



**STUDYING THE PREVALENCE AND ETIOLOGY OF CLASS II SUBDIVISION
MALOCCLUSION UTILIZING CONE-BEAM COMPUTED TOMOGRAPHY**

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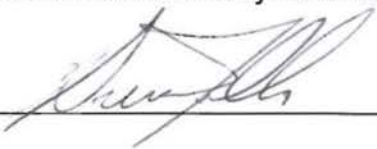
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DEDICATION

This thesis is dedicated to my wife, Peychi. It may be cliché but it is with the utmost sincerity that I say, “I could not have done it without you.” You’ve carried more than your share of the load these past two years; all while working full time, pursuing your own board certification and giving birth to our beautiful baby girl, Jolie. Eight years ago, I asked you to join me on this great adventure. You said, “Yes! This is going to be so much fun!” And you were right! We’ve been around the world and now the next step in our adventure begins as we pack up two kids and head to Naples, Italy. I can’t imagine being on this journey with anyone else.

To my kids, Reed and Jolie. I arrive painfully early to work each day, before either of you are awake, so that I can accomplish my tasks and still make it home to see you before you go to bed. All of my stress vanishes the minute I walk through the door and see your beautiful smiling faces. I love you two more than you can imagine.

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Finally, thank you to Dr. Ricardo Vendrell, my training officer and mentor. You’ve taught me to pay attention to the details and “never trade speed for accuracy” – invaluable lessons. Looking forward to sharing a beer as colleagues at a future AAO meeting.

ABSTRACT

Introduction: Treatment of the Class II subdivision malocclusion has long been a challenge for orthodontists. Asymmetric occlusal relationships can occur due to any number of combinations of dentoalveolar or skeletal deviations. Identifying the etiology of asymmetry allows the clinician to make the most prudent treatment decisions and ultimately, achieve optimal treatment outcomes. It was noted by Edward Angle that there seemed to be a higher occurrence of asymmetric occlusion in the Class II Division 2 (II/2) malocclusion than the Class II Division 1 (II/1) malocclusion. The Class II/2 phenotype is unique in its presentation. Further, the morphologic features of the Class II/2 malocclusion are so distinct and consistent, that it often has little in common with the Class II/1 malocclusion other than the Class II molar relationship. Despite these differences, the literature is replete with Class II studies that fail to make the distinction between Class II/1 and Class II/2 malocclusions. Grouping the two Class II types together potentially leads to misleading results and conclusions. Another potential source of error in traditional studies of asymmetry in Class II malocclusions is the use of conventional radiographic techniques in the determination of dentoalveolar and skeletal asymmetries. Cone-beam computed tomography (CBCT) eliminates magnification error and many of the problems associated with traditional imaging methods and is more ideally suited to the study of asymmetry. The aim of this study was to 1) determine the prevalence of subdivision malocclusion in Class II/1 and Class II/2 subtypes and 2) compare bilateral dentoalveolar and skeletal linear measurements between patients with

Class II/1 subdivision and Class II/2 subdivision malocclusions using pretreatment CBCT slices. **Methods:** Pretreatment intraoral photographs of patients screened for treatment at the Wilford Hall Ambulatory Surgical Center Tri-Service Orthodontic Residency Program (TORP) were used to identify those patients with Class II malocclusion. Likewise, photographs were used to determine the existence of subdivision malocclusions. Pretreatment CBCT images were then used to divide the subjects, Division 1 or Division 2, based on predetermined cephalometric criteria. Utilizing CBCT images, bilateral linear dentoalveolar and skeletal measurements were made on 20 patients with Class II/1 subdivision malocclusion and 20 patients with Class II/2 subdivision malocclusions. Measurements were compared between the two groups, aiming to determine the etiology of the subdivision. **Results:** 256 patients in the population at hand were determined to have Class II malocclusions. 22.9% (49 of 214) of those characterized as Class II/1, presented with a subdivision malocclusion (defined by the molar relationship being at least one-half step Class II on one side and Class I on the other) while 50% (21 of 42) of Class II/2 patients presented with a subdivision malocclusion. Six of eight bilateral linear measurements demonstrated greater asymmetry in the Class II/2 subdivision population, including all measurements based on mandibular landmarks. These differences were significant ($p < 0.05$) for two of the eight measures: condylian-pogonion (Co-Po) and condylian-mandibular first molar (Co-Mn6). **Conclusions:** Subdivision malocclusions were more prevalent in the Class II/2 population than in the Class II/1 population. The Class II/2 subdivision group demonstrated

greater mandibular asymmetry suggesting a mandibular skeletal etiology to subdivision malocclusion in Class II/2 patients.

