The Relationship between the Cranial Base to Dental Compensation in the Transverse Dimension

by

Amir Aminoshariae D.M.D., M.S.

Submitted in partial fulfillment of the requirements for

the degree of Master of Science in Dentistry

Thesis Advisor: Manish Valiathan D.D.S., M.S.D.

Committee Members:

Juan Martin Palomo, D.D.S., M.S.D.
Ali Zakir Syed, B.D.S., M.S.

DEDICATION

I wish to dedicate this thesis to my fiancée Tina for her unconditional love, devotion, and patience during my pursuit of orthodontic education. This thesis is also dedicated to my mother, stepfather, sister, brother, extended family and friends for all their love and support over the years. I especially wish to dedicate this thesis to my deceased father whose selfless sacrifices for the family will never be forgotten.

ACKNOWLEDGEMENTS

My path to orthodontics would not have been possible without the guidance and support of many individuals along the way. My education at Case Western Reserve University, from Undergraduate to Professional/Graduate has been a long but fruitful journey.

I would like to thank Dr. Manish Valiathan, Dr. Juan Martin Palomo, and Dr. Mark Hans for giving me the opportunity to attend one of the most reputable orthodontic programs known internationally. Additionally, the continuous devotion by the faculty and staff has enriched me with an education that I will utilize for the rest of my career.

To my classmates I thank you for the laughs and tears shared over thirty months.

ABSTRACT

Title: The Relationship between the Cranial Base to Dental Compensation in the Transverse Dimension

Article type: Original article

Keywords: Case Western Reserve University Transverse Analysis, cone beam computed tomography (CBCT), buccolingual inclination, maxillary first molar, mandibular first molar, transverse dental compensation, cranial base.

Objective: To examine the relationship between the width of the cranial base to the molar inclination in the buccolingual direction.

Methods: The sample stratified one hundred cases from the CWRU's Orthodontic Clinic (45 males and 55 females). Samples were screened based on Cranial Index values corresponding to cephalic form. 38 dolichocephalic, 20 mesocephalic, and 32 brachycephalic samples were selected. Corresponding facial forms were calculated. Measurements were taken to determine transverse width for anterior, middle, and posterior cranial fossae. Skeletal width for the maxilla and mandible were measured as well. Molar angulation was determined using the CWRU Transverse Analysis. All measurements used version 11.8.06.24 Dolphin3D imaging (Patterson Dental Supply, Inc., St. Paul, MN) software. Initial records were reviewed to determine whether previous orthodontic treatment was performed.

Results: Linear measurements ranged from 0.926 to 0.997 Cronbach intraclass correlation (95% confidence interval). All angulations ranged from 0.885 to 0.949. Cranial and Facial Index Spearman rho correlation values were highly statistically significant ($p<0.000$). Mean left buccolingual inclinations of maxillary and mandibular first molars were 103.8±5.2º and 75.8±5.3 º, respectively. Mean right buccolingual inclinations of maxillary and mandibular first molars were 104.0±5.3º and 77.1±5.4 º, respectively. Cranial and facial index stratification did not show statistically significant differences with molar angulation. Correlation analysis demonstrated associations between several measurements. Multivariate regression analysis demonstrated mandibular molars having high predictive values to maxillary molars ($p=0.020$). Measurements for maxillary molars and maxillary width (BiJugale, BiZyg) demonstrated strong association on mandibular molars ($p=0.020$, 0.001, and 0.037).

Conclusion: Cranial index did not correlate well with molar angulation whereas facial index showed a weak relationship. Specifically, the cranial base appears to demonstrate influence on molar angulation in an indirect fashion. However, mandibular molar angulation seems to behave independently. In accordance to growth literature, we propose a theoretical model describing the events that lead to dental compensation.

TABLE OF CONTENTS

DEDICATION.....2

ACKNOWLEDGEMENTs.....3

ABSTRACT.....4

LIST OF FIGURES.....7

LIST OF TABLES.....8

REVIEW OF THE LITERATURE.....9

LITERATURE REFERENCES.....36

STATEMENT OF THESIS.....41

MANUSCRIPT FOR PUBLICATION.....42

INTRODUCTION.....44

MATERIAL AND METHODS.....46

RESULTS.....53

DISCUSSION.....57

CONCLUSION.....62

REFERENCES.....64

APPENDICES

IRB APPROVAL.....88

INFORMED CONSENT DOCUMENT.....89

RAW KEY.....90

RAW DATA.....91

RAW DATA INTRACLASS CORRELATION.....94

RAW DATA CORRELATION.....95

RAW DATA SKEWNESS.....97

List of Figures

Figure 1. Overall Orientation

Figure 2. Preliminary external landmark orientation

Figure 3. Orientation: a) Coronal b) Axial c) Sagittal

Figure 4. Cephalic Index: cranial width: cranial length

Figure 5. Facial Index: Facial height: zygomatic width

Figure 6. Molar Angulation: a) Maxillary b) Mandibular

Figure 7. Maxilla: a) Jugale b) Greater Palatal Foramen

Figure 8. Mandible: a) Lingula b) Mental Foramen

Figure 9. Anterior Cranial Fossa: a) Anterior Cranial Base b) Optic Canal

Figure 10. Middle Cranial Fossa: a) Carotid Canal b) Foramen

Figure 11. Posterior Cranial Fossa: a)Jugular Foramen/Fossa b) Internal Auditory Meatus

Figure 12. Histogram distribution a) Cranial Index b) Facial Index

Figure 13. Histogram distribution age

Figure 14. Histogram distributions of anterior cranial fossa parameters

Figure 15. Histogram distributions of middle cranial fossa parameters

Figure 16. Histogram distributions of posterior cranial fossa parameters

Figure 17. Histogram distributions maxillary parameters

Figure 18. Histogram distributions mandibular parameters

Figure 19. Histogram distributions of molar angulation parameters

Figure 20. Histogram distributions average maxillary and mandibular molar angulations

Figure 21. Growth Theory of Dental Compensation Flow Chart

List of Tables

Table I: Descriptive Summaries of CBCT subjects

Table II: Sample Stratification

Table III: Association between Cranial Index and Facial Index

Table IV: Association between Cranial Index to Molar Angulation

Table V: Association between Facial Index to Molar Angulation

Table VI: Parameter Correlations a)Parametric b)Nonparametric

Table VII: Maxillary Molar Angulation Regression Models

Table VIII: Mandibular Molar Angulation Regression Models

REVIEW OF THE LITERATURE

In comparison of cranial size anthropologists required a reliable method. The Cephalic Index (CI) was first described by Swedish anatomist Anders Retzius in the 19th Century[10]. After establishment in 1840, the CI gained popularity by Carleton S. Coon in the 1960s to describe human populations. The "craniofacial complex" represented the evaluation of skull size within living individuals. The ratio of maximum width to maximum length categorizes cranial patterns into brachycephalic (>80%), mesocephalic (75-79.9%), and dolichocephalic (<74.9%. Analogously, the facial index categorizes euryprosopic (<84.9%), mesoprosopic (85-89.9%), leptoprosopic (>90%) by calculating the morphological face height: width ratio (N-Gn:Zyr-Zyl). These percentages were based on works cited from anthropologist Leslie Farkas in 1986[10]. The ranges within these categories are all race, ethnic, and gender-specific. By utilizing established anthropologic methods, orthodontists improved diagnostic analysis. Studies by Enlow et al held the belief that facial morphology was templated by the foundation of the cranial base[7]. For example, a dolichocephalic individual would personify narrow width, long skull morphology. The nasomaxillary complex would favor a more protrusive position with a retrognathic mandibular articulation. The resultant manifestation would phenotype a leptoprosopic facial pattern. A brachycephalic phenotype would demonstrate the opposite findings just aforementioned resulting

in a euryprosopic facial form. Although a misnomer, the two cranial patterns have commonly been used interchangeably with the two facial patterns. Furthermore, no overall consensus has been reached in the literature due to the unpredictable factor of dental occlusion. As to be discussed in a homologous manner later, compensation of the dentition has also presented difficult in validity assessment. Nevertheless, despite inherent variability, the cranial and facial indices provide a method for standardization among researchers as well as communication among clinicians.

Within the cranial vault lays the cranial base representing a foundation for diagnosis and treatment planning. Dr. Arne Bjork's research had established that the cranial base, despite irregularity in size and shape, relatively stabilizes before the age of ten likely around six years of age[3]. In following publications, he continued to discuss the positioning of the maxilla and mandible due to the morphology of the cranial base. Spatial position of the jaws, deriving from the cranial base area, subsequently influences the occlusion. Proverbially speaking, area is commonly defined as the length multiplied by width. Past literature has focused on the length of the cranial base with minimal reference on the width. Cranial length is composed of anatomical subcomponents which include the anterior, middle, and posterior cranial fossa. Cephalometrically,

posterior (Articulare [Ar] to Sella [S]) and anterior (Sella to Nasion[N]) cranial lengths articulate an angle. This angle or flexure of the cranial base (Ar-S-N) has been shown to increase from Class III to Class II patients. Hopkin et al further concluded that "the dimensions of the cranial base are a major factor in determining anteriorposterior relationships of the jaws and the dental arches which must be taken into account in diagnosis and treatment.[16]" Should the same concept be applied in the transverse dimension? Currently, lack of consensus definition of the cranial width appears in the literature.

Measurements of anthropologic skulls calculate the distance between the left and right Euryon (Eu) to measure maximum cranial width. Euryon is defined as the most lateral point on the parietal region of the head[10]. The width between these landmarks represents the cranial width in the cephalic index. However, due limitations of accurately identifying internal structures within the middle and posterior cranial fossa, researchers focused their attention to externally and anteriorly using Posteroanterior (PA) radiographs. Wei et al measured ten variables from which all were derived from the transverse component[44]. Their study using 84 male and 22 female Chinese subjects depicted differences in ethnicity as well as among gender (in comparisons to other population studies). In males, 93.9 +/-0.45mm and in females 91.8+/-0.85mm represented the

averages and error of the mean for anterior cranial base widths. Anterior cranial base width was one of the ten parameters evaluated by measuring the distance between the frontozygomatic process-cranial base lateral extensions. Randomization of gender and ethnic subgroups was not observed thus potentially resulting in sample size errors. No calculation of power or sample size was discussed. A Type I error could have resulted from the authors falsely detecting a difference between samples. However, another study used 90 frontal cephalograms where subjects ranged between 18 to 28 years of age as well as Angle Classification. Katiyar et al also evaluated the anterior cranial width by similar methodology[44]. It was also reliably determined to be 90mm for both gender and did not display statistically significant differences among Angle Classes[21] unlike the previous mentioned study[44]. A nonstatistical trend was observed where Class II div 1 and female subjects had the narrowest widths and Class III males had the widest bases. However, a limitation within the study was all subjects were growth-mature. Not having age-stratified results, presents difficulty in width comparisons of growing patients. In order to accomplish this feat, the sample size needed to be larger.

Starting in the late 1990s, stabilized, functional occlusion became a point of emphasis by the American Board of Orthodontics (ABO) in proper finishing. Developing and

implementing an objective grading system, the ABO analysis utilizes both radiographs and dental study models in order to evaluate quality of orthodontic care. “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[5].” This statement is made according to the American Board of Orthodontics Objective Grading System (ABOGS) regarding ideal intercuspation of dentition. In the absence of a posterior crossbite, skeletal discrepancies become challenging to diagnose due to dental compensations. Several methods involving radiographs, plaster models, photographs, etc. have developed in the literature to analyze the transverse. The ABOGS represents one of such types.

From 1994 to 1998 four field tests methodically formulated this grading system. 100 cases were assessed with 15 measured criteria in 1995. Seven of fifteen criteria depicted 85% of the total inadequacies. Root angulation, buccolingual posterior teeth inclination, marginal ridges, overjet, alignment, occlusal contacts, and occlusal relationships represented the aforesaid criteria. The remaining eight were never disclosed. In the subsequent year, another field test was conducted to evaluate an examiner’s own reliability. Three hundred cases were assessed

by four examiners. The intraexaminer reliability confirmed the 1995 results. The interexaminer reliability was not a point of emphasis. In 1997, 832 cases were evaluated presenting moreover similar results. In that field test, the measurement of interproximal contacts added to the previous seven criteria. The final field test's objective in 1998 was to calibrate the system. Training practitioners to use the system prior to examination produced the most successful results of the four field tests[5,29]. Evaluation of the buccolingual inclination of posterior teeth in both arches was to be determined using flat surfaces from the left and right occlusal surfaces. In the maxilla, the straight edge should contact the palatal cusps of the molars and premolars. The buccal cusps should be within 1mm. If the maxillary buccal cusps are between 1-2 mm from the straight edge surface, one point shall be subtracted for that tooth[3].

Prior to the introduction of the ABOGS, in 1969, Ricketts et al presented their analysis of the transverse skeletal component[34]. Using the frontal/PA cephalogram, two different points measured bilaterally represented the maxilla and mandible. Jugale or "J-point" represented the "depth of the concavity of the lateral maxillary contours, at the junction of the maxilla and the zygomatic buttress." The antegonial notch or "Ag" analogously represented the mandibular interdistance. The

point was measured at the “innermost height of contour along the curved outline of the inferior mandibular border, below and medial to the gonial angle.” Subtracting the two interjaw measurements and comparing them to age-adjusted normative values (growth), amount of expansion was calculated. The normative ratios from the ages of 9 to 16 (not gender stratified) ranged from 81.6% to 77.4%.

Cortella et al. implemented Ghafari’s research and developed normative values for transverse values[6,12]. Their sample consisted of 5000 Bolton-Brush serial cephalometric records from the longitudinal growth model. After stratifying for age (5-18 years old), they emphasized that the values themselves are not as significant but rather the ratio between the maxilla and mandible. As the mandible first spikes then lags in (horizontal) growth to the maxilla, the ratio decreases then plateaus from 78.5% to 75.0% in their sample. AP directional growth follows a similar pattern. The rate of width growth of the maxilla slows down before mandibular width. Interestingly, the mandibular width appeared to be similar between males and females until the age of 11 to 12 years. The posterior region demonstrates more differential growth despite an overall decline in rate. Cortella proclaimed that the “greater growth observed in the mandible relative to the maxilla suggest the presence of a compensatory mechanism that allows the

preservation of normal occlusion (no crossbite) between the posterior teeth." This observation was explained by the increase in maxillary intermolar width (Moorrees et al[28]) representing 52% of Bijugale increase. Meanwhile the mandibular intermolar distance only explains 17% by Biantegonial distances. Difficulty in accurately tracing molars presented a hurdle in further investigations. Recently, development of normal ranges for molar angulations have been promising however studies do not factor the influence of the cranial base growth[1,6,9,12,25,26,31,34,40].

Using the "Six Keys to Normal Occlusion" by LF Andrews in 1970[1], Dr. Andrews and his son developed their "six elements philosophy of orthodontic diagnosis[2]." Element III primarily focuses on the transverse relationship encompassing both skeletal and dental landmarks. The "WALA" (named after their initials) corresponded with the buccal aspect of the alveolar bone prominence to the mucogingival junction. Because the mandible cannot expand with traditional orthodontic treatment, the maxilla therefore becomes the modifiable component. The WALA of the mandible rests 2mm from the center of the crown also known as facial axis (FA) point. Using the WALA-FA discrepancy, the angulation of the mandibular molars can be determined. Estimating the change in FA needed for proper molar inclination, the maxillary width will then be assessed. The difference between the maxilla and the mandible provides the expansion

required. Andrews stated that ideal interdigitation of the dentition necessitates 5mm more in the maxillary width than the mandibular width. Study models become extensively used in this transverse analysis.

Cone-Beam Computed Tomography (CBCT) in orthodontic practice has gained much popularity. Some claim they can replace most other diagnostic tools[32]. The advent of technology may provide consistency amongst clinicians in diagnosis and treatment planning. Ironically, it still has reluctant acceptance currently despite its construction of a 3-dimensional imaging. Advocates argue the cost, practicality, and liability do not provide the practitioner with any realistic benefits versus 2D images. Many however propose that CBCT provide invaluable information to the orthodontist and referring healthcare providers. The use of 3D imaging also enhances the quality of care for the patient providing a visual demonstration of their malocclusion. The standard cephalogram, panorex, study casts, and photographs provide limited resources to assess the transverse dimension. Three-dimensional imaging has enabled clinicians to better diagnosis skeletal and dental discrepancies in this plane. In 2004, Podesser et al. evaluated the maxilla in the *European Journal of Orthodontics* by using ten random subjects. Using coronal slices at the canine and molar regions, transverse measurements (i.e. skeletal, alveolar, angulation,

etc.) were demonstrated to very reproducible as long as one examiner performed the assessment[32]. The interclass correlation was not as strong as intraclass correlation in this study. As mentioned previously, another benefit for 3D imaging use is in describing skeletal terms and asymmetry (i.e. pitch, roll, and yaw) to patients.

Pitch, the rotation of an object around the transverse axis, roll, the rotation of an object around the anteroposterior axis, and yaw, rotation of an object around the vertical axis all can be conceptual communicated. There is no consensus 3D classification of asymmetry nor evaluations on transverse dental compensation in these patients currently. Compiling all 2D resources together may still potentially provide less information than a 3D image in significantly less time and inconvenience to the patient.

The use of cone-beam reintroduced frontal analysis back into the literature. It has yet to become a major focus in orthodontic planning. Historically, dental compensations have caused difficulty in accurately diagnosing posterior crossbites due to transverse discrepancies. Essentially, many patients presenting without transverse discrepancies may have been treated with expansion as well and vice versa. These type I and II errors have been well-documented[26]. Ghafari claimed that “the PA cephalometric record can only serve as a guide for diagnosis,

and cannot dictate the ultimate therapy, nor replace the clinical judgment of the orthodontist[12].” In his determination, only 50% of the population can be accounted for by bijugale-antegonial transverse difference. Furthermore, in his sample of study, Ghafari did not find crossbites or skeletal tendencies when the molar angulations were within two standard deviations from the mean ratio of J-J:Ag-Ag. These findings become clinically relevant when practitioners look to expand due to the presence or lack thereof crossbite. This ambiguity (four standard deviations) leaves vast clinical judgment to providers. The inherent variability with the maxillary width may be a correlation of the variability in cranial base width. Therefore it can be hypothesized that some or all of the remaining 50% from Ghafari’s evaluation of the transverse dimension could reasonably derive from the cranial base.

The University of Pennsylvania desired a convenient method in clinically determination of expansion. Expanding on Ghafari’s work, UPenn developed their analysis without the need of plaster models. Tamburrino et al[40] describe a CBCT method in which the axial and saggital slices of the first molars provide the reference planes for the frontal image. The interdistances were determined by jugulare and antegonial landmarks as previously aforementioned. The ideal difference between the maxillary and mandibular jaws was determined to be 5mm. Both

Ricketts' and Andrews' analyses depicted a similar relationship[34,2]. However, despite consistency among these evaluations, the decision for maxillary expansion is completely derived from skeletal landmarks that may be far removed from spatial positioning of the first molars. In other words, we may still fail to expand when we should. Conversely, we may expand when we should not.

Recently in the *American Journal of Orthodontics and Dentofacial Orthopedics* (AJODO), Boston University (BU)demonstrated a CBCT method for transverse analysis[25,26]. Miner et al. analysed 241 patients with and without crossbites. Using their specific orientation for their reference planes, normal molar angulations were calculated to be 98° and 104° to the occlusal plane for the maxillary and mandible, respectively. These angulations were further defined as "superior" or "inferior" convergent depending on the standard deviation from the mean. The "superior" convergent subsample demonstrated a maxillomandibular skeletal width greater than the control. The inclination of the posterior dentition was buccal and lingual for the maxillary and mandibular molars, respectively. The "inferior" convergent group depicted a wider maxilla with palatal compensation to the normal mandible.

Miner et al utilized this information with a subsequent "Part II" study evaluating three methods of determining

posterior crossbites. Each of these transverse analyses were valued for specificity, sensitivity, and accuracy. Sensitivity was defined as true positives divided by the sum of true positives and false negatives. Specificity was defined as true negatives divided by the sum of true negatives and false positives. Accuracy was calculated as the correctly identified positives and negatives divided by the whole population. Comparing Transpalatal Width Measurements (TWM, similar to Rickett's analysis), J-Point (similar to Tamburrino's analysis), and the Cone-Beam Transverse (CBT, Miner's analysis), only the CBT was both sensitive and specific. TWM overestimated the prevalence of crossbites whereas J-point was least sensitive but acceptable in detecting true noncrossbites. Overall, the CBT method was deemed most accurate. This conclusion from the study presented strong evidence in the literature in support of further CBCT-utilized analyses.

With the ABO stressing the importance of root parallelism for proper occlusion, the University of Southern California (USC) also implemented the CBCT in measuring angulations of the molar dentition in order to accurate measure whole tooth (including root inclinations) into diagnosis and treatment planning without the concern of anatomical structures overlapping each other[41]. Until recently, panoramic radiographs were the gold standard however various studies have expressed

their inaccuracies (i.e. distorted orthogonal images on majority of the dentition)[11,30]. Six parameters of spatial (mesidodistal, faciolingual, and occlusogingival positions) and angulation (mesiodistal, faciolingual, and axial inclinations) were analyzed. Using synthetic teeth imbedded in transparent maxillary and mandibular typodonts, whole teeth were evaluated first by a coordinate measuring system then by their root vector analysis to confirm results. This *in vitro* study incorporated 1.58mm stainless steel balls for the parameters by embedding them onto the teeth. This CBCT analysis used Dolphin 3D software for the digital imaging and communication (DICOM) data in accordance to their methodology. 3 planes of view were examined. Intraclass correlation was determined to be 0.995 with the coordinate measuring system (only mesiodistal angulation) and 0.998 (mesiodistal angulation) 1.000 (faciolingual inclination) for the USC method. The limitation in the study of the coordinate system was the inability to measure faciolingual inclinations. Similar to the BU method, however, their values were demonstrated to be very reliable, repeatable, and accurate. Another positive of using these images is having dentofacial structures in 1:1 ratio. The limitation expressed by the authors correctly stated the difficulty of implementing the USC root vector system for moderate-severe malocclusions and also the exposure to radiation

from repeated CBCTs. The trend of decreasing radiation in improved CBCT machines has made the latter point recently moot. Improvement in methodology will improve the former. The benefits of having a simplified, consistent method using the cone-beam tomographic imaging was demonstrated in both the BU and USC systems.

