CHANGES IN BUCCOLINGUAL INCLINATION OF MANDIBULAR CANINES AND FIRST MOLARS AFTER ORTHODONTIC TREATMENT USING CBCT

by

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DEDICATION

This thesis is dedicated to my mother Anthoula, father Manoli, sister Evi. I am sincerely grateful for your unconditional love and unending support. You truly helped me to make my dream of becoming an Orthodontist come true.

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Abstract

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This study had three objectives: 1. Measure and report mean and ranges of the final inclination and change in inclination for mandibular canines and first molars after orthodontic treatment; 2. Compare the inclination of mandibular canines and first molars before and after orthodontic treatment; 3.Compare the post-treatment change in the inclination of lower canines and first molars with the post-treatment change in the intercanine and intermolar width. Seventy patients between the ages of 11 and 14 years of age treated in the Case Western Reserve University graduate orthodontic clinic who had cone beam computed tomographs taken before and after orthodontic treatment were selected. All patients were treated with full upper and lower pretorqued/preangulated fixed appliances for a minimum of

22 months. Buccolingual inclination was measured by using a commercially available software program (Accurex, Cybermed Inc - Seoul, Korea). The inclination angle was formed by a line passing through the long axis of the tooth and a line tangent to the lower border of the mandible (bilaterally). Initial and final casts were used to measure intercanine and intermolar width. Demographic information as well as treatment approach and dental and facial characteristics were abstracted from the treatment record. The data was mainly analyzed with a paired sample t-test and analysis of variance. The mean angulation of the left and right mandibular canines before treatment was 97.8±4.6 and 96.8±3.9, respectively. The mean before treatment angulation of the left and right mandibular molars was 74.7±5.1 and 76.4±4.5, respectively. After treatment, the mean for the lower left canine was 94.7±4.8, and the mean for the lower right canine was 93.9±4.1. The post treatment means for molar angulation were 77.0±4.9 for the left side and 77.4±5.0 for the right side. All differences were statistically significant. Mean intercanine width also increased significantly (1.2±1.7mm mean change), while intermolar width did not change significantly with treatment

(0.3±1.6mm). Females showed more reduction in canine inclination compared to males. The use of triangular elastics was associated with greater decreases in mandibular canine inclination. In this sample, it was concluded that orthodontic treatment decreased the angulation of the mandibular canines by moving the roots buccally, which potentially positions the mandibular canine root outside of the alveolar bone.

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LITERATURE REVIEW

Andrew's study(1972) of 120 cases of non-orthodontic normal occlusions identified six significant characteristics that have become hallmarks of a well-completed orthodontic case. Molar relationship, crown angulation, crown inclination, rotations, spaces, and occlusal plane were determined as the keys for a static occlusion. His six keys were established as meaningful to him, not solely because all were present in each of the 120 non-orthodontic normal occlusions, but also because the lack of even one of the six was a defect predictive of an incomplete end result in treated models. Apart from some specific situations, like the presence of space related to peg-shaped laterals, this statement is generally true. One of these keys was the inclination of the crowns. More specifically, Andrews mentioned that incisors are inclined toward the buccal or labial surface and upper posterior teeth are inclined lingually, similarly from the canine to the premolars, with molar crowns inclined slightly more than the canines and premolars. According to Andrews, lower posterior teeth are inclined lingually, progressively more from canine to molars. The author arrived at these conclusions after

gathering his data during a period of four years (1960 to 1964) with the cooperation of local dentists and orthodontists. His 120-model selection was based on cases that had never had orthodontic treatment, had a bite that looked generally correct, had teeth that were straight and pleasing in appearance and would not benefit from orthodontic treatment. His tentative conclusions were reached after studying intensively the crowns of his multisource collection to ascertain which characteristics would be found consistently in all the models. In order to validate his keys, he examined and compared 1150 postorthodontic models treated and presented as the best orthodontic results to national meetings by the leaders in the field at that time. The limitations to his evidence and subsequent results were that Andrews used his critical thinking and subjective criteria (based on his experience) for evaluating the casts in order to determine his six keys, which until now are well-known among Orthodontists (Andrews LF, 1972).

According to the American Board of Orthodontics (ABO), buccolingual inclination is one of the important criteria that determine if the examiners/orthodontists are producing "Board quality" results. In an effort to

enhance the reliability of the examiners and to provide the candidates with a tool to assess the adequacy of their finished orthodontic results, the board established the Objective Grading System in 1998. Based on that system, and in order to establish proper occlusion in maximum intercuspation and avoid balancing interferences there should not be a significant difference between the heights of the buccal and lingual cusps of the maxillary and mandibular molars and premolars. 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, the straight edge should contact the buccal cusps of contralateral mandibular molars. The lingual cusps should be within 1 mm of the surface of the straight edge. This scoring system was developed through a series of four field tests over a period of 5 years (1994-1998). During the first field test, 100 cases were evaluated, and a series of 15 criteria were assessed based on the final casts and panoramic radiographs. The pool of these cases and their initial characteristics is not stated. Seven out of fifteen criteria showed 85% of the total

inadequacies (alignment, marginal ridges, buccolingual inclination of the posterior teeth, overjet, occlusal relationships, occlusal contacts, and - mesiodistal - root angulation). ABO did not give any more details about the other eight characteristics, and they did not define the inadequacies (ABO 1998).

The second field test (300 cases) confirmed the previous results, but there wasn't adequate interexaminer reliability. The third field test, in 1997, confirmed the importance of the above seven criteria by using a new instrument that was considered to give more accurate measurements. At that time, interproximal contacts were added as the eighth category. During the final test, the new and improved measuring instrument was introduced, and the participants had an extensive training and calibration session before the actual examination in order to increase the reliability. The ABO committee finally decided to introduce the above eight criteria, without giving any details related to the procedure that was followed by the examiners - directors regarding the inadequacies on the models when assessing these criteria (ABO 1998).

Another study that agrees with the above statements and reports the appropriate buccolingual crown inclination - uprighting of the posterior teeth as a characteristic of an acceptable occlusion - was by Marshall et al (2003). Their intention was to evaluate changes in molar crown torque and intermolar arch width from the time of permanent first molar eruption to early adulthood. Their sample was obtained from the Iowa Facial Growth Study and included 89 boys and 86 girls of primarily northern European descent and above average socioeconomic status. Some characteristics of the sample were that there were no facial or skeletal disharmony, and normal molar and canine occlusions were present. Their inclusion criteria was very clear. They included cases 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. Measurements were made with the dental casts lying flat on the art portion with the occlusal surfaces facing upward. The gauge they were using 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 were recorded to conform to convention in reporting torque.

In this study, by Marshal et al., there were two operators for the measurements, and the error of measurement was determined by computing the mean differences between their measurements on casts of two subjects. The mean difference between investigator determinations was tested for the significance of its deviation from zero. For the first molar measurements, the Wilcoxon signed rank test tested the hypothesis that the median correlation was zero. The principle finding of this study is 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. The molar uprighting that they found naturally occurring during normal growth supports the board's criteria. In other words, their findings justified the importance of achieving upright posterior teeth during orthodontic treatment. Limitation of that study was that, although their initial population was 175

males and females, the final sample size after applying the inclusion criteria was limited to 36 subjects. Their statistical analysis can not be considered the most appropriate because the two subjects used for the reliability were too few. Ideally, intra-class correlation should have been used.

Ross et al. (1990) investigated the correlations between faciolingual tooth inclinations and variations in vertical skeletal growth patterns by using the molar occlusal surface inclination. Study subjects included 20 male and 52 female patients, ranging in age from 9.5 to 41.5 years. Four groups were selected for this study. Group 1 had subjects with ideal occlusion, according to Andrew's six keys, with seven males and fourteen females. Group 2 had subjects whose MP-SN angle(from cephalograms) was equal to or lower than 26 degrees (8 males, 8 females). In Group 3, the MP-SN angle was equal to 32 degrees (8 males, 10 females). In group 4 the MP-SN angle was 38 degrees (4 males, 13 females). The faciolingual inclination of the occlusal surface (OS) of the 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.

For the measurements, 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. Authors 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. Plus or minus 90 degrees was determined as the inclination of the occlusal surface. The final mean molar occlusal surface inclination for the lower molar is - 7.1° with a standard deviation of 4.6°, and there was no significant difference among the different groups. This finding is highly suspect because there were large standard deviations, and it would be important to have more information regarding the intra-examiner reliability. There was also a significant difference in the proportion among males and females. Also, this study poses the question over which one of the pool of the subjects participated in the study: were they randomly selected? It also fails to determine if the results were

mostly applicable on the Caucasian population. Furthermore, skeletal growth pattern is not the appropriate expression for the specific sample, since skeletal growth is not a term that applies to adults. Finally, in group 1 the MP-SN angle was not mentioned, and the last two groups were represented only by one absolute value related to MP-SN angle without knowing if 28-31 degrees and 33-37 degrees were excluded.

Tsunori et al. (1998) examined the inclination of the mandibular molars, and they found a relationship between the facial type and the buccolingual inclination. The study consisted of 39 dry skulls of male Asiatic - Indians from the Department of Anatomy, Nihon University School School of Dentistry at Matsudo, Japan. The occlusions were Class I or Class II with minimal crowding. All lower third molars were present. Authors used CT scans of the mandibular body and lateral cephalogram for their measurements. The guidelines of the lower second premolar, first molar, and second molar sections were defined through the center of each tooth in the lateral views. Sections in the first and second molars were made parallel to their axes in the 2-mm

mesial position for taking photographs of the mesial root.

The following measurements on the lower left central incisor, second premolars, and first and second molars were described: height and width of the cortical bone, buccal cortical bone thickness, lingual cortical bone thickness, basal cortical bone thickness, tooth inclination, and bone inclination. The assignments related to the facial types were based on FMA, palatal to mandibular plane, gonial angle, and FHI (ratio of posterior facial height to anterior facial height). Researchers reported that the inclination of the second premolars and first and second molars were significantly smaller in the short-faced group than in the average- and long- faced groups.

The results were correlated with the different masticatory function among the three facial types. In other words, they explained the results by mentioning that the lower molars' torque has to do with the stability and balanced position among the tongue and buccal pressure. In this study, mandibular tooth axial inclinations for average facial type male Asiatic Indians are 80.2° (SD 4.6) for first molars and 70.9° (SD 5.4)

for second molars. For the reliability test, authors reassessed a series of 20 subjects 2 months after the initial measurement, but did not report the typical interclass correlation. Authors used the following formula for the error variance calculation:

$$Ve = \Sigma(x_1-x_2)^2 / 2n$$

The mean differences were less than 1mm or 1 degree. A small number of significant mean differences between the first and second measurements of some variables probably reflected their difficulty in the identification of tooth axis. Limitations of this study were that the method for measuring the lower molar inclination on the transverse slice was not very clearly defined (as well as the width, height, and the other cortical bone measurements), and that it may be applicable only on males and dependent upon the sample's ethnic origin. In addition, authors did not mention if there was any previous orthodontic treatment, any posterior crossbites. Also their results were based on indirect measurements from standardized radiographs, and they didn't mention the age of the skulls.

Masumoto et al. (2001) measured the buccolingual inclination of the lower first and second molars, and they also reported association between the inclination and the facial types. Authors examined 31 dry skulls of modern (1880-1920) Japanese males (mean age 27 years, range 18-45 years of age) and reported that the occlusion was normal with minimal dental discrepancy (without defining exactly this discrepancy) without crossbite or facial asymmetry. Researchers took two computed tomograms of the coronal sections at the first and second molars. The slice thickness was 1mm, and the standard plane for positioning consisted of the mid-point of both centrals and the mesiobuccal cusp of both first molars. The standard plane was positioned perpendicular to the vertical line of the positioning light in the computer tomography machine. The guideline of each molar was made parallel to its axis through the mesial cusp to obtain tomograms of each mesial root. On the lateral view, the central axes of the molars were passing through the mid-point of the mesiodistal crown width, and the midpoint of both middle points at one-third of the root apex of both the mesial and distal roots, and the angle between the basal line (inferior border of mandible) and the tooth

axis (central fossa and mid-point at one-third of the distance from the root apex) was used.

Masumoto et al. reported that the mean angle (may not be the most appropriate measure of central tendency) of the first molar (N=62) was 78.2 degrees (SD: 4.70) for average facial height (n=17), 79.4 (SD: 5.35) for short faced(n=7), and 77.7 (SD: 4.81)for long faced(n=7). Range was not mentioned. The conclusion was that facial types are associated with the cortical bone thickness of the mandibular body, and the buccolingual inclination of first and second molars. A limitation of the study was the fact that examiners had difficulties in the identification of some reference points, especially tooth axes. Therefore, a small number of significant mean differences between the first and second measurements of the same variables were seen. The sample had also a wider age range (18-45 years of age), and the groups were small (7 short-faced, 17 average-faced, 7 long-faced). Furthermore, authors didn't accurately define the occlusion of the sample and the number of the operators. Finally, ranges related to the measurements were not reported.

In addition to angulation, lower arch width is considered to play a significant role in the stability of the orthodontic result. Back in 1976, Gardner and Chaconas studied 103 cases, 74 of which were treated non-extraction and 29 with the extraction of four first premolars. There were 62 females and 41 males in their study group. Using the Angle classification, 33 of the 103 pre-treatment cases were Class I, 52 Class II, Div.1, 5 Class II, Div. 2 and 13 Class II, subdivision. The ages of the patients ranged from 6 years at the beginning of the treatment to 27 years at the removal of retention devices.

The inclusion criteria were the following: the records of each case had to be complete, a minimum of one year was felt to be ample time for any relapse to occur, the initial case had to have a full complement of teeth exclusive of the third molars, the results of treatment had to be within acceptable limits(determined by subjective evaluation of the molar relationship, the presence or absence of crowding and the degree of overjet and overbite present), and the treatment of these cases was accomplished by the full-banded bioprogressive edgewise technique. Authors used the lower casts to

measure the arch widths of canines, premolars, and molars and an arch depth. Intercanine width was determined as the distance between the cusp-tip center of one permanent canine to the other, and inter-first molar width was stated as the distance between the buccal surface at the buccal groove of the first molars. Researchers found that the intercanine width was expanded during treatment (mean difference was 1.23 mm in non-extraction group and 1.92 mm in extraction cases). Examiners also reported a strong tendency to return to or close to its original pretreatment width in both non-extraction and extraction groups following treatment. Intermolar width increased 2.04 mm in nonextraction cases and decreased 1.46 mm in extraction cases. Importantly, these changes in the intermolar width were stable during the post-retention period.

