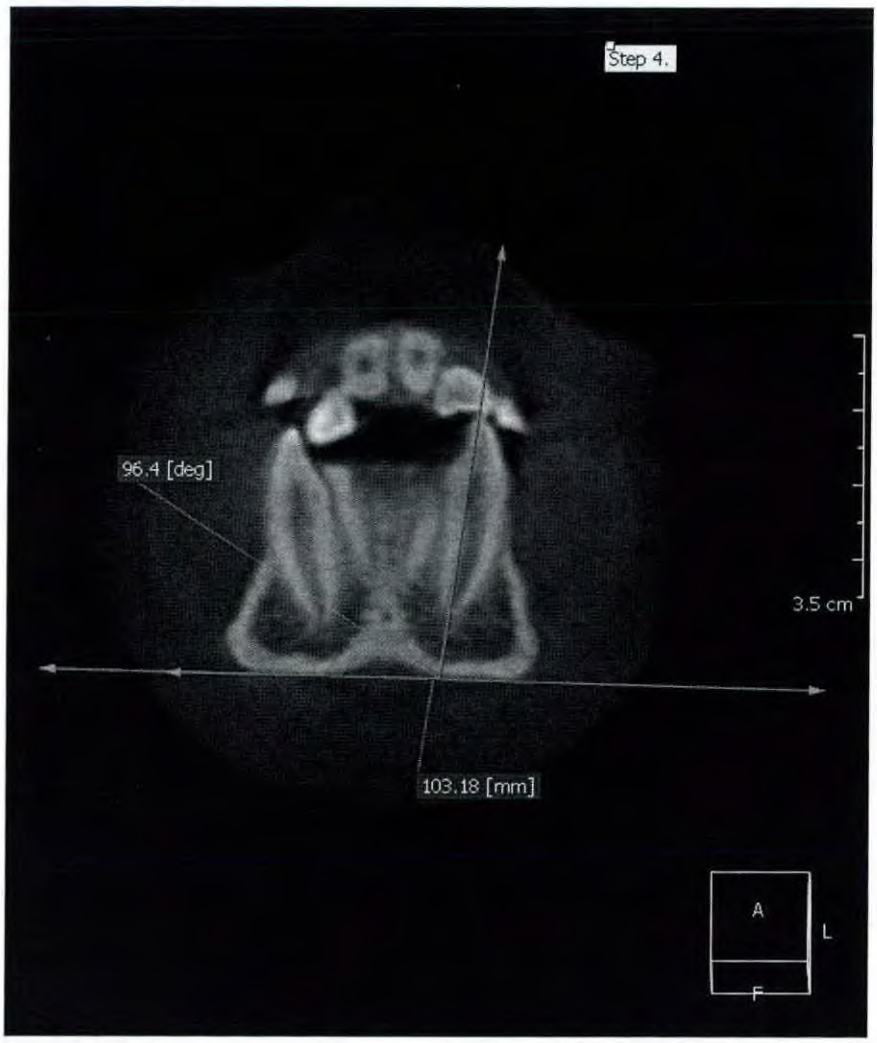


Figure 5. Location of the mandibular first molar in the axial plane

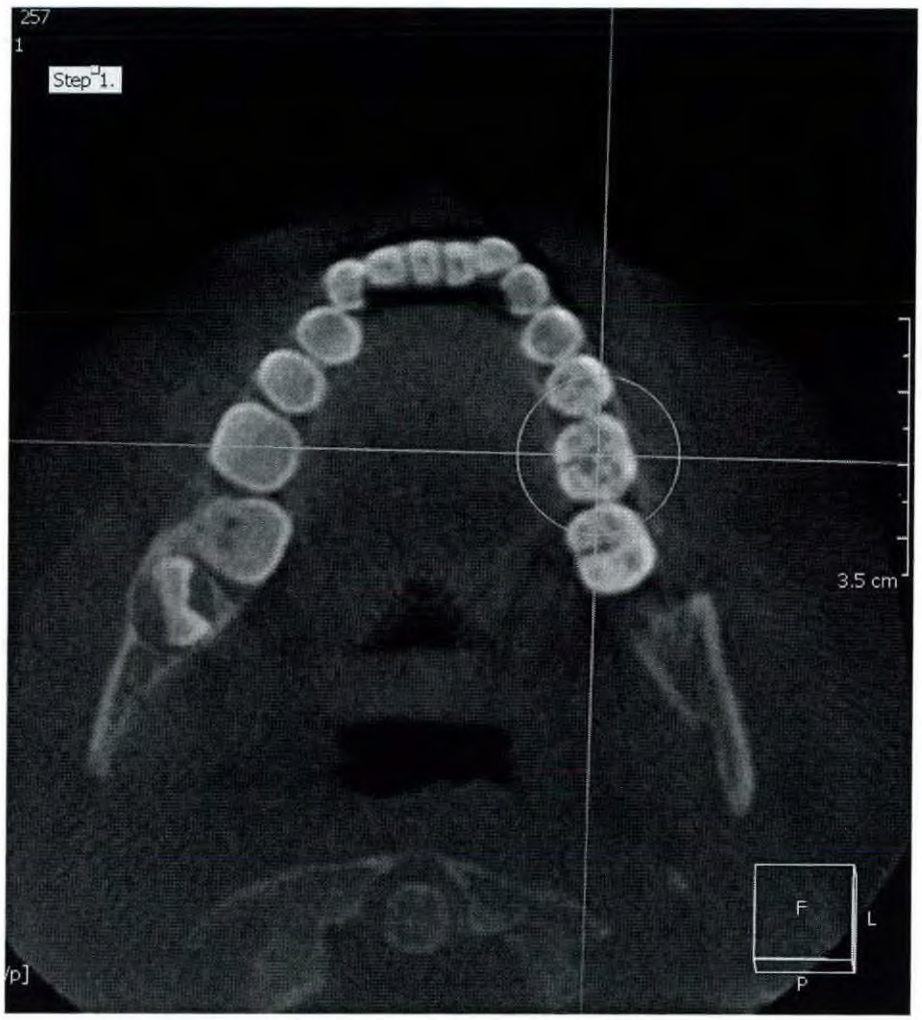