Like these institutions, Case Western Reserve University (CWRU), Karamitsou et al also developed a protocol[20] in CBCT-measured maxillary first molar and canine angulations. Means, standard deviations and ranges were also determined. The study sample size consisted of 97 subjects from ages 12 to 15. All measurements were recorded using On Demand 3D software.

Orientation of the subject in the DICOM file was described in a procedure by Wu et al[45]. In the Coronal slice, the centers of the left and right optic foramina are aligned. The axial view aligned the centers of the left and right foramina ovale) and having the foramen cecum bisect the midpoint of the bilateral landmarks. Finally, the sagittal view is used to correct for any tilting of head by aligning the axial plane to McRae’s plane (opthision to basion landmarks). The long axes of maxillary molars were measured relative to the lower border of the nasal cavity. The mesiopalatal cusp to the palatal root apex constructed line represents the tooth fulcrum bearing occlusal forces. This line is then connected to another constructed line

from root apex to contralateral root apex (parallel to the nasal floor). The resultant angle forms the maxillary molar angulation. Intraexaminer reliability was observed to be acceptable (intraclass correlation coefficient greater than or equal to 0.96). Mean molar angulations for the right and left were 99.2 +/- 5.3 and 101.7 +/- 5.4, respectively. The range for the maxillary left molar was 88.5 to 117.5 and 86.6 to 112.8 on the right side. The mean maxillary right canine angulation was 103 +/- 6 and 105.9 +/- 6.5 for the left maxillary canine. The respective ranges were 91.8 to 123.8 on left side and 89.5 to 123.4 on right side. The difference in mean inclination between the left and right sides was statistically significant for both molars and canines. The authors reportedly claimed that this difference was statistically significant (2.9º and 2.5º for the canines and the molars, respectively) however it did not appear to be clinically significant. Interestingly, no differences related to gender, age, expander status nor molar classifications were noted among the groups. Thus, they hypothesized that the discrepancy between the sides, although nonclinical in relevance, could be attributed to the preference to unilateral mastication and/or the preference in unilateral side of sleep pattern. A third, unmentioned explanation, skeletal asymmetry, will later be discussed here.

Dr. Shewinvanakitkul et al[35] implemented the same reliable

method of measuring buccolingual inclinations but onto mandibular first molars and canines. Means and standard deviations were evaluated in a sample size consisted of 108 subjects (56 male and 52 female). The mandibular molar, using the same protocol (mandibular plane was used in lieu of nasal floor), were measured from the root apex of the mesial root but to the crown central groove. Unlike the former measurements using cusp tips, this groove-apex relationship similarly represents the fulcrum of the occlusal forces upon the tooth. The mean mandibular canine inclination was 98.0 +/- 4.1 degrees and mean mandibular molar inclination is 74.6 +/- 4.7 degrees. Significant differences in molar angulations in Angle classification were observed. Molar angulation was 73.5 +/- 3.7 degrees in Class II patients, while Class I patients were found to have an average molar angulation of 75.7 +/- 4.9 degrees. Similarly, mandibular molar angulations for subjects treated with expansion and those treated without expansion also appeared to be different. Those treated with expansion averaged 73.3 +/- 4.8 degrees and those treated without expansion measured at 75.3 +/- 4.6 degrees. From both studies, one could present a reasonably argument on whether a few degrees in discrepancy makes any clinical implication especially when Ghafari demonstrated two standard deviations from the mean produced no crossbites. The additional benefit from this

protocol methodology is the accessibility on any DICOM software program.

Mentioned previously, a reason for the observed bilateral differences could have been explained by investigation in transverse asymmetries [23,25,26,42]. Significant correlation was found between mandibular transverse asymmetry and maxillary molar inclination on the mandibular shifted side (r=0.58) and nonshifted side (r=0.38). Asymmetry indices were calculated by subtracting mean and standard deviation values on shifted from nonshifted sides via dental models. The asymmetry index of maxillary molar inclination significantly correlated with mandibular transverse asymmetry (r=-0.78). Similar observations were noted for mandibular transverse asymmetries vs mandibular molar inclincations. R-values were determined to be 0.42 on shifted sides and 0.57 on nonshifted. The asymmetry index of mandibular molar inclination significantly correlated with mandibular transverse asymmetry (r=-0.63)[23]. Despite a mild asymmetry, each of these studies postulated that dental compensation in the molar teeth would occur in order to achieve balanced occlusion. Kusayama et al. made five conclusions based on their research: 1) occlusal planes slant to shifted sides, 2) the Curve of Spee is different (smaller) on nonshifted side (i.e. noncrossbite side), 3) smaller lateral Overjets on shifted sides, 4) labial tipping max molars with lingual tipping of mand

molars on shifted side and vice versa for nonshifted side and 5) mandibular dental arch asymmetry due to lateral deviation of cuspid and 2nd molar in facial asymmetry.

Tyan et al observed similar results while researching molar compensation in mandibular prognathic and facial assymetric subjects[42]. Comparing a balanced gender mix of 33 orthognathic patients to 45 prognathic patients, maxillary first molar inclination was determined using the frontozygomatic plane and mandibular first molar inclination using the mandibular plane. Class III groups were subdivided into Translation (T-type) and Roll (R-type) type for mandibular asymmetry. The T-type had similar left and right rami, bodies, and a maxillary occlusal plane without a cant whereas the R-type had similar bodies but rami varied with a maxillary occlusal plane canted. Conceptually, the T-type “translates” forward relative to the maxilla potentially affecting the pitch. The R-type “rolls” to one side relative to the other side. Yaw was not evaluated in this particular study. The results showed that the R-types displayed more dental transverse compensation than T-types. This information affirms that mandibular asymmetry type influence the amount and direction of molar compensation in maxilla. Shigefuji et al earlier confirmed similar results that greater molar axis change on deviated sides using 11 subjects in their sample[36]. The discrepancies observed therefore could be

attributed to skeletal asymmetries during facial growth.

Like the Bjork studies, Enlow et al argued that “when this change [facial growth] in the middle cranial fossa takes place, where must an equivalent change also occur if balance is to be sustained?”[7]. Lengthening or expanding the middle cranial fossa places the maxilla in a more protusive and lateral position, respectively. The mandible “counterpart” matches the corresponding enlargement. Further, an expanding middle cranial fossa is matched by a vertical and horizontal increase in the ramus. The movement of the maxilla, in response to expansive growth of the cranium, inferiorly and anteriorly displaces the dentition passively. The teeth themselves through remodeling of the socket function similarly to “mesial drift.” Enlow named this phenomenon “vertical drift of the tooth” which acts concurrently to dental eruption. The width of alveolar bone limits the lateral boundaries of the tooth inclination. From these three planes of space (transverse, vertical, and AP) the dentition is given freedom to compensate for the spatial positioning of the skeletal base. This compensation of structures, described by Enlow, is the fine-tuning of structures to counteract rotations produced by primary and secondary displacement in the middle and anterior cranial fossa growth. Similar principles could be extrapolated in dental compensation. The ability for teeth to stabilize the occlusion is given by the

boundaries preestablished. Orthodontic/orthopedic intervention attempts to disrupt this homeostasis. Stability ultimately arises from the magnitude and direction of clinical influence or by nature's own intrinsic control. Growth leads to desired or undesired equilibrium (malocclusion). Intervention results in a either fabricated equilibrium or relapse.

Biologic response and ultimately long term prognosis of orthodontic treatment have been topics in many forums. The angulation of the posterior dentition is an area of attention that reaches many disciplines of dentistry. In prosthodontics, the arc drawn from bilateral occlusal planes is annotated the Curve of Wilson. This arc is subject to change dependent upon angulation of posterior teeth. A flattened Curve of Wilson correlates to linguaverted molars whereas a steepened, exaggerated representation derives from "plunging" palatal cusps. This orientation has been noted in some patients with temporomandibular disorders where the palatal cusps act as fulcrum in initial occlusal contacts[37]. The Curve of Wilson also increases the likelihood of interferences of the dentition in working and non-working lateral excursions. The masticatory system achieves better harmony minimizing hyperactivity of the musculature. A common goal in orthodontics is minimize this arc which may improve the centric relation: centric occlusion discrepancy as well as maintaining virgin dental anatomy.

Gingival health has also been established as fundamental in dental examination. In a study by Herberger and Vanarsdall[14], patients were evaluated for periodontal health pre- and post-expansion treatment. The research demonstrated greater gingival recession could result from dental expansion as opposed to skeletal expansion. Similarly, interferences in the lateral movements of the mandible could affect the long-term periodontium[13]. Diminishing premature contacts was theorized to inhibit unnatural lateral forces on teeth thus stabilizing the level of attachment for high risk periodontal patients. Improvement of airway constriction presented yet another discipline of dentistry that has gained much popularity in the literature. Increases in sleep apnea risk have been correlated with narrow, high palate patients. A proper transverse relationship in mouth-breathing patients has been shown to improve impairment of nasal passages. Therefore, the occlusal balance of the maxillary and mandibular molars appears to be critical for orthodontic as well as oral health.

The magnitude of transverse dental compensation often varies to the same extent from any skeletal deformity. Skeletal asymmetry has shown that transverse dental compensation is statistically correlated with transverse skeletal asymmetry. Compensatory buccolingual inclinations in molars can often mask underlying transverse skeletal discrepancies[42]. In facial

asymmetry cases, this compensation is often observed to preserve the dental occlusion. Transverse alveolar growth has been demonstrated to occur greater in the maxilla than in the mandible[15] however some reports have been demonstrated to occur in both arches[25,26,42]. Maxillary molars erupt with buccal crown inclination and upright palatally as maxillary intermolar width increases during the first few decades of life. In tandem, mandibular molars erupt in an opposite manner with lingual crown inclination and upright buccally as mandibular intermolar width increases[15,25,26]. In addition, incisors along with the posterior dentition incline toward the deviated, asymmetric sides.

Hesby et al reported that the changes observed occurred as a gradient from the maxilla basal bone inferiorly to the mandibular alveolar bone. In other words, the greatest change during growth was observed from the maxilla, maxillary molar alveolus, mandible, and then mandibular molar alveolus. From the "Equilibrium Theory[33]" the authors argued the tongue and buccal soft tissue may play an influence on the mandibular dentition. In evaluating patients with the Frankel appliance (not in their study), decreased tongue and cheek forces did not demonstrate similar results in mandibular molar uprighting. Due to the constraints of the mandibular transverse bone (i.e. fused medial suture) the expansive maxilla in growth (i.e. patent palatal suture) allows maxillary molar dentition to lateral tip.

The relative higher degree of uprighting observed in the maxillary posterior may then be attributed to cheek pressures as well as occlusal response to the limitations of the mandibular molars. Generally speaking, the posterior dentition, they argue, compensate the growing patient in the transverse dimension by modifying the alveolar width. Boundaries of the alveolar width are determined by basal bone discrepancies and soft tissue forces.

When posterior crossbites present, equilibrium is achieved from these demands[34]. Analogous configurations have been shown in growing class II subjects are similarly observed in the anterior-posterior depiction. Clinical implications from their study proclaim limiting mandibular “expansion” only to uprighting the dentition. This concept is supported by the observations of the mandibular molars rarely exceeding 90 degrees relative to the mandibular plane[8,35,39]. Without surgical intervention of the mandibular medial suture, the mandible dictates the maxillary expansive potential. Conversely, spontaneous buccal torque of the mandibular posterior teeth after palatal expansion supports this premise as well[43]. Furthermore, their conclusions imply that transverse dental compensation can truly only be observed in the maxillary posterior without orthopedic intervention. Similarly, Dr. James McNamara’s often quoted “foot and shoe” analogy relates the

former as the mandible and the latter as the maxilla. Increasing the shoe size enables the foot to properly slide into place. Deduction from the analogy, the “toes” would represent the dentition. If the maxilla is enlarged, the foot will have proper room to fit inward as long as the “toes” are straight. With ample “wiggle room,” the dentition will properly line up in accordance to occlusal demands.

Facial patterns in the vertical as well as the transverse dimensions appear to have significant weight on the dental pattern of occlusion. Class II div 1 and Class III patients appear to demonstrate relatively deficient maxillary widths in comparison to their mandibular counterparts. Maxillary inclinations of posterior teeth with buccal angulations have been correlated with vertical patterns. Conversely, lingual inclinations have also been suggested tendencies with horizontal growth patterns. Mandibular dentition has not been consistently demonstrated to exhibit the same compensation possibly due to the limitations of the basal bone[15,25,26]. Overall, this principle cannot be applied to the individual but rather the population as whole. Nevertheless, cone-beam computed tomography has opened many doors for the future of orthodontic diagnosis and treatment. Unlike the frontal analysis in PA cephalograms, one can better reliably measure buccolingual angulations of maxillary molar and canines. By evaluating slices generated by

the cone-beam, identifiable anatomical structures in addition to previously arbitrarily determined (i.e. jugule, antegonial notch, etc.) landmarks help better assist diagnosis. The CWRU analysis, like BU's CBT and USC's root vector method, provides a very statistically accurate mode of posterior crossbite diagnosis including any dental compensation. With the facilitated views of molar angulations via CBCT, clinicians can quickly and more importantly reliably retrieve information. Incorporating the cranial base in discussion of the transverse dimension however, has become an overlooked component. The logical next step in the current literature is to research this association on its effect of the maxillary and mandibular interrelationships. The aim of this thesis is to evaluate this potential influence of the cranial base to molar angulations with respect to their transverse boundaries.

LITERATURE REFERENCES

1) Andrews, L. F. (1972). The six keys to normal occlusion. American Journal of Orthodontics, 62(3), 296–309.

2) Andrews L.F. & Andrews, W.A. (2001). Andrews Analysis. In: Syllabus of the Andrews Orthodontic Philosophy. 9th ed. Six Elements Course Manual.

3) Angelopoulos C. Cone beam tomographic imaging anatomy of the maxillofacial region. Dent Clin North Am. 2008 Oct; 52(4): 731-752.

4) Björk, Arne. Cranial base development. American Journal of Orthodontics , Volume 41 , Issue 3 , 198 – 225. 1955

5) Casko, J. S., Vaden, J. L., Kokich, V. G., Damone, J., James, R. D., Cangialosi, T. J., … Bills, E. D. (1998). Objective grading system for dental casts and panoramic radiographs. American Board of Orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 114(5), 589–599.

6) Cortella, S., Shofer, F. S., & Ghafari, J. (1997). Transverse development of the jaws: norms for the posteroanterior cephalometric analysis. American Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 112(5), 519–522.

7) Enlow, D.H., Hans, M.G. Essentials of Facial growth. 2nd ed. Ann Arbor, MI: Needham Press; 2008

8) Evangelinakis, N., Palomo, J.M., Narendran, S., et al. (2010) Changes in buccolingual inclination of mandibular canines and first molars after orthodontic treatment using CBCT. Master’s thesis, Case Western Reserve University

9) Ferrario, V. F., Sforza, C., Colombo, A., Ciusa, V., & Serrao, G. (2001). Three-Dimensional Inclination of the Dental Axes in Healthy Permanent Dentitions - A Cross-Sectional Study in a Normal Population. Angle Orthodontist, 71(4), 257–264.

10) Franco, F. C. M., de Araujo, T. M., Vogel, C. J., & Quintão, C. C. A. (2013). Brachycephalic, dolichocephalic and mesocephalic: Is it appropriate to describe the face using skull patterns? Dental Press Journal of Orthodontics, 18(3), 159–63.

11) Garcia-Figueroa, M. a., Raboud, D. W., Lam, E. W., Heo, G., & Major, P. W. (2008). Effect of buccolingual root angulation on the mesiodistal angulation shown on panoramic radiographs. American Journal of Orthodontics and Dentofacial Orthopedics, 134(1), 93–99.

12) Ghafari, J., Cater, P. E., & Shofer, F. S. (1995). Effect of film-object distance on posteroanterior cephalometric measurements: suggestions for standardized cephalometric methods. American Journal of Orthodontics and Dentofacial Orthopedics: Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 108(1), 30–37.

13) Harrell SK. Occlusal forces as a risk factor for periodontal disease. Periodon. 2003; (32): 111-117.

14) Herberger T, Vanarsdall RL. Rapid Palatal Expansion: Long-Term Stability and Periodontal Implications [master’s thesis]. University of Pennsylvania; 1987.

15) Hesby, R. M., Marshall, S. D., Dawson, D. V., Southard, K. a., Casko, J. S., Franciscus, R. G., & Southard, T. E. (2006). Transverse skeletal and dentoalveolar changes during growth. American Journal of Orthodontics and Dentofacial Orthopedics, 130(6), 721–731.

16) Hopkin G.B., W. J. B. Houston, and G. A. James (1968) The Cranial Base as an Aetiological Factor in Malocclusion. The Angle Orthodontist: July 1968, Vol. 38, No. 3, pp. 250-255.

17) Jacobs, J. D., & Sinclair, P. M. (1983). Principles of orthodontic mechanics in orthognathic surgery cases. American Journal of Orthodontics, 84(5), 399–407.

18) Jacobs, J. D., Sinclair, P. M., Stoelinga, P. J., Leenen, R. J., Miner, R. M., Al Qabandi, S., … Hausamen, J. E. (1992). Elimination of transverse dental compensation is critical for treatment of patients with severe facial asymmetry. American

Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 99(3), 167–173.

19) Janson, G., Bombonatti, R., Cruz, K. S., Hassunuma, C. Y., & Del Santo, M. (2004). Buccolingual inclinations of posterior teeth in subjects with different facial patterns. American Journal of Orthodontics and Dentofacial Orthopedics, 125(3), 316–322.

20) Karamitsou et. al (2010). Pretreatment Buccal Inclination of Maxillary First Molars and Canines. Master's Thesis, Case Western Reserve University.

21) Katiyar, R.et al (2013). Comparison of Transverse Dimension in Various Malocclusion Groups : A Posteroanterior Cephalometric Study. The Journal of Indian Orthodontic Society, 47(December), 249–254.

22) Kim, Y. Il, Choi, Y. K., Park, S. B., Son, W. S., & Kim, S. S. (2012). Three-dimensional analysis of dental decompensation for skeletal Class III malocclusion on the basis of vertical skeletal patterns obtained using cone-beam computed tomography. Korean Journal of Orthodontics, 42(5), 227–234.

23) Kusayama, M., Motohashi, N., & Kuroda, T. (2003a). Relationship between transverse dental anomalies and skeletal asymmetry. American Journal of Orthodontics and Dentofacial Orthopedics, 123(3), 329–337.

24) Marshall, S., Dawson, D., Southard, K. a., Lee, A. N., Casko, J. S., & Southard, T. E. (2003). Transverse molar movements during growth. American Journal of Orthodontics and Dentofacial Orthopedics, 124(6), 615–624.

25) Miner, R. M., Al Qabandi, S., Rigali, P. H., & Will, L. a. (2012). Cone-beam computed tomography transverse analysis. Part I: Normative data. American Journal of Orthodontics and Dentofacial Orthopedics, 142(3), 300–307.

26) Miner, R. M., Al Qabandi, S., Rigali, P. H., & Will, L. a. (2015). Cone-beam computed tomography transverse analyses. Part

2: Measures of performance. American Journal of Orthodontics and Dentofacial Orthopedics, 148(2), 253–263.

27) Miyamoto, M., Palomo, J.M., Narendran, S., et al. (2012) Changes in buccolingual inclination of maxillary canines and first molars after orthodontic treatment using CBCT. Master's thesis, Case Western Reserve University.

28) Moorees CFA, The Size of the Dental Arch. In: Moorrees CFA, editor. The Dentition of the Growing Child. Cambridge (MA): Harvard Press; 1959. 87-110.

29) Murakami, K., Deguchi, T., Hashimoto, T., Imai, M., Miyawaki, S., & Takano-Yamamoto, T. (2007). Need for training sessions for orthodontists in the use of the American Board of Orthodontics objective grading system. American Journal of Orthodontics and Dentofacial Orthopedics, 132(4), 1–6.

30) Owens AM, Johal A. Near-end of treatment panoramic radiograph in the assessment of mesiodistal root angulation. Angle Orthodontics. 2008;78:475-81.

31) Palomo, J. M., Valiathan, M. and Hans, M. G. (2014) 3D Orthodontic Diagnosis and Treatment Planning, in Cone Beam Computed Tomography in Orthodontics: Indications, Insights, and Innovations (ed S. D. Kapila), John Wiley & Sons, Inc., Ames, USA.

32) Podesser et. al., Quantitation of Transverse Maxillary Dimensions Using Computed Tomography: A Methodological and Reproducibility Study. Eur J Orthod. 2004 Apr;26(2):209-15.

33) Proffit WR, Fields HW. Contemporary Orthodontics. 4th ed. Mosby; 2007.

34) Ricketts RM. Introducing Computerized Cephalometrics. Rocky Mountain Data Systems; 1969.

35) Shewinvanakitkul et al (2008), Using CBCT to Measure Buccolingual Inclination of Mandibular Canines and First Molars. Masters Thesis, Case Western Reserve University.

36) Shigefuji R, Motohashi N, Kuroda T. Longitudinal changes of molar dental compensation following orthognathic surgery in facial asymmetry patients. Jpn J Deform. 2001;11:11-20

37) Secchi A.G. & Wadenya R. Early Orthodontic Diagnosis and Correction of Transverse Skeletal Problems. New York State Dental Journal. Jan 2009; 75(1): 47-50.

38) Stoelinga, P. J., & Leenen, R. J. (1981). Class II anomalies: a coordinated approach to the management of skeletal, dental, and soft tissue problems. Journal of Oral Surgery (American Dental Association : 1965), 39(11), 827–841.

39) Streit, L., Palomo, J.M., Narendran, S., et al. (2012) The CWRU transverse analysis: developing norms. Master's thesis, Case Western Reserve University

40) Tamburrino, R. K., Boucher, D. M. D. N. S., Vanarsdall, D. D. S. R. L., & Secchi, A. (2010). Roth Williams Legacy Fund Donors The Transverse Dimension : Diagnosis and Relevance to Functional Occlusion, (September), 1–6.

41) Tong, H., Enciso, R., Van Elslande, D., Major, P. W., & Sameshima, G. T. (2012). A new method to measure mesiodistal angulation and faciolingual inclination of each whole tooth with volumetric cone-beam computed tomography images. American Journal of Orthodontics and Dentofacial Orthopedics, 142(1), 133–143.