In the absence of permanent canines, the measurement of the inter-canine width was subjectively estimated (biased). On the other hand, measuring cases in the absence of canines is against their inclusion criteria (full complement of teeth). The conclusions may also not be applicable in Class III cases, since that was the only Angle classification that was not included in the study.

The various range of the post-retention times (from 1 to 13 years with a mean of 5.2 years for nonextraction and 5.3 for extraction cases) for measuring the final relapse and the absence of any report regarding crowding (potential confounder) was another limitation of the study. Finally, the treatment was based on the full-banded bioprogressive edgewise technique, which nowadays is not commonly used, with the bonded straightwire appliances being the predominant technique. (Gardner et al 1976)

Housley et al., in 2003, used a sample which was treated with expanding lingual arch appliances in the maxilla and mandible. The purpose was to detect the stability after orthodontic treatment. The sample consisted of 29 white patients, 12 male and 17 female, who had received non-extraction orthodontic therapy. Patients were selected based on the availability of their long-term records. Patients with missing permanent teeth or congenitally absent teeth were excluded from this study. The mean pre-treatment 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(SD: 2 Years 4 months). The mean pre-treatment crowding in the

mandibular arch was 3.33 mm, and the expansion appliance was used for 3.5±1.3 months. Twelve of the cases were Class I, 11 Class II Div. 1, and 6 Class II Div.2 before treatment. Apart from the expanding appliance, a fixed edgewise appliance with a .022 slot bracket system was used. After treatment, 19 patients were using Hawley retainers in the lower arch, and 10 patients fixed lower retainer. Dental casts and cephalometric x-rays were used for the measurements. Arch crowding, arch perimeter, arch length, and arch width at the permanent canines, first premolars, second premolars, and permanent first molars were measured on photocopies of mandibular casts, before treatment, after treatment, and after retention. Arch width was measured as the distance between the cusp tips of the contralateral canines and the distance between the central occlusal landmarks of the premolars and the molars. Authors reported 1.52 mm increase of the inter-canine width (from 24.94±1.66 to 26.41±1.02) and 0.92 mm increase of the inter-molar width immediately after treatment. Researchers found that patients with fixed retention showed minimal changes in the arch measurement, in contrast to those with Hawley retainers who had variable changes. In those patients who had removable

retention, only eight percent on average (no absolute values are given) of the arch width increase at the canines was maintained after the retention stage. In addition, 1.15±1.43 mm change with treatment and -1.06±0.82 mm change after retention was reported. On the other hand, about 60%- 70% of the expansion remained at the first and second premolars and the first molars. So, it was concluded that transverse expansion was more stable in the posterior region of the mandibular arch, rather than in the anteriors and that the mandibular intercanine width increase could only be maintained by using fixed retainers.

However, in this study authors considered as post-retention stage the removal of the Hawley from the Hawley group and the maintenance of the fixed retainer in the fixed retention group, which by definition is incorrect. Probably there would be different results if researchers would have removed both retainers or maintained both in their third-stage measurements. The sample size was also small (29 cases), with only 19 patients in the Hawley category and 10 in the fixed, so the results could be merely produced due to chance. Furthermore, the arch width measurements were indirect measurements on

photocopies, so the measurements could have substantial measurement bias since no data exists regarding reliability. Moreover, the sample consisted only of white patients who didn't have Angle's Class III classification and were selected based on the availability of their long term records (Housley et al., 2003).

Although canine and molar width can be measured accurately on dental casts, measuring the inclination of the canines and molars estimates the crown inclination rather than the actual root inclination, which is determined by the long axis of the tooth. Many of the past studies were based on the crown inclination measured on models. Such examples (mentioned above) are the studies from Andrews (1944), Ross et al. (1990), by Marshall et al. (2003), as well as the ABO objective grading system (1998). Janson et al. (2004), used the casts in order to measure the long axis of the posterior teeth on models in subjects with different facial patterns. Tsunori et al. (1998) and Masumoto et al. (2001) used computed tomograms to measure the faciolingual inclination of teeth on dry skulls. Kasai et al. (2001) also used CT scans to determine the correlation between buccolingual inclination and the wear

of lower second premolars and first and second molars in ancient and modern Japanese skulls.

The clinical application of 3-dimensional craniofacial imaging may be considered one of the most exciting and revolutionary topics in dentistry. Cone-beam computed tomography (CBCT), also known as cone-beam volumetric tomography (CBVT), has followed the trend of computed tomography (CT) in medicine, in which, clinical applications were immediately recognized (Mah et al., 2004). A key feature of CBCT images is the ability to navigate through the volumetric data set in any orthogonal slice window (axial, lateral, and anteroposterior views). Instead of just analyzing two-dimensional cross-sectional images from a three-dimensional patient, clinicians can now analyze in 3D. Three-dimensional CBCT images provide additional diagnostic information on: 1) size, shape, and position of mandibular condyle heads; 2) width of the tooth-bearing portion; 3) morphology, inclination, displacement, or deviation of the lateral and medial surfaces of the mandibular rami and body; 4) dental root positioning; 5) localization of impacted or supernumerary teeth; 6) palatal morphology; and 7) morphology of sites

for placing implants or osteotomies. This information can help in the identification of affected structures, treatment planning, and comparisons with long-term follow-up of treatment stability (Cevidanes et al, 2006). Use of the CBCT can now allow us to measure the buccolingual inclination of the teeth by using the true long axis of the tooth.

Recenly, Shewinvanakitkul et al (2009), developed a method to measure buccolingual inclination using Cone Beam Computerized Tomography (CBCT). Authors used pretreatment Cone Beam Computed Tomography (CBCT) scans from patients between 11 and 14 years of age. The study sample was nased on nearly 200 pretreatment patient records consisting of CBCT scans, study models, photographs, and medical history forms. The purpose was first to develop a reliable method to measure buccolingual inclination of mandibular canines and the first molars using CBCT. The researchers also measured and reported mean and ranges of the inclination, intercanine, and intermolar width using CBCT for inclination and study models for the arch width. In addition, authors compared inclination, intercanine, and intermolar width between patients with Rapid Maxillary

Expander (RME) and without RME, as well as patients with pre-treatment posterior crossbite and without posterior crossbite in RME group.

Intra-examiner reliability was 0.95 for both mandibular canine and first molar. For the mandibular canines, the mean inclination before treatment was 98.0 ± 4.1°, and the mean intercanine width was 26.0 ± 2.2 mm. For the mandibular molars, the mean inclination before treatment was 74.6 ° ± 4.7 °, and the mean intermolar width was 40.9 ± 2.7 mm. A very weak pretreatment relationship was observed between the inclination of the lower first molars and the intermolar width, as well as the inclination of the lower canines and the intercanine width. Mandibular first molar inclination decreased in Class II (molar) cases and in patients receiving expander. Furthermore, there was no statistical significant difference between the age and gender groups.

The tooth inclination related to the orthodontic treatment is affected by the orthodontic techniques. Andrews described a pre-adjusted bracket that gives a 3-dimensional control and its built-in guidance design helps achieve the six keys for static occlusion. With the Straight-Wire bracket, wirebending is minimized. Each

progressively larger archwire delivers an amount of its deflected energy to each tooth. The built-in features of the Straight-Wire Appliance (SWA) guide the teeth along direct vector lines, virtually eliminating jiggling, round tripping, and other excessive movements. The bases of the brackets are inclined for each tooth type to achieve proper tooth ''torque''- with the center of each slot at the same height as the middle of the clinical crown (versus measurement from insical/cusp tip). This innovation was replacing the edgewise slot-torque that is not compatible with true straight-wire treatment. Andrews explained that SWA slots are not torque even though they may appear to be because of the design of the face of the bracket (Andrews 1976).

A few years later Roth reported that, after using some of the earlier prototype Straight-Wire brackets on approximately 30 patients, he switched his entire practice over to the Straight-Wire Appliance, convinced of its multiple advantages: 1)ease of archwire construction, 2)no need for inter-bracket span, 3)ease of archwire placement, 4)less round tripping, 5)better control of tooth positions, 6)shorter treatment time, 7)patient comfort, 8)more convenient space closure,

9)ease of ligation, bracket identification, 10)easier bracket placement, 11)advantage in surgical cases. Nevertheless, he states that it is much easier to control tooth positions with bracket placement than by bending wire(Roth 1976). Although Roth introduced further modifications in an attempt to reduce the number of bracket types required using Andrew's prescription, Roth maintained -11 degree torque for the lower canines and -30 degree torque for the lower first molars (Thickett et al., 2007).

Later on, McLaughlin, Bennett, and Trevisi introduced some further modifications to improve the results of completed cases. In their MBT prescription, one of the modifications was to change the lower first molar torque by 10 degrees in order to prevent the 'rolling in' of lower molars. For the lower canines, the -11 degrees torque has not been satisfactory, as they judge that it tends to leave the lower canine roots in a prominent position in most cases. Therefore, a range of -6, 0, +6 degrees torque is available in their prescription (McLaughlin et al, 2001). At this point it is worth mentioning that the above bracket torque values are not directly comparable to the numbers that were

previously mentioned regarding the inclinations of the lower teeth (Tsunori et al (1998), Masumoto et al (2001), Shewinvanakitkul et al (2009)). The inclination values were based on angles related to basal line (inferior border of mandible) and tooth axis. This is in contrast to torque numbers, which have to do with the angle that is related to the base of the bracket, and the slot of the bracket, taking also into consideration the crown morphology.

The impact of orthodontic treatment on the existing pre-treatment inclination values for mandibular canines and first molars (Shewinvanakitkul et al.) is unknown and is the basis for the present study. It would be also important to determine if there is any association of the change in post-treatment inclination with the change in archwidth.

REFERENCES

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

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

Andrews LF. The straight-wire appliance. Extraction brackets and classification of treatment. J CLin Orthod 1976;10:99-114

Ash MM, Nelson SJ. 2003. *Wheeler's Dental Anatomy, Physiology and Occlusion*. 8th edition. Saint Louis, MO. WB Saunders Company.

Burke SP, Silveira AM, Goldsmith LJ, Yancey JM, Stewart AV, Scarfe WC. A meta-analysis of mandibular intercanine width in treatment and postretention. Angle Orthod 1997;68:53-60.

Cevidanes LH, Styner MA, Proffit WR. Image analysis and superimposition of 3-dimensional cone-beam computed tomography models, Am J Orthod Dentofacial Orthop. 2006;129:611-8.

Erdinc AE, Nanda RS, Isiksal E. Relapse of anterior crowding in patients treated with extraction and nonextraction of premolars. Am J Orthod Dentofacial Orthop 2006;129:775-84.

Gardner SD, Chaconas SJ. Posttreatment and postretention changes following orthodontic therapy. Angle Orthod 1976;46:151-61.

Germane N, Bentley B, Isaacson RJ, Revere JH. The morphology of canines in relation to preadjusted appliances. Angle Orthod 1990;60:49-54

Gioka C, Eliades T. Material-induced variation in the torque expression of preadjusted appliances. Am J Orthod Dentofacial Orthop 2004;125:323-8.

Harris EF. A longitudinal study of arch size and form in in untreated adults. AM J Orthod 1997;111:419-27

Housley JA, Nanda RS, Currier GF, McCune DE. Stability of transverse expansion in the mandibular arch. Am J Orthod Dentofacial Orthop 2003;124:184-188.

Janson G, Bombonatti R, Cruz KS, Hassunuma CY. Buccolingual inclinations of posterior teeth in subjects with different facial patterns. Am J Orthod Dentofacial Orthop 2004;125:316-22.

Kasai K, Kawamura A, Correlation between buccolingual inclination and wear of mandibular teeth in ancient and modern Japanese. Arch Oral Biol. 2001;46:269-73.

Mah J, hatcher D. Three-dimensional craniofacial imaging. Am J Orthod Dentofacial Orthop 2004; 126:308-9.

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

Masumoto T, Hayashi I, Kawamura A, Tanaka K, Kasai K, Relationships among facial type, buccolingual molar inclination, and cortical bone thickness of the mandible. Eur J Orthod. 2001;23:15-23.

McLaughlin RP, Bennett J, Trevisi H. Systemized Orthodontic Treatment Mechanics, Mosby 2001;36-38

Mestriner MA, Enoki C, Mucha JN. Normal torque of the buccal surface of mandibular teeth and its relationship with bracket positioning: a study in normal occlusion. Braz Dent J. 2006;17:155-60

Ricketts RM. Bioprogressive therapy as an answere to orthodontic needs. Part I. Am J Orthod 1976;70:241-267.

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

Roth RH. Five year clinical evaluationof the Andrews Straight-Wire appliance. J Clin Orthod 1976;10:836-50

Shewinvanakitkul et al, Using CBCT to Measure Buccolingual Inclination of Mandibular Canines and First Molars. Masters Thesis, Case Western Reserve University, 2009.

Sebanc J, Brantley WA, Pincsak JJ, Conover JP, Variability of effective root torque as a function of edge bevel on orthodontic arch wires. Am J Orthod 1984;86:43-51.

Slutzkey S, Levin L. Gingival recession in young adults: Occurrence, severity, and relationship to past orthodontic treatment and oral piercing. Am J Orthod Dentofacial Orthop 2008;134:652-6

Thickett E, Taylor N, Hodge T. Choosing a preadjusted orthodontic appliance prescription for anterior teeth, J Orthod 2007;34:95-100

Tsunori M, Mashita M, Kasai K. Relationship between facial types and tooth and bone characteristics of the mandible obtained by CT scanning. Angle Orthod 1998;68:557-562.