Figure 6. Location of the mandibular first molar in the sagittal plane

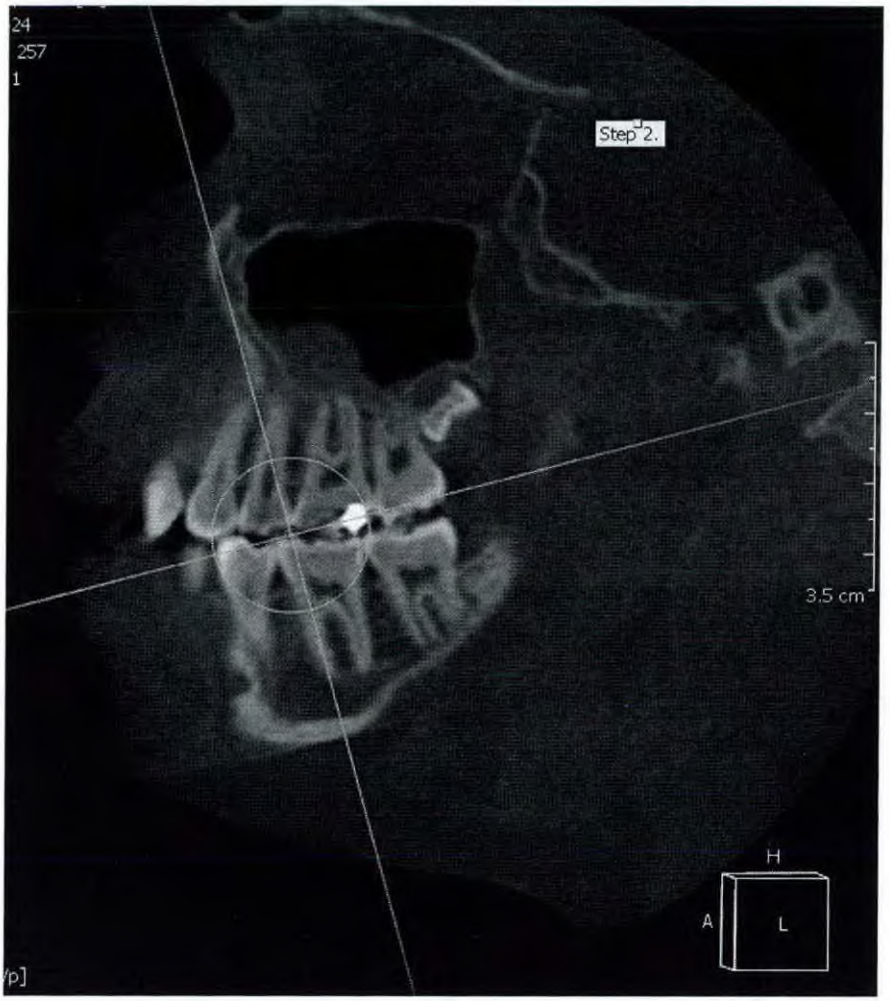


Figure 7. Location of the mandibular first molar in the coronal plane