42) Tyan, S., Park, H.-S., Janchivdorj, M., Han, S.-H., Kim, S.-J., & Ahn, H.-W. (2015). Three-dimensional analysis of molar compensation in patients with facial asymmetry and mandibular prognathism. The Angle Orthodontist, (March), 150720064124003.

43) Vanarsdall, R. L., Secchi, A. G., Chung, C. H., & Katz, S. H. (2004). Mandibular basal structure response to lip bumper treatment in the transverse dimension. Angle Orthodontist, 74(4), 473–479.

44) Wei Shy et al. Cranial Width Dimensions. Angle Orthodontics. 1970; 40: 141-147.

45) Wu, R., Palomo, J.M., Landers, M., et al. (2012 Anatomically based cranial landmarks for three-dimensional superimposition. Master's thesis, Case Western Reserve University.

STATEMENT OF THESIS

The objective of the study is to determine if the width of the transverse cranial base dimension has an effect on buccal-lingual molar angulation.

It is hypothesized that:

First, the cranial base width will relate to the maxillary base width. Second, the cranial base width will not associate to the mandibular width. Last, the cranial base will have associations with the molar angulation, predominately in the maxilla.

MANUSCRIPT FOR PUBLICATION

The Relationship between the Cranial Base to Dental Compensation in the Transverse Dimension

Authors: Amir Aminoshariae D.M.D., M.S. 1

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

Juan Martin Palomo, D.D.S., M.S.D. 3

Ali Zakir Syed, B.D.S., M.S. 4

1. Resident, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH

2. Professor and Fellowship Director, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH

3. Professor and Program Director, Department of Orthodontics at Case School of Dental Medicine in Cleveland, OH

4. Associate Professor, Department of Oral Maxillofacial Radiology at Case School of Dental Medicine in Cleveland, OH

Corresponding Author:

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

INTRODUCTION

The base of the cranium has been a focal point in orthodontic diagnosis and treatment planning ever since the introduction of the lateral cephalogram. In comparison of cranial size both orthodontists and anthropologists required a reliable method. The Cephalic Index (CI) was first described by Swedish anatomist Anders Retzius in the 19th Century[10]. After establishment in 1840, the CI gained popularity by Carleton S. Coon in the 1960s to describe human populations. The "craniofacial complex" represented the evaluation of skull size within living individuals. The ratio of maximum width to maximum length categorizes cranial patterns into brachycephalic (>80%), mesocephalic (75-79.9%), and dolichocephalic (<74.9%. Analogously, the facial index categorizes euryprosopic (<84.9%), mesoprosopic (85-89.9%), leptoprosopic (>90%) by calculating the morphological face height: width ratio (N-Gn:Zyr-Zyl). These percentages were based on works cited from anthropologist Leslie Farkas in 1986[10]. The ranges within these categories are all race, ethnic, and gender-specific. Although strong correlations exist between cranial and facial indices, they are not homologous terms and thus cannot be used interchangeably.

Traditionally, the cranial base has been broken into the anterior, middle, and posterior cranial fossae[7]. Each respective compartment has been extensively evaluated for growth and

development. Studies by Enlow et al held the belief that facial morphology was templated by the foundation of the cranial base[7]. Further, their “counterpart principle” fundamental point includes that growth increases maintain the craniofacial form and pattern. In other words, growth in one area is matched by a complement in order to achieve balance.

In evaluation of the transverse dimension, several analyses exist for clinical practice. Many scholars[6,12,34,43] have used the frontal cephalogram to analyze the ratio between maxillary and mandibular width. Jugale or “J-point” represented the “depth of the concavity of the lateral maxillary contours, at the junction of the maxilla and the zygomatic buttress.” The antegonial notch or “Ag” analogously represented the mandibular interdistance. The point was measured at the “innermost height of contour along the curved outline of the inferior mandibular border, below and medial to the gonial angle.”

Cone-beam computed tomography (CBCT) has extended the possibilities of analysis beyond the traditional radiographs. With the facilitated views of molar angulations via CBCT, clinicians can quickly and reliably retrieve information. Several institutions have begun researching and developing CBCT-methods for transverse analysis. The Boston University (BU), University of Southern California (USC), and Case Western Reserve University (CWRU) methods are few examples of the

growing trend in this field[25,26,31,41].

Incorporating the cranial base in discussion of the transverse dimension however, has yet to become integral in orthodontic practice. The next step in literature is to research this association on its effect of the maxillary and mandibular interrelationships. The aim of this thesis is to evaluate this potential influence of the cranial base to molar angulations with respect to their transverse boundaries.

MATERIALS AND METHODS

The Case Western Reserve University (CWRU) Institutional Review Board approved this study (IRB 2015-1354). The Department of Orthodontics at CWRU School of Dental Medicine treats all severities of malocclusion. Data is compiled from pre-existing patient Cone Beam Computed Tomography scans (CB MercuRay, Hitachi Medical Systems America Co. – Twinsburg, OH). Images were taken in the Craniofacial Imaging Center at CWRU at the patients' initial records appointments prior to December 2, 2015. Records included medical and dental history forms, complete photographs, study models, and consent forms (Appendix 1) for treatment as well as radiographs. The following inclusion criteria were used:

1. nonsyndromic patients voluntarily seeking orthodontic treatment at the orthodontic department

2. no previously initiated treatment
3. pretreatment CBCT scans
4. no extracted permanent molars
5. no previous dental restorations on measured molars

This retrospective cohort study selected one hundred cases out of the 6489 total previously taken images. Sample size calculation in this population was performed prior to the beginning of the study using the SAS Power and Sample Size 3.1 of SAS (Statistical Analysis System) software for Windows version 9.1.3 (SAS Institute Inc. Cary, NC, USA). Expecting the minimum correlation of 0.60 with power of 0.80 and alpha of 0.05 and two-sided test, the minimum sample size for the experimental cases was 15 per group.

Thirty-eight dolichocephalic, twenty mesocephalic, and thirty-two brachycephalic samples were selected using the Cephalic Index ranges. Euryprosopic, mesoprosopic, and leptoprosopic designations were similarly assigned to these patients using the Facial Index however subjects were not screened by this criterion. The distance between the optic canals, foramen ovale, and jugular foramen will be measured bilaterally. These landmarks were chosen to represent the anterior, middle, and posterior cranial fossa, respectively. The widths between anterior cranial base (measured by the intersection of the frontozygomatic process-cranial base lateral

extensions), carotid canals, and internal acoustic meatuses were also determined as redundant representations. Maxillary/mandibular first molar angulations and maxillary/mandibular skeletal widths were also recorded. All measurements were recorded by a single operator (AA) and retested to determine intraclass reliability. Maxillary and mandibular molar angulations within one standard deviation from the mean were defined as superior or inferior convergent.

Statistical tests were completed to assess normal distribution of data and probability of significance. Multivariate regression analysis was performed to assess association of factors to dental compensation (i.e. molar angulation). Descriptive statistics (means, standard deviations and ranges) was used to evaluate the data. Normally distributed variables were tested by Pearson Correlation Coefficicient, ANOVA, and multivariate regression analysis. Kruskal-Wallis and Spearman’s rho were used for non-parametric analysis. In order to assess reliability, intra-class correlation coefficient was used based on repeated measurements on 10 subjects selected using a random number generator.

All measurements used version 11.8.06.24 Dolphin3D imaging (Patterson Dental Supply, Inc., St. Paul, MN) software. All measurements were taken from two planes and averaged in record.

Subject Orientation

Preliminary orientation is used by the “Orientation” tab in Dolphin3D software. External landmarks (Supraorbital rims, Frankfort Horizontal, and True Vertical) are used for initial positioning. The internal landmark protocol developed by Wu et al was implemented as a standard method for the measured variables (Figure 1)[45].

1. Coronal view - adjusting the head, the axial plane was set through the center of the left and right optical foreman (Figure 3a). Aligning these structures prevented the head rotation.
2. Axial view - adjusting the head, the coronal plane was set through the center of left foreman ovale to the center of right foramen ovale (Figure 3b). Aligning these structures prevented left and right tilting of head.
3. Sagittal view - was set by sagittal plane through foreman cecum to the intersection of coronal plane and axial plane. The axial plane overlaps McRae's plane denoted by the anterior border of foramen magnum (basion) to the posterior border of foramen magnum (opisthion) (Figure 3c). Aligning these structures prevented superior and inferior tilting of the head.

Method of Cranial and Facial Index Measurements

Once orientation of the subject is completed, it is critical for it to remain unchanged for the subsequent measurements. Cranial/Cephalic index is determined by measuring cranial width by length. Width landmarks used were Opisthocranion (midsagittal point of the occipital squama) and Glabella (most prominent point of the frontal bone in the midsagittal plane). Length landmarks used the left and right Eurion (most lateral point of the neurocranium) (Figure 4). Facial index is measured by taking the Nasion to Gnathion length to the width between Zygomatic processes. Nasion was determined by using the frontonasal-intranasal sutures. Gnathion was determined by the most anterior-inferior point of the chin contour (Figure 5).

Brachycephalic (>80%), mesocephalic (75-79.9%), and dolichocephalic (<74.9%) were categories based on the calculated Cephalic Index ratio. The Facial Index ratio classifies euryprosopic (<84.9%), mesoprosopic (85-89.9%), leptoprosopic (>90%) analogously.

Method of Molar Inclination Measurements

Implementing the protocol by Karamitsou et al, maxillary first molar angulations are measured by passing a line through the palatal root apex and mesiopalatal cusps. If a root apex

dilacerations were present, a “bestfit” line is constructed passing through the propagation of force down the long axis of the tooth. The palatal root often depicts the longest root with the largest diameter providing ease in identification. In ideal cusp-to-fossa occlusion, this root also bears the functional forces. A second line is then constructed tangent to the floor of the nasal cavity.

Mandibular molars were measured similarly[35]. In the transverse slice, a line is drawn from the central fossa through the middle of the root apices representing the long axis of the tooth. Same adjustments for mandibular molars are made as for maxillary molars with abnormal root morphology. A tangential line is drawn for the mandibular border.

Inclinations are calculated by measuring the angles formed by the respective intersecting lines viewed in the transverse slice. Maxillary molar angulations above or below one standard deviation from the mean are classified as “superior” convergent and “inferior” convergent, respectively[25].

CBCT Landmarks

The following landmarks were identified using a Maxillofacial Cone Beam Computed Tomography Atlas[3]. Distances were measured bilaterally in each available plane for the respective points. Averages were taken in each landmark from the coronal and axial

slices. (Figures 6-11)

1. Maxilla
    a. Jugale (BiJug) – junction of zygoma and maxilla
    b. Greater Palatal Foramen (BiGPF)- radiolucency travelling posterior-anteriorly just superior to maxillary palatal roots
2. Mandible
    a. Lingula (BiLingula) – radioopacity superior and medial to mandibular foramen
    b. Mental Foramen (BiMF) – radiolucency inferior and lateral to mandibular bicuspids
3. Anterior Cranial Fossa
    a. Anterior Cranial Base (ACB) - frontozygomatic process-cranial base lateral extensions
    b. Optic Canal (BiOpt) – adjacent to anterior clinoid processes of sella
4. Middle Cranial Fossa
    a. Foramen Ovale (BiOvale) – radiolucency anteriomedial to mandibular condyles and adjacent to sphenoid sinus
    b. Carotid Canal (BiCar) – radiolucency posterior to foramen ovale and medial to mandibular condyle
5. Posterior Cranial Fossa
    a. Jugular Foramen (BiJF) – radiolucency posterior border of external auditory canal and medial to mastoid air

cells

b. Internal Acoustic Meatus (BiIAM)- posterior-medial border between middle and posterior cranial fossa

Statistical Analysis

Testing of normal distribution was performed on each parameter a well as descriptive statistics (means, standard deviations and ranges). SPSS software (Statistical Package for the Social Sciences, SPSS 17.0, Inc. – Chicago, IL) was used for analysis of data variables. Kruskal-Wallis and Spearman's rho tests were used for non-parametric analysis. Normally distributed variables used independent ANOVA and Pearson correlation. Multivariate regression models were performed for assessment of predictive value of independent variables. Intra-class correlation coefficient was used based on repeated measurements on 10 of the 100 subjects randomly selected. Cronbach intraclass correlation was determined based a 95% confidence interval.

RESULTS

All pretreatment records taken between the years of 2009-2015 (N=6459) were included in the study. 3159 records were excluded for not having a CBCT volume, previous orthodontic treatment, or patients exhibiting a history of medical syndrome.

One hundred subjects were then selected from the remaining records. The final sample population included 45 males and 55 males ranging from 10.75 to 54.50 years old (average 15.03±5.57 years). Cronbach intraclass correlation was determined to range from 0.885 to 0.997 with the respective variables (95% confidence interval). All linear measurements ranged from 0.926 to 0.997. All angulations ranged from 0.885 to 0.949. Mean left buccolingual inclinations of maxillary and mandibular first molars were 103.8±5.2º and 75.8±5.3 º, respectively. Mean right buccolingual inclinations of maxillary and mandibular first molars were 104.0±5.3º and 77.10±5.4 º, respectively. Average molar variables were created by taken the arithmetic average of each side. Descriptive statistics is tabulated in Table I.

All parameters were tested for normal distribution (Kolmogorov-Smirnov). “Age”, “CranialWidth”, “CranialIndex”, “BiZyg”, “BiOptCan” and “UR6angle” appeared not to follow a Gaussian distribution. Figures 12-20 demonstrate the histograms of all parameters including their respective bell curves. Omitting outliers then reexamining the variables, only “Age” remained nonparametric.

Table II demonstrates the sample stratification according to cephalic and facial form. Although groups were selected based on cranial index, a corresponding facial form was not always observed. Using a Spearman rho test, the R-value of

Cranial Index to Facial Index was 0.461 with a p=0.000 (Table III). β-coefficient was determined to be -0.747(p=0.000) with a constant of 1.505 (p=0.000). With respect to molar angulation, neither Cranial Index nor Facial Index appears to have a statistical significance (Table IV-V).

Pearson and Spearman correlation values were described ($p<0.01$ and $p<0.05$) in Table VI. Statistical significance was determined on a 95% and 99% Confidence Intervals (two-tailed). Single and double asterisks respectively represent the former and latter values. The anterior cranial fossa variables (BiOptCan and AntCranBase) demonstrated strong association to the middle cranial fossa and maxillary width. The Spearman rho values correlated strongly with cranial and facial width measurements. The middle cranial fossa variables demonstrated strong relationships to the posterior cranial fossa and mandibular width parameters. More consistent associations were observed with mandibular measurements than the posterior cranium. Similarly, both the posterior cranium and mandibular width show links to maxillary molar angulation. Interestingly, maxillary molar angulation demonstrated stronger association to mandibular molar angulation than maxillary width measurements. Facial index (including contributive factors) also showed to be associative with maxillary molar angulation. Other than the transverse skeletal and dental components of the maxilla, the

mandibular molar showed no statistical significance to other measured parameters.

Regression analysis was performed against each molar angulation variable (Table VII-VIII). R-values valued at 0.530, 0.769, and 0.808 for maxillary molars, respectively (average, left, and right first molars). Similarly, the values included 0.636, 0.827, and 0.837 for the mandible (average, left, and right first molars). P-values were all statistically significant ($p<0.05$). The left and right molar angulation demonstrated strong predictive associations on one another ($p<0.000$). Opposing mandibular molar effects were only demonstrated in the maxillary right molar. In both first molar angles, BiJugale displayed influence ($p=0.096$ and 0.037 UL6 and UR6, respectively) but was only statistically significant in the maxillary right first molar. However, with respect to the average molar angulation, BiJugale did not display the same relationship as demonstrated individually. Bilaterally in the mandible, molar angulation was explained by several factors. Similar to the maxillary counterpart, mandibular molars were strongly influenced by contralateral molars. Further, the opposing occluding molar did not portray a relevant relationship. Among left and right molar angulation, BiGreatPal and BiJugale demonstrated the largest effect on mandibular molar angulation. Average mandibular molar angulation also

exemplified both predictive factors as well as for AVG_U6. Bonferroni adjustments ($p<0.003$) were evaluated only in the average molars angulations.

DISCUSSION

The aim of this study was to determine 1) cranial base influence on the molar dentition and 2) examine transverse interrelationships (i.e. maxillary and mandibular width, cranial base and molar angulation). The mean and standard deviations for molar angulation were consistent with previous research theses at CWRU[8, 20, 27, 35, 39]. These values also relate well to Miner et al[25, 26] after factoring a correction from occlusal plane to apical base. Their data found differences in bilateral crossbites as a result of narrow maxilla and unilateral crossbites due to wider mandibles. Our data were in accordance to this information. Dental compensations were observed despite the presence of crossbites. All of our other linear measurements were also consistent with previous literature. After examination of outliers, Gaussian curves were observed in all parameters except for “Age.” Both the age and the cephalic form of the patients were screened and selected in this sample of convenience. Therefore, nonparametric distribution was expected was to be expected in either or both parameters.

To avoid confounding factors in our regression models,

CranialIndex and FacialIndex were omitted in individual molar prediction. For analysis, only component parameters of CranialIndex and FacialIndex were used for predictive value. Some inherent overlaps in measurements were unavoidable due to the proximity or similarity in anatomy (i.e. BiZyg vs BiJugale, etc.). However, we do not believe these to play a major role in our final regression analysis of the variables in totality.

Similarly, average molar variables were used to predict average molar forecasting (i.e. AVG_U6 vs AVG_L6, vice versa) to avoid confounding. Using these variables in a regression analysis, an interrelationship between the maxillary and mandibular components was observed. Molar angulation examination prior to averaging the values demonstrated only a relationship with each other with very little to occluding molars. This information suggests that dental compensation results both from skeletal imbalance but also from the contralateral teeth. Previous studies have revealed similar findings[36, 42]. Shigefuji et al showed greater compensation on the deviated/noncrossbite side of mandibular assymetric cases. Tyan et al demonstrated greater maxillary molar inclination in assymetric Class III cases where the mandibular rami were of equal length bilaterally (T-type) and greater mandibular molar inclination in samples where mandibular rami were of unequal length (R-type). Relatively, the R-type demonstrated more

compensation than the T-type.

The literature has demonstrated that maxillary molars erupt with buccal crown inclination and upright palatally. The mandibular molars have been shown to perform the opposite action[15,25,26]. Hesby et al propose that the changes occur as a gradient from maxillary to the mandibular basal bone. They claim that "the greatest width change occurs superiorly (jugale point)… smallest width change occurs inferiorly (midalveolar point of the mandible)". Their transverse mandibular base bone changes did not follow this pattern. Our data support this idea where the mandibular molars appear to act independently from width structures measures. Furthermore, the chronologic manner in which the mandibular first molars erupt (earliest of all permanent dentition) may suggest that these teeth are genetic/biologic rather than occlusal driven.

Enlow et al help explain our results with the "counterpart principle of craniofacial growth"[7]. The theory can be summarized in the following manner: the maxillary arch is said to be countered by the mandibular arch; the anterior cranial fossa to the palate and maxillary apical base; the middle cranial fossa to the mandibular rami; and the zygomatic arch (bridging cranial fossa and the ramus) to all respective counterparts. Our data follow this pattern in both correlation and regression values. Figure 21 shows a summarized illustration of the overall

interrelationships. Enlow et al described the growth of the cranial base, compartment by compartment. “Growth of any given facial or cranial part relates specifically to other structural and geometric counterparts.” A change in one area is balanced by growth in another. Our data demonstrates these overlapping compartments behave more like a wave rather than toppled dominos. For instance, the completion of the growth in the anterior cranial base coincides with the eruption of the first permanent dentition: mandibular molars. Shortly thereafter, the maxillary molar begins emergence into the oral cavity. Alveolar bone, bounded by the basal bone, provides the medium from which teeth are angulated. Wider spaced alveolar bone (by transverse growth in the skeletal bone) displaces teeth further apart. The “vertical drift” of the posterior teeth ultimately arise to the buccolingual compensation.

Often in orthodontic treatment planning, practitioners “treat to the mandibular arch.” The philosophy is supported by our observations. The widening of the cranial base and mandibular counterparts provide the volume from which mandibular molar reside. Stronger associations to mandibular molar angulation [compared to maxillary width] suggests than functional occlusion addressed to the mandibular dentition rather than spatial positioning plays a more critical factor in maxillary molar inclination. Hesby et al observed similar

patterns where the maxillary molars upright once contacting the mandibular molars. Vanarsdall et al claimed that when introducing orthopedic forces compared to standard edgewise appliances in growing populations, the posterior dentition erupt to continue provide occlusion[43]. Their data demonstrated transverse changes in mandibular basal bone as well [in conjunction with lip bumpers]. Proffit would argue that the "equilibrium theory" would have been altered due to the introduction of the appliances[33]. Our results would imply that both the changes in soft tissue pressure as well as the disruption of differential growth allow the mandibular molars more freedom to erupt in the alveolar bone. The maxillary molar would therefore drift to a harmonious occlusal position barring any external influences (i.e. tongue, habits, primary failure of eruption, etc.).

It is evident as demonstrated by the wide variation in molar angulation that hard tissue alone does not explain the variance in our data sample. Molar angulation appeared to be largely independent of cranial index, facial index, cranial width, maxillary width, and mandibular width as a whole. Greater emphasis is needed when evaluating soft tissue forces upon dentition. The "equilibrium theory" needs to be re-examined for a primary role in transverse compensation. Tongue and buccal forces would be interesting variables to include in

our regression models.

Other future considerations for studies would also require investigation of the morphology of posterior cusps. Flat and steep incline planes also appeared to demonstrate varying angulation. The occlusal wear of teeth may be due to a self-correction mechanism. Another area of adaptation to explore is the enigmatic temporomandibular joint. What associations are there with the TMJ and dental compensation? Does splint therapy affect angulation? Finally, the last area to examine would be the morphology of roots themselves. Dilacerated roots present challenges in both measurements as well as determining long axis of occlusal forces. A recommendation would be to implement a modification to the CWRU Transverse Analysis by utilizing the functional cusps' root canals. This alteration could potentially improve intraclass correlation measurements and thus decreasing Type I (α) and II (β) errors, increasing the power of future studies. Having this more systematic approach in angulation measurements facilitates additional examiners and thus also improving the interclass correlation.