Ugur T, Yukay F. Normal faciolingual inclinations of tooth crowns compared with treatment groups of standard and pretorqued brackets. Am J Orthod Dentofacial Orthop 1997;112:50-7

STATEMENT OF THESIS

The objectives of the study are to: 1. Measure and report the mean and ranges of the post-treatment and change in inclination, intercanine, and intermolar width for adolescent orthodontic patients using CBCT for inclination and study model for arch width; 2.Assess inclination, intercanine and intermolar width before and after orthodontic treatment and evaluate if there is any difference in inclination or/and width before and after orthodontic treatment; 3.Compare the post-treatment change in the inclination of lower canines and first molars with the post-treatment change in the intercanine and intermolar width.

It is hypothesized that:

1) No difference exists in mandibular canine inclination before and after orthodontic treatment;

2) No difference exists in mandibular first molar inclination before and after orthodontic treatment;

3) No difference exists in mandibular intercanine width before and after orthodontic treatment;

4) No difference exists in mandibular intermolar width before and after orthodontic treatment;

5) No relationship exists between the post-treatment change in inclination of mandibular canines and post-treatment change in intercanine width;

6) No relationship exists between the post-treatment change in inclination of mandibular first molars and post-treatment change in intermolar width.

If any of these hypotheses are rejected, differences and/or relationships will exist between our measurements.

CHANGES IN BUCCOLINGUAL INCLINATION OF MANDIBULAR CANINES AND FIRST MOLARS AFTER ORTHODONTIC TREATMENT USING CBCT

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Objectives: To determine the effect of orthodontic treatment on the buccolingual inclination of the mandibular canines and first molars. **Methods:** Seventy patients between the ages of 11 and 14 years of age treated in the Case Western Reserve University graduate orthodontic clinic who had cone beam computed tomographs taken before and after orthodontic treatment were selected. All patients were treated with full upper and lower pretorqued/preangulated fixed appliances for a minimum of 22 months. Buccolingual inclination was measured by using a commercially available software program (Accurex, Cybermed Inc – Seoul, Korea). Buccolingual inclination was defined as the angle formed by a line passing through the long axis of the tooth and a line tangent to the lower border of the mandible (bilaterally). Initial and final casts were used to measure intercanine and intermolar width. Demographic information as well as treatment approach and dental and facial characteristics were abstracted from the treatment record. Data were analyzed using paired sample t-tests, independent sample t-tests and analysis of variance. A p-value of 0.05 was used to assign statistical significance. **Results:** The mean angulation of the left and right mandibular canines before treatment was 97.8±4.6 and 96.8±3.9, and for the left and right mandibular molars it was 74.7±5.1 and 76.4±4.5, respectively. After treatment the means for the lower left and right canines were 94.7±4.8 and 93.9±4.1, respectively and the means for left and right molar angulation were 77.0±4.9 and 77.4±5.0, respectively. All angular treatment differences were statistically significant. Mean intercanine width also increased significantly (1.2±1.7mm mean change), while intermolar width did not change significantly with treatment (0.3±1.6mm). **Conclusions:** In this sample, orthodontic treatment decreased the angulation of the mandibular canines and increased intercanine width. This combination of movements suggests that buccal movement of the canine roots exceeds buccal crown movement. The clinical significance of these movements to post treatment stability is an important area for future study.

INTRODUCTION

Andrew's study[1] of 120 cases of non-orthodontic normal occlusions identified six significant characteristics that have become hallmarks of a well-completed orthodontic case. One of these keys was tooth inclination. According to Andrews, the lower posterior teeth should be inclined lingually, progressively more from canine to molars. The American Board of Orthodontics[2] has also stated that buccolingual inclination is one of the important criteria to determine if orthodontists are producing "board quality" results. Buccolingual crown inclination with uprighting of the posterior teeth was a characteristic of an acceptable occlusion in a study by Marshall et al[3]. They found 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. [3]

In addition to proper angulation, maintaining lower arch width, especially intercanine width, is considered to play a significant role in the stability of the orthodontic result. Gardner and Chaconas[4] found that the intercanine width was expanded 1.23 mm in non-extraction cases and 1.92 mm in extraction cases. Following treatment the authors reported a strong tendency for intercanine width to return to its original pretreatment value in both non-extraction and extraction groups. Intermolar width increased 2.04 mm in nonextraction cases and decreased 1.46 mm among the extraction cases. In contrast to intercanine width, these changes in the intermolar width were stable during the post-retention period.

Housley et al[5] also found that transverse expansion was more stable in the posterior region of the mandibular arch.

Although canine and molar width can be measured accurately on dental casts, inclination of the roots of the teeth must be estimated using the crowns of the teeth. Recently, Shewinvanakitkul et al[6], developed a method to measure the buccolingual inclination of fully erupted mandibular canines and molars using Cone Beam Computed Tomography (CBCT) scans from patients between 11 and 14 years of age. Intra-examiner reliability for the method was 0.95 for both mandibular canine and first molar angulations. They found that the mean inclination of the mandibular canine in untreated cases was 98.0 ± 4.1° and the mean inclination for untreated mandibular molars, was 74.6 ± 4.7 °. The impact of orthodontic treatment on these values was unknown and is the basis for the present study.

The purpose of the present study is to: 1) Measure and report mean and ranges of the final inclination and change in inclination for mandibular canines and first molars after orthodontic treatment; 2) Compare the inclination of mandibular canines and first molars before and after orthodontic treatment; 3) Compare the post-treatment change in inclination with posttreatment change in arch width respectively.

MATERIALS AND METHODS

The Case Western Reserve University Institutional Review Board (IRB) approved the experimental protocol. Subjects were selected from a sample of

patients presenting to the dental school for comprehensive orthodontic treatment in the graduate clinic. Data were derived from existing pre-treatment and post-treatment 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 2006 using the 2mA setting and the largest field of view (0.28 voxel size) . A total of 200 pretreatment patient records consisting of CBCT scans, study models, photographs and medical history forms were available. Sample size calculations using an estimated mean standardized effect size of two degrees with an alpha of 0.05 and beta of 0.1 indicated that the minimum sample size should be 47 subjects.

The following inclusion criteria were applied to all patients who had scans in 2006:

1. Completed orthodontic treatment before December 15th, 2008
2. Age between 11 and 14 years old at the time of the initial scan.
3. Fully erupted mandibular canines and first molars, determined using study models
4. No previous orthodontic treatment, based on medical history form
5. No deciduous mandibular teeth present
6. No missing or extracted permanent teeth in mandibular arch
7. No restoration of the dental cusps of measured teeth
8. No severe rotations ($\geq 90°$) of the mandibular canines or first molars
9. No buccal crossbites

10. Landmarks (cusp tips and root apices) of measured teeth were clearly visible on the CBCT scan

Seventy subjects met these inclusion criteria and 130 subjects did not. Thirty-seven 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 severely rotated mandibular canines, second premolars or first molars, 10 subjects had mandibular deciduous teeth, 6 subjects had poor images and 13 subjects received no treatment or were transferred to other clinics/offices. Out of 108 remaining subjects 37 didn't have available final records (CBCT and study models) and one was missing the final study models. The final sample consisted of 36 female and 34 male patients, with an average age of 13.07±1.03 years. Following the method developed by Shewinvanakitkul et.al. briefly illustrated in figures 1-7, 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. 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 (.jpg) image, and was labeled using a patient identifier. Slice thickness was fixed at 0.28 mm (as a function of the standard voxel height). Measurements were based on slices of the left and right canines, and the left and right first molars. Measurements were repeated after a three week interval on 29 subjects. Patient demographic information, molar

classification, expander status, crossbite status, bracket slot, bracket prescription, bracket design, facial height, rectangular archwire (period of time that was used), triangular elastic wear, treatment duration, initial and final PAR score and reduction in PAR score 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.

Inclination and arch width measurements (see Figure 1-9) (Shewinvanakitkul et al. 2008, modification of Tsunori et al. 1998)

Mandibular canine inclination (degrees) was defined as the angle between a line passing through the long axis of mandibular canine (cusp tip to root apex), and a line tangent to the inferior border of the mandible apical to the mandibular canines. Mandibular first molar inclination (degrees) was defined as the angle between a line passing through the long axis of molar (central groove to root apices), and a line tangent to the inferior border of the mandible apical to the molars.

Mandibular intercanine width (mm) was defined as the 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) was defined as the 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

Means and standard deviations were calculated for each variable. Paired sample t-test compared inclinations and widths before and after orthodontic treatment. Independent sample t-tests and analysis of variance (ANOVA) were used to compare the outcomes for the potential explanatory variables. Pearson Correlation examined relationships between tooth inclination and arch width. Linear regression analysis explored the relationships among explanatory variables and the outcome. Measurements were repeated after a 3-week interval on 29 randomly selected subjects and reliability was estimated using intraclass correlation (r^2). All statistics were calculated using the Statistical Package for the Social Sciences (SPSS 17.0, Inc. – Chicago, IL).

RESULTS

Demographics

The study sample consisted of 34 male and 36 female subjects for a total of 70 subjects, whose average age was 13.07 ± 1.0 years, with a range from 11.0 – 14.7 years. Most subjects were Caucasoid (n=62) with six Negroid, and two Mongoloid subjects. Patients were treated by four orthodontic residents under the supervision of 13 instructors. One resident and one instructor were assigned to each patient. The mean initial PAR score was 20.9±8.8, the mean post treatment PAR score was 5.6±3.2, and mean percent reduction in PAR score was 70.2±19.0%. A descriptive

summary of anthropological group, gender, expander status, bracket slot, canine bracket torque, first molar bracket torque, bracket design, facial height, extractions is shown in Table 1 and Table 2. A summary of the descriptive variables that changed after orthodontic treatment is shown in Table 3.

Inclination and width for mandibular canines and first molars

Data for right and left sides were collected separately. A preliminary t-test showed no difference between right and left sides for the inclinations after treatment, in contrast to the initial inclinations. Although there was no significant difference between initial left and right side canine inclination, the left and right first molar inclinations were found to be statistically significant different and therefore data were not pooled for subsequent analyses.

For the mandibular left and right canines, the mean initial inclination was 97.8 ± 4.6 degrees and 96.8 ± 3.9 degrees respectively and the mean intercanine width was 25.8 ± 2.2 mm. For the mandibular first molars, the mean initial inclination was 74.7 ± 5.1 degrees for the left and 76.4 ± 4.5 degrees for the right ones. The mean intermolar width was 41.2 ± 2.6 mm (Table 4).

Regarding the final inclinations and widths (Table 4), the mean left canine inclination was 94.7 ± 4.8 degrees (-3.1 ± 4.6 degrees mean change with a decrease in 77.1% of the subjects) and the mean right canine inclination was 93.9 ± 4.1 degrees (-2.9 ± 3.9 degrees mean change with a decrease in 78.6% of the subjects). The final mean intercanine width was 27.0 ± 1.8 mm (1.2 ± 1.7 mm mean change). For the mandibular molars, the mean final inclination was 77.0 ± 4.9 degrees for the left (2.2

± 5.0 degrees mean change, with an inclination increase in 72.9% of the subjects) and 77.4 ± 5.0 for the right molar (1.1 ± 4.0 degrees mean change, with an inclination increase in 64.3% of the subjects). The mean intermolar width was 41.5 ± 2.4 mm (0.3 ± 1.6 mm mean change).

Differences among the groups and reliability

Comparisons between initial and final inclinations and widths were made using paired t-tests. There were statistically significant differences in inclination for the canines (left and right) and first molars (left and right) as well as intercanine width when pretreatment values were compared to post treatment values. Looking at Table 4, intermolar width was the only independent variable that showed no statistical difference. From this table we can clearly see that intraexaminer reliability was high ($r^2 \geq 0.94$).

Exploring differences among the independent variables, we found a statistically significant difference between males and females for the change in inclination during treatment for the mandibular canines (bilaterally), with females having more labial root movement compared to males (Table 5). No other significant differences were found for independent variable groups (Table 7) although there was a tendency for triangular vertical elastics to decrease cuspid angulation. (Table 6).

Correlations between change in canine inclination and intercanine width as well as change in first molar inclination and intermolar width were not strong ($r \leq 0.6$) (Table 8).

DISCUSSION

The goal of the present study was to investigate the effects of orthodontic treatment on the buccolingual inclination of the lower canines and molars. Although the study sample was randomly selected from all available records the resulting sample was predominately non-extraction and Caucasian. Therefore, these results should be interpreted in that context. Our results showed a significant difference between initial and final buccolingual inclinations for both the canines and the first molars.

Angulation changes were much larger for the canines compared to the first molars. The average four degree decrease in canine angulation is both clinically and statistically significant. If one considers that intercanine width increased an average of 1.2mm then the decrease in canine inclination is even more surprising. For example, a mandibular canine averages 27 mm in length[7] so a change in inclination of - 3°, causes the root apex to move buccaly about 2 mm (2x27xsin1.5+0.6). This means that the average patient in this sample had canines that were expanded by over 5mm at the apex. This finding could be potentially correlated with other studies that have shown a relationship between gingival recession and orthodontic treatment.[8] Our results suggest that canine roots are being moved buccally more than the crowns. It is not clear whether this excess buccal movement is related to canine bracket torque. However, our results do suggest that positive torque in the lower cuspid might help maintain buccal canine inclination and prevent canine roots from being moved into the dense cortical bone of the mandible. It is interesting that two

prominent clinicians, Robert Ricketts and Dwight Damon, have both recommended +7° torque in the canine bracket so that the roots are contained in cancellous bone.[9] Our results support the observations of these clinicians. Further studies are needed to determine the impact of the observed changes in canine angulation on the stability of orthodontic treatment results.

We did not find any differences related to age, anthropological group, expander status, bracket slot, bracket prescription, bracket design, facial height, rectangular archwire use, treatment duration, molar classification, crossbite groups, initial PARscore or reduction in PARscore. The most likely explanation for this finding was that subdividing our sample resulted in small groups that lacked the statistical power to discern the impact of these confounding variables. It is likely that some of these factors, such as bracket prescription, do influence canine inclination. However, additional studies are needed to answer these questions.