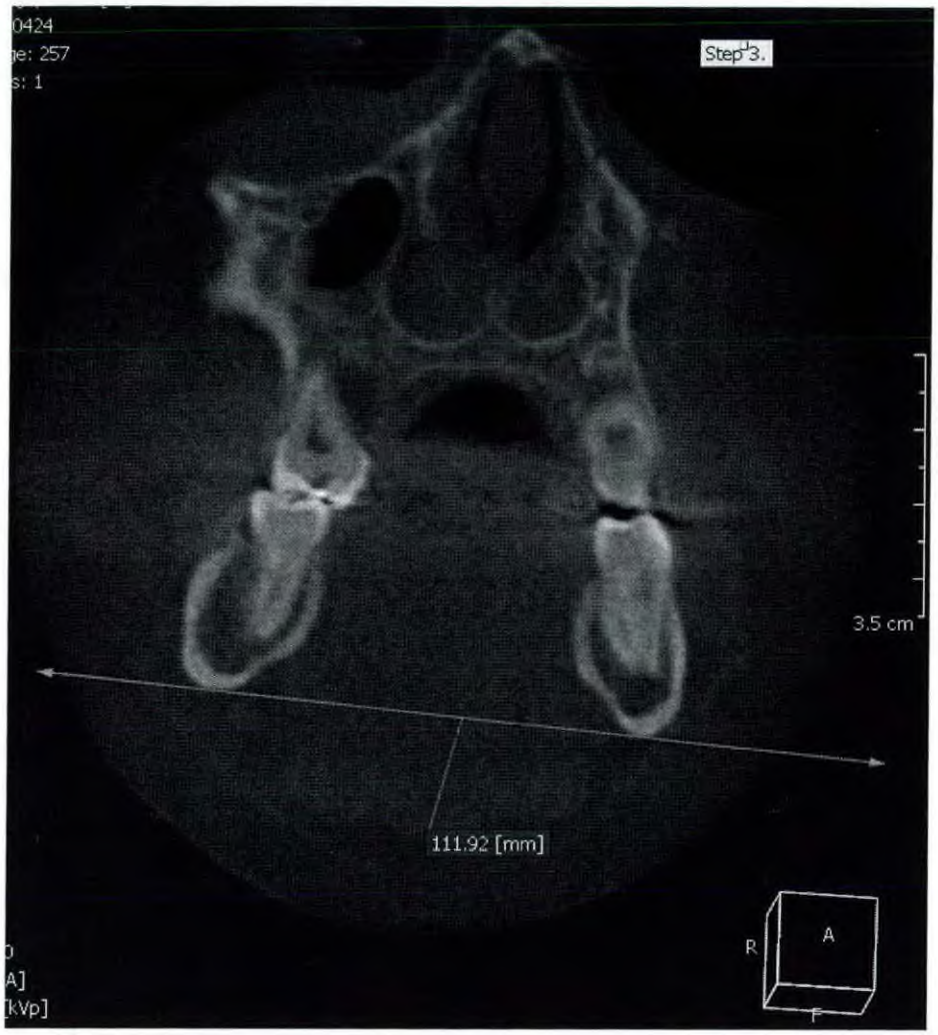


Figure 8. Measurement of the mandibular first molar inclination through the long axis of the tooth