CONCLUSION

Cranial growth and dental development research has illustrated cessation of anterior cranial base growth and eruption of the mandibular first molars around the same

chronologic time of six years. Mandibular molars appear to erupt independently of the cranial base and nasomaxillary complex possibly suggesting a genetic programming that ultimately determines mandibular molar angulation. By compartmentalizing the cranial base, we are attempting to explain the dental compensation by isolating different regions of the cranium. In reality, it is evident that these areas confound for one another. The relationships behave more like several pebbles creating overlapping ripples in the water rather than a single cascade. In addition, greater emphasis on soft tissue analysis seems critical. As the cranium grows, the underlying structures and substructures all compensate for each other in the presence of tongue and cheek pressures. By describing the interrelationships within the craniofacial region, we provide an applicable growth theory to dental compensation. Disruption or modification at any point in growth and development could have potential impact on molar inclination. Future investigation in these angulations may provide a modality vital to diagnosis and treatment planning of the growing individual.

REFERENCES

1) Andrews, L. F. (1972). The six keys to normal occlusion. American Journal of Orthodontics, 62(3), 296–309.

2) Andrews L.F. & Andrews, W.A. (2001). Andrews Analysis. In: Syllabus of the Andrews Orthodontic Philosophy. 9th ed. Six Elements Course Manual.

3) Angelopoulos C. Cone beam tomographic imaging anatomy of the maxillofacial region. Dent Clin North Am. 2008 Oct; 52(4): 731-752.

4) Björk, Arne. Cranial base development. American Journal of Orthodontics , Volume 41 , Issue 3 , 198 – 225. 1955

5) Casko, J. S., Vaden, J. L., Kokich, V. G., Damone, J., James, R. D., Cangialosi, T. J., … Bills, E. D. (1998). Objective grading system for dental casts and panoramic radiographs. American Board of Orthodontics. American Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 114(5), 589–599.

6) Cortella, S., Shofer, F. S., & Ghafari, J. (1997). Transverse development of the jaws: norms for the posteroanterior cephalometric analysis. American Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 112(5), 519–522.

7) Enlow, D.H., Hans, M.G. Essentials of Facial growth. 2nd ed. Ann Arbor, MI: Needham Press; 2008

8) Evangelinakis, N., Palomo, J.M., Narendran, S., et al. (2010) Changes in buccolingual inclination of mandibular canines and first molars after orthodontic treatment using CBCT. Master’s thesis, Case Western Reserve University

9) Ferrario, V. F., Sforza, C., Colombo, A., Ciusa, V., & Serrao, G. (2001). Three-Dimensional Inclination of the Dental Axes in Healthy Permanent Dentitions - A Cross-Sectional Study in a Normal Population. Angle Orthodontist, 71(4), 257–264.

10) Franco, F. C. M., de Araujo, T. M., Vogel, C. J., & Quintão, C. C. A. (2013). Brachycephalic, dolichocephalic and mesocephalic: Is it appropriate to describe the face using skull patterns? Dental Press Journal of Orthodontics, 18(3), 159–63.

11) Garcia-Figueroa, M. a., Raboud, D. W., Lam, E. W., Heo, G., & Major, P. W. (2008). Effect of buccolingual root angulation on the mesiodistal angulation shown on panoramic radiographs. American Journal of Orthodontics and Dentofacial Orthopedics, 134(1), 93–99.

12) Ghafari, J., Cater, P. E., & Shofer, F. S. (1995). Effect of film-object distance on posteroanterior cephalometric measurements: suggestions for standardized cephalometric methods. American Journal of Orthodontics and Dentofacial Orthopedics: Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 108(1), 30–37.

13) Harrell SK. Occlusal forces as a risk factor for periodontal disease. Periodon. 2003; (32): 111-117.

14) Herberger T, Vanarsdall RL. Rapid Palatal Expansion: Long-Term Stability and Periodontal Implications [master’s thesis]. University of Pennsylvania; 1987.

15) Hesby, R. M., Marshall, S. D., Dawson, D. V., Southard, K. a., Casko, J. S., Franciscus, R. G., & Southard, T. E. (2006). Transverse skeletal and dentoalveolar changes during growth. American Journal of Orthodontics and Dentofacial Orthopedics, 130(6), 721–731.

16) Hopkin G.B., W. J. B. Houston, and G. A. James (1968) The Cranial Base as an Aetiological Factor in Malocclusion. The Angle Orthodontist: July 1968, Vol. 38, No. 3, pp. 250-255.

17) Jacobs, J. D., & Sinclair, P. M. (1983). Principles of orthodontic mechanics in orthognathic surgery cases. American Journal of Orthodontics, 84(5), 399–407.

18) Jacobs, J. D., Sinclair, P. M., Stoelinga, P. J., Leenen, R. J., Miner, R. M., Al Qabandi, S., … Hausamen, J. E. (1992). Elimination of transverse dental compensation is critical for treatment of patients with severe facial asymmetry. American

Journal of Orthodontics and Dentofacial Orthopedics : Official Publication of the American Association of Orthodontists, Its Constituent Societies, and the American Board of Orthodontics, 99(3), 167–173.

19) Janson, G., Bombonatti, R., Cruz, K. S., Hassunuma, C. Y., & Del Santo, M. (2004). Buccolingual inclinations of posterior teeth in subjects with different facial patterns. American Journal of Orthodontics and Dentofacial Orthopedics, 125(3), 316–322.

20) Karamitsou et. al (2010). Pretreatment Buccal Inclination of Maxillary First Molars and Canines. Master's Thesis, Case Western Reserve University.

21) Katiyar, R.et al (2013). Comparison of Transverse Dimension in Various Malocclusion Groups : A Posteroanterior Cephalometric Study. The Journal of Indian Orthodontic Society, 47(December), 249–254.

22) Kim, Y. Il, Choi, Y. K., Park, S. B., Son, W. S., & Kim, S. S. (2012). Three-dimensional analysis of dental decompensation for skeletal Class III malocclusion on the basis of vertical skeletal patterns obtained using cone-beam computed tomography. Korean Journal of Orthodontics, 42(5), 227–234.

23) Kusayama, M., Motohashi, N., & Kuroda, T. (2003a). Relationship between transverse dental anomalies and skeletal asymmetry. American Journal of Orthodontics and Dentofacial Orthopedics, 123(3), 329–337.

24) Marshall, S., Dawson, D., Southard, K. a., Lee, A. N., Casko, J. S., & Southard, T. E. (2003). Transverse molar movements during growth. American Journal of Orthodontics and Dentofacial Orthopedics, 124(6), 615–624.

25) Miner, R. M., Al Qabandi, S., Rigali, P. H., & Will, L. a. (2012). Cone-beam computed tomography transverse analysis. Part I: Normative data. American Journal of Orthodontics and Dentofacial Orthopedics, 142(3), 300–307.

26) Miner, R. M., Al Qabandi, S., Rigali, P. H., & Will, L. a. (2015). Cone-beam computed tomography transverse analyses. Part

2: Measures of performance. American Journal of Orthodontics and Dentofacial Orthopedics, 148(2), 253–263.

27) Miyamoto, M., Palomo, J.M., Narendran, S., et al. (2012) Changes in buccolingual inclination of maxillary canines and first molars after orthodontic treatment using CBCT. Master’s thesis, Case Western Reserve University.

28) Moorees CFA, The Size of the Dental Arch. In: Moorrees CFA, editor. The Dentition of the Growing Child. Cambridge (MA): Harvard Press; 1959. 87-110.

29) Murakami, K., Deguchi, T., Hashimoto, T., Imai, M., Miyawaki, S., & Takano-Yamamoto, T. (2007). Need for training sessions for orthodontists in the use of the American Board of Orthodontics objective grading system. American Journal of Orthodontics and Dentofacial Orthopedics, 132(4), 1–6.

30) Owens AM, Johal A. Near-end of treatment panoramic radiograph in the assessment of mesiodistal root angulation. Angle Orthodontics. 2008;78:475-81.

31) Palomo, J. M., Valiathan, M. and Hans, M. G. (2014) 3D Orthodontic Diagnosis and Treatment Planning, in Cone Beam Computed Tomography in Orthodontics: Indications, Insights, and Innovations (ed S. D. Kapila), John Wiley & Sons, Inc., Ames, USA.

32) Podesser et. al., Quantitation of Transverse Maxillary Dimensions Using Computed Tomography: A Methodological and Reproducibility Study. Eur J Orthod. 2004 Apr;26(2):209-15.

33) Proffit WR, Fields HW. Contemporary Orthodontics. 4th ed. Mosby; 2007.

34) Ricketts RM. Introducing Computerized Cephalometrics. Rocky Mountain Data Systems; 1969.

35) Shewinvanakitkul et al (2008), Using CBCT to Measure Buccolingual Inclination of Mandibular Canines and First Molars. Masters Thesis, Case Western Reserve University.

36) Shigefuji R, Motohashi N, Kuroda T. Longitudinal changes of molar dental compensation following orthognathic surgery in facial asymmetry patients. Jpn J Deform. 2001;11:11-20

37) Secchi A.G. & Wadenya R. Early Orthodontic Diagnosis and Correction of Transverse Skeletal Problems. New York State Dental Journal. Jan 2009; 75(1): 47-50.

38) Stoelinga, P. J., & Leenen, R. J. (1981). Class II anomalies: a coordinated approach to the management of skeletal, dental, and soft tissue problems. Journal of Oral Surgery (American Dental Association : 1965), 39(11), 827–841.

39) Streit, L., Palomo, J.M., Narendran, S., et al. (2012) The CWRU transverse analysis: developing norms. Master's thesis, Case Western Reserve University

40) Tamburrino, R. K., Boucher, D. M. D. N. S., Vanarsdall, D. D. S. R. L., & Secchi, A. (2010). Roth Williams Legacy Fund Donors The Transverse Dimension : Diagnosis and Relevance to Functional Occlusion, (September), 1–6.

41) Tong, H., Enciso, R., Van Elslande, D., Major, P. W., & Sameshima, G. T. (2012). A new method to measure mesiodistal angulation and faciolingual inclination of each whole tooth with volumetric cone-beam computed tomography images. American Journal of Orthodontics and Dentofacial Orthopedics, 142(1), 133–143.

42) Tyan, S., Park, H.-S., Janchivdorj, M., Han, S.-H., Kim, S.-J., & Ahn, H.-W. (2015). Three-dimensional analysis of molar compensation in patients with facial asymmetry and mandibular prognathism. The Angle Orthodontist, (March), 150720064124003.

43) Vanarsdall, R. L., Secchi, A. G., Chung, C. H., & Katz, S. H. (2004). Mandibular basal structure response to lip bumper treatment in the transverse dimension. Angle Orthodontist, 74(4), 473–479.

44) Wei Shy et al. Cranial Width Dimensions. Angle Orthodontics. 1970; 40: 141-147.

45) Wu, R., Palomo, J.M., Landers, M., et al. (2012 Anatomically based cranial landmarks for three-dimensional superimposition. Master's thesis, Case Western Reserve University.

Table I: Descriptive Summaries of CBCT subjects

Age

Parameter	Minimum	Maximum	Mean	Std. Deviation
Age	10.75	54.50	15.0299	5.57025

Gender

Gender	N	Percent (%)
Male	45	45.0
Female	55	55.0

Cephalic and Facial Index

Parameter	Minimum	Maximum	Mean	Std. Deviation
CranialWidth	115.5	144.0	130.634	6.2806
CranialLength	152.2	177.5	164.708	4.9817
CranialIndex	.72	.89	.7937	.04301
BiZyg	103.3	138.0	118.107	6.0509
NaGn	92.9	131.9	107.640	7.7339
FacialIndex	.77	1.13	.9125	.06968

Cranial Fossa Measurements

Parameter	Minimum	Maximum	Mean	Std. Deviation
BiOptCan	17.0	27.5	21.724	1.9993
AntCranBase	81.6	108.9	93.135	4.1881
BiForOvale	44.9	66.5	54.570	3.4969
BiCarCan	24.8	39.0	31.348	2.5280
BiJugularFor	57.4	86.9	72.186	5.2624
IntAudCan	41.7	63.8	52.092	4.5621

Maxillary and Mandibular Measurements

Parameter	Minimum	Maximum	Mean	Std. Deviation
BiGreatPal	27.00	42.40	32.3340	2.48447
BiJugale	55.20	82.80	65.1940	4.27600
BiLingula	63.80	87.70	74.3340	4.28986
BiMental	37.60	53.50	45.3430	2.92247

Maxillary and Mandibular Molar Measurements

Parameter	Minimum	Maximum	Mean	Std. Deviation
UL6angle	81.4	115.9	103.824	5.2438
UR6angle	79.5	117.4	103.974	5.2818
AVG_U6	81.8	115.5	103.925	4.8821
LL6angle	64.5	97.5	75.837	5.3371
LR6angle	62.4	100.5	77.143	5.4213
AVG_L6	65.6	89.6	76.515	4.9724

Table II: Sample Stratification

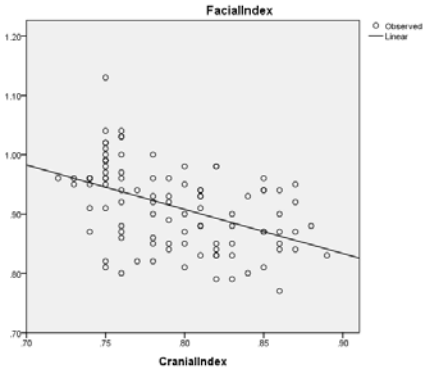
Cranial Index	Frequency	Facial Index	Frequency
Dolichocephalic	38	Euryprosopic	20
Mesocephalic	30	Mesoprosopic	21
Brachycephalic	32	Leptoprosopic	59
Total	100	Total	100

Table III: Association between Cranial Index and Facial Index

a) **Correlations**

CranialIndex vs FacialIndex	
Spearman's rho	-.489
Sig. (2-tailed)	.000
N	100

b) **Scatter Plot**



c)FacialIndexModel

Coefficient	B	t	Sig.
Constant	1.505	13.037	0.000
CranialIndex	-0.747	-5.140	0.000

R=0.461 R^2=0.212 p=0.000

Table IV: Association between Cranial Index to Molar Angulation

ANOVA		F	Sig.
UL6angle	Dolichocephalic	1.583	.211
	Mesocephalic		
	Brachycephalic		
UR6angle	Dolichocephalic	.031	.970
	Mesocephalic		
	Brachycephalic		
LL6angle	Dolichocephalic	.060	.942
	Mesocephalic		
	Brachycephalic		
LR6angle	Dolichocephalic	.762	.469
	Mesocephalic		
	Brachycephalic		

Table V: Association between Facial Index to Molar Angulation

ANOVA		F	Sig.
UL6angle	Euryprosopic	.245	.783
	Mesoprosopic		
	Leptoprosopic		
UR6angle	Euryprosopic	1.256	.289
	Mesoprosopic		
	Leptoprosopic		
LL6angle	Euryprosopic	1.061	.350
	Mesoprosopic		
	Leptoprosopic		
LR6angle	Euryprosopic	1.093	.339
	Mesoprosopic		
	Leptoprosopic		

Table VI: Parameter Correlations

Pearson Correlation	P<0.01	P<0.05
Age	NaGn, BiJugularFor	FacialIndex, LL6angle, BiGreatPal
CranialWidth	CranialIndex, BiZyg, FacialIndex, BiOptCan, BiForOvale, BijugualFor, AntCranBase, BiCarCan, IntAudCan, BiMental, BiLingula, BiJugale	NaGn, UL6angle
CranialLength	CranialIndex	AntCranBase
CranialIndex	CranialWidth, CranialLength, NaGn, FacialIndex, BiOptCan, BiForOvale, BiJugularFor, BiCarCan, InAudCan, BiJugale	BiLingula
BiZyg	CranialWidth, CranialIndex, NaGn, FacialIndex, BiOptCan, BiForOvale, BiJugularFor, AntCranBase, BiCarCan, IntAud, BiMental, BiLingula, BiGreatPal, BiJugale	UR6angle
NaGn	Age, BiZyg, FacialIndex,	CranialWidth, CranialIndex, BiLingula
FacialIndex	CranialWidth, CranialIndex, BiZyg, NaGn, BiOptCan, BiCarCan, BiLingula, BiJugale	Age, BiForOvale, BiJugularFor
BiOptCan	CranialWidth, CranialIndex, FacialIndex, BiZyg, BiForOvale, AntCranBase, BiCarCan, BiLingula, BiGreatPal, BiJugale	
AntCranBase	CranialWidth, BiZyg, BiOptCan, BiForOvale, BiCarCan, BiLingula	CranialLength, BiGreatPal
BiForOvale	CranialWidth, CranialIndex, BiZyg, BiOptCan, BiJugularFor, AntCranBase, BiCarCan, IntAudCan, BiMental, BiLingual	FacialIndex
BiCarCan	CranialWidth, CranialIndex, BiZyg, FacialIndex, BiOptCan, BiForOvale, BiJugularFor, AntCranBase, IntAudCan, BiMental, BiLingula, BiGreatPal, BiJugale	
BiJugalarFor	BiForOvale, BiCarCan, IntAudCan, BiLingula, CranialIndex	LR6, FacialIndex
IntAudCan	CranialWidth, CranialIndex, BiZyg, BiForOvale, BiJugularFor, BiCarCan, UL6angle, UR6angle, BiMental, BiLingula	
UL6angle	CranialWidth, IntAudCan, UR6angle	LL6angle, BiMental
UR6angle	IntAudCan, UL6angle, LL6angle, Bimental, BiLingula	BiZyg, BiJugale
LL6angle	Age, UR6angle, LR6angle	UL6angle
LR6angle	LL6angle, BiGreatPal, BiJugale	BiJugularFor
BiMental	CranialWidth, BiZyg, BiForOvale, BiCarCan, IntAudCan, UR6angle, BiLingula, BiJugale	UL6angle, BiGreatPal
BiLingula	CranialWidth, BiZyg, FacialIndex, BiOptCan, AntCranBase, BiForOvale, BiCarCan, BiJugularFor, IntAudCan, UR6angle, BiMental, BiJugale	CranialIndex, NaGN,BiGreatPal
BiGreatPal	BiZyg, BiOptCan, BiCarCan, LR6angle, BiJugale	Age, AntCranBase,BiMental, BiLingula
BiJugale	CranialWidth, CranialIndex, BiZyg, FacialIndex, BiOptCan, AntCranBase, BiCarCan, LR6angle, BiMental, BiLingula, BiGreatPal	UR6angle

Table VII: Maxillary Molar Angulation Regression Models

a) UR6 Model

Coefficient	B	t	Sig.
Constant	31.514	1.719	0.089
Age	0.074	0.950	0.345
BiOptCan	0.298	1.327	0.188
AntCranBase	0.065	0.579	0.564
BiForOvale	0.076	0.542	0.589
BiCarCan	0.029	0.167	0.868
BiJugularFor	-0.123	-1.343	0.183
IntAudCan	0.133	1.235	0.220
UL6angle	0.626	8.208	0.000
LL6angle	-0.345	-3.181	0.002
LR6angle	0.095	0.815	0.418
BiMental	0.145	0.898	0.372
BiLingula	0.179	1.383	0.170
BiGreatPal	-0.081	-0.444	0.658
BiJugale	0.251	2.120	0.037
CranialWidth	-0.056	-0.663	0.509
CranialLength	0.062	0.796	0.429
BiZyg	-0.203	-1.886	0.063
NaGn	-0.026	-0.463	0.645

R=0.808 R^2=0.653 p=0.000 .

b)UL6 Model

Coefficient	B	t	Sig.
Constant	29.545	1.490	0.140
Age	-0.090	-1.070	0.288
BiOptCan	-0.163	-0.668	0.506
AntCranBase	-0.189	-1.589	0.116
BiForOvale	-0.104	-0.692	0.491
BiCarCan	0.125	0.664	0.508
BiJugularFor	0.021	0.210	0.834
IntAudCan	0.088	0.757	0.451
UR6angle	0.726	8.208	0.000
LL6angle	0.075	0.608	0.545
LR6angle	0.031	0.244	0.807
BiMental	-0.013	-0.073	0.942
BiLingula	-0.113	-0.807	0.422
BiGreatPal	-0.107	-0.547	0.586
BiJugale	-0.217	-1.685	0.096
CranialWidth	0.064	0.707	0.482
CranialLength	-0.017	-0.208	0.836
BiZyg	0.228	1.966	0.053
NaGn	0.029	0.474	0.637

R=0.769 R^2=0.592 p=0.000 .

c)AVG_U6 Model

Coefficient	B	t	Sig.	Bonferroni Adjustment
Constant	98.292	4.462	0.000	*0.000
Age	-0.047	-0.462	0.645	10.32
BiOptCan	0.144	0.493	0.623	9.968
AntCranBase	-0.203	-1.407	0.163	2.608
BiForOvale	-0.068	-0.371	0.712	11.392
BiCarCan	0.200	0.878	0.383	6.128
BiJugularFor	-0.159	-1.327	0.188	3.008
IntAudCan	0.278	2.062	0.042	0.672
AVG_L6	-0.272	-2.369	0.020	0.320
BiMental	0.318	1.542	0.127	2.032
BiLingula	0.037	0.223	0.824	13.184
BiGreatPal	-0.097	-0.436	0.664	10.624
BiJugale	0.120	0.779	0.438	7.008
CranialWidth	0.003	0.027	0.979	15.664
CranialLength	0.052	0.511	0.611	9.776
BiZyg	0.054	0.382	0.703	11.248
NaGn	0.002	0.024	0.981	15.696

R=0.530 R^2=0.281 p=0.020 *Significant .