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I. BACKGROUND AND LITERATURE REVIEW

A. Introduction

Edward H. Angle contributed much to the specialty of orthodontics, including his system for the classification of malocclusion. According to Angle, if the mesiobuccal cusp of the maxillary first molar rests in the buccal groove of the mandibular first molar, and if the rest of the teeth are aligned, ideal occlusion will result. Furthermore, Angle believed that the maxillary first molar demonstrated constancy in its position within the maxilla. Therefore, the variable anteroposterior position of the mandibular first molar determines the malocclusion. Malocclusions were divided into three classes, each representing a variation of the anteroposterior molar relationship. They are as follows:

(1) Class I – those malocclusion cases exhibiting normal mesiodistal relations of the jaws and dental arches as indicated by the normal locking of the first permanent molars.

(2) Class II – a distal relation of the lower arch when related to the upper arch, the lower first permanent molar locking more than one-half of a cusp distal to normal relation with the upper first permanent molar. This class is divided into Division 1, i.e., those cases exhibiting protruding upper incisors; and Division 2, those cases exhibiting retruded, or upright, upper incisors.

(3) Class III – a mesial relation of the lower arch to the upper arch, the lower first molar locking more than one-half cusp mesial to normal relation with the upper first molar.

Accurate diagnosis of skeletal and dental components of a given malocclusion is paramount in making the most prudent orthodontic treatment decisions. The presentation of Class II malocclusion is highly variable in its particular components, and etiology, and must be evaluated on an individual case-by-case basis. With limitless combinations of skeletal and dental components, and the multifactorial nature of the developing malocclusion, it is helpful to identify commonalities in various types of malocclusions. The Class II malocclusion, per Edward H. Angle's classification system, is broadly defined as one in which there is a distal relationship of the mandibular teeth relative to the maxillary teeth of more than one-half the width of the cusp (Angle 1899). Angle recognized that there was a subset of Class II malocclusion, the Class II/2 type, which exhibits a triad of features that make it distinctive in its presentation. They are, according to Angle: Deep bite, retroclined maxillary incisors and a posteriorly positioned mandibular dental arch. Characteristics of the II/2 malocclusion have been well-documented, if not agreed upon, throughout the history of orthodontic literature. In short, these can be summarized as follows: *skeletal components* include a hypo-divergent pattern, decreased lower face height, low mandibular plane angle, decreased gonial angle, and commonly, adequate mandibular body length and width in comparison to Class II/1 type (Blair 2009, Renfroe 1948, Hellman 1944). *Dental components* include, as Angle discerned, retroclination of the maxillary central incisors, minimal overjet and excessively deep bite. Angle postulated that the unilateral malocclusion (or subdivision) is highly associated

with the Class II/2 pattern. However, there is a paucity of evidence in the scientific literature to either confirm or refute this assertion.

Angle characterized the Class II Division 1 malocclusion as having a narrowing of the maxillary arch with protrusive incisors accompanied by abnormal function of the lips and some form of nasal obstruction and mouth breathing. The Class II Division 2 malocclusion is characterized, according to Angle, by less narrowing of the maxillary arch and lingual inclination of the maxillary incisors. Angle believed the Division 2 malocclusion to be associated with normal nasal and lip function. A malocclusion is further classified as a subdivision when the malocclusion exists on one side of the arches but is normal on the other (Angle 1899). The offending side determines the namesake of the subdivision (Siegel 2002).

One of the major weaknesses of Angle's classification system is that it only considers the anteroposterior dimension when classifying the malocclusion. Calvin Case, one of the strongest critics of the Angle classification system, stated

For the very advantage of perfect harmony and unanimity in our literature and teaching, the author would gladly have adopted the Angle classification, were it not for the fact that as it now stands it cannot be made to express a large number of very important characters of malocclusion which should be fully recognized and systematically included...furthermore, the Angle classification does not recognize those wide differences in the character of certain malocclusions which have the same distomesial occlusion of the buccal teeth (Case 1921).

On a similar note, Ackerman and Proffit postulated that malocclusions having the same Angle classification may be *analogous* (having the same occlusal relationship), but may not be *homologous* (having all characteristics in common). They assert their own diagnosis and classification scheme which corrects for the deficiencies of the Angle system. In their view, there is a tendency to treat analogous malocclusions in a similar fashion. As two analogous malocclusions may require entirely different treatment plans, it would be ill-advised to treat them in the same manner (Proffit, 1969).

Yet another major criticism of the Angle classification system is that it does not differentiate between dentoalveolar and skeletal discrepancies. Angle assumed a certain constancy of position of the maxillary first molar which led to his conclusion that the molar relationship determines the relative anteroposterior position of the maxilla and mandible. Angle writes,

“These classes are based on the mesio-distal relations of the teeth, dental arches and jaws, which depend primarily upon the positions mesio-distally assumed by the first permanent molars on their erupting and locking. Hence in diagnosing cases of malocclusion we must consider, first, the mesio-distal relations of the jaws and dental arches, as indicated by the relation of the lower molars with the upper molars – the keys to occlusion; and second, the positions of the individual teeth, carefully noting their relations to the line of occlusion” (Angle 