Figure 9. Measurements on study models

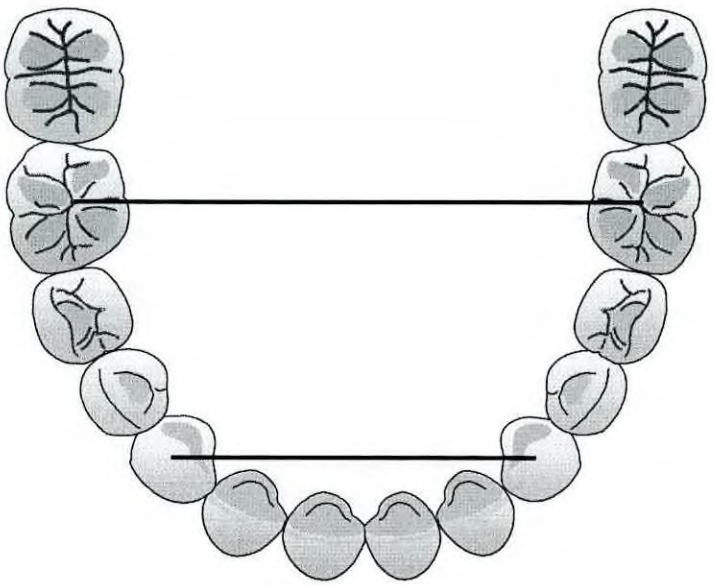


Figure 10. Average inclination of the mandibular canine

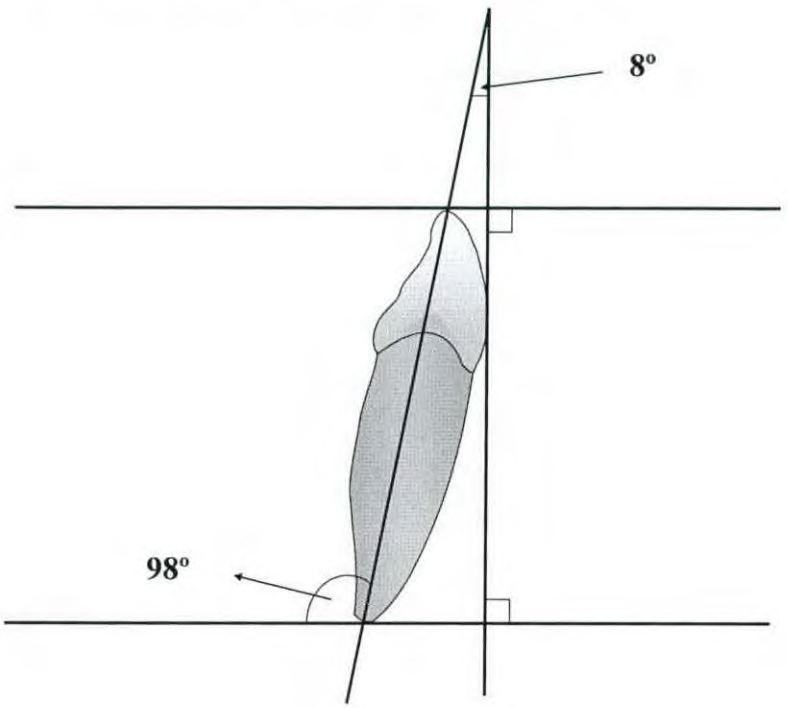
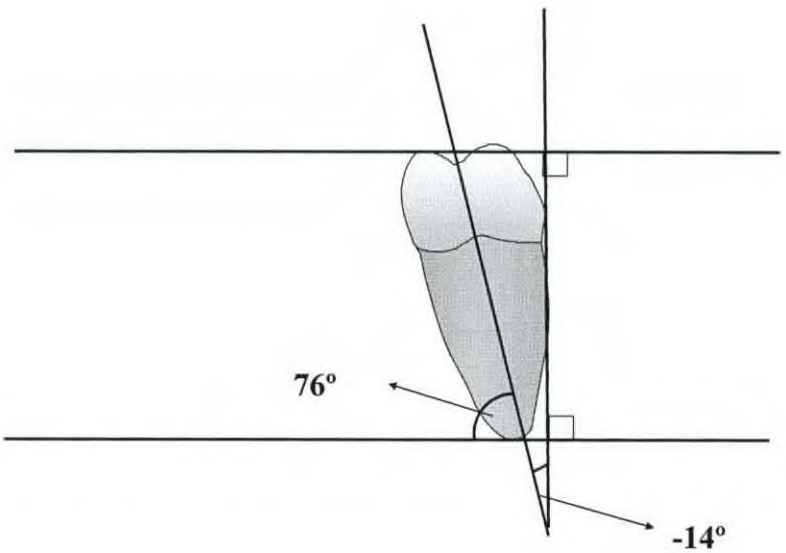


Figure 11. Average inclination of the mandibular first molar



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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.

Please note that this only applies to existing data.

CUTOFF DATE: 05/04/2007

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

05/05/2007 and after are NOT covered by this exemption.

Responsible Investigator: **Mark Hans**
Department: **Dentistry - General**
IRB Protocol Number: **20070419**
Title: ***A New Method to Measure Buccolingual Inclination Using CBCT***
Co-Investigator: **Wanvadee Shewinvanakitkul**

Exemption Date: May 4, 2007

APPENDIX 2

Raw Data: Age, Anthropological Group, Gender, Molar Classification, Expander Status, Crossbite Status, Left Canine and Right Canine Inclination, Left and Right First Molar Inclination, Intercanine Width and Intermolar Width.