In contrast to changes in canine inclination, the changes in molar inclination, while statistically significant are probably not clinically significant. This in itself is an interesting finding if one considers that most untreated occlusions are stable. Following this rationale, the clinician should strive to maintain the initial angulations of the teeth when those angulations are within the "normal" range. In this sample, the first molars started with an average inclination of 75.5° (approximately -14.5° torque) and after treatment their crowns were buccally inclined for both our major bracket prescriptions, with less change in the group with less bracket torque (-25°). At this point we should take into consideration that on the buccal surface of the

mandibular first molar we find the buccal cervical ridge in the cervical third. From that ridge the buccal outline curves sharply lingually. As a result, bracket slots for the mandibular first molars are inclined to compensate for the inclination of the facial surface of the tooth[10]. In our study even a -25° bracket (for the specific initial mean inclination) might cause an increase in the angulation of the mandibular first molar. Ugur et al[11] reported that mandibular first molars had a significant increase in lingual crown torque after orthodontic treatment compared with normal occlusion groups and they suggested that molar torque should be handled carefully during treatment. Their study was based on the crown inclination on study models and not on the true long axis of the teeth. Our results showed that mandibular first molars upright during orthodontic treatment and that is definitely an acceptable treatment outcome, taking into consideration the initial lingual eruption of mandibular molars, followed by a reduction in their buccal root inclination in absence of orthodontic treatment[3]. Furthermore, our study showed no significant difference in intermolar width before and after treatment, despite the fact that there was an increase in crown inclination of the mandibular molars. This is in agreement with our finding that change in inclination of mandibular molars have not a strong correlation with final and change in intermolar width respectively.

One final finding that deserves some discussion is that females had greater increases in lingual root inclination compared to males. As reported in other studies[12] we also found that males had larger intermolar widths at the end of the orthodontic treatment. One explanation for these findings could be the possibility of having

greater cooperation with elastic wear among females compared to males throughout treatment. Females are more concerned with aesthetics and they tend to follow orthodontic instructions more carefully. In our study we also considered the triangular elastics to mandibular canines, a category of elastics which was accurately defined by the treatment notes. Both, the group with no triangular elastic wear and the group that was using bilateral triangular elastics appeared to have a reduction in the buccal crown inclination during treatment. But the group that was using the bilateral triangular elastics had almost twice as much change and that difference was trending towards significance. This is probably associated with the fact that the force is applied buccal to the center of resistance of the mandibular canines.

CONCLUSION

1) A significant change in buccolingual inclination of mandibular canines and first molars was observed with orthodontic treatment; 2) Mandibular canine torque decreases with treatment and at the same time there is a small but significant increase in intercanine width; 3) Mandibular first molar torque increases with treatment while intermolar width does not significantly change; 4) Females had significantly greater change in canine inclination compared to males; 5) Bilateral triangular elastic wear to the mandibular canines cause greater change in canine inclination compared to cases with no triangular elastic wear; 6) Changes in inclination were not strongly correlated with changes in intercanine and intermolar width.

TABLE 1.--Descriptive Summary of demographics, expander status, bracket slot and bracket torque among the study sample (N=70)

Variables	Group	Total	Percent
Anthropological Group	Caucasoid	62	88.6
	Negroid	6	8.5
	Mongoloid	2	2.9
Gender	Male	34	48.6
	Female	36	51.4
Expander Status	No expander	56	80.0
	Haas	3	4.3
	Hyrax	4	5.7
	Bonded	4	5.7
	Pendex	1	1.4
	Twin Block	1	1.4
	Quad Helix	1	1.4
Bracket Slot	0.018	16	22.9
	0.022	48	68.6
	Bidimensional	6	8.6
Canine Bracket Torque	0° canine inclination	19	27.1
	-7 canine inclination	42	60.0
	-11° canine inclination	9	12.9
First Molar Bracket Torque	-20° molar inclination	15	21.4
	-25° molar inclination	42	60.0
	-27° molar inclination	9	12.9
	-28° molar inclination	4	5.7

TABLE 2.--Descriptive Summary of bracket design, facial height, extractions, rectangular archwire and triangular elastic wear among the study sample (N=70)

Variables	Group	Total	Percent
Bracket design	Conventional	48	68.6
	Self-Ligating	22	31.4
Facial Height	Decreased	8	11.4
	Normal	53	75.7
	Increased	9	12.9
Extractions	None	65	92.9
	Maxillary second premolars/Mandibular second premolars	1	1.4
	One mandibular incisor	1	1.4
	Maxillary first premolars	1	1.4
	Maxillary left premolar	1	1.4
	Right second premolars/Left first premolars	1	1.4
Rectangular Archwire	0 months	5	7.1
	1-3 months	6	8.6
	4-6 months	6	8.6
	Over 6 months	53	75.7
Triangular Elastic Wear	None	28	40.0
	Bilaterally	36	51.4
	Unilaterally (either left or right)	6	8.6

TABLE 3.-- Summary of the descriptive variables that changed with treatment (N=70)

Variables	Group	Initial		Final	
		Total	Percent	Total	Percent
Molar Classification	Class I	31	44.3	54	77.1
	Class II Div 1	17	24.3	5	7.1
	Class II Div 2	3	4.3	0	0
	Class III	2	2.9	1	1.4
	Class II Subdivision Right	7	10.0	3	4.3
	Class II Subdivision Left	6	8.6	5	7.1
	Class III Subdivision Right	3	4.3	1	1.4
	Class III Subdivision Left	1	1.4	1	1.4
Crossbite	None	47	67.1	65	92.9
	Left canine	2	2.9	1	1.4
	Right canine	2	2.9	0	0
	Left first molar	2	2.9	2	2.9
	Right first molar	2	2.9	1	1.4
	All right posterior	1	1.4	0	0
	Left premolars	2	2.9	0	0
	Left and right canines	1	1.4	0	0
	Left and right premolars	1	1.4	0	0
	Left molars	0	0	1	1.4
	Right canine and posteriors	1	1.4	0	0
	Right molars	1	1.4	0	0
	Left second premolar and left first molar	1	1.4	0	0
	Right second premolar and right first molar	3	4.3	0	0
	Right second premolar	2	2.9	0	0
	Right first premolar	1	1.4	0	0
	Left and right second premolar	1	1.4	0	0

TABLE 4.--Reliability, Means, Standard Deviations and Range of Mandibular Canine and First Molar Inclination and Arch Width before and after treatment (N=70)

	Initial		Final		Change		Intra-examiner reliability (r^2)
Variables (N=70)	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Left canine inclination (°)	97.8 ±4.6	88.5 - 111.1	94.7 ± 4.8	81.7 - 106.5	-3.1 ± 4.6**	-12.0 - 13.1	0.96
Right canine inclination (°)	96.8 ± 3.9	88.6 - 108.6	93.9 ± 4.1	85.3 - 103.8	-2.9 ± 3.9**	-13.4 - 5.5	0.95
Left molar inclination (°)	74.7 ± 5.1	61.9 - 86.7	77.0 ± 4.9	66.4 - 91.9	2.2 ± 5.0**	-13.4 - 13.2	0.97
Right molar inclination (°)	76.4 ± 4.5	67.4 - 86.0	77.4 ± 5.0	65.6 - 90.6	1.1 ± 4.0*	-7.9 - 11.0	0.94
Intercanine width (mm)	25.8 ± 2.2	21.0 - 31.6	27.0 ± 1.8	22.6 - 31.5	1.2 ± 1.7**	-4.2 - 6.9	0.99
Intermolar width (mm)	41.2 ± 2.6	33.5 - 46.2	41.5 ± 2.4	35.5 - 48.0	0.3 ± 1.6	-4.0 - 3.8	0.99

* $P \leq 0.05$, ** $P \leq 0.001$

TABLE 5.--Gender Differences in Mandibular Canine and First Molar Inclination, Intercanine Width and Intermolar Width (N=70)

Variables	Male (n=34)			Female (n=36)		
	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	96.7 ± 4.9	94.9 ± 4.9	-1.7 ± 4.6*	98.9 ± 4.2	94.5 ± 4.8	-4.4 ± 4.4*
Right Canine inclination (°)	96.3 ± 4.0	94.3 ± 3.8	-1.9 ± 4.1*	97.4 ± 3.8	93.5 ± 4.3	-3.9 ± 3.6*
Left First molar inclination (°)	74.9 ± 4.6	78.0 ± 5.1	3.1 ± 4.8	74.6 ± 5.5	76.0 ± 4.7	1.4 ± 5.1
Right First molar inclination (°)	77.7 ± 4.2	78.5 ± 5.2	0.8 ± 3.8	75.1 ± 4.4	76.4 ± 4.6	1.4 ± 4.3
Intercanine width (mm)	25.7 ± 2.4	27.3 ± 1.9	1.6 ± 1.9	25.9 ± 2.0	26.8 ± 1.7	0.8 ± 1.5
Intermolar width (mm)	41.8 ± 2.2	42.2 ± 2.2*	0.4 ± 1.5	40.5 ± 2.7	40.8 ± 2.4*	0.3 ± 1.6

* $P \leq 0.05$, ** $P \leq 0.001$

TABLE 6.--Elastic Wear Differences in Mandibular Canine and First Molar Inclination, Intercanine and Intermolar Width after excluding Unilateral Elastics(N=64)

Variables	No triangular elastic wear (n=28)			Triangular elastic wear bilaterally (n=36)		
	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	97.0 ± 5.2	95.1 ± 4.6	-1.9 ± 5.2	98.0 ± 4.0	94.1 ± 5.2	-4.0 ± 4.2
Right Canine inclination (°)	97.0 ± 5.1	95.3 ± 4.6	-1.7 ± 4.5	96.8 ± 2.9	93.2 ± 3.6	-3.6 ± 3.4
Left First molar inclination (°)	74.6 ± 5.1	77.3 ± 5.4	2.7 ± 4.8	74.8 ± 5.2	76.8 ± 4.6	2.0 ± 5.5
Right First molar inclination (°)	77.6 ± 4.5	79.3 ± 4.5	1.8 ± 4.4	75.6 ± 4.5	76.1 ± 5.1	0.5 ± 4.0
Intercanine width (mm)	25.2 ± 2.8	26.8 ± 2.1	1.6 ± 2.1	26.2 ± 1.7	27.2 ± 1.6	0.9 ± 1.5
Intermolar width (mm)	40.9 ± 3.1	41.3 ± 3.1	0.4 ± 1.5	41.4 ± 2.3	41.6 ± 1.9	0.2 ± 1.7

* $P \leq 0.05$, ** $P \leq 0.01$

TABLE 7.--Facial Height Differences in Mandibular Canine and First Molar Inclination, Intercanine Width and Intermolar Width (N=70)

Variables	Decreased Facial Height(N=8)			Normal Facial Height(N=53)			Increased Facial Height(N= 9)		
	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	94.6 ± 3.9	93.9 ± 2.6	-0.7 ± 3.7	97.8 ± 4.6	94.7 ± 5.3	-3.1 ± 4.8	100.6 ± 4.0	95.5 ± 2.7	-5.1 ± 3.6
Right Canine inclination (°)	95.6 ± 3.1	94.7 ± 3.8	-1.0 ± 3.7	97.1± 4.1	94.1 ± 4.2	-3.0 ± 4.1	96.6 ± 4.1	92.2 ± 3.4	-4.5 ± 2.5
Left First molar inclination (°)	73.1 ± 4.7	75.4 ± 3.3	2.3 ± 4.7	74.8 ± 5.0	76.8 ± 5.2	2.1 ± 5.3	75.8 ± 5.9	79.1 ± 4.1	3.4 ± 3.2
Right First molar inclination (°)	76.9 ± 5.7	78.6 ± 5.3	1.7 ± 4.4	76.1 ± 4.5	77.2 ± 5.2	1.1 ± 4.2	77.2 ± 3.5	77.9 ± 3.3	0.6 ± 2.6
Intercanine width (mm)	24.3 ± 2.4	26.5 ± 1.2	2.2 ± 1.7	26.0 ± 2.0	27.2 ± 1.8	1.1 ± 1.8	26.1 ± 2.8	26.8 ± 2.2	0.7 ± 1.1
Intermolar width (mm)	40.6 ± 2.8	40.4 ± 1.9	-0.2 ± 1.3	41.2 ± 2.6	41.6 ± 2.4	0.3 ± 1.7	41.1 ± 2.5	41.8 ± 2.8	0.7 ± 0.7

* $P \leq 0.05$, ** $P \leq 0.001$

TABLE 8.--Correlations among Changes in Mandibular Inclinations and Changes in Widths (N=70)

	Change in Intercanine width		Change in Intermolar width	
	Pearson Correlation	Significance	Pearson Correlation	Significance
Change in Left Canine inclination	0.60	0.00	-	-
Change in Right Canine inclination	0.56	0.00	-	-
Change in Left Molar inclination	-	-	0.54	0.00
Change in Right Molar inclination	-	-	0.58	0.00

Figure 1. Locate the canine in the axial view, the point at which the root is longest in sagittal view

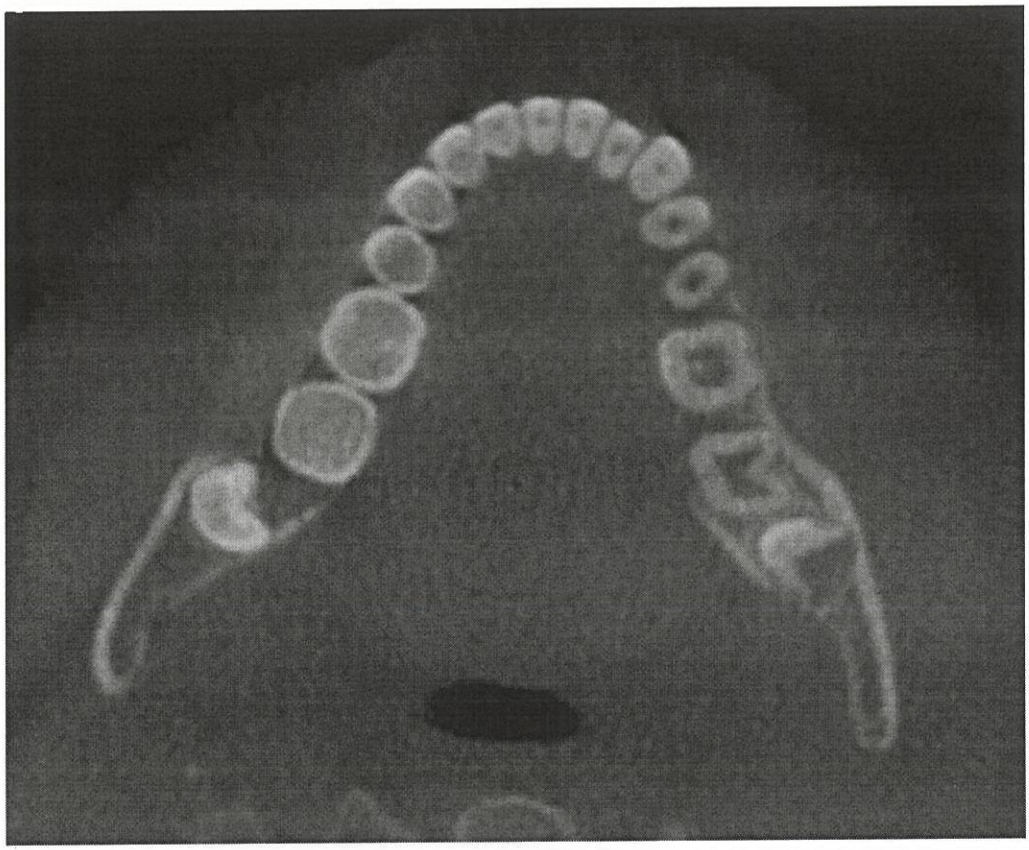


Figure 2. In the sagittal view, position the line representing the coronal slice along the long axis of the tooth.