Table VIII: Mandibular Molar Angulation Regression Models

a) LL6 Model

Coefficient	B	t	Sig.
Constant	35.421	2.016	0.047
Age	0.117	1.554	0.124
BiOptCan	0.449	2.104	0.038
AntCranBase	0.118	1.100	0.275
BiForOvale	0.090	0.663	0.509
BiCarCan	0.118	0.701	0.485
BiJugularFor	-0.110	-1.247	0.216
IntAudCan	0.289	2.891	0.005
UR6angle	-0.321	-3.181	0.002
UL6angle	0.060	0.608	0.545
LR6angle	0.688	8.358	0.000
BiMental	-0.226	-1.467	0.146
BiLingula	0.200	1.612	0.111
BiGreatPal	-0.425	-2.507	0.014
BiJugale	0.099	0.843	0.402
CranialWidth	-0.036	-0.442	0.660
CranialLength	0.043	0.569	0.571
BiZyg	-0.217	-2.093	0.040
NaGn	0.021	0.380	0.705

$R=0.827$ $R^2=0.684$ $p=0.000$

b)LR6 Model

Coefficient	B	t	Sig.
Constant	22.104	1.254	0.213
Age	-0.047	-0.631	0.530
BiOptCan	-0.115	-0.530	0.598
AntCranBase	0.027	0.255	0.799
BiForOvale	-0.079	-0.590	0.557
BiCarCan	-0.122	-0.732	0.466
BiJugularFor	-0.011	-0.127	0.899
IntAudCan	-0.156	-1.521	0.132
UR6angle	0.086	0.815	0.418
UL6angle	0.024	0.244	0.807
LL6angle	0.673	8.358	0.000
BiMental	0.196	1.284	0.203
BiLingula	-0.252	-2.080	0.041
BiGreatPal	0.602	3.750	0.000
BiJugale	0.240	2.123	0.037
CranialWidth	-0.038	-0.477	0.635
CranialLength	-0.089	-1.202	0.233
BiZyg	0.016	0.150	0.881
NaGn	0.026	0.473	0.638

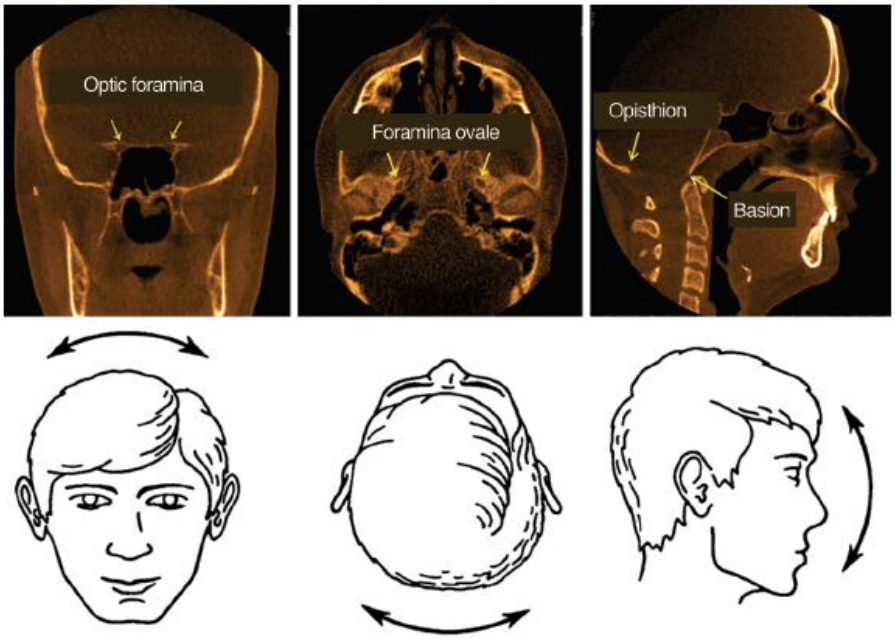
$R=0.837$ $R^2=0.701$ $p=0.000$.

c)AVG_L6 Model

Coefficient	B	t	Sig.	Bonferroni Adjustment
Constant	94.715	4.684	0.000	*0.000
Age	0.091	0.964	0.338	5.408
BiOptCan	0.488	1.828	0.071	1.136
AntCranBase	0.204	1.524	0.131	2.096
BiForOvale	-0.010	-0.058	0.954	15.264
BiCarCan	0.015	0.070	0.944	15.104
BiJugularFor	-0.179	-1.625	0.108	1.728
IntAudCan	0.218	1.734	0.087	1.392
AVG_U6	-0.233	-2.369	0.020	0.32
BiMental	-0.082	-0.425	0.672	10.752
BiLingula	-0.127	-0.825	0.412	6.592
BiGreatPal	0.274	1.335	0.186	2.976
BiJugale	0.482	3.613	0.001	*0.016
CranialWidth	-0.104	-1.019	0.311	4.976
CranialLength	-0.088	-0.934	0.353	5.648
BiZyg	-0.268	-2.119	0.037	0.592
NaGn	0.087	1.262	0.210	3.360

R=0.636 R^2=0.404 p=0.000 *Significant .

Figure 1. Overall Orientation.



(Based on Wu et al. (2012); drawings courtesy of Robert W. Patricy)

Figure 2. Preliminary external landmark orientation.

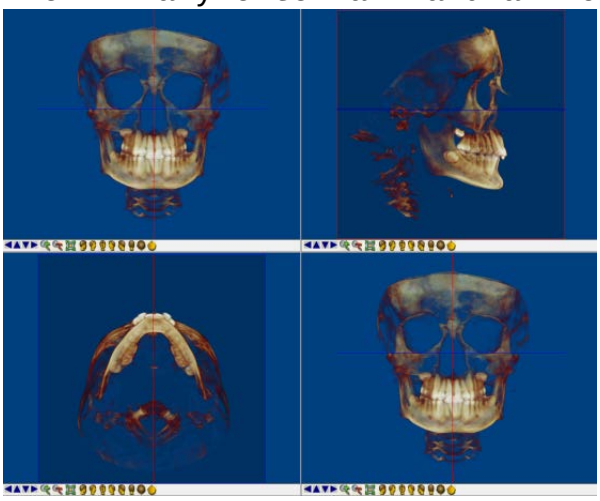
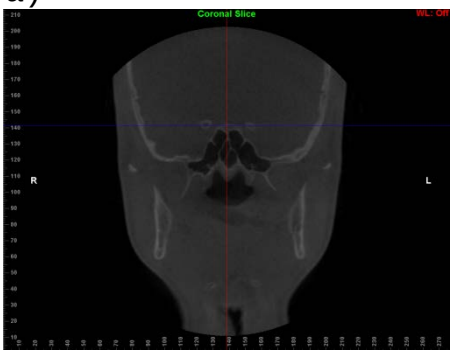
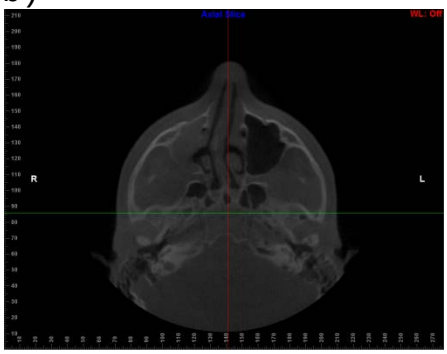


Figure 3. Orientation: a) Coronal b) Axial c) Sagittal

a)



b)



c)

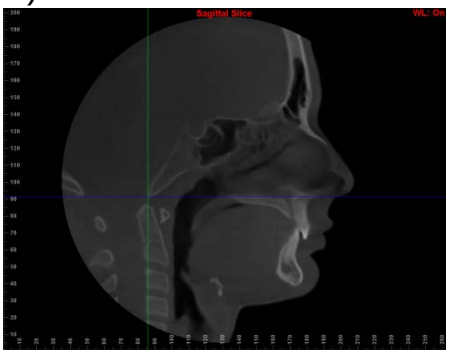


Figure 4. Cephalic Index: cranial width: cranial length

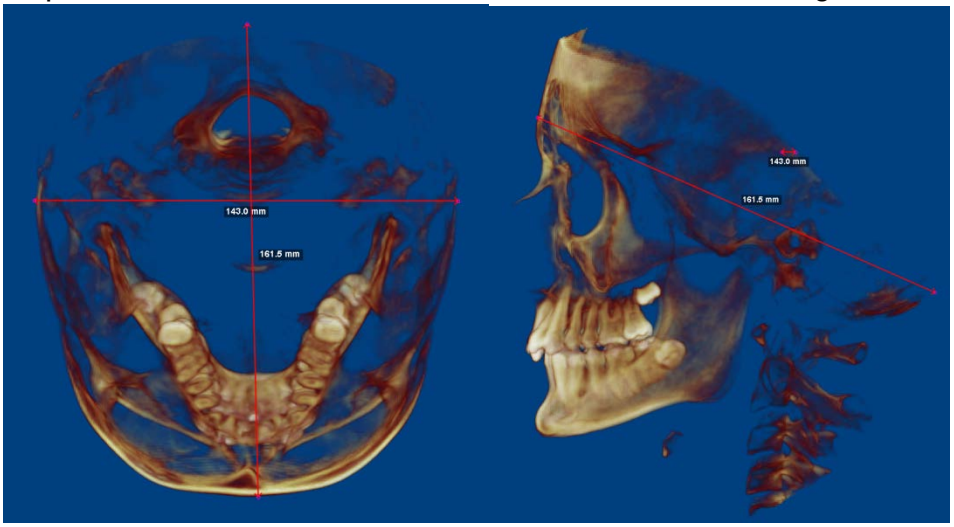


Figure 5. Facial Index: Facial height: zygomatic width

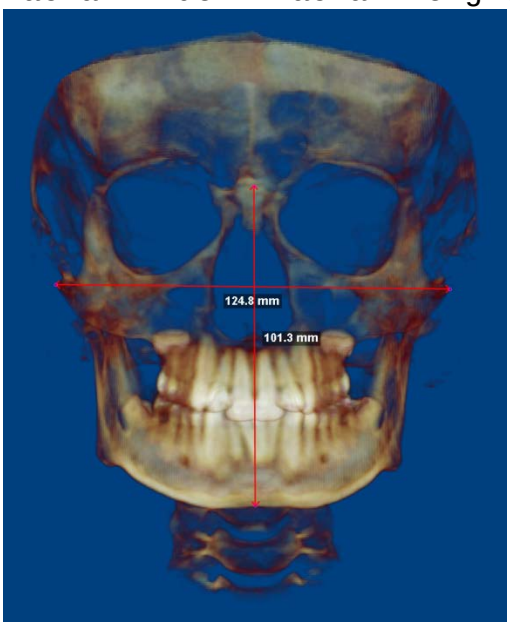
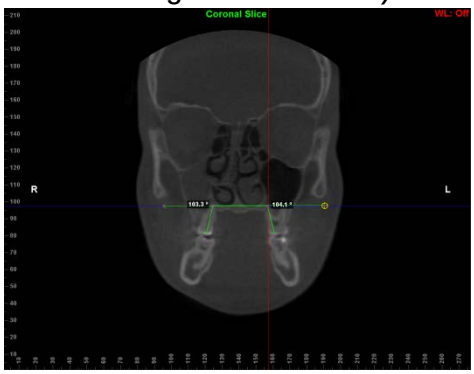


Figure 6. Molar Angulation: a) Maxillary b) Mandibular

a) 

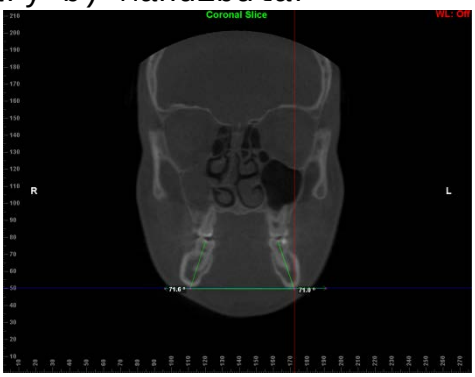
b) 

Figure 7. Maxilla: a) Jugale b) Greater Palatal Foramen

a) b)

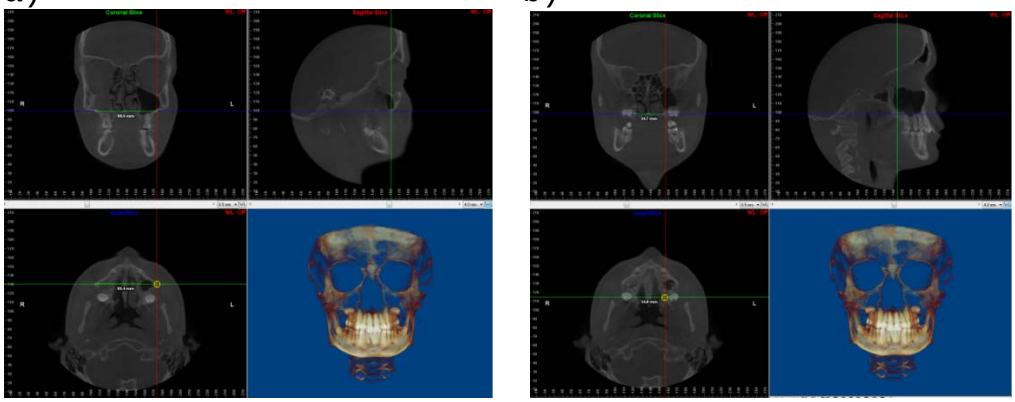


Figure 8. Mandible: a) Lingula b) Mental Foramen

a) b)

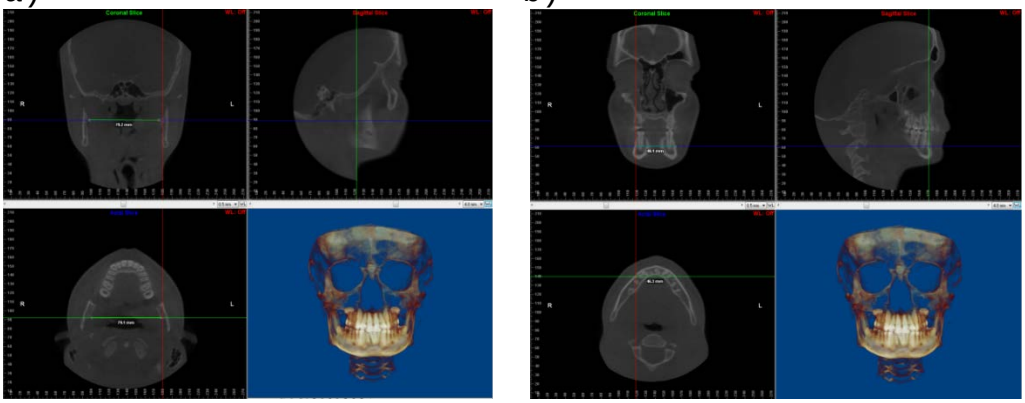


Figure 9. Anterior Cranial Fossa: a) Anterior Cranial Base b) Optic Canal

a) b)

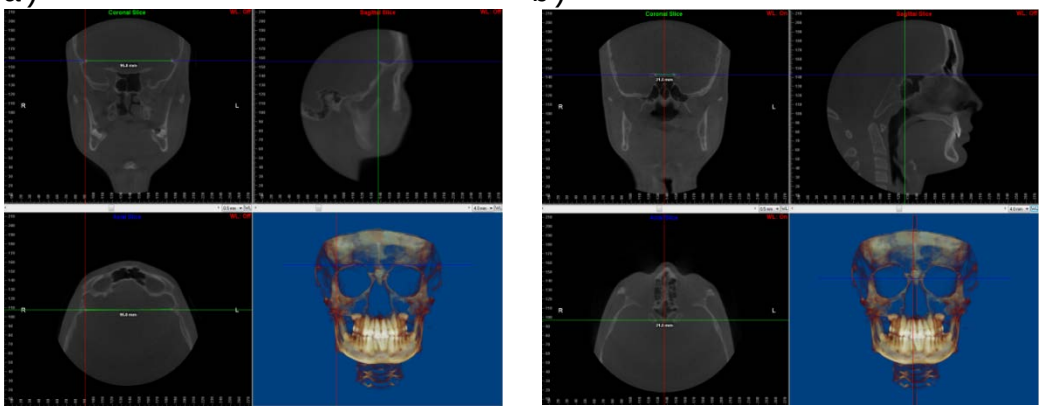


Figure 10. Middle Cranial Fossa: a) Carotid Canal b) Foramen Ovale

a) b)

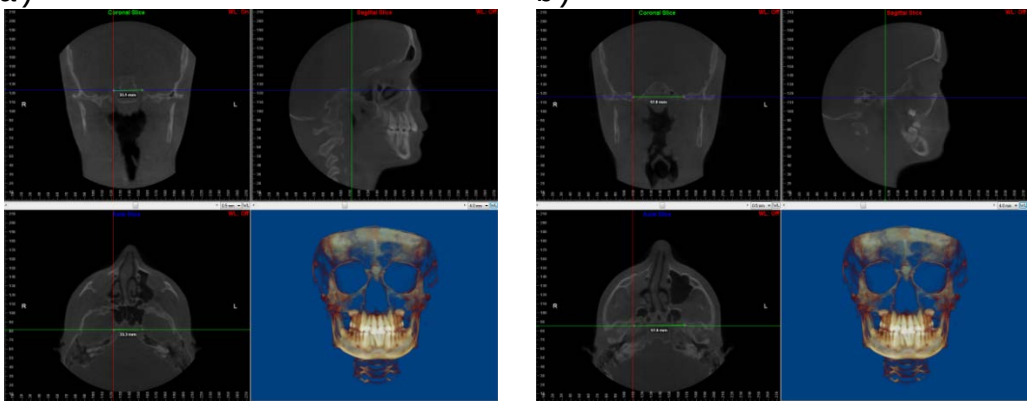


Figure 11. Posterior Cranial Fossa: a)Jugular Foramen/Fossa b) Internal Auditory Meatus

a) b)

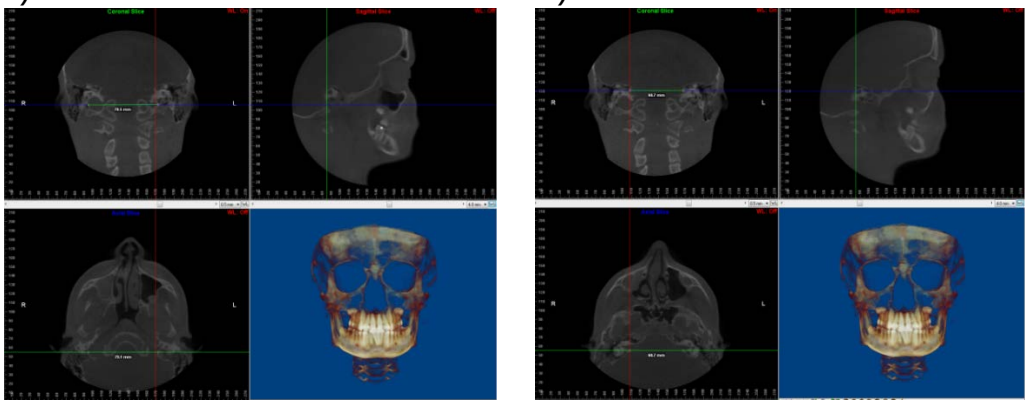


Figure 12. Histogram distribution a) Cranial Index b) Facial Index

a) b)

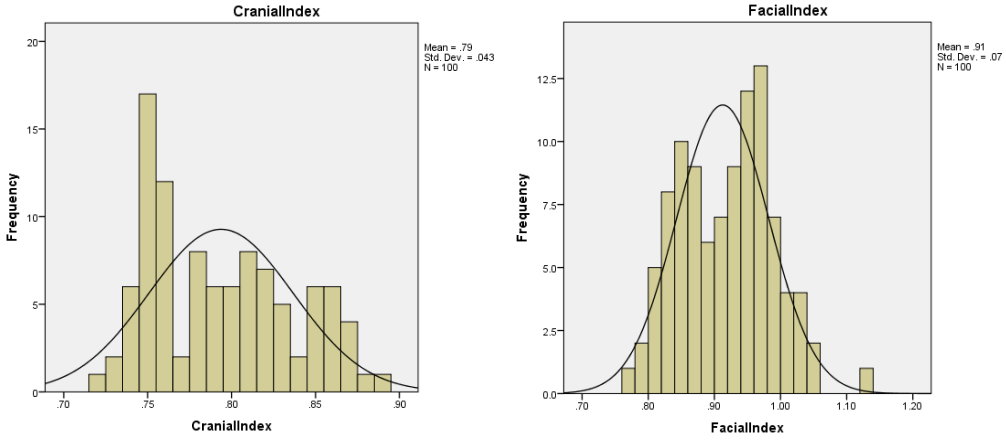


Figure 13. Histogram distribution age

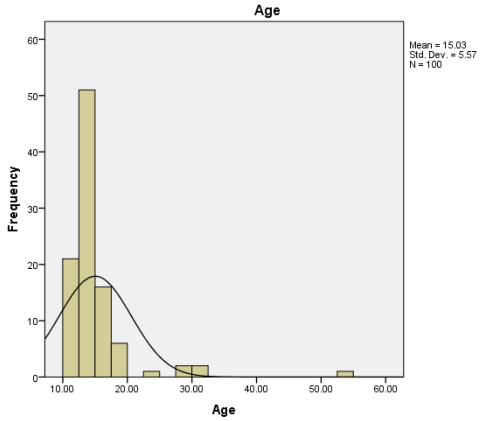


Figure 14. Histogram distributions of anterior cranial fossa parameters

a) b)

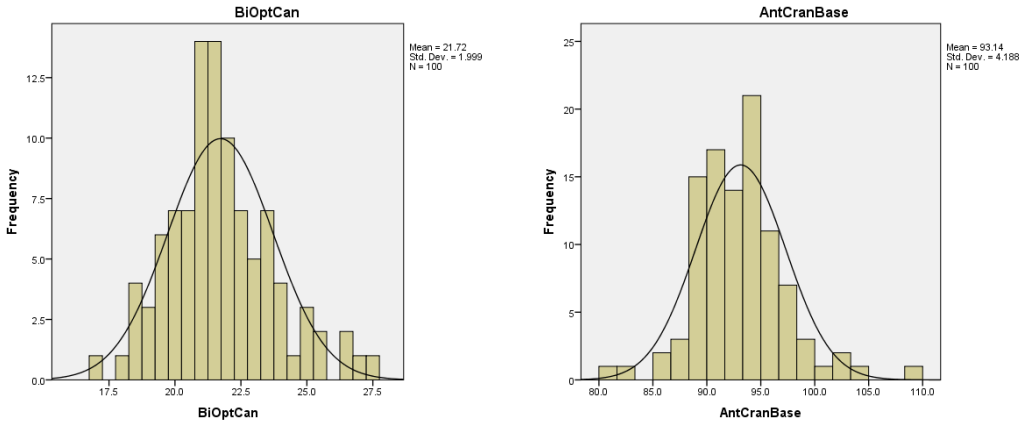


Figure 15. Histogram distributions of middle cranial fossa parameters

a) b)