TABLE 1.--All data

subject	Age (mo)	Age gp	ATP	Gender	Molar Cl	Expander	Crossbite	Left canine	Right canine	Left molar	Right molar	Intercanine	Intermolar
1	143	1	1	1	1	0	0	97.5	96.6	74.1	74.1	26.07	40.39
2	163	2	1	2	1	1	0	100.1	94.4	72.7	66.5	24.57	39.23
3	164	2	1	1	1	0	0	108	100.5	81.1	80.1	28.94	42.08
4	156	2	1	1	5	6	0	92.6	97	74.1	73.8	21.6	41.41
5	173	2	1	2	1	0	0	98.7	96.8	75.9	78.9	24.28	43.39
6	161	2	1	1	2	2	0	99.5	108.5	71	78.2	23.66	39.44
7	145	1	1	1	5	0	0	98.1	92.6	79.1	79.2	25.36	41.82
8	133	1	1	1	8	0	0	90	88.3	73.6	74.3	22.95	41.14
9	141	1	1	2	7	3	8	98.3	101.2	71.1	75.8	26.75	40.1
10	143	1	1	2	2	0	0	97.2	99.7	81.6	77.6	29.47	44.9
11	165	2	1	1	4	3	6	95.9	88.6	69.6	72.2	21.22	38.38
12	158	2	2	1	5	3	6	96.3	100.5	78.7	80.3	24.5	44.43
13	162	2	1	2	1	0	4	94.7	95.5	64.9	72.6	22.36	40.1
14	158	2	1	2	3	0	0	95.1	103.3	74	79.4	25.56	42.39
15	166	2	1	2	5	0	0	107	90.8	72	75.3	25.96	43.96
16	156	2	1	1	2	0	0	98.6	102.9	71.2	71.6	27.39	43.37
17	145	1	1	1	1	0	0	98.6	96.6	72.1	71.6	26.06	44.27
18	154	1	1	1	2	0	0	97.6	96.3	71.8	81.2	25.08	42.12
19	177	2	1	2	3	2	1	102.7	98.5	68	72.6	24.01	34.59
20	146	1	1	1	5	0	0	105.4	92	75.2	75	26.42	41.09
21	163	2	1	1	1	0	0	95.1	96.6	74.9	76.9	24.87	41.5
22	156	2	1	1	1	0	0	94	96.8	77.9	69.1	26.27	41.79
23	165	2	1	1	7	0	0	91.5	94.8	68.7	77.6	26.07	43.3
24	164	2	1	1	6	0	1	99.3	99	69.9	79.7	27.56	38.75
25	146	1	1	2	2	2	0	101.1	102.4	71	75.2	25.92	38.38
26	152	1	1	1	7	0	0	102.4	96.2	73.8	73.7	27.18	41.74
27	176	2	1	2	1	3	9	96.5	101.5	79.2	78	25	39.55