Figure 3. In the coronal view, draw the reference line tangent to the base of mandible.

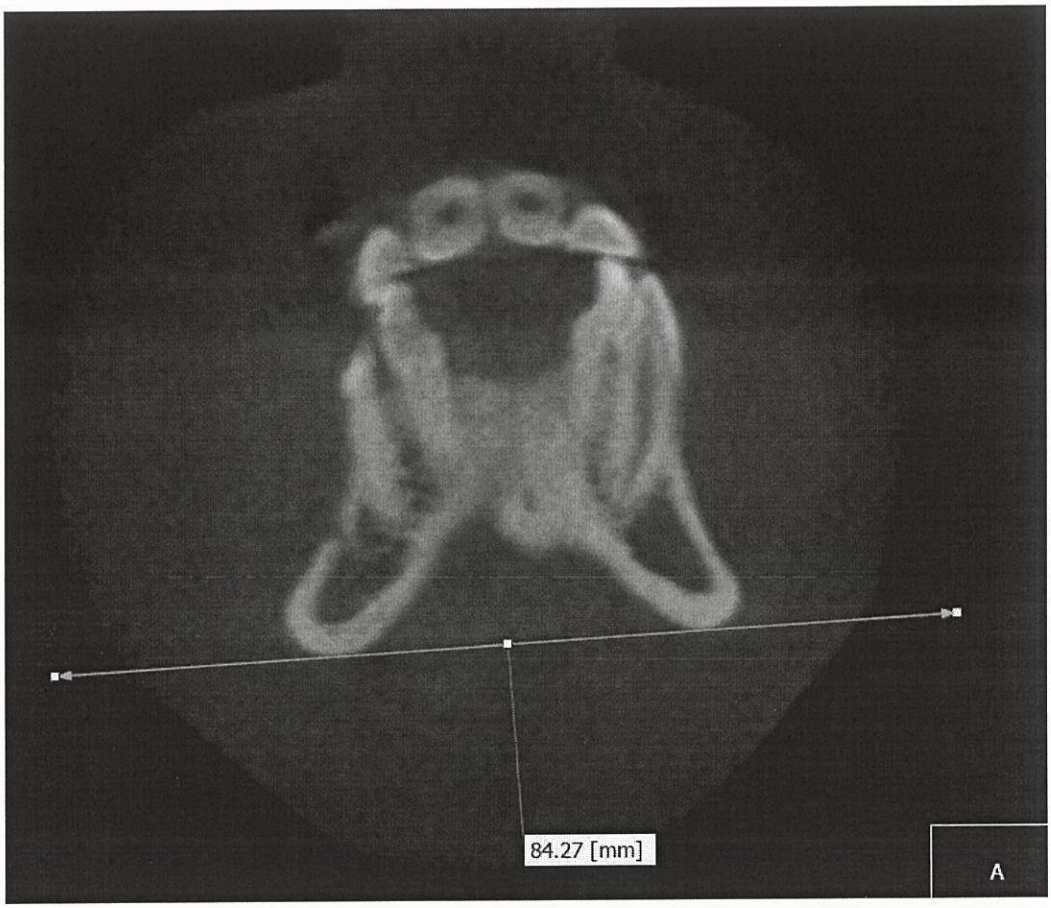


Figure 4. Measure the inclination through the long axis of the tooth

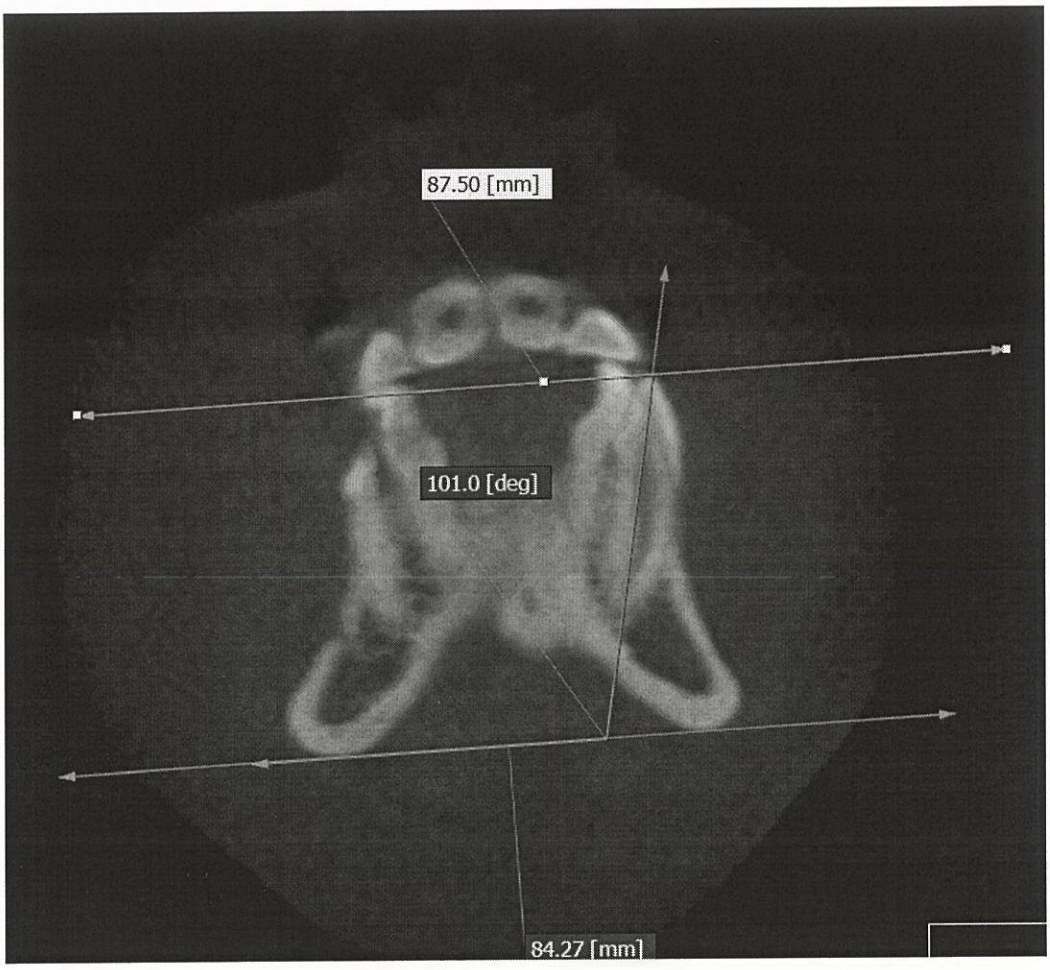


Figure 5. Locate molar in the axial view, the point at which the root is longest in the sagittal view.

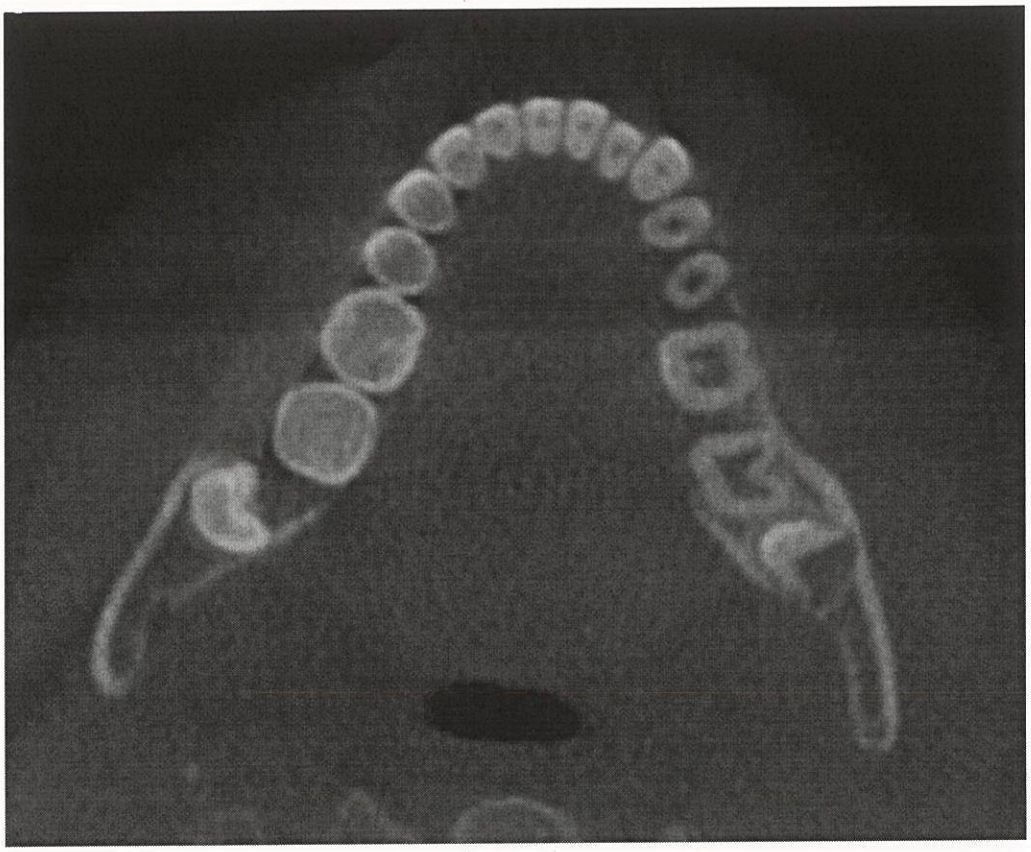


Figure 6. In the sagittal view, position the line representing the coronal slice along the plane of the mesial cusp tip and the mesial root apex.

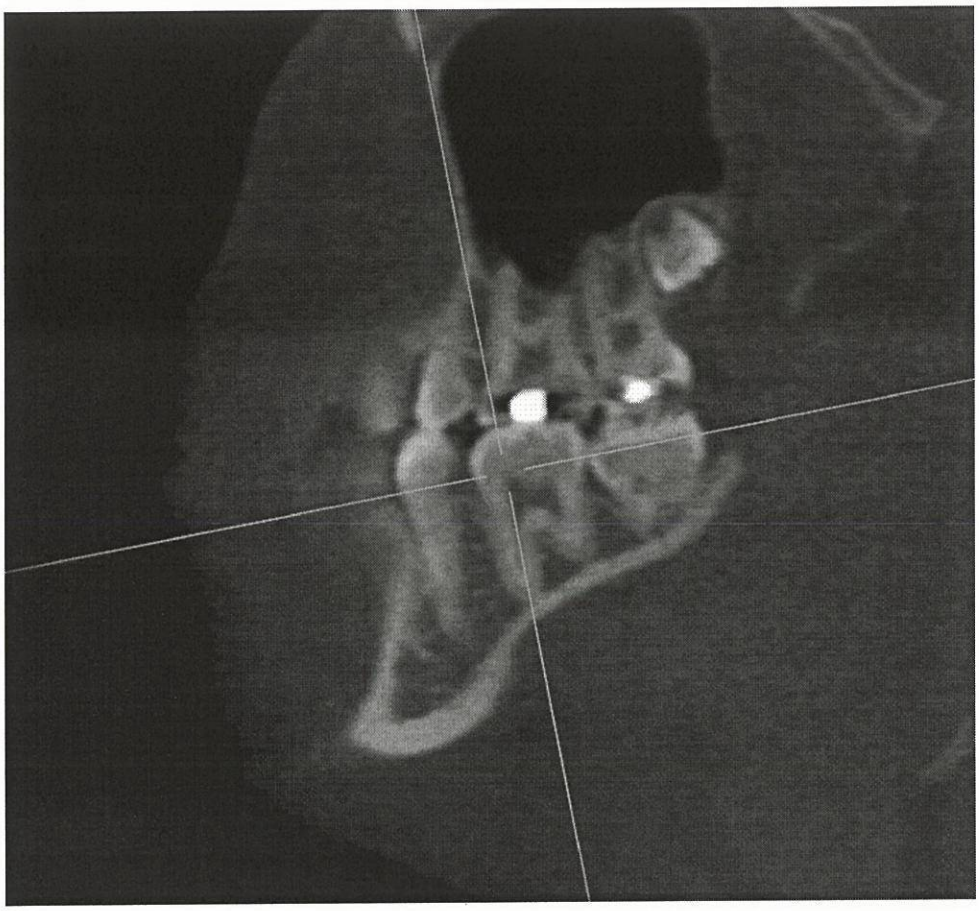
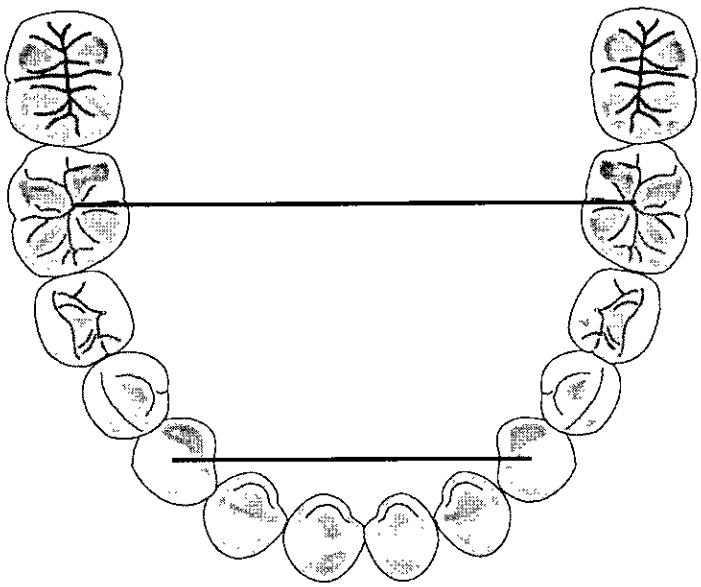


Figure 7. In the coronal view, draw the reference line tangent to the base of mandible and measure the inclination through the long axis of the molar (line between the central groove and root apex).