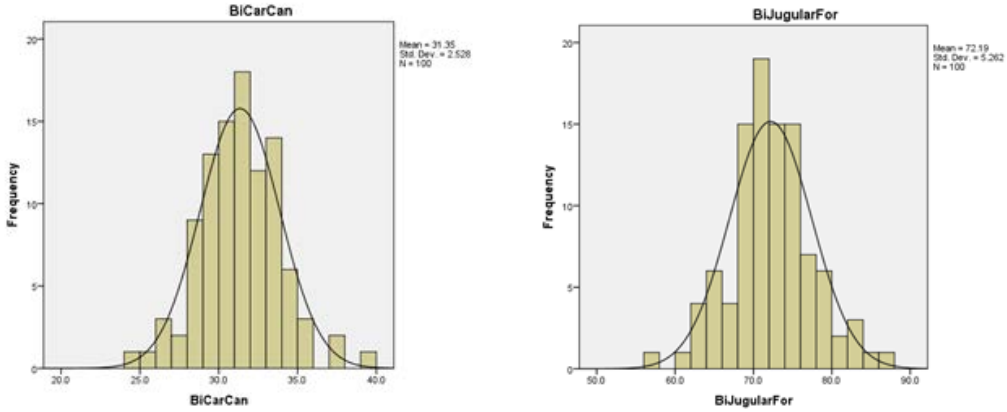


Figure 16. Histogram distributions of posterior cranial fossa parameters

a) b)

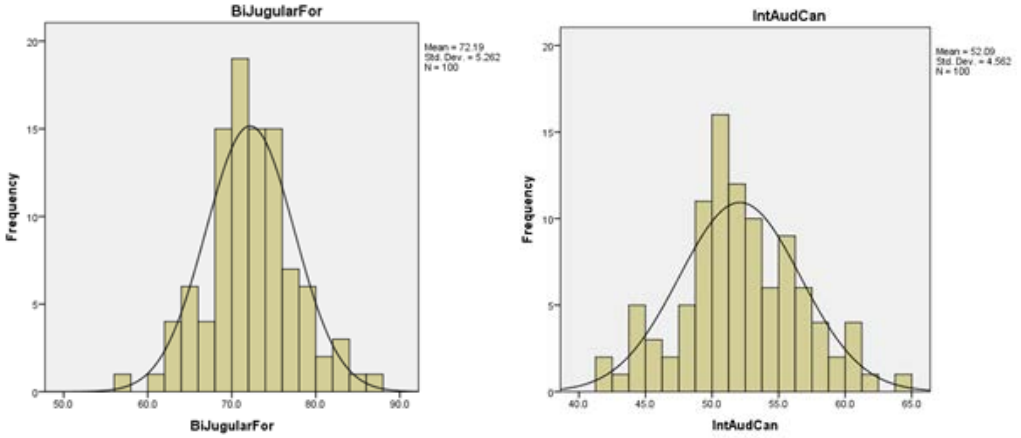


Figure 17. Histogram distributions maxillary parameters

a) b)

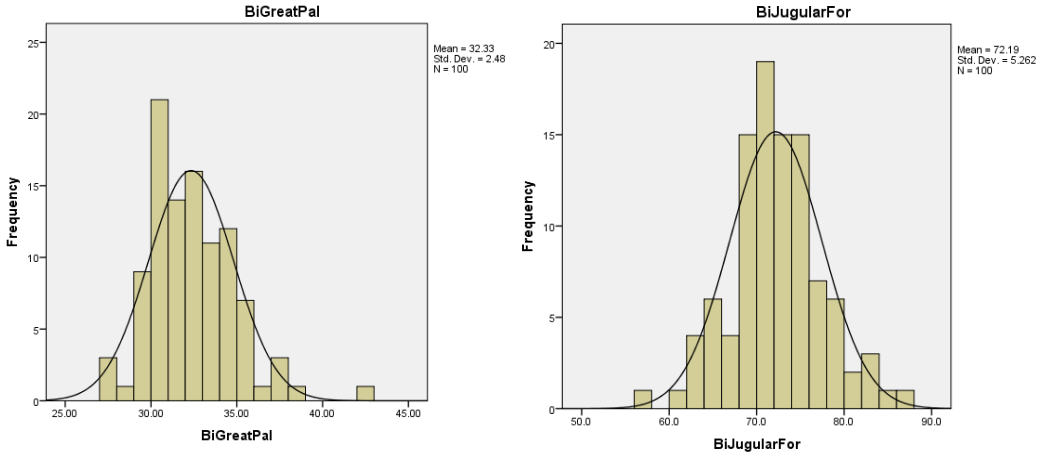


Figure 18. Histogram distributions mandibular parameters

a) b)

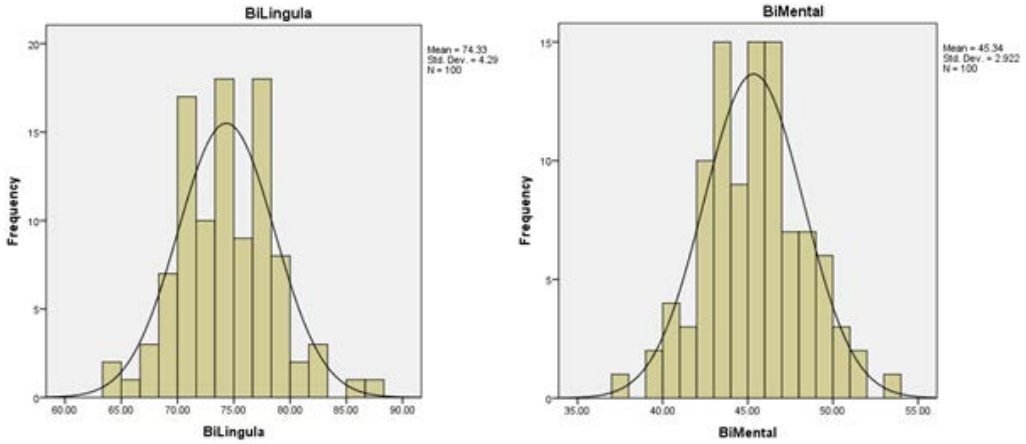


Figure 19. Histogram distributions of molar angulation parameters

a) b)

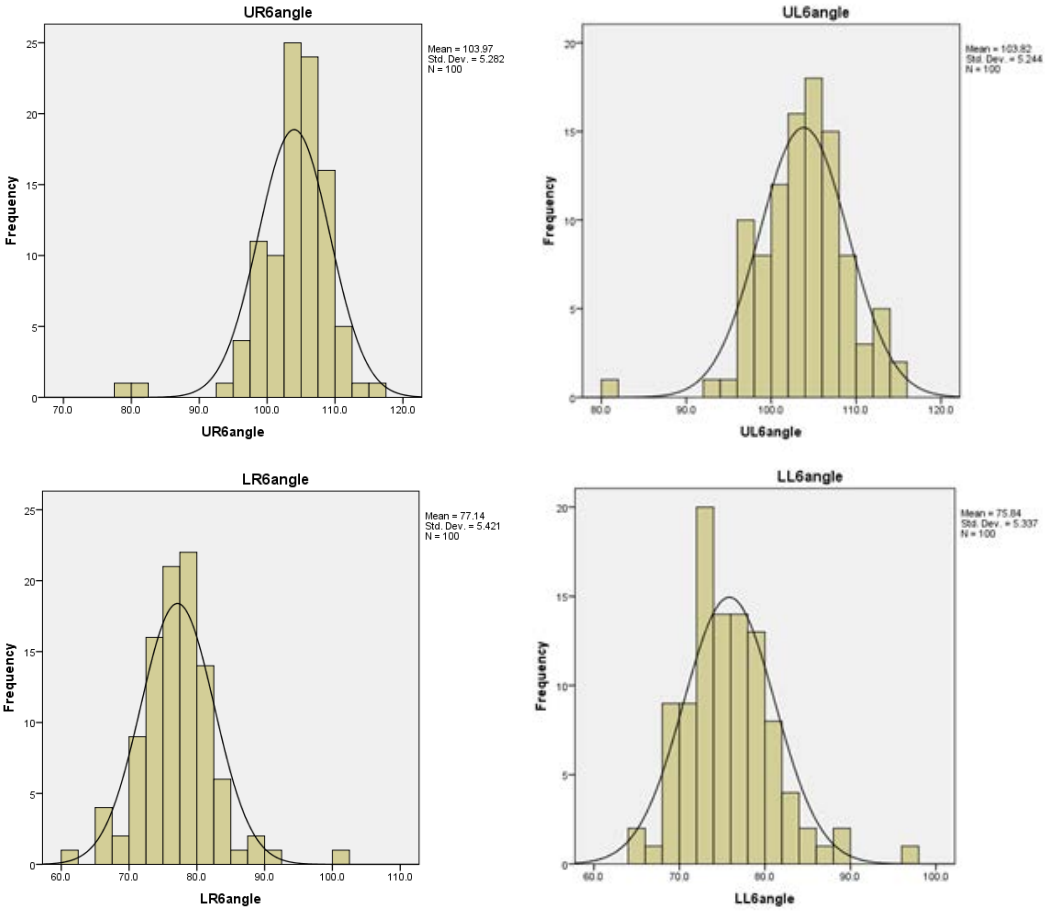


Figure 20. Histogram distributions average maxillary and mandibular molar angulations

a) b)

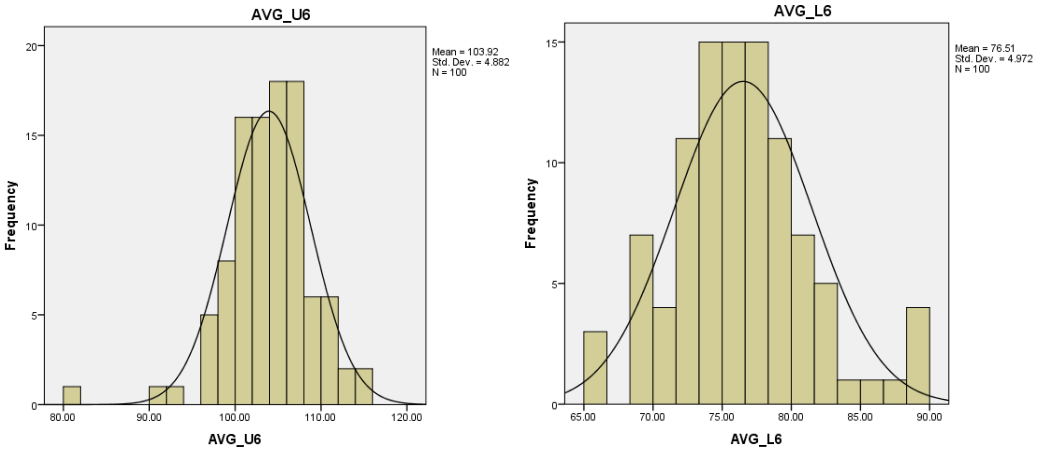
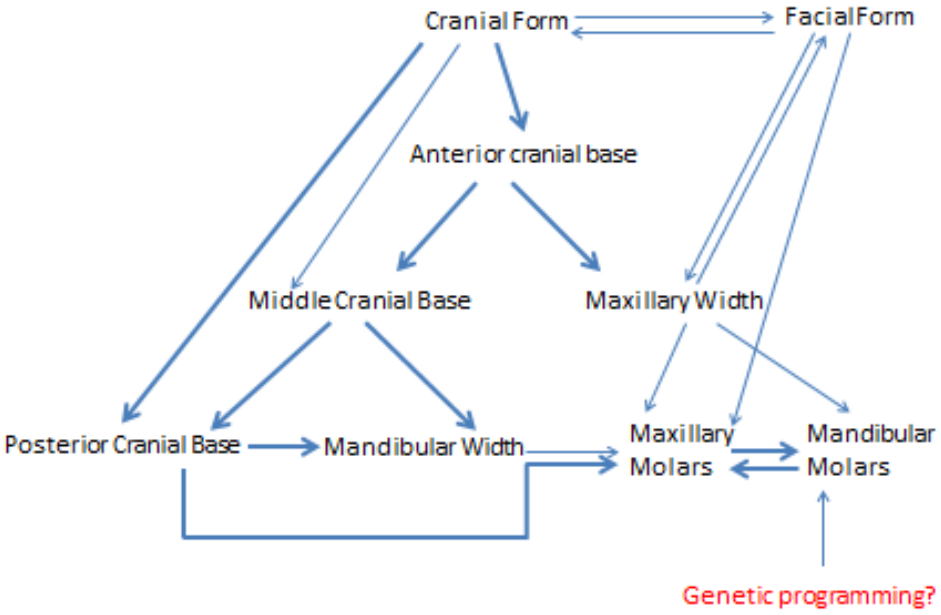


Figure 21. Growth Theory of Dental Compensation Flow Chart



APPENDIX 1
IRB Approval

CASE WESTERN RESERVE UNIVERSITY EST. 1826

NOTICE OF EXEMPTION #4

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

CWRU IRB Protocol Number:	**IRB-2015-1354**
Protocol Title:	***The Relationship between the Cranial Base to Dental Compensation in the Transverse Dimension***
Responsible Investigator (RI):	**Manish Valiathan**
Co-Investigator (CI):	**Ali Syed, Amir Aminoshariae, Juan Martin Palomo, Manish Valiathan**
RI Department:	**Case Western Reserve University IBC and SBER IRB - DEN - Orthodontics**
Exemption Date:	**12/02/2015**

This protocol is exempt under the #4 category because this involves *EXISTING RETROSPECTIVE DE-IDENTIFIED* data. Prospective data is NOT included in this exemption. If you intend to collect prospective data for this study, then this study might not be eligible for an exemption and you must contact the Institutional Review Board (IRB) office as soon as possible.

De-identified pre-existing data collected **after 12/02/2015** are NOT covered by this exemption.

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

PLEASE NOTE THAT THIS ONLY APPLIES TO EXISTING DATA.

IF YOU WISH TO CHANGE THIS EXEMPTED PROTOCOL IN ANY WAY, YOU MUST SUBMIT AN ADDENDUM REQUEST AND WAIT FOR IRB APPROVAL PRIOR TO IMPLEMENTING ANY PROTOCOL CHANGE.

Any changes to the protocol that put it under the purview of the CWRU IRB would require a formal application to, and approval of, the CWRU IRB prior to implementation of the change. Contact the CWRU IRB office for further assistance.

APPENDIX 2
Informed Consent

Department of Orthodontics
Imaging Informed Consent / Authorization Form

PLEASE READ CAREFULLY

Based on Clinical Examination, we, Case Western Reserve University Department of Orthodontics (Case Ortho), are recommending a thorough diagnosis and treatment plan. In order to accomplish this important preliminary step, with your consent, we will need radiographic records that may include Cone Beam Computed Tomography (CBCT) of the Oro-Facial Complex (head and teeth).

Previously, we and most other orthodontists used panoramic and cephalometric radiographs (x-rays), which are two dimensional (2D) images and frequently needed supplementation for specific areas or were undiagnostic for other areas.

Over the past several years, the use of 3D CBCT has become feasible because of reduced radiation exposure and greater availability. These images allow the healthcare professional to obtain a 360 degree/3D image series and therefore a more complete analysis. We at Case orthodontics believe that before beginning an important healthcare initiative such as orthodontic care, obtaining the best available, technologically advanced diagnostics are of fundamental importance to make sure that treatment is based on a sound foundation.

Because it is always the patient's decision after informed consent, we feel that patients should be given all relevant information before consenting to diagnostics and/or treatment. In this regard, please understand that 2D technology involves less radiation than 3D CBCT. The specific exposure varies with the equipment used, the areas of imaging, and the personal protective equipment used. We offer all imaging through the most advanced equipment. Our CBCT has been modified in order to provide less radiation exposure than its commercially available version. All protective equipment is used and the equipment is regularly maintained and evaluated to ensure patient protection.

Once the 3D CBCT is finished, we receive the imaging series and review it for the information relevant to orthodontics, as well as for any other information that is apparent to us. We at Case Ortho are not radiologists, we are orthodontists. If we observe an area that should be further evaluated, you will be notified and a radiologist or other specialist can be consulted. However, some patients prefer that a radiologist review the image series. **The current cost for that service is $75.**

I prefer that a radiologist reviews my CBCT: Yes:_____ (Initials) No:_____ (Initials)

I (Patient or Patient's legal representative) acknowledge that all of my questions have been answered, and that Case Ortho has explained the reason for the diagnostics, the alternative diagnostics, the potential complications of the recommended and alternative diagnostics and of not having the 3D CBCT imaging, and I give my consent for authorized personnel of the Craniofacial Imaging Center (CIC) to perform diagnostic volumetric imaging (x-ray) services.

I understand that this release allows the CIC unrestricted use of diagnostic data and treatment records for teaching, demonstration and/or scientific publications, and there will be no compensation for the use of such records. I also understand that my personal information will be kept private and protected according to HIPAA standards.

I accept full financial responsibilities for all procedures done at the CIC, unless prohibited by law. To the extent permitted by law, I give my consent to the CIC for their use and disclosure of my protected health information to carry out payment activities in connection with this claim. I also understand that there is a $25.00 fee for any returned checks.

I understand that I may revoke this authorization at any time by written notice to Case Western Reserve University ("Case") Privacy Official, at Case University, at 10900 Euclid Avenue, Cleveland, Ohio 44106. I also understand that if I revoke this authorization, the revocation will not have any effect on actions taken by Case before Case received the revocation. I also understand that more information regarding revocation of this authorization may be covered in Case's Notice of Privacy Practices.

Date	Signature of Individual or Guardian or Individual's Legal Representative.	Printed Name

APPENDIX 3

Key

Age	Age (years)
CranialWidth	Width of cranium (mm)
CranialLength	Length of cranium (mm)
CranialIndex	Width of cranium / Length of cranium x 100
BiZyg	Zygomatic interdistance (mm)
NaGn	Nasion to Gnathion (mm)
FacialIndex	Zygomatic width / Nasion to Gnathion x 100
BiOptCan	Optical canal interdistance (mm)
AntCranBase	Anterior cranial base point interdistance (mm)
BiForOvale	Foramen ovale interdistance (mm)
BiCarCan	Carotid canal interdistance (mm)
BiJugularFor	Jugular foramen/fossa interdistance (mm)
IntAudCan	Internal auditory canal interdistance (mm)
UL6angle	Maxillary right first molar angle (°)
UR6angle	Maxillary left first molar angle (°)
AVG_U6angle	Mean maxillary first molar angle (°)
LL6angle	Mandibular left first molar angle (°)
LR6angle	Mandibular right first molar angle (°)
AVG_L6angle	Mean mandibular first molar angle (°)
BiMental	Mental foramen interdistance (mm)
BiLingula	Lingual interdistance (mm)
BiGreatPal	Greater palatal foramen interdistance (mm)
BiJugale	Jugale point interdistance (mm)

APPENDIX 4
Raw Data

#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gender (M=0, F=1)	1	1	0	0	1	1	0	0	1	1	0	1	0	0	0
Age	18	16	11.25	13.75	11.08	14.75	15.33	29	14.33	12.5	13	18.92	12.17	11.33	15.25
cranial width	133.6	125.3	140.6	137.6	134.1	139.2	143.6	140.4	134.6	129.6	138.9	134.6	132.7	133.7	136.3
cranial length	163.1	166.1	168.7	174.3	167.1	173.3	164.6	162.2	161.7	163.7	164.3	173.4	165.0	168.3	156.4
cranial index	**0.82**	**0.75**	**0.83**	**0.79**	**0.80**	**0.80**	**0.87**	**0.87**	**0.83**	**0.79**	**0.85**	**0.78**	**0.80**	**0.79**	**0.87**
zyg-zyg	126.6	120.6	123.9	124.3	115.7	122.7	124.8	138	124.3	115.7	124.8	119.5	116.9	110.8	118.6
N-Gn	100.1	115.7	104.7	106.1	94	104.7	119	126.5	103.4	103.4	101.3	119.6	105	102.3	103
facial index	**0.79**	**0.96**	**0.85**	**0.85**	**0.81**	**0.85**	**0.95**	**0.92**	**0.83**	**0.89**	**0.81**	**1.00**	**0.90**	**0.92**	**0.87**
bioptic canal	25.1	24	22.3	21.1	20.9	22.9	22.1	23.5	23.2	20.9	21.5	21.9	20.4	19	22.5
biforamen ovale	59	46.9	58.4	57.4	54.4	55.4	66.5	59.9	57.5	53.6	57.7	53.7	51.5	53.4	55.4
bijugalar foramen	76.8	65.6	79.1	76.1	70.6	68	78.9	69.1	73	75.7	80.8	75.2	73.8	75.1	73.8
anterior cranial base	89.1	93.8	95.8	97.8	91.6	92.8	102.3	96.8	95.9	87.2	95.8	94.4	88.8	94.2	91.5
carotid canal	33.1	30.4	33.7	34.2	29.2	33.4	31.8	32.5	34.8	27.5	33.1	30.8	33.3	31.9	35.6
internal auditory canal	54.9	42.9	61	57.6	52.6	55.5	62	59.9	53.6	46.3	60.9	50.3	57.3	51.5	60.6
UL6 angle	105.6	103.9	106.5	102.1	113.6	100.7	115.9	114.3	106.3	111.7	107.4	108.9	113.9	113.2	113.1
UR6 angle	104.7	110.7	110.2	106.7	117.4	102.8	113.4	109.6	106.2	108.6	107.8	102.8	107	110.7	109.3
LL6 angle	70.8	78.7	69.8	76.1	69.9	75.4	66.8	82.2	72.4	70.1	70.7	71.1	72.7	74.3	78
LR6 angle	74.6	100.5	67	73.8	62.4	73.7	71.2	82.2	74.1	70.3	71.6	74.2	75.6	78.7	84.9
Bimental	44.3	49.5	50.5	48.5	47.1	46	49.2	50.7	48.2	43.4	46.5	50.7	51	44.4	46.6
BiLingula	82.4	76.9	85.7	83.1	74.4	73.7	82.3	87.7	76.3	73.4	77.6	73.6	73.6	69.4	74.3
BiGreatPal	34	42.4	32.9	29.5	30.6	34.4	32.2	33.8	35.6	27	34.4	34.5	31.4	31.4	34.1
BiJugale	70.5	82.8	71.2	73.3	68.8	72	69	64.8	64.1	56.6	69.4	67	67.7	64.7	68