28	157	2	1	2	3	0	0	97.6	94.8	73.4	78.5	27.79	41.61
29	140	1	1	2	2	0	0	101.1	101.7	73.3	72.6	26.12	42.45
30	173	2	1	2	2	0	0	96.3	90.4	64.4	70	25.87	40.39
31	177	2	1	1	2	0	0	91.4	91.4	77	70.5	22.17	40.67
32	153	1	1	2	2	5	5	103.4	95.9	86.4	69.7	25.35	41.61
33	164	2	1	1	1	3	0	96.9	101.7	70	72.6	27.96	42.34
34	175	2	1	1	3	0	0	99.6	98	76.3	81.6	28.14	44.52
35	139	1	1	2	1	0	0	94.5	99.3	65.7	71.4	24.71	36.61
36	164	2	1	2	3	6	0	91.3	89.9	72.5	65.8	21.91	33.58
37	167	2	2	1	8	0	2	100.6	107.1	83.5	83	27.77	44.77
38	149	1	1	2	1	7	2	102.9	100.4	77.5	75.4	26.57	41.01
39	155	1	1	1	2	0	0	102.3	97.3	72.1	71.4	24.68	37.96
40	168	2	1	2	2	0	0	108.1	100.6	76.4	72.3	26.49	41.68
41	139	1	1	2	1	0	0	101.9	103.4	76.8	79.5	28.32	41.29
42	175	2	1	2	2	0	0	101.6	100.7	71.2	74.8	24.36	38.34
43	142	1	1	1	1	0	0	97.4	96.4	82.2	84.6	26.07	44.9
44	140	1	1	2	5	0	0	97.7	99.8	72.1	67	24.33	41.25
45	165	2	1	1	1	0	0	99.1	98.9	74.2	78.2	26.44	39.4
46	142	1	1	1	2	4	0	96	95.3	75	69.3	25.84	42.53
47	167	2	1	1	6	0	0	97	94.6	78.4	75.4	25.24	40.23
48	144	1	1	2	1	1	7	98.2	97	65.2	73.9	25.94	41.8
49	153	1	2	1	4	2	6	105.6	100.7	68.8	74.7	26.1	39.63
50	150	1	1	2	2	0	7	93.1	89.5	75.9	75.2	23.92	39.88
51	161	2	1	2	2	6	0	102.2	99.8	75.7	75.2	26.34	42.13
52	161	2	2	2	1	0	0	105.4	100.3	88.2	80.2	31.16	45.88
53	145	1	1	2	2	2	2	98.5	94.1	71	64.6	28	37.82
54	166	2	1	1	1	0	0	88.8	89.5	77.8	77.2	22.64	41.72
55	145	1	1	2	1	0	0	94.9	100.1	79.4	69.5	25.88	37.96
56	172	2	1	2	2	1	4	101.7	99.4	77.4	81.7	26.1	46.03
57	164	2	1	1	2	2	0	100.6	101.2	72.2	73.2	27.48	40.82

58	153	1	1	2	1	0	0	95.2	93.4	74.8	72.6	25.28	38.86
59	174	2	1	2	2	0	0	101.4	94.1	74.3	65.9	26.6	37.69
60	149	1	3	2	1	0	0	101.7	100.7	80.8	74.4	28.34	41.63
61	178	2	2	1	5	0	0	91.7	98.1	80.5	79.9	24.44	44.48
62	171	2	1	1	1	0	0	96.2	102.5	68	74.4	25.34	39.58
63	144	1	1	2	1	0	0	93.8	91.3	72.7	74.8	30.23	44.51
64	137	1	3	2	9	0	0	104.4	100.1	79.1	77.8	27.39	41.47
65	160	2	2	1	1	0	0	99.7	100.8	79.1	79.2	28.98	41.83
66	164	2	2	2	1	0	0	97.6	103.5	78	79.4	24.48	38.1
67	175	2	3	1	4	0	0	100.7	91.9	69.9	71.7	28.8	43.47
68	144	1	1	2	8	0	0	96.1	88.5	74.7	71.1	23.82	38.51
69	156	2	1	1	6	0	2	98.5	99	76.6	78.8	27.16	43.93
70	139	1	1	1	1	0	4	98.5	93.1	77.5	84.5	26.95	44.67
71	153	1	1	1	4	0	8	99.5	95.9	69.9	69.4	25.75	35.88
72	153	1	1	1	1	0	0	100.3	98	79	77.7	27.93	40.64
73	167	2	1	1	1	0	0	97.8	96.1	74.3	72.7	24.8	40.31
74	177	2	1	2	9	1	2	101.4	100.6	68.2	61.5	26.39	39.75
75	153	1	2	1	1	0	0	97.4	105.2	88.6	90	30.06	45.06
76	177	2	1	2	5	0	0	100.2	100.8	68.7	71	24.72	38.29
77	155	1	1	2	1	1	10	98.7	97.8	78.1	76.3	29.24	45.99
78	143	1	1	1	3	0	0	94.6	101.1	74.3	72.7	26.33	44.43
79	163	2	1	2	1	0	0	94.9	95.4	71.7	72.5	25.27	41.28
80	133	1	1	2	3	0	0	92.6	94.1	74.1	71.3	22.64	38.96
81	169	2	1	2	1	0	2	99.6	101.5	73.2	81.9	27.74	43.28
82	177	2	1	1	5	2	5	102.3	99.6	75.9	73	26.83	41.48
83	171	2	1	1	1	0	0	91.4	93.9	67.6	74.8	21.27	38.05
84	165	2	1	2	1	0	0	97.5	94.7	79.6	75.3	24.39	40.53
85	169	2	1	1	5	0	5	105.7	95.1	83.5	70	24.59	40.85
86	146	1	1	1	6	0	0	94.6	95.1	71.1	76.9	27.1	44.76
87	176	2	1	1	2	1	3	97.6	99.4	81.1	72.9	25.96	41.54