Figure 8. Measurements on study models



REFERENCES

1. Andrews LF. The six keys to normal occlusion. Am J Orthod 1944; 30:196-205.
2. American Board of Orthodontics. Objective grading system for dental casts and panoramic radiographs. Am J Orthod Dentofacial Orthop 1998;114:296-309.
3. Marshall S, Dawson D, Southard KA, Lee AN, Casko JS, Southard TE. Transverse molar movements during growth. Am J Orthod Dentofacial Orthop 2003;124:615-24.
4. Gardner SD, Chaconas SJ. Posttreatment and postretention changes following orthodontic therapy. Angle Orthod 1976;46:151-61.
5. Housley JA, Nanda RS, Currier GF, McCune DE. Stability of transverse expansion in the mandibular arch. Am J Orthod Dentofacial Orthop 2003;124:184-88.
6. Shewinvanakitkul W, Palomo JM, Narendran S, Hans MG. Using CBCT to Measure Buccolingual Inclination of Mandibular Canines and First Molars. Masters Thesis, Case Western Reserve University, 2009.
7. Ash MM, Nelson SJ. 2003. Wheeler's dental anatomy, physiology and occlusion. 8th ed. W.B. Saunders Company. Saint Louis. MO.
8. Slutzkey S, Levin L. Gingival recession in young adults: Occurrence, severity, and relationship to past orthodontic treatment and oral piercing. Am J Orthod Dentofacial Orthop 2008;134:652-6.
9. Ricketts RM. Bioprogressive therapy as an answer to orthodontic needs. Part I. Am J Orthod 1976;70:241-67.
10. Thickett E, Taylor N, Hodge T. Choosing a preadjusted orthodontic appliance prescription for anterior teeth, J Orthod 2007;34:95-100.
11. Ugur T, Yukay F. Normal faciolingual inclinations of tooth crowns compared with treatment groups of standard and pretorqued brackets. Am J Orthod Dentofacial Orthop 1997;112:50-7.
12. Harris EF. A longitudinal study of arch size and form in in untreated adults. AM J Orthod 1997;111:419-27

APPENDIX 1

IRB Approval

Case Western Reserve University
Institutional Review Board

NOTICE OF EXEMPTION (#2)

Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior

Responsible Investigator: **Mark Hans**
Department: **Dental Orthodontics**
IRB Protocol Number: **20081003**
Title: ***Changes in buccolingual inclination of lower canines and first molars after orthodontic treatment using CBCT***
Co-Investigator: **Nikolaos Evangelinakis**

Exemption Date: October 6, 2008

The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(2). The IRB will not conduct subsequent reviews of this protocol.

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

APPENDIX 2

Raw Data: Date of Birth, Date of Initial Records, Age, Date of treatment Initiation, Date of Final Records, Treatment Duration, Race, Gender, Initial and Final Molar Classification, Expander Status, Initial and Final Crossbite Status, Initial PARscore, Reduction in PARscore, Resident, Bracket Slot, Bracket prescription, Bracket Design, Facial Height, Triangular Elastic Wear, Ractangular Archwire Use, Initial and Final Left Canine and Right Canine Inclination, Initial and Final Left and Right First Molar Inclination, Initial and Final Intercanine Width and Initial and Final Intermolar Width

TABLE 1.--ALL DATA

Subject	DOB	IniRec	Age0	Start	FinRec	Duration	Race	Gender	Iniclass	Finclass	RME
1	10/17/1991	7/6/2006	5314	11/1/2006	11/26/2008	745	1	1	5	1	0
2	11/18/1993	4/27/2006	4491	8/10/2006	3/13/2008	573	1	2	7	1	0
3	9/16/1991	6/16/2006	5325	9/13/2006	8/4/2008	681	1	2	2	1	0
4	7/17/1991	4/24/2006	5332	10/18/2006	8/4/2008	646	1	2	2	1	2
5	10/13/1993	6/15/2006	4575	11/6/2006	7/30/2008	624	1	2	2	2	0
6	5/22/1994	4/24/2006	4304	9/12/2006	7/2/2008	650	1	2	2	1	0
7	8/11/1992	5/9/2006	4962	10/17/2006	6/24/2008	607	1	1	1	1	0
8	7/1/1992	4/27/2006	4990	1/9/2007	11/5/2008	656	1	2	1	1	0
9	7/24/1991	4/25/2006	5326	11/21/2006	11/18/2008	717	1	1	6	6	0
10	8/31/1992	4/27/2006	4931	10/18/2006	8/26/2008	668	1	2	1	1	0
11	8/1/1992	4/24/2006	4957	10/9/2006	10/13/2008	724	1	1	1	1	0
12	1/11/1992	4/26/2006	5159	8/30/2006	10/29/2008	779	1	1	1	1	0
13	7/25/1993	6/5/2006	4643	10/4/2006	10/7/2008	723	1	1	6	6	0
14	4/8/1992	11/1/2006	5258	12/6/2006	2/18/2008	432	1	1	2	2	0
15	6/4/1993	4/26/2006	4655	7/10/2006	11/27/2007	497	1	1	1	1	0
16	7/15/1991	4/27/2006	5337	9/6/2006	11/19/2008	793	1	2	5	1	0
17	7/12/1994	5/31/2006	4291	12/11/2006	10/29/2008	678	1	2	6	1	0
18	5/26/1993	4/27/2006	4664	12/14/2006	9/11/2008	627	1	2	1	1	2
19	7/18/1993	4/26/2006	4611	8/2/2006	8/6/2008	724	1	2	1	5	0
20	10/27/1994	6/28/2006	4213	9/13/2006	11/18/2008	785	1	2	7	1	3
21	4/5/1994	4/26/2006	4353	10/19/2006	6/28/2008	609	1	2	1	1	1
22	4/23/1993	4/27/2006	4697	7/13/2006	7/31/2008	738	1	1	2	1	0
23	11/15/1993	10/16/2006	4664	10/30/2006	9/22/2008	682	1	2	1	6	7

Subject	DOB	IniRec	Age0	Start	FinRec	Duration	Race	Gender	Iniclass	Finclass	RME
24	12/9/1991	4/27/2006	5192	9/7/2006	6/9/2008	632	1	2	1	1	0
25	5/3/1992	4/26/2006	5047	7/10/2006	10/29/2008	829	1	1	1	1	0
26	3/8/1994	4/24/2006	4378	7/11/2006	10/22/2008	821	1	1	1	7	0
27	7/7/1993	4/26/2006	4622	10/31/2006	7/21/2008	621	2	1	1	1	2
28	3/25/1995	4/27/2006	4003	9/12/2006	10/28/2008	766	1	2	3	1	0
29	3/19/1995	4/24/2006	4006	9/6/2006	7/30/2008	684	1	1	8	1	0
30	11/23/1992	6/21/2006	4902	8/24/2006	11/13/2008	799	1	1	6	1	0
31	10/12/1992	4/24/2006	4886	7/11/2006	1/28/2008	557	1	1	1	1	0
32	5/19/1992	6/5/2006	5070	8/31/2006	11/4/2008	784	1	1	6	1	0
33	8/6/1994	4/25/2006	4231	7/25/2006	5/13/2008	648	1	2	1	1	0
34	10/19/1993	4/26/2006	4520	11/22/2006	11/12/2008	710	1	2	2	1	0
35	7/12/1992	4/24/2006	4976	11/27/2006	11/13/2008	706	1	1	4	8	3
36	9/1/1994	4/26/2006	4207	10/25/2006	11/5/2008	730	1	1	1	1	0
37	12/4/1992	4/26/2006	4835	11/27/2006	1/31/2008	424	2	1	1	1	0
38	2/15/1993	4/24/2006	4762	10/5/2006	9/22/2008	707	2	1	5	1	3
39	8/22/1994	4/24/2006	4214	10/24/2006	11/11/2008	737	1	2	2	1	0
40	11/13/1993	4/26/2006	4495	10/25/2006	10/15/2008	710	3	2	1	1	0
41	11/6/1991	4/25/2006	5223	11/6/2006	6/2/2008	566	1	2	2	2	0
42	4/21/1992	5/12/2006	5075	7/18/2006	9/23/2008	785	1	2	2	5	0
43	2/7/1993	4/24/2006	4770	8/9/2006	11/12/2008	813	1	2	2	1	0
44	9/13/1994	6/19/2006	4248	10/9/2006	11/12/2007	393	1	2	1	1	0
45	6/23/1994	7/10/2006	4349	11/2/2006	8/4/2008	632	1	1	5	1	0
46	10/14/1992	4/24/2006	4884	10/25/2006	11/10/2008	735	1	2	1	1	0
47	7/7/1993	4/25/2006	4621	10/31/2006	11/24/2008	744	1	2	2	1	5
48	10/31/1992	4/26/2006	4869	12/11/2006	10/15/2008	664	2	2	1	1	0

Subject	DOB	IniRec	Age0	Start	FinRec	Duration	Race	Gender	Iniclass	Finclass	RME
49	12/17/1991	4/26/2006	5183	9/26/2006	11/11/2008	765	1	2	2	6	1
50	11/24/1993	4/27/2006	4485	8/22/2006	9/16/2008	744	1	1	2	2	0
51	8/25/1992	4/27/2006	4936	7/13/2006	11/5/2008	832	1	2	1	1	0
52	2/26/1993	4/25/2006	4752	10/10/2006	10/29/2008	739	1	2	3	1	0
53	2/2/1994	4/24/2006	4414	10/9/2006	4/14/2008	545	1	2	2	1	2
54	10/17/1992	4/24/2006	4881	8/7/2006	6/25/2008	678	1	1	7	1	0
55	8/8/1991	4/25/2006	5312	11/2/2006	4/30/2008	538	1	2	1	1	3
56	6/8/1991	4/26/2006	5373	10/16/2006	11/24/2008	758	2	1	5	1	0
57	9/23/1991	6/14/2006	5316	11/15/2006	3/12/2008	477	1	1	2	1	0
58	9/20/1992	6/21/2006	4965	10/18/2006	4/16/2008	538	1	1	1	1	0
59	5/4/1994	4/24/2006	4322	11/15/2006	8/27/2008	642	1	1	1	1	0
60	6/18/1994	4/25/2006	4279	8/22/2006	5/29/2008	637	1	1	1	1	0
61	10/18/1992	4/26/2006	4882	7/25/2006	1/31/2008	546	2	2	1	1	0
62	5/5/1994	4/27/2006	4324	10/12/2006	11/20/2008	758	1	1	3	6	0
63	8/27/1991	4/26/2006	5294	11/29/2006	11/24/2008	715	3	1	4	4	0
64	10/19/1991	4/26/2006	5242	9/14/2006	11/17/2008	783	1	2	2	2	0
65	4/6/1992	4/27/2006	5075	12/13/2006	10/27/2008	674	1	1	1	5	0
66	4/16/1993	4/24/2006	4701	10/25/2006	10/24/2008	719	1	1	5	1	6
67	1/10/1994	5/17/2006	4459	10/31/2006	11/17/2008	737	1	1	1	1	0
68	6/13/1992	4/24/2006	5005	8/31/2006	4/17/2008	587	1	2	5	1	0
69	8/30/1992	4/24/2006	4928	9/7/2006	6/9/2008	632	1	2	1	1	1
70	2/26/1994	4/27/2006	4393	10/16/2006	11/25/2008	759	1	1	6	1	0

Subject	Inixbite	Finxbite	Inipar	Reduct	Resident	Bracslot	Bracpx	Bracdesi	Facheigh	Extract	Triangles	RectAWcateg
1	0	0	37	81.1	2	3	2	1	1	0	1	3
2	3	0	18	77.8	2	2	1	3	1	0	1	3
3	0	0	26	92.3	1	2	4	1	1	0	9	3
4	1	0	15	60	3	2	2	2	3	0	0	3
5	0	0	27	85.2	3	2	4	1	1	0	0	1
6	0	0	18	61.1	4	1	5	1	1	0	1	3
7	0	0	14	85.7	3	2	2	1	1	0	0	3
8	0	0	11	36.4	1	2	4	1	2	0	0	0
9	0	0	21	66.7	3	2	1	1	1	10	0	3
10	0	0	6	66.7	1	2	2	2	1	0	1	3
11	0	0	11	81.8	2	2	4	1	1	3	1	3
12	0	0	19	89.5	1	1	2	1	1	0	0	3
13	2	0	22	90.9	3	1	5	1	2	0	1	3
14	0	0	26	57.7	4	2	3	4	1	0	9	3
15	0	0	12	100	4	1	2	1	1	0	0	3
16	0	0	24	66.7	1	3	2	1	1	0	1	3
17	15	0	15	53.3	3	2	2	2	1	0	1	2
18	10	0	11	9.1	4	1	2	1	1	0	1	3
19	0	3	20	80	3	2	3	4	1	0	1	3
20	8	0	12	66.7	1	2	1	1	1	0	9	2
21	7	0	25	76	2	2	1	3	1	0	1	3
22	18	0	27	85.2	1	2	1	3	1	0	0	3
23	2	0	19	68.4	2	2	2	2	1	0	1	3