#	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Gender (M=0, F=1)	0	1	1	1	0	0	1	1	1	0	0	1	1	1	1
Age	13.75	17.5	12.5	12.42	16.75	12.75	13	12.25	15.58	12.92	14.17	16.08	13.5	13.08	10.75
cranial width	136.5	132.4	131.7	135.4	130.1	131.1	125.9	140.4	125.7	130.6	136.0	122.5	130.2	126.6	130.7
cranial length	168.9	163.8	173.8	165.3	159.9	167.8	167.4	157.1	166.1	172.2	171.7	157.7	165.6	160.4	152.2
cranial index	**0.81**	**0.81**	**0.76**	**0.82**	**0.81**	**0.78**	**0.75**	**0.89**	**0.76**	**0.76**	**0.79**	**0.78**	**0.79**	**0.79**	**0.86**
zyg-zyg	117	117.6	116	116.3	122.6	118.8	114.5	123.8	118.7	117	125	117.4	115.3	112.4	113.7
N-Gn	106.9	103.4	93.3	98.7	114.7	97.4	92.9	103	104.8	101.2	116.2	108.3	97.1	108	98.5
facial index	**0.91**	**0.88**	**0.80**	**0.85**	**0.94**	**0.82**	**0.81**	**0.83**	**0.88**	**0.86**	**0.93**	**0.92**	**0.84**	**0.96**	**0.87**
bioptic canal	20	20.8	19.6	22.3	20.8	26.3	18.7	21	19.7	22.9	21.7	21.3	23.6	21.5	22.7
biforamen ovale	50.1	53.9	53.9	51.6	47.1	51	52.5	55.8	52.1	56.5	53.3	51.1	55.4	56.4	54
bijugalar foramen	73.4	72.3	74.5	62.2	71	74.9	72.8	74.5	67	70.5	71.8	64	75	75.7	68.1
anterior cranial base	91.9	93.6	92.8	92.1	90	92.4	89.1	90.1	97.3	92.9	92.3	93.4	89.2	88.2	93.4
carotid canal	33.8	30.3	31.7	26.5	26.9	30.7	29.9	35.3	31.4	32.2	33	35.9	30.7	32.9	29.4
internal auditory canal	57.9	52.9	50.3	50.9	50.5	55.4	50.2	58.3	44.8	51.6	56.4	43.8	51.6	52.1	57
UL6 angle	108.2	108.4	104.7	102.3	104.9	106.5	101.9	107.7	100	103.8	111.9	108.6	101.2	103.3	110.9
UR6 angle	107.8	108.6	102.6	98.3	103.3	106.6	101.2	107	101.3	105.5	110.7	106.3	105.1	104.4	104.2
LL6 angle	76.5	76.3	77.1	75	75.3	78.4	77.2	73.4	75.6	76.2	75.2	74.1	69.3	79.5	79.7
LR6 angle	75.6	73.5	77.1	83.9	76.6	77.2	80	78.3	76.5	77.4	74.4	77.2	79.1	78.1	82.9
Bimental	43.4	41.6	44.4	39.7	43.8	45.5	41.7	51.7	43.1	48.7	49.7	45.3	45.3	42.9	45
BiLingula	68.8	70.2	74.7	67.5	76.2	73.7	70.8	77.7	71.3	74	80.3	71.7	66.2	63.8	70.9
BiGreatPal	30	29	32	31.7	30.6	33.7	31.4	30.4	29.5	27.2	31.2	33.2	34.1	30.9	34
BiJugale	66.1	64.4	63.5	64	66.2	70.3	64.5	72	67.2	67.3	66.1	68.2	65.3	65.9	65.4

#	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Gender (M=0, F=1)	1	1	1	0	0	1	1	1	1	0	1	0	0	0	0
Age	13.58	14	12	12	13.42	16.92	15	16.58	14	14	12.17	13.17	12.5	13.83	13
cranial width	138.8	130.9	136.0	130.8	134.3	128.6	126.4	130.7	139.2	126.2	136.0	139.0	132.5	137.9	132.9
cranial length	162.4	155.5	165.4	168.9	168.4	159.3	154.0	168.4	163.4	158.2	167.3	158.5	159.8	158.3	163.8
cranial index	**0.86**	**0.84**	**0.82**	**0.77**	**0.80**	**0.81**	**0.82**	**0.78**	**0.85**	**0.80**	**0.81**	**0.88**	**0.83**	**0.87**	**0.81**
zyg-zyg	117	111.8	108	121.9	113.7	115.6	109.8	131.7	110.9	119.8	118.6	117.9	115.6	129.9	125.2
N-Gn	105.6	104.1	106	99.7	107.5	107.8	107.2	112.8	106.2	117.4	104.8	103.7	104.1	108.7	117.6
facial index	**0.90**	**0.93**	**0.98**	**0.82**	**0.95**	**0.93**	**0.98**	**0.86**	**0.96**	**0.98**	**0.88**	**0.88**	**0.90**	**0.84**	**0.94**
bioptic canal	20.2	20.9	21.4	21.5	21.4	19.6	20.9	21.9	21.8	22.9	23.3	21.5	22.5	25.2	23.6
biforamen ovale	49.7	53	55.9	55.9	49.6	50.1	52.4	56.6	54.5	55.6	56.2	59.5	55.9	59.7	56.2
bijugalar foramen	63.5	77.3	72	74.1	69	64	70	72.3	76.6	73.4	78	83.7	74.2	83.1	68.1
anterior cranial base	96.8	91.4	86.5	90.7	96.5	90.1	90.9	93.8	91	89.9	96.1	94.6	90.2	91.5	90.7
carotid canal	30.9	29.9	31.1	31.5	30	30.6	28.2	30.6	30.5	28.6	33.1	32.4	24.8	37.7	29.8
internal auditory canal	54.8	52.8	50	47.3	49	49.7	49.9	58.6	63.8	55	57.1	60.9	48.1	53.1	51.8
UL6 angle	106	102.5	97.1	107.6	96.9	101.8	81.4	105.9	103	103.2	105.8	105	96.9	109.1	103.3
UR6 angle	108	103.5	99.4	103.2	99.8	101.6	82.1	104.5	106.1	103.2	105.8	105.3	99.1	107.2	100.3
LL6 angle	77.7	72.2	79.7	73	81.3	75.6	76.6	72.4	75.9	80.2	72	85.1	79.5	71.4	78.6
LR6 angle	80.9	74.6	78.9	75.4	80.4	80.7	78.3	72.8	76.8	80.8	72.2	81.3	75.9	75.9	78.3
Bimental	46.9	46.8	46.4	44.7	46.1	41.8	40.9	47.3	45.2	47.9	44	48.3	43.8	46.1	49.6
BiLingula	69	72	71	79.7	71.1	70	70.9	78.5	70.5	75.2	75.2	79.7	74.8	80.2	73
BiGreatPal	31.5	32.3	30.2	32.6	33.2	30.5	37.9	33.6	31.6	32.9	34.5	29.4	30	35.6	31.5
BiJugale	65.2	66.2	69.5	69.1	70.2	69.7	60.9	61.3	60.5	64.1	63.1	63.3	64.6	64	70.2

#	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
Gender (M=0, F=1)	1	1	0	1	0	1	0	1	0	0	1	0	1	1	1
Age	14.17	10.75	14.17	13.75	13	29.17	13.75	12.33	14.17	14.08	14.5	14	32	12.33	14.33
cranial width	115.5	131.0	138.0	126.1	123.8	125.3	125.4	128.9	127.0	125.1	124.0	123.0	118.4	123.3	123.8
cranial length	153.0	163.5	162.0	167.1	163.8	165.8	166.1	171.2	177.5	167.6	164.5	163.2	158.9	165.5	166.1
cranial index	**0.75**	**0.80**	**0.85**	**0.75**	**0.76**	**0.76**	**0.76**	**0.75**	**0.72**	**0.75**	**0.75**	**0.75**	**0.75**	**0.75**	**0.75**
zyg-zyg	109.2	118.9	113.6	113.2	110.8	113.1	118.1	111	112	111.1	116	121	118.1	103.3	119.1
N-Gn	99.6	103.5	99.3	112.6	114.9	116	117.7	110.1	107.3	115.6	117.3	121.6	120.7	101.9	113
facial index	**0.91**	**0.87**	**0.87**	**0.99**	**1.04**	**1.03**	**1.00**	**0.99**	**0.96**	**1.04**	**1.01**	**1.00**	**1.02**	**0.99**	**0.95**
bioptic canal	22.6	24	24.2	20.1	18.3	23.5	21.2	19	20.1	18.7	20.9	20.7	22.4	17	26.5
biforamen ovale	51.9	44.9	52.2	52.2	54.4	54.8	58.6	52.7	46.8	53	52.1	58.5	56.7	51.1	53.5
bijugalar foramen	57.4	67.2	68.5	73.2	71.9	65.5	75.5	72.1	68	78.8	71.5	79.6	65.5	69.2	70.8
anterior cranial base	85.9	90.9	91	82.8	90.1	91.8	93.6	89.1	89.6	93	94	92.5	95.9	87.5	89.7
carotid canal	29.8	31.6	33.4	29.4	29.8	29.7	31.4	32.9	28.1	34.1	28	34.1	33.9	28.7	31.6
internal auditory canal	49.1	48.9	51.6	55.2	53.6	44.3	52.8	56	50.2	58.9	45.5	56.2	51	52.6	45.7
UL6 angle	94.5	104	105.8	105.4	100.7	104.6	97.8	99.4	105.4	96.2	102.7	106.1	105	105.1	105.7
UR6 angle	97.4	108.7	104.6	105.2	100.8	104	105.9	104.3	104.1	98.1	102.5	105.4	107.3	105.1	107.8
LL6 angle	79.5	70.9	74.6	70.8	70.7	75.7	68.7	73.8	75.2	80.5	79.1	74.9	87.3	79.4	72.9
LR6 angle	79.9	67.1	77.5	73	71.4	75	70.8	71.9	78.1	79	77	75.5	87.6	80.4	73.8
Bimental	45.1	40.2	43.8	43.1	45.9	42	48.1	46.2	45.1	43.8	42.9	45.5	42.9	42.1	43.7
BiLingula	74.5	77.5	73.8	74	68.3	68.4	77	72.3	71.6	74.9	70.4	76.2	71.1	68.7	74.8
BiGreatPal	30.7	30.9	33.5	30.5	30.2	32	35.4	33.1	31.4	28.2	33.6	33.4	36	33.4	30.7
BiJugale	59	60.2	64.8	64.7	59.7	61.1	63.7	62.1	61.6	61.8	63.8	64.9	63.4	61.3	60.3

#	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75
Gender (M=0, F=1)	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1
Age	24.83	12	18.58	31.83	11.25	12.75	13.17	12.75	13.67	13.25	12.25	13.75	12.75	13	15
cranial width	134.4	122.4	121.6	126.8	125.5	142.5	140.4	126.1	126.4	120.6	135.2	125.8	128.7	125.7	138.7
cranial length	155.6	163.2	162.9	169.6	165.9	166.7	167.2	168.9	162.5	159.5	159.0	169.3	171.5	168.4	170.6
cranial index	**0.86**	**0.75**	**0.75**	**0.75**	**0.76**	**0.86**	**0.84**	**0.75**	**0.78**	**0.76**	**0.85**	**0.74**	**0.75**	**0.75**	**0.81**
zyg-zyg	122.3	109.5	119.7	117	116.5	121.4	119.6	113.2	113.7	105.4	119.4	109.9	119.8	113.2	116.2
N-Gn	115	112.1	117.4	131.9	109.8	93.8	96.1	109.8	109	102.5	112.6	105.6	98.1	108.3	96.9
facial index	**0.94**	**1.02**	**0.98**	**1.13**	**0.94**	**0.77**	**0.80**	**0.97**	**0.96**	**0.97**	**0.94**	**0.96**	**0.82**	**0.96**	**0.83**
bioptic canal	22.1	20.9	22.9	20.2	21.9	26.8	20.6	20.2	24.1	21.3	21.1	18.8	22.1	21.1	23.3
biforamen ovale	56.9	50.9	55.3	54.2	57.2	60.7	58.1	51.7	54.3	51.9	59	52.9	52.7	52.8	57.7
bijugalar foramen	72.2	64.1	72.1	70.9	73	78.5	76.6	71.3	74.5	70.2	71.5	71.5	73.2	67.7	66.7
anterior cranial base	97.7	91.2	90	95.7	93.4	102.5	90	88.8	95	81.6	96.4	93	94.2	95	99.9
carotid canal	32.3	29.5	28.4	30.5	33.4	34	32.3	29.6	32.5	28.8	31.7	31.7	30.6	28.4	32.3
internal auditory canal	50.5	48.3	55.5	51.9	50.6	49.4	52.9	44.6	54.4	51.5	49.8	41.7	51.5	52.2	51.9
UL6 angle	104	106.3	100.7	92.9	107.4	97	106	101.8	104.1	113.1	107.4	96.8	107.6	108.5	98.1
UR6 angle	102.7	108.8	104.2	92.9	109.5	102	108	98.9	79.5	109.6	106.4	95.9	109.6	105.5	103
LL6 angle	78	81.2	83.4	81.9	69.8	72.2	80.9	73.3	97.5	69.3	64.6	72.6	76.7	77.9	77.5
LR6 angle	81.5	83.5	84.3	78	78	77.6	81.4	76.7	80.9	71.4	66.5	73.3	77.9	77	77.9
Bimental	43.6	45.2	47.5	44.8	48.4	45.6	46.6	46.3	40.1	42.6	45.2	37.6	46.3	42.8	43.2
BiLingula	72.9	70.3	76.2	76.7	72	71.6	77.6	68.8	71.4	72.4	76.8	71.9	79.4	70.7	75.3
BiGreatPal	35.2	33	32.5	31.5	32	32.7	37.5	30.6	32.9	27.7	32.4	29.2	34.2	30.5	31.9
BiJugale	63.2	64.9	63.7	64.1	63.8	68.2	67.9	61.3	62.2	55.2	61.9	56	69.4	61.2	63.2

#	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
Gender (M=0, F=1)	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0
Age	13.17	14.25	13.42	14.5	12.33	11	14.83	11.25	13.08	15.25	12	15.17	13.75	19.75	17.5
cranial width	133.6	133.6	144.0	134.4	133.7	137.3	131.0	123.1	126.4	125.8	125.9	126.8	136.9	129.9	119.8
cranial length	164.0	162.2	166.7	163.3	157.0	161.8	160.0	166.9	173.1	169.7	166.7	166.1	164.5	165.9	161.1
cranial index	**0.81**	**0.82**	**0.86**	**0.82**	**0.85**	**0.85**	**0.82**	**0.74**	**0.73**	**0.74**	**0.76**	**0.76**	**0.83**	**0.78**	**0.74**
zyg-zyg	115	126	129.6	126.3	118.6	115.5	124.5	113.8	119.6	119	106.6	115.3	115.2	117.1	119.5
N-Gn	107	105.8	109	104.6	111.8	100.1	103.7	108.6	113.4	114.5	102.4	118.9	101	108.8	114.9
facial index	**0.93**	**0.84**	**0.84**	**0.83**	**0.94**	**0.87**	**0.83**	**0.95**	**0.95**	**0.96**	**0.96**	**1.03**	**0.88**	**0.93**	**0.96**
bioptic canal	20	21.9	27.5	25.6	21.4	22.1	25.2	20.6	21.3	24.4	19.5	21.3	21.2	21.5	20.6
biforamen ovale	52.3	53.7	60.8	57.8	57.2	54.4	54.5	53.1	51.4	58.3	52.6	54.6	54.3	55.3	52.9
bijugalar foramen	68.8	76.9	69.4	68.7	69.9	75.8	77.3	75.1	71.5	69.9	61.7	80.1	70	62.5	69.4
anterior cranial base	88.5	93.8	108.9	94.2	89.9	90.4	93	89.6	96.3	99.4	90.1	98.1	94.2	96.2	92.5
carotid canal	29.7	32.1	37.7	34.6	31.4	31.6	31.3	28.1	30.5	31.1	30.9	31.9	30.2	26.2	25.2
internal auditory canal	45.5	51.7	50.4	54.3	57.2	55.6	55	49.8	50.7	49.7	41.9	54	49.1	50.1	54.6
UL6 angle	103.2	102.3	97.9	106	106.4	101.4	102	101.3	108.2	105.1	103.8	108.6	99	96.9	103.3
UR6 angle	101.4	103.9	102.7	108.2	106.8	102.9	103	105.4	105.5	105.3	97.8	112.3	101.8	100.4	103.8
LL6 angle	75.2	72.2	84.8	76.3	81.5	73.1	73.9	71.3	73	77.5	81.7	73.3	82.5	83	73.8
LR6 angle	78	73.7	77.3	80.3	81.1	72.7	78.6	73.7	79.6	78	89.6	76	82.1	83.2	74.6
Bimental	42.3	49.1	47.8	44.3	44	44.5	48.8	45.4	47.7	46.5	45.5	43.7	42.5	46.5	42.7
BiLingula	64.2	78.9	78.3	77.8	76.8	73.4	77.4	77.1	77.1	79.6	68.2	76.8	71.1	72.4	76.9
BiGreatPal	30.5	34.4	30.9	38	32.7	30.7	31.8	32.5	35.1	32.4	30.7	30.5	29.2	32.5	29.6
BiJugale	60.2	69.8	66.7	71.3	67	67.7	66.3	61.5	64.2	63.6	62.7	65.4	67.8	59.9	62.5

#	91	92	93	94	95	96	97	98	99	100
Gender (M=0, F=1)	0	1	1	0	0	0	1	1	0	1
Age	13.83	54.5	15.75	15.33	13.17	16	11	14.33	13.75	16.92
cranial width	130.7	123.5	130.8	123.1	143.1	127.1	122.7	129.5	130.1	120.4
cranial length	170.8	165.8	157.4	168.7	165.9	166.4	165.3	166.5	167.1	157.6
cranial index	**0.77**	**0.74**	**0.83**	**0.73**	**0.86**	**0.76**	**0.74**	**0.78**	**0.78**	**0.76**
zyg-zyg	128	120.2	125.2	119.3	126.2	132.3	110.5	122	121.8	117.6
N-Gn	120	109.8	98.4	114	107.4	122.2	95.7	110	103.3	102.3
facial index	**0.94**	**0.91**	**0.79**	**0.96**	**0.85**	**0.92**	**0.87**	**0.90**	**0.85**	**0.87**
bioptic canal	21.9	18.6	21.5	19.5	25.6	20.6	18	20.5	19.4	23.3
biforamen ovale	58.4	54.7	60.2	59.4	60.9	50.9	49.1	51.2	56.8	56.3
bijugalar foramen	86.9	63.3	75.9	70.1	84.6	70.9	70.7	70.9	82.5	68.5
anterior cranial base	104.6	94.5	94.4	92.8	98.2	101.5	98.7	94.6	95.8	94.3
carotid canal	32.2	31.5	33.5	27.9	39	33.9	29	31.6	32.5	33.1
internal auditory canal	56.3	50.6	50.7	48.1	52.5	48.4	44.9	50.9	47.5	48.9
UL6 angle	97.4	99.9	102	100.6	98.3	99.9	98.5	105.3	100.1	98
UR6 angle	96.8	105.7	99	100.4	98.7	99.8	97.3	103.7	99.6	107.6
LL6 angle	88	77.1	68.9	69.7	78.2	73.9	68.4	64.5	72.2	89.9
LR6 angle	90.6	78.7	69	67.3	77.2	77.2	71.3	68.2	79.4	87.2
Bimental	43.9	53.5	46.8	40	43.8	49.4	43.1	39.6	45.5	47
BiLingula	79.1	76.2	79.4	74.5	76.2	77.6	72.2	70.1	73.8	77.8
BiGreatPal	34.8	35.3	31.8	29.8	37.5	31.7	30	29.8	34.1	35.9
BiJugale	73.7	67.1	65.2	59	64.8	70.7	57.6	59.5	66.7	71.7

APPENDIX 5
Raw Data Intraclass Correlation

Random#	cranial wid	cranial leng	**cranial inde**	zyg-zyg	N-Gn	**facial index**	bioptic can	biforamen	bijugalar fo	anterior cre	carotid	internal	UL6 angle	UR6 angle	LL6 angle	LR6 angle	Bimental	BiLingula	BiGreatPal	BiJugale
17	132.4	163.8	**0.81**	118.1	102.4	**0.87**	20.5	54.7	71.5	92.7	30	51.4	106.4	106.6	77.8	74.5	41.8	70.9	31.6	69.9
32	130.9	155.5	**0.84**	112	104.5	**0.93**	20.5	53.9	75.7	91.6	29.7	51.4	104.5	104.2	74.1	75.2	45.3	72.3	32.1	65.7
7	143.6	164.6	**0.87**	124.1	118.8	**0.96**	22.4	66.5	79.1	101.9	31.4	61.4	110.4	114.4	70	71.6	50.3	82	32.7	68.9
39	139.2	163.4	**0.85**	111.3	106.2	**0.95**	22	55.1	77	90.9	30.8	63.1	104.2	104.9	74.1	73.2	44.9	70.9	31	61.1
6	139.2	173.3	**0.80**	123.1	105.2	**0.85**	22.7	55	67.6	93.6	34	56.2	101.2	104.3	76.4	74.2	45.8	74.1	34.7	73.1
1	133.6	163.1	**0.82**	126	100.1	**0.79**	24.8	58.5	78.1	90.1	33.4	53.4	104.9	104.5	71.1	75.3	43.9	82.5	33.9	70.2
14	133.7	168.3	**0.79**	111.6	104.1	**0.93**	19.2	53.6	74.8	93.9	30.4	52.9	108	105.4	76.1	79.7	44.9	70.2	31.1	64.6
25	130.6	172.2	**0.76**	116.2	101.5	**0.87**	23	56.6	71	93.9	33.4	52.4	102.5	105.1	77.2	77.9	49.3	74.4	26.9	68.1
9	134.6	161.7	**0.83**	123.8	103	**0.83**	22.9	57.1	71.9	96.5	34.1	54.6	105.8	106	73.1	75.7	48.6	75.8	36.2	65.2
16	136.5	168.9	**0.81**	116.3	106.8	**0.92**	19.6	52.1	74.9	93	34.5	58.5	105.9	106.5	77.3	76.5	42.9	69.8	30.6	65.4
17	132.4	163.8	**0.81**	117.6	103.4	**0.88**	20.8	53.9	72.3	93.6	30.3	52.9	108.4	108.6	76.3	73.5	41.6	70.2	29	64.4
32	130.9	155.5	**0.84**	111.8	104.1	**0.93**	20.9	53	77.3	91.4	29.9	52.8	102.5	103.5	72.2	74.6	46.8	72	32.3	66.2
7	143.6	164.6	**0.87**	124.8	119	**0.95**	22.1	66.5	78.9	102.3	31.8	62	115.9	113.4	66.8	71.2	49.2	82.3	32.2	69
39	139.2	163.4	**0.85**	110.9	106.2	**0.96**	21.8	54.5	76.6	91	30.5	63.8	103	106.1	75.9	76.8	45.2	70.5	31.6	60.5
6	139.2	173.3	**0.80**	122.7	104.7	**0.85**	22.9	55.4	68	92.8	33.4	55.5	100.7	102.8	75.4	73.7	46	73.7	34.4	72
1	133.6	163.1	**0.82**	126.6	100.1	**0.79**	25.1	59	76.8	89.1	33.1	54.9	105.6	104.7	70.8	74.6	44.3	82.4	34	70.5
14	133.7	168.3	**0.79**	110.8	102.3	**0.92**	19	53.4	75.1	94.2	31.9	51.5	113.2	110.7	74.3	78.7	44.4	69.4	31.4	64.7
25	130.6	172.2	**0.76**	117	101.2	**0.86**	22.9	56.5	70.5	92.9	32.2	51.6	103.8	105.5	76.2	77.4	48.7	74	27.2	67.3
9	134.6	161.7	**0.83**	124.3	103.4	**0.83**	23.2	57.5	73	95.9	34.8	53.6	106.3	106.2	72.4	74.1	48.2	76.3	35.6	64.1
16	136.5	168.9	**0.81**	117	106.9	**0.91**	20	50.1	73.4	91.9	33.8	57.9	108.2	107.8	76.5	75.6	43.4	68.8	30	66.1