88	149	1	1	2	7	0	3	100.9	96.9	71.6	73.6	25.76	41.3
89	149	1	1	1	2	0	0	100.6	97.5	72.6	75	25.95	40.37
90	154	1	1	2	2	0	0	110.4	103.3	79.4	77.3	27.85	42.3
91	164	2	1	1	1	0	0	91	96	74.2	77.8	21.72	36.72
92	161	2	1	1	6	0	0	97.2	96.4	77.8	72.3	27.46	44.55
93	172	2	1	2	1	0	0	95.8	98.1	72.9	80.6	27.89	41.86
94	165	2	1	2	1	0	0	99.8	97.1	75.7	76.5	23.72	38.86
95	153	1	1	1	2	0	0	100.4	95.8	67.8	71.2	27.92	43.13
96	156	2	1	1	3	0	0	105.8	106.8	76.2	75.4	31.1	44.51
97	179	2	1	2	1	0	0	95.9	100.7	73.6	73.3	28.93	40.83
98	178	2	1	1	5	0	0	106.3	99.3	84.4	82.3	26.29	40.41
99	159	2	1	2	1	0	0	97.9	96.7	75.8	69.6	23.86	37.38
100	156	2	3	2	8	0	0	105.3	100.7	83.9	87	27.46	41.73
101	153	1	1	1	1	0	1	94.8	89	75.9	73.5	24.47	40.19
102	151	1	1	1	1	0	0	99.8	96.4	70.2	71.3	25.51	41.22
103	178	2	2	1	7	0	2	92.4	104.2	74.8	81.9	27.27	39.14
104	158	2	1	2	6	0	0	98.9	100.9	73.5	78.4	23.77	39.69
105	155	1	1	2	2	0	0	100.2	101.1	69.2	73.2	23.49	33.2
106	146	1	1	2	6	0	0	97.2	94.3	80.9	76.9	25.96	43
107	171	2	1	1	6	0	0	104.6	97.4	73	74.6	28.84	42.23
108	174	2	1	1	2	0	0	95.5	95.1	70.8	73.7	26.62	43.12

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

Age gp = Age group

1 = 11-12 years old

2 = 13-14 years old

ATP = Anthopological group

1 = Caucasoid

2 = Negroid

3 = Mongoloid

Gender

1 = Male

2 = Female

Molar Cl = Molar Classification

1 = Class I

2 = Class II division 1

3 = Class II division 2

4 = Class III

5 = Class II subdivision right

6 = Class II subdivision left

7 = Class III subdivision right

8 = Class III subdivision left

9 = others (missing maxillary first molar, Class II molar on one side and Class III molar on the other side)

Expander = Expander status

0 = none

1 = Haas

2 = Hyrax

3 = Bonded

4 = Herbst

5 = Pendex

6 = Twin block

7 = Quad Helix

Crossbite = Crossbite status

0 = none

1 = Left canine

2 = Right canine

3 = Left first molar

4 = Right first molar

5 = Left posterior teeth

6 = Right posterior teeth

7 = Left premolars

8 = left and right canines

9 = left and right premolars

10 = Right canine and posterior teeth

Left canine = Inclination of left mandibular canine (°)

Right canine = Inclination of right mandibular canine (°)

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

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

Intercanine = Intercanine width (mm)

Intermolar = Intermolar width (mm)

TABLE 2.-- Reliability Raw Data: Mandibular canine and first molar inclination, intercanine width and intermolar width of thirty randomly selected subjects

subject	Left canine	Right canine	Left molar	Right molar	Intercanine	Intermolar
3	108.5	100.2	80.2	79	28.96	41.98
7	98.4	93	79	78.9	25.75	41.69
9	98.5	101.2	72.1	74.1	26.88	40.09
15	106.2	93	72.7	76.9	25.68	43.22
18	98.3	96.6	72	80	25.14	42.06
19	102.1	96.8	68.8	70.8	24.1	34.51
21	95.9	96.7	73.4	76.8	24.84	41.46
25	101.6	101.2	70.7	75.2	26.19	38.35
28	95.8	97.1	74.7	78.1	27.73	41.57
34	99.5	97.7	77.2	80.6	28.1	44.51
35	95.6	98.7	65	71	24.74	36.64
39	100.5	97.1	73.1	70.3	24.51	37.82
47	95.7	94.4	78.8	76.2	25.25	40.24
49	105.8	99.8	69.6	75.2	25.89	39.75
52	104.2	101.2	87	82.5	31.25	45.37
67	102.1	92.5	71	71.5	28.9	43.41
72	101.1	97.6	78.2	76.9	27.94	40.52
73	99.8	96.6	76.6	71.9	24.85	40.2
75	98.9	106.8	87.8	89.2	30.17	45.07
77	98.6	98.1	78.1	75.2	29.13	45.92
79	94.5	94.7	71.1	70.9	25.17	41.28
81	101.7	99.6	74.6	80	27.53	43.37
83	91.3	94.7	66.6	74.8	21.22	38.04
85	106.2	96.3	82.4	68.6	24.58	40.84
87	98.7	99.7	80.8	74.3	25.91	41.64
93	94.9	97.2	72.7	80.7	27.93	41.73
94	99.6	96.3	76.1	78.3	23.53	38.67
95	99.7	96.8	67.5	71.8	27.85	43.14
97	96.6	100.2	73	73.6	28.78	40.8
98	105.8	99.5	84	81.6	26.47	40.21