Subject	Inixbite	Finxbite	Inipar	Reduct	Resident	Bracslot	Bracpx	Bracdesi	Facheigh	Extract	Triangles	RectAWcateg
24	0	0	5	60	3	2	2	2	1	0	1	3
25	0	0	15	73.3	1	1	2	1	2	0	1	0
26	0	0	27	70.4	1	1	5	1	1	0	1	3
27	6	0	23	65.2	4	2	2	2	2	0	1	3
28	0	0	29	86.2	2	2	2	1	1	0	1	3
29	0	0	25	80	2	2	3	4	1	0	1	3
30	0	0	12	50	3	2	2	2	1	0	1	2
31	0	0	11	45.5	2	1	2	1	1	0	0	1
32	0	0	13	15.4	1	2	1	1	1	0	1	3
33	0	0	15	100	4	2	1	1	3	0	1	2
34	7	0	21	66.7	3	2	4	1	1	0	0	0
35	14	0	26	38.5	3	2	2	2	2	5	0	3
36	4	0	13	30.8	4	2	4	1	1	0	0	3
37	0	0	10	80	4	1	2	1	1	0	0	3
38	14	4	43	81.4	2	2	1	3	1	0	0	3
39	0	0	26	76.9	2	2	2	1	1	15	1	3
40	0	0	26	84.6	4	3	2	1	2	0	9	3
41	0	0	29	79.3	4	1	2	1	1	0	0	3
42	0	0	34	82.4	3	2	1	1	1	0	0	0
43	0	0	32	75	2	2	4	1	3	0	0	3
44	0	0	27	63	4	2	2	2	1	0	0	3
45	0	0	12	66.7	2	3	2	1	1	0	9	3
46	4	0	20	70	4	2	4	1	1	0	0	1
47	13	0	43	90.7	2	2	1	3	1	0	1	3
48	0	0	13	53.8	3	2	3	4	2	0	0	3

Subject	Inixbite	Finxbite	Inipar	Reduct	Resident	Bracslot	Bracpx	Bracdesi	Facheigh	Extract	Triangles	RectAWcateg
49	12	0	30	80	1	2	2	1	1	0	0	3
50	0	0	21	61.9	1	2	1	1	1	0	0	1
51	0	0	7	14.3	2	2	2	1	1	0	1	3
52	0	0	25	84	2	2	2	1	3	0	1	3
53	0	0	19	63.2	4	2	1	1	1	0	1	3
54	0	0	15	73.3	2	1	2	1	1	0	1	2
55	9	0	14	71.4	2	3	2	1	2	0	1	2
56	15	3	32	56.3	3	2	1	3	1	0	0	1
57	0	0	17	100	4	1	5	1	1	0	0	3
58	1	1	99	99	4	3	2	1	3	0	0	3
59	0	0	11	63.6	4	2	1	1	1	0	0	3
60	0	0	22	90.9	3	2	2	1	3	0	1	3
61	0	0	14	71.4	2	2	2	1	1	0	1	3
62	0	0	16	75	3	2	2	2	1	0	1	3
63	0	11	34	58.8	1	2	2	2	1	0	1	3
64	17	0	26	69.2	2	1	2	1	1	6	1	3
65	0	0	44	86.4	3	2	4	1	3	0	0	1
66	0	0	27	77.8	1	2	2	1	3	0	0	3
67	0	0	14	71.4	2	1	5	1	1	0	1	3
68	14	0	27	77.8	4	2	1	3	2	0	9	3
69	0	0	22	81.8	1	1	2	1	1	0	1	3
70	3	0	22	90.9	1	1	2	1	1	0	1	0

Subject	IL3	IR3	IL6	IR6	IIC	IIM	FL3	FR3	FL6	FR6	FIC	FIM
1	106.5	98.4	83.8	84.9	26.63	40.13	100.6	99.3	91.9	86.9	27.55	42.01
2	99.8	96.1	71.3	74.1	25.68	41.47	95.3	90.3	79.3	79.6	26.74	42.58
3	101.3	98.5	72.5	72	24.67	38.55	99.4	92.7	74.8	74.9	25.42	39.39
4	101.2	95.9	68.5	70.8	24.12	34.77	93.7	101.4	75.5	79.3	26.4	36.69
5	100.8	100.5	65.8	70.9	23.97	33.54	91.9	99.4	75	77.9	26.04	35.46
6	97.4	97.7	81.7	75.4	29.48	44.71	96.5	96.6	79.4	75.8	30.49	44.8
7	88.5	93.6	72.6	77.6	21.66	36.6	93	98.8	80.7	80.1	24.37	38.71
8	97.4	93.7	80.5	78.2	23.97	39.92	98.8	88	83.3	75.5	24.63	39.56
9	91.2	91.7	76.3	70.8	22.49	40.26	92.8	93.6	82.3	76.6	26.83	40.75
10	93.7	94.5	69.3	73.3	24.9	40.9	81.7	89.4	72.4	70.4	24.8	40.65
11	107.6	98.6	80.3	81.3	29.47	42.5	102.2	97.3	74.2	77.4	28.76	38.54
12	96.3	103.9	67.7	74.9	25.59	39.4	88.9	93.4	75.1	78.6	26.66	40.04
13	98.6	98.7	75.7	84.3	27.45	43.75	95.5	94.7	79	81	28.07	44.06
14	93	93.3	72.1	72.5	26.83	42.92	93.6	92.5	69.5	70.5	26.92	41.25
15	99.9	98.3	77.5	81.4	27.8	40	102.9	97.4	84.1	81.5	28.57	42.57
16	98	99.9	68.5	69.3	24.7	38.83	92.5	98.8	71.5	73.4	27.09	39.1
17	99	94.1	81.8	76	26.81	43.51	97.7	90.7	80.6	71.2	27.92	41.93
18	96.9	99	77.8	72.3	29.4	45.25	89.1	90.9	75.4	65.6	27.86	43.68
19	95.2	93.7	74.8	72.9	25.65	38.65	99.5	96.6	80.6	76.1	29.77	40.74
20	98.5	102.6	70.3	75.8	26.8	39.77	94	93.2	72.4	79.2	26.25	41.16
21	97.3	97.1	61.9	76.3	26.52	41.56	91.2	92.3	75.1	81.1	27.77	44.76
22	105.9	107.4	78.4	75.6	31.6	44.3	101.5	94	75.2	76.6	30.85	45.27

Subject	IL3	IR3	IL6	IR6	IIC	IIM	FL3	FR3	FL6	FR6	FIC	FIM
23	103.1	100.1	78.2	75.4	26.56	40.56	93.6	91.9	81.7	77.6	26.71	41.39
24	93	95.4	72	79.7	28.33	41.88	83.6	88.1	73.6	75.4	24.18	40.43
25	97.6	95.7	72.6	75.5	25.06	40.05	93.2	90.1	74.5	74.3	26.6	40.13
26	99.8	94.4	72.8	77.1	26.17	43.8	97	96.5	78.3	77.8	28.48	43.38
27	104.6	100.7	68.6	73.7	26.2	38.81	97.5	93.7	78.9	74.1	26.64	38.8
28	92.4	94	74.7	73	22.62	39.07	88.2	91	72.1	73	24.9	38.71
29	89.4	89.5	73.4	73.1	23.21	41.18	83.4	88.1	76.4	68.6	23.94	43.05
30	96.9	95.8	79	72.2	27.59	44.88	89.1	91.5	73.8	68.7	26.98	42.4
31	94.4	95.8	72.7	77.4	25.05	42.42	93.7	89	73.8	83.8	24.6	41.52
32	94.4	93.6	78	76.2	25.04	40.29	100.6	96.8	84.2	81.2	28.47	42.62
33	96.1	97.2	71.3	67.6	24.8	41.26	94.3	93.5	68.3	67.4	25.8	40.07
34	92.3	91.7	72.5	77.1	24.25	39.95	94.2	94.2	66.4	70.9	25.87	37.06
35	95.5	88.8	68.4	73	21.21	38.36	92.7	90.4	74.8	75.8	22.62	39.45
36	97.4	93.9	77.7	83.3	27.32	44.31	99.4	91.4	78.4	78.8	26.55	42.63
37	98.5	102.5	78.4	83.5	28.56	41.75	90.4	101.7	82.1	87.4	29.14	43.33
38	96.8	100.5	78.6	84.9	24.5	45.12	99.1	98.6	86.1	82.3	29.05	46.07
39	99.3	102.2	75.2	73.1	26.7	42.56	98.7	96.4	77.6	80.3	29.21	39.49
40	103.8	98.6	79.7	76.6	28.35	41.02	99	94.4	81.5	77.8	29.78	42.51
41	95.5	88.6	76.6	71.2	25.49	39.53	92.3	87.3	68.2	76.7	24.73	40.11
42	111.1	101	76.8	72	27.19	41.52	106.5	102.1	71.7	72.9	28.23	40.89
43	93	100.1	73.4	81	25.39	42.3	92.3	95.6	74.1	80.4	25.78	40.15
44	101.8	108.6	77.2	82.5	28.29	40.11	93.4	103.8	74.4	84.8	27.93	40.82
45	98.3	93.2	81.8	81.1	25.79	41.33	97.5	92.5	83.5	81	27.47	42.23
46	95	94.2	65.6	73.1	22.16	39.92	91.6	93.9	66.8	71.8	25.07	38.21
47	102.5	94.9	86.7	70.1	25.44	41.42	93.9	93	73.3	77.2	26.24	41.41

Subject	IL3	IR3	IL6	IR6	IIC	IIM	FL3	FR3	FL6	FR6	FIC	FIM
48	103.1	99.1	86.3	79.8	31.16	45.89	92.4	94.5	86.8	80.9	29.25	47.17
49	103.4	97.1	77.1	86	25.88	46.16	97.9	94.5	79.3	78.1	27.04	44.17
50	100.4	98.1	75.1	80.9	25.31	39.95	95.9	90.5	81.6	81.7	27.65	40.17
51	99.9	96.5	74.4	77.1	24.07	38.81	89	89.2	78.3	79.5	24.37	40.57
52	94.4	96.6	74.2	81.9	28.07	41.68	97.8	91.3	78.3	77.3	28.91	40.83
53	102	100.6	69.2	77.8	26.04	38.12	96.2	95.4	75.6	78.7	26.71	40.21
54	91.4	95.3	68.9	78	26.15	43.01	85.3	95.7	75	79.4	28.39	42.79
55	97.7	101.3	77.5	78.8	25.03	39.3	93	96.8	77.5	83.4	26.37	40.65
56	91.2	96	82.6	79.6	24.58	44.13	104.3	100.6	84.5	90.6	31.52	47.97
57	96.9	97.7	76.7	81	27.75	44.47	96	95.3	79.2	80.1	29.39	45.1
58	89.2	89.3	74.7	78.2	23.23	41.91	88.6	89	76.3	84.8	26.87	42.03
59	95.3	99.1	70.3	76.1	25.71	40.12	89.1	99.1	77.5	76.5	25.28	41.22
60	98.5	96.5	81.7	84.5	26.2	44.21	94.9	96.3	78.8	82.8	27.05	43.18
61	97.1	103	82.2	79.8	24.02	37.74	100.8	92.3	80.4	84.9	25.73	38.57
62	95.1	98.6	77.2	75.7	26.65	44.87	94.5	95.6	69.1	72.3	27.71	44.54
63	100.4	92.5	70	71.2	28.26	42.6	96.6	86.6	79.6	72	27.93	44.23
64	101.4	93.9	72.5	68.5	27.31	37.68	95.2	85.3	78.8	69.1	27.31	39.44
65	91.1	93.7	66.1	75	21.03	38.71	94.3	96.6	76.7	76.4	25.85	39.48
66	93	95.6	75	75.9	21.28	40.35	94.9	93.5	75.3	80.3	24.97	40.87
67	99.3	97	70.7	75.2	26.07	41.14	96.2	97.8	73.3	78.7	29.32	42.36
68	106.8	93.2	72.8	75.2	26.03	42.94	97.4	86.9	76	78.1	27.21	43.94
69	98.6	94.8	73	67.4	24.29	38.41	99.7	93.9	79.6	74.8	25.46	41.04
70	94	95.3	71.2	77.7	27.16	44.14	92.3	89.9	68.4	71.2	27.36	42.74

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

DOB = Date of birth (mm/dd/yyyy)

IniRec = Date of initial records (mm/dd/yyyy)

Age0 = Age at initial records in days

Start = Date of treatment initiation (mm/dd/yyyy)

FinRec = Date of final records (mm/dd/yyyy)

Duration = Treatment duration in days

Race

1 = Caucasoid

2 = Negroid

3 = Mongloid

Gender

1 = Male

2 = Female

Iniclass = Initial Molar Classification

Finclass = Final 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)

RME = Expander status

0 = none

1 = Haas

2 = Hyrax

3 = Bonded

4 = Herbst

5 = Pendex

6 = Twin block

7 = Quad Helix

Inixbite = Initial crossbite status

Finxbite = Final Crossbite status

0=None

1=Maxillary first premolars/mandibular first premolars

2=Maxillary first premolars/mandibular second premolars

3=Maxillary second premolars/mandibular second premolars

4=Maxillary second premolars/mandibular first premolars

5=One mandibular incisor

6=Maxillary first premolars

7=Maxillary second premolars

8=Mandibular first premolars

9=Mandibular second premolars

10=Maxillary left premolar

11=Maxillary right premolar

12=Mandibular left premolar

13=Mandibular right premolar

14=Maxillary first premolars/two mandibular incisors

15=Right second premolars(maxilla and mandible)/left first premolars(maxilla and mandible)

Inipar = Initial PARscore (continuous)

Reduct = % Reduction in PARscore (continuous)