Cronbach alpha - intraclass reliability

cranial wid	cranial leng	cranial inde	zyg-zyg	N-Gn	facial index	bioptic can	biforamen	bijugalar fo	anterior cre	carotid	internal	UL6 angle	UR6 angle	LL6 angle	LR6 angle	Bimental	BiLingula	BiGreatPal	BiJugale
0.993	*0.992*	*0.987*	*0.997*	*0.995*	*0.995*	*0.994*	*0.992*	*0.979*	*0.990*	*0.948*	*0.982*	*0.885*	*0.896*	*0.949*	*0.885*	*0.980*	*0.998*	*0.967*	*0.926*

APPENDIX 6
Raw Data Correlation
a) Parametric Correlation (Pearson)

Correlations

		Age	CranialWidth	CranialLength	CranialIndex	BiZyg	NaGn	FacialIndex	BiOptCan	AntCranBase	BiForOvale	BiCarCan	BiJugularFor	IntAudCan	UL6angle	UR6angle	LL6angle	LR6angle	BiMental	BiLingula	BiGreatPal	BiJugale
Age	Pearson Correlation	1	-.187	-.056	-.135	.193	.399**	.243*	-.039	.145	.093	.005	-.264**	-.046	-.099	-.027	.202*	.175	.192	.112	.205*	.007
	Sig. (2-tailed)		.063	.581	.182	.055	.000	.015	.699	.150	.360	.962	.008	.650	.331	.791	.044	.081	.055	.267	.041	.945
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CranialWidth	Pearson Correlation	-.187	1	.089	.832**	.438**	-.248*	-.527**	.341**	.338**	.416**	.433**	.373**	.459**	.203*	.196	-.088	-.134	.267**	.277**	.088	.357**
	Sig. (2-tailed)	.063		.378	.000	.000	.013	.000	.001	.001	.000	.000	.000	.000	.043	.050	.383	.185	.007	.005	.384	.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CranialLength	Pearson Correlation	-.056	.089	1	-.473**	.034	.041	.011	-.143	.212*	-.087	.000	.091	-.093	.011	.073	-.113	-.142	.065	.058	-.098	.074
	Sig. (2-tailed)	.581	.378		.000	.738	.689	.911	.155	.034	.389	.999	.366	.411	.914	.470	.263	.159	.523	.565	.330	.461
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
CranialIndex	Pearson Correlation	-.135	.832**	-.473**	1	.362**	-.235*	-.461**	.376**	.180	.416**	.377**	.286**	.458**	.178	.125	-.012	-.031	.196	.201*	.126	.260**
	Sig. (2-tailed)	.182	.000	.000		.000	.018	.000	.000	.073	.000	.000	.004	.000	.076	.214	.905	.758	.051	.045	.212	.009
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiZyg	Pearson Correlation	.193	.438**	.034	.362**	1	.270**	-.418**	.464**	.507**	.468**	.445**	.307**	.298**	.182	.197*	-.072	-.052	.439**	.694**	.318**	.445**
	Sig. (2-tailed)	.055	.000	.738	.000		.007	.000	.000	.000	.000	.000	.002	.003	.070	.050	.474	.607	.000	.000	.001	.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
NaGn	Pearson Correlation	.399**	-.248*	.041	-.235*	.270**	1	.760**	-.040	.194	.089	-.031	.001	.074	-.012	-.046	.138	.109	.165	.199*	.097	-.028
	Sig. (2-tailed)	.000	.013	.689	.018	.007		.000	.689	.053	.378	.760	.995	.463	.903	.651	.171	.279	.101	.047	.338	.782
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
FacialIndex	Pearson Correlation	.243*	-.527**	.011	-.461**	-.418**	.760**	1	-.348**	-.163	-.227*	-.325**	-.199*	-.127	-.144	-.189	.179	.134	-.143	-.275**	-.115	-.330**
	Sig. (2-tailed)	.015	.000	.911	.000	.000	.000		.000	.105	.023	.001	.048	.209	.153	.059	.074	.183	.155	.006	.254	.001
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiOptCan	Pearson Correlation	-.039	.341**	-.143	.376**	.464**	-.040	-.348**	1	.263**	.353**	.347**	.109	.112	.050	.099	.154	.121	.152	.323**	.331**	.275**
	Sig. (2-tailed)	.699	.001	.155	.000	.000	.689	.000		.008	.000	.000	.281	.266	.623	.325	.126	.230	.130	.001	.001	.006
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
AntCranBase	Pearson Correlation	.145	.338**	.212*	.180	.507**	.194	-.163	.263**	1	.391**	.375**	.179	.066	-.118	-.041	.148	.086	.178	.334**	.208*	.262**
	Sig. (2-tailed)	.150	.001	.034	.073	.000	.053	.105	.008		.000	.000	.075	.513	.241	.683	.141	.395	.076	.001	.039	.009
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiForOvale	Pearson Correlation	.093	.416**	-.087	.416**	.468**	.089	-.227*	.353**	.391**	1	.426**	.474**	.373**	.052	.091	.004	-.120	.271**	.454**	.165	.132
	Sig. (2-tailed)	.360	.000	.389	.000	.000	.378	.023	.000	.000		.000	.000	.000	.606	.369	.968	.234	.006	.000	.100	.190
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiCarCan	Pearson Correlation	.005	.433**	.000	.377**	.445**	-.031	-.325**	.347**	.375**	.426**	1	.364**	.270**	.140	.158	.020	.001	.285**	.317**	.279**	.345**
	Sig. (2-tailed)	.962	.000	.999	.000	.000	.760	.001	.000	.000	.000		.000	.007	.166	.117	.847	.991	.004	.001	.005	.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiJugularFor	Pearson Correlation	-.264**	.373**	.091	.286**	.307**	.001	-.199*	.109	.179	.474**	.364**	1	.451**	.103	.061	-.175	-.236*	.137	.355**	.077	.154
	Sig. (2-tailed)	.008	.000	.366	.004	.002	.995	.048	.281	.075	.000	.000		.000	.308	.545	.081	.018	.174	.000	.447	.127
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
IntAudCan	Pearson Correlation	-.046	.459**	-.093	.458**	.298**	.074	-.127	.112	.066	.373**	.270**	.451**	1	.300**	.273**	.039	-.115	.331**	.392**	.046	.191
	Sig. (2-tailed)	.650	.000	.411	.000	.003	.463	.209	.266	.513	.000	.007	.000		.002	.006	.701	.253	.001	.000	.646	.058
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
UL6angle	Pearson Correlation	-.099	.203*	.011	.178	.182	-.012	-.144	.050	-.118	.052	.140	.103	.300**	1	.720**	-.253*	-.159	.228*	.174	-.072	.077
	Sig. (2-tailed)	.331	.043	.914	.076	.070	.903	.153	.623	.241	.606	.166	.308	.002		.000	.011	.115	.022	.084	.477	.445
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
UR6angle	Pearson Correlation	-.027	.196	.073	.125	.197*	-.046	-.189	.099	-.041	.091	.158	.061	.273**	.720**	1	-.344**	-.157	.365**	.270**	.024	.238*
	Sig. (2-tailed)	.791	.050	.470	.214	.050	.651	.059	.325	.683	.369	.117	.545	.006	.000		.000	.118	.000	.007	.809	.017
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
LL6angle	Pearson Correlation	.202*	-.088	-.113	-.012	-.072	.138	.179	.154	.148	.004	.020	-.175	.039	-.253*	-.344**	1	.710**	-.047	-.063	.159	.169
	Sig. (2-tailed)	.044	.383	.263	.905	.474	.171	.074	.126	.141	.968	.847	.081	.701	.011	.000		.000	.645	.531	.113	.093
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
LR6angle	Pearson Correlation	.175	-.134	-.142	-.031	-.052	.109	.134	.121	.086	-.120	.001	-.236*	-.115	-.159	-.157	.710**	1	.084	-.139	.405**	.349**
	Sig. (2-tailed)	.081	.185	.159	.758	.607	.279	.183	.230	.395	.234	.991	.018	.253	.115	.118	.000		.403	.168	.000	.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiMental	Pearson Correlation	.192	.267**	.065	.196	.439**	.165	-.143	.152	.178	.271**	.285**	.137	.331**	.228*	.365**	-.047	.084	1	.499**	.248*	.491**
	Sig. (2-tailed)	.055	.007	.523	.051	.000	.101	.155	.130	.076	.006	.004	.174	.001	.022	.000	.645	.403		.000	.013	.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiLingula	Pearson Correlation	.112	.277**	.058	.201*	.694**	.199*	-.275**	.323**	.334**	.454**	.317**	.355**	.392**	.174	.270**	-.063	-.139	.489**	1	.232*	.349**
	Sig. (2-tailed)	.267	.005	.565	.045	.000	.047	.006	.001	.001	.000	.001	.000	.000	.084	.007	.531	.168	.000		.020	.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiGreatPal	Pearson Correlation	.205*	.088	-.098	.126	.318**	.097	-.115	.331**	.208*	.165	.279**	.077	.046	-.072	.024	.159	.405**	.248*	.232*	1	.428**
	Sig. (2-tailed)	.041	.384	.330	.212	.001	.338	.254	.001	.038	.100	.005	.447	.646	.477	.809	.113	.000	.013	.020		.000
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BiJugale	Pearson Correlation	.007	.357**	.074	.260**	.445**	-.028	-.330**	.275**	.262**	.132	.345**	.154	.191	.077	.238*	.169	.349**	.491**	.349**	.428**	1
	Sig. (2-tailed)	.945	.000	.461	.009	.000	.782	.001	.006	.009	.190	.000	.127	.058	.445	.017	.093	.000	.000	.000	.000	
	N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

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

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

b) Nonparametric Correlation (Spearman)

Correlations

			Age	CranialWidth	CranialLength	CranialIndex	BiZyg	NaGn	FacialIndex	BiOptCan	AntCranBase	BiForOvale	BiCarCan	BiJugularFor	IntAudCan	UL6angle	UR6angle	LL6angle	LR6angle	BiMental	BiLingula	BiGreatPal	BiJugale
Spearman's rho	Age	Correlation Coefficient	1.000	-.175	-.139	-.093	.338**	.447**	.192	.131	.260**	.100	.057	-.176	-.021	-.140	-.078	.165	.133	.010	.171	.188	.029
		Sig. (2-tailed)	.	.081	.167	.359	.001	.000	.055	.195	.009	.320	.570	.080	.839	.164	.438	.101	.186	.923	.088	.060	.777
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	CranialWidth	Correlation Coefficient	-.175	1.000	.037	.844**	.388**	-.287**	-.558**	.330**	.242*	.379**	.425**	.333**	.437**	.201*	.156	-.032	-.064	.281**	.241*	.102	.414**
		Sig. (2-tailed)	.081	.	.713	.000	.000	.004	.000	.001	.015	.000	.000	.001	.000	.045	.122	.754	.528	.005	.016	.311	.000
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	CranialLength	Correlation Coefficient	-.139	.037	1.000	-.462**	.018	.037	.000	-.204*	.201*	-.084	.007	.059	-.079	-.074	-.051	-.092	-.194	.067	.049	-.086	.030
		Sig. (2-tailed)	.167	.713	.	.000	.859	.717	.999	.042	.045	.405	.941	.558	.437	.462	.612	.363	.053	.506	.631	.397	.765
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	CranialIndex	Correlation Coefficient	-.093	.844**	-.462**	1.000	.323**	-.273**	-.489**	.397**	.128	.400**	.371**	.277**	.397**	.195	.134	.013	.043	.196	.147	.136	.353**
		Sig. (2-tailed)	.359	.000	.000	.	.001	.006	.000	.000	.205	.000	.000	.005	.000	.052	.184	.899	.671	.050	.144	.176	.000
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiZyg	Correlation Coefficient	.338**	.388**	.018	.323**	1.000	.217*	-.450**	.431**	.440**	.502**	.459**	.269**	.274**	.168	.188	-.114	-.098	.453**	.713**	.374**	.472**
		Sig. (2-tailed)	.001	.000	.859	.001	.	.030	.000	.000	.000	.000	.000	.007	.006	.094	.061	.257	.332	.000	.000	.000	.000
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	NaGn	Correlation Coefficient	.447**	-.287**	.037	-.273**	.217*	1.000	.736**	-.045	.174	.061	-.046	-.053	.057	-.017	-.008	.108	.006	.127	.131	.079	-.133
		Sig. (2-tailed)	.000	.004	.717	.006	.030	.	.000	.654	.083	.544	.650	.600	.571	.867	.940	.287	.955	.208	.194	.435	.189
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	FacialIndex	Correlation Coefficient	.192	-.558**	.000	-.489**	-.450**	.736**	1.000	-.311**	-.163	-.250*	-.365**	-.203*	-.126	-.112	-.120	.171	.082	-.185	-.326**	-.138	-.422**
		Sig. (2-tailed)	.055	.000	.999	.000	.000	.000	.	.002	.104	.012	.000	.042	.212	.266	.235	.088	.420	.066	.001	.169	.000
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiOptCan	Correlation Coefficient	.131	.330**	-.204*	.397**	.431**	-.045	-.311**	1.000	.190	.425**	.285**	.067	.165	.092	.176	.136	.130	.218*	.360**	.407**	.253*
		Sig. (2-tailed)	.195	.001	.042	.000	.000	.654	.002	.	.058	.000	.004	.507	.101	.363	.080	.177	.197	.029	.000	.000	.011
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	AntCranBase	Correlation Coefficient	.260**	.242*	.201*	.128	.440**	.174	-.163	.190	1.000	.323**	.363**	.067	.046	-.064	-.004	.073	.033	.181	.306**	.239*	.191
		Sig. (2-tailed)	.009	.015	.045	.205	.000	.083	.104	.058	.	.001	.000	.506	.648	.530	.971	.471	.743	.072	.002	.017	.057
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiForOvale	Correlation Coefficient	.100	.379**	-.084	.400**	.502**	.061	-.250*	.425**	.323**	1.000	.459**	.443**	.338**	-.007	.089	-.014	-.055	.298**	.493**	.272**	.185
		Sig. (2-tailed)	.320	.000	.405	.000	.000	.544	.012	.000	.001	.	.000	.000	.001	.941	.380	.889	.588	.003	.000	.006	.065
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiCarCan	Correlation Coefficient	.057	.425**	.007	.371**	.459**	-.046	-.365**	.285**	.363**	.459**	1.000	.359**	.340**	.151	.232*	-.041	-.024	.308**	.376**	.281**	.410**
		Sig. (2-tailed)	.570	.000	.941	.000	.000	.650	.000	.004	.000	.000	.	.000	.001	.134	.020	.684	.809	.002	.000	.005	.000
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiJugularFor	Correlation Coefficient	-.176	.333**	.059	.277**	.269**	-.053	-.203*	.067	.067	.443**	.359**	1.000	.455**	.113	.091	-.310**	-.301**	.207*	.355**	.099	.185
		Sig. (2-tailed)	.080	.001	.558	.005	.007	.600	.042	.507	.506	.000	.000	.	.000	.264	.367	.002	.002	.039	.000	.329	.066
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	IntAudCan	Correlation Coefficient	-.021	.437**	-.079	.397**	.274**	.057	-.126	.165	.046	.338**	.340**	.455**	1.000	.335**	.356**	.022	-.059	.310**	.324**	.127	.232*
		Sig. (2-tailed)	.839	.000	.437	.000	.006	.571	.212	.101	.648	.001	.001	.000	.	.001	.000	.826	.562	.002	.001	.208	.020
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	UL6angle	Correlation Coefficient	-.140	.201*	-.074	.195	.168	-.017	-.112	.092	-.064	-.007	.151	.113	.335**	1.000	.756**	-.250*	-.155	.155	.135	.070	.107
		Sig. (2-tailed)	.164	.045	.462	.052	.094	.867	.266	.363	.530	.941	.134	.264	.001	.	.000	.012	.124	.124	.181	.486	.291
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	UR6angle	Correlation Coefficient	-.078	.156	-.051	.134	.188	-.008	-.120	.176	-.004	.089	.232*	.091	.356**	.756**	1.000	-.204*	-.145	.297**	.285**	.145	.206*
		Sig. (2-tailed)	.438	.122	.612	.184	.061	.940	.235	.080	.971	.380	.020	.367	.000	.000	.	.042	.150	.003	.004	.151	.040
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	LL6angle	Correlation Coefficient	.165	-.032	-.092	.013	-.114	.108	.171	.136	.073	-.014	-.041	-.310**	.022	-.250*	-.204*	1.000	.786**	-.042	-.106	.109	.134
		Sig. (2-tailed)	.101	.754	.363	.899	.257	.287	.088	.177	.471	.889	.684	.002	.826	.012	.042	.	.000	.682	.294	.280	.182
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	LR6angle	Correlation Coefficient	.133	-.064	-.194	.043	-.098	.006	.082	.130	.033	-.055	-.024	-.301**	-.059	-.155	-.145	.786**	1.000	.050	-.179	.278**	.192
		Sig. (2-tailed)	.186	.528	.053	.671	.332	.955	.420	.197	.743	.588	.809	.002	.562	.124	.150	.000	.	.624	.074	.005	.055
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiMental	Correlation Coefficient	.010	.281**	.067	.196	.453**	.127	-.185	.218*	.181	.298**	.308**	.207*	.310**	.155	.297**	-.042	.050	1.000	.498**	.294**	.478**
		Sig. (2-tailed)	.923	.005	.506	.050	.000	.208	.066	.029	.072	.003	.002	.039	.002	.124	.003	.682	.624	.	.000	.003	.000
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiLingula	Correlation Coefficient	.171	.241*	.049	.147	.713**	.131	-.326**	.360**	.306**	.493**	.376**	.355**	.324**	.135	.285**	-.106	-.179	.498**	1.000	.267**	.341**
		Sig. (2-tailed)	.088	.016	.631	.144	.000	.194	.001	.000	.002	.000	.000	.000	.001	.181	.004	.294	.074	.000	.	.007	.001
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiGreatPal	Correlation Coefficient	.188	.102	-.086	.136	.374**	.079	-.138	.407**	.239*	.272**	.281**	.099	.127	.070	.145	.109	.278**	.294**	.267**	1.000	.290**
		Sig. (2-tailed)	.060	.311	.397	.176	.000	.435	.169	.000	.017	.006	.005	.329	.208	.486	.151	.280	.005	.003	.007	.	.003
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
	BiJugale	Correlation Coefficient	.029	.414**	.030	.353**	.472**	-.133	-.422**	.253*	.191	.185	.410**	.185	.232*	.107	.206*	.134	.192	.478**	.341**	.290**	1.000
		Sig. (2-tailed)	.777	.000	.765	.000	.000	.189	.000	.011	.057	.065	.000	.066	.020	.291	.040	.182	.055	.000	.001	.003	.
		N	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

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

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

APPENDIX 7
Raw Data Skewness

	N	Skewness	Std. Error of Skewness	Kurtosis	Std. Error of Kurtosis
Age	100	4.582	0.241	26.8	0.478
CranialWidth	100	0.102	0.241	-0.674	0.478
CranialLength	100	-0.206	0.241	-0.031	0.478
CranialIndex	100	0.384	0.241	-1.005	0.478
BiZyg	100	0.39	0.241	0.627	0.478
NaGn	100	0.431	0.241	0.037	0.478
FacialIndex	100	0.179	0.241	-0.281	0.478
BiOptCan	100	0.555	0.241	0.492	0.478
BiForOvale	100	0.123	0.241	0.83	0.478
BiJugularFor	100	0.119	0.241	0.467	0.478
AntCranBase	100	0.613	0.241	2.051	0.478
BiCarCan	100	0.141	0.241	0.756	0.478
IntAudCan	100	0.122	0.241	-0.023	0.478
UL6angle	100	-0.56	0.241	2.496	0.478
UR6angle	100	-1.591	0.241	6.339	0.478
LL6angle	100	0.879	0.241	2.115	0.478
LR6angle	100	0.703	0.241	3.208	0.478
BiMental	100	0.13	0.241	0.098	0.478
BiLingula	100	0.271	0.241	0.482	0.478
BiGreatPal	100	0.806	0.241	1.962	0.478
BiJugale	100	0.582	0.241	1.961	0.478
AVG_U6	100	-0.91	0.241	3.598	0.478
AVG_L6	100	0.406	0.241	0.503	0.478