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

Variables	N	Minimum	Maximum	Mean	Std. Deviation
Left canine (°)	108	88.8	110.4	98.60	4.24
Right canine (°)	108	88.3	108.5	97.61	4.19
Left molar (°)	108	64.4	88.6	74.78	4.85
Right molar (°)	108	61.5	90.0	75.08	4.70
Intercanine width (mm)	108	21.22	31.16	25.976	2.06
Intermolar width (mm)	108	33.20	46.03	41.11	2.57

APPENDIX 3

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

TABLE 4.-- Left and Right Mandibular Canines

Left canine (n=78)	Right canine (n=78)	P-Value
Mean ± SD	Mean ± SD	
98.4 ± 4.0	97.7 ± 4.1	0.135

TABLE 5.-- Left and Right Mandibular First Molars

Left first molar (n=78)	Right first molar (n=78)	P-Value
Mean ± SD	Mean ± SD	
74.4 ± 4.8	74.7 ± 4.5	0.586

APPENDIX 4

Pearson Correlation for Mandibular Canines and First Molar Inclination, Intercanine Width and Intermolar Width.

TABLE 6.--Mandibular Right canine and others

Pair	Pearson Correlation	Sig. (2-tailed)
R3 and L3	.377	.000
R3 and L6	.169	.080
R3 and R6	.332	.000
R3 and IC	.393	.000
R3 and IM	.117	.226

TABLE 7.--Mandibular Right first molar and others

Pair	Pearson Correlation	Sig. (2-tailed)
R6 and L3	.079	.415
R6 and R3	.332	.000
R6 and L6	.463	.000
R6 and IC	.283	.003
R6 and IM	.441	.000

TABLE 8.--Mandibular Left Canine and others

Pair	Pearson Correlation	Sig. (2-tailed)
L3 and R3	.377	.000
L3 and L6	.220	.022
L3 and R6	.079	.415
L3 and IC	.461	.000
L3 and IM	.113	.243

TABLE 9.--Mandibular Left first molar and others

Pair	Pearson Correlation	Sig. (2-tailed)
L6 and L3	.220	.022
L6 and R3	.169	.080
L6 and R6	.463	.000
L6 and IC	.287	.003
L6 and IM	.395	.000

TABLE 10.--Mandibular Intercanine width and others

Pair	Pearson Correlation	Sig. (2-tailed)
IC and L3	.461	.000
IC and R3	.393	.000
IC and L6	.287	.003
IC and R6	.283	.003
IC and IM	.558	.000

TABLE 11.--Mandibular Intermolar Width and others

Pair	Pearson Correlation	Sig. (2-tailed)
IM and L3	.113	.243
IM and R3	.117	.226
IM and L6	.395	.000
IM and R6	.441	.000
IM and IC	.558	.000

APPENDIX 5

Width and Inclination of Mandibular Canines and First Molars for Caucasoid Subjects excluding Subdivision Malocclusion

TABLE 12 .--Width and Inclination of Mandibular Canines and First Molars for Class I, II and III Caucasoid subjects excluding Subdivision Malocclusion*

Variables	Minimum	Maximum	Mean±SD
Canines (°) (N=142)	88.6	110.4	97.7±4.0
First molars (°) (N=142)	64.4	86.4	74.2±4.2
Intercanine width (N=71) (mm)	21.2	31.1	25.7±2.1
Intermolar width (N=71) (mm)	33.2	46.0	40.7±2.7

*Right and left canines and first molars were combined because these were no statistically significant differences between the left and the right sides.

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