Resident

1 = Dr. Leung

2 = Dr. Shewinvanakitkul

3 = Dr. Peters

4 = Dr. Kacer

Bracslot = Bracket slot

1 = 0.018 in

2 = 0.022 in

3 = Bidimensional

Bracpx = Bracket prescription

1 = MBT

2 = Roth

3 = Damon

4 = Tip-edge

5 = Alexander

Bracdesi = Bracket Design

1 = Conventional

2 = In-ovation

3 = Smart-Clip

4 = Damon

5 = Alexander

Facheigh = Facial Height

1 = Normal

2 = Increased

3 = Decreased

Extract = Extractions

0=None

1=Maxillary first premolars/mandibular first premolars

2=Maxillary first premolars/mandibular second premolars

3=Maxillary second premolars/mandibular second premolars

4=Maxillary second premolars/mandibular first premolars

5=One mandibular incisor

6=Maxillary first premolars

7=Maxillary second premolars

8=Mandibular first premolars

9=Mandibular second premolars

10=Maxillary left premolar

11=Maxillary right premolar

12=Mandibular left premolar

13=Mandibular right premolar

14=Maxillary first premolars/two mandibular incisors

15=Right second premolars(maxilla and mandible)/left first premolars(maxilla and mandible)

Triangles = Triangular elastics

0=None

1=Bilaterally

9=Unilaterally(not specified)

RectAWcateg = Duration of rectangular archwire use

0=None

1=Less than 3 months

2=From 3 months to 6 months

3=Over 6 months

IL3 = Initial inclination of left mandibular canine (°)

IR3 = Initial inclination of right mandibular canine (°)

IL6 = Initial inclination of left mandibular first molar (°)

IR6 = Initial inclination of right mandibular first molar (°)

IIC = Initial Intercanine width (mm)

IIM = Initial Intermolar width (mm)

FL3 = Final inclination of left mandibular canine (°)

FR3 = Final inclination of right mandibular canine (°)

FL6 = Final inclination of left mandibular first molar (°)

FR6 = Final inclination of right mandibular first molar (°)

FIC = Initial Intercanine width (mm)

FIM = Initial Intermolar width (mm)

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

Subject	Left canine	Right canine	Left molar	Right molar	Intercanine	Intermolar
1	105.70	98.70	84.00	84.70	26.59	40.05
3	102.60	99.50	70.50	74.20	24.66	38.38
5	101.60	100.20	65.00	71.70	23.75	33.45
7	89.10	94.60	73.90	78.40	21.85	36.88
8	98.00	92.10	78.50	77.50	24.42	40.33
9	91.30	90.50	76.00	71.70	22.56	40.11
11	107.20	97.10	79.80	80.50	29.46	42.10
13	97.80	99.30	75.20	84.40	27.65	43.83
15	99.80	98.40	77.40	82.80	28.11	40.34
17	98.00	94.60	80.70	75.50	26.54	43.49
19	94.70	93.90	74.50	71.50	25.51	38.73
21	96.70	96.20	62.50	76.10	26.71	41.73
23	103.70	99.70	79.30	77.20	26.80	40.86
25	96.10	95.70	73.50	76.00	25.11	39.96
28	92.20	94.00	74.70	73.50	22.75	39.03
30	96.10	95.80	78.50	72.50	27.54	45.01
32	96.40	94.00	77.60	76.70	25.20	40.74
34	92.50	91.70	71.90	77.50	24.36	40.29
36	98.80	93.30	76.70	85.20	27.24	44.56
37	100.00	101.80	78.70	81.40	29.14	41.81
38	97.30	100.30	78.50	84.20	24.67	45.10
40	102.70	99.10	80.20	76.90	28.74	41.06
41	96.40	89.90	76.40	69.20	25.78	40.32
43	93.60	100.80	73.30	79.30	26.15	42.63
45	98.50	93.30	81.00	79.00	25.70	41.60
47	101.30	93.90	85.40	70.00	25.47	41.66
49	104.30	97.50	77.90	85.50	26.13	46.37
51	99.30	96.00	74.80	75.70	24.11	38.81
53	102.00	101.80	70.00	79.10	26.21	38.26

APPENDIX 3

Paired t-test for Initial and Final Inclination between the Left and Right Mandibular Canines and First Molars

TABLE 3.—Initial Left and Right Mandibular Canines

Left canine (n=70)	Right canine (n=70)	P-Value
Mean ± SD	Mean ± SD	
97.8 ± 4.6	96.8 ± 3.9	0.071

TABLE 4.—Initial Left and Right Mandibular First Molars

Left first molar (n=70)	Right first molar (n=70)	P-Value
Mean ± SD	Mean ± SD	
74.7 ± 5.1	76.4 ± 4.5	0.011

TABLE 5.—Final Left and Right Mandibular Canines

Left canine (n=70)	Right canine (n=70)	P-Value
Mean ± SD	Mean ± SD	
94.7 ± 4.8	93.9 ± 4.1	0.201

TABLE 6.—Final Left and Right Mandibular First Molars

Left first molar (n=70)	Right first molar (n=70)	P-Value
Mean ± SD	Mean ± SD	
77.0 ± 4.9	77.4 ± 5.0	0.409

APPENDIX 4

Comparison of Means and Standard Deviations of Mandibular Canine and First Molar Inclination and Arch Width for potential explanatory variables (N=70)

TABLE 7.—Rectangular Archwire Time Period Differences in Mandibular Canine and First Molar Inclination and Width (N=70)

Variables	Rectangular Archwire not used (n=5)			Rectangular Archwire for less than 3 months (n= 6)			Rectangular Archwire from 3 to 6 months (n=6)			Rectangular Archwire for over 6 months (n=53)		
	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	98.5 ± 7.4	97.0 ± 5.9	-1.5 ± 3.1	95.5 ± 4.3	95.3 ± 4.7	-0.2 ± 7.7	96.6 ± 2.8	92.2 ± 4.4	-4.4 ± 2.5	98.1 ± 4.6	94.7 ± 4.8	-3.4 ± 4.5
Right Canine inclination (°)	95.5 ± 3.5	92.9 ± 5.6	-2.6 ± 4.1	96.4 ± 2.5	95.0 ± 4.7	-1.4 ± 5.0	97.7 ± 3.5	93.6 ± 2.4	-4.2 ± 3.1	96.9 ± 4.2	93.9 ± 4.1	-3.0 ± 4.0
Left First molar inclination (°)	74.7 ± 3.9	72.9 ± 6.6	-1.9 ± 4.0	71.3 ± 6.8	76.4 ± 6.2	5.1 ± 4.3	74.8 ± 5.3	74.6 ± 4.2	-0.2 ± 4.0	75.1 ± 4.9	77.7 ±4.6	2.6 ± 5.1
Right First molar inclination (°)	76.1 ± 2.5	73.0 ± 2.0	-3.1 ± 3.2	76.2 ± 3.9	80.4 ± 6.5	4.2 ± 4.7	74.7 ± 4.2	74.9 ± 6.6	0.2 ± 3.7	76.6 ± 4.7	77.8 ± 4.5	1.2 ± 3.8
Intercanine width (mm)	25.5 ± 1.6	26.5 ± 1.4	1.0 ± 0.6	23.7 ± 1.7	26.8 ± 2.5	3.1 ± 2.5	26.2 ± 1.1	27.0 ± 1.0	0.8 ± 1.1	26.1 ± 2.3	27.1 ± 1.8	1.0 ± 1.6
Intermolar width (mm)	41.1 ± 1.8	40.1 ± 2.1	-1.0 ± 1.2	39.8 ± 3.6	40.5 ± 4.2	0.7 ± 2.0	42.0 ± 2.2	41.5 ± 1.1	-0.5 ± 1.6	41.2 ± 2.5	41.7 ± 2.2	0.5 ± 1.5

* P ≤0.05, ** P ≤0.001

Table 8.—Bracket Prescription Differences in Mandibular Canine and First Molar Inclination and Width (N=70)

Variables	0° Canine, -20° First Molar Bracket Torque (MBT) (n=15)			-7° Canine, -25° First Molar Bracket Torque (Modified. Roth, Alexander) (n= 42)			0° Canine, -28° First Molar Bracket Torque (Damon) (n=4)			-11° Canine, -27° First Molar Bracket Torque (Tip-Edge) (n=9)		
	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	99.3 ± 5.7	96.8 ± 4.8	-2.5 ± 6.0	97.6 ± 3.9	93.9 ± 4.6	-3.7 ± 4.1	95.2 ± 5.8	92.2 ± 6.7	-3.0 ± 6.7	97.3 ± 5.3	96.0 ± 4.0	- 1.3± 4.0
Right Canine inclination (°)	97.9 ± 4.1	94.7 ± 4.1	-3.3 ± 5.0	96.9 ± 4.0	93.6 ± 4.3	-3.3 ± 3.8	93.9 ± 3.9	92.9 ± 3.6	-1.0 ± 3.1	96.1 ± 3.3	94.3 ± 3.4	-1.8 ± 3.2
Left First molar inclination (°)	74.6 ±6.1	77.5 ± 5.3	2.9 ± 6.7	75.0 ± 4.4	77.2 ± 4.5	2.2 ± 4.4	76.7 ± 6.5	78.3 ± 7.3	1.7 ± 3.6	72.7 ± 6.0	74.4 ± 5.3	1.7 ± 5.7
Right First molar inclination (°)	75.5 ± 4.4	78.6 ± 5.0	3.1 ± 3.5	76.7 ± 4.6	77.6 ± 5.1	0.9 ± 4.1	74.6 ± 3.5	74.0 ± 5.6	-0.6 ± 3.4	76.9 ± 4.4	76.0 ± 3.1	-0.9 ± 4.1
Intercanine width (mm)	25.8 ± 2.0	27.6 ± 1.8	1.8 ± 2.2	26.0 ± 2.1	27.0 ± 1.8	1.0 ± 1.4	26.7 ± 3.3	27.5 ± 2.7	0.8 ± 2.5	24.7 ±2.5	26.0 ± 1.2	1.3 ± 1.8
Intermolar width (mm)	41.5 ± 1.9	42.6 ± 2.5	1.1 ± 1.3	41.2 ± 2.6	41.5 ± 2.0	0.3 ± 1.4	42.2 ± 3.0	43.1 ± 2.9	0.9 ± 1.7	40.0 ± 3.1	38.9 ± 2.0	-1.0 ± 1.9

Table 9.—Initial Crossbite Status Differences in Mandibular Canine and First Molar Inclination and Width (N=70)

Variables	No crossbite (n=47)			Crossbite on the Left (n= 7)			Crossbite on the Right (n=13)			Crossbite Bilaterally(n=3)		
	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	97.4 ± 4.6	94.5 ± 5.2	-2.9 ± 4.5	96.6 ± 4.9	92.7 ± 2.3	-3.9 ± 3.9	99.2 ± 4.4	96.2 ± 3.9	-3.0 ± 6.2	100.7 ± 4.5	96.2 ± 4.6	-4.5 ± 0.2
Right Canine inclination (°)	97.0 ± 3.8	94.4 ± 4.1	-2.6 ± 3.6	94.3 ± 2.8	92.9 ±4.2	-1.5 ± 4.3	96.2 ± 3.6	92.6 ± 4.2	-3.6 ± 4.0	103.8 ± 3.2	94.7 ± 1.9	-9.1 ±4.5
Left First molar inclination (°)	74.9 ± 4.7	77.2 ± 5.0	2.3 ± 4.7	72.4 ± 7.5	73.5 ± 4.6	1.1 ± 9.2	75.2 ± 5.3	78.5 ± 4.8	3.3 ± 3.6	75.4 ± 4.4	75.0 ± 2.6	-0.4 ± 2.7
Right First molar inclination (°)	76.3 ± 4.4	77.5 ± 4.7	1.2 ± 3.3	74.9 ± 3.3	77.7 ± 5.1	2.8 ± 6.4	77.3 ± 5.7	76.5 ± 6.4	-0.9 ± 5.0	76.7 ± 1.8	79.7 ± 3.4	3.0 ± 1.8
Intercanine width (mm)	25.8 ± 2.2	27.0 ± 1.8	1.2 ± 1.6	25.2 ± 1.4	26.8 ± 0.7	1.6 ± 1.1	25.8 ± 2.2	27.2 ± 2.0	1.4 ± 2.3	27.8 ± 3.4	27.8 ± 2.6	0.0 ± 1.2
Intermolar width (mm)	40.9 ± 2.4	41.2 ± 2.1	0.3 ± 1.5	40.7 ± 2.9	41.0 ± 3.0	0.3 ± 2.0	42.3 ± 2.9	42.4 ± 2.9	0.1 ± 1.7	41.1 ± 2.8	42.4 ± 2.5	1.2 ± 0.2

* P ≤0.05, ** P ≤0.001

Table 10.—Initial and Final Molar Classification Status Differences in Mandibular Canine and First Molar Inclination and Width

Variables	Class I Initial with Class I Final Molar Classification(n=27)			Class II Initial with Class I Final Molar Classification (n=10)		
	Initial	Final	Change	Initial	Final	Change
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Left Canine inclination (°)	97.7 ± 4.2	93.6 ± 5.3	-4.1 ± 4.7	98.2 ± 4.5	96.2 ± 2.9	-2.9 ± 3.4
Right Canine inclination (°)	97.7 ± 3.9	93.9 ± 4.2	-3.8 ± 3.7	98.1 ± 4.1	95.5 ± 2.5	-3.2 ± 5.1
Left First molar inclination (°)	74.6 ± 5.6	77.1 ± 4.6	2.5 ± 4.4	75.3 ± 5.1	75.1 ± 3.7	-0.4 ± 6.1
Right First molar inclination (°)	77.2 ± 4.3	78.2 ± 5.4	1.0 ± 3.7	75.7 ± 4.1	77.4 ± 3.0	2.0 ± 4.5
Intercanine width (mm)	26.0 ± 2.3	26.6 ± 1.7	.6 ± 1.7	26.3 ± 2.5	27.6 ± 2.1	1.1 ± 1.0
Intermolar width (mm)	40.9 ± 2.2	41.3 ± 2.1	.3 ± 1.6	41.0 ± 3.0	41.0 ± 3.2	-0.2 ± 1.9

* P ≤0.05, ** P ≤0.001

APPENDIX 5

Built-in Bracket Torque in Sample's Fixed Straightwire Appliances

Table 11.— Mean, Standard Deviation and Range of Built-in Torque(N=70)

Bracket Torque	Minimum	Maximum	Mean ± SD
Mandibular Canine Torque	-11.0	0.0	-5.6 ± 3.7
Mandibular First Molar Torque	-28.0	-20.0	-24.4 ± 2.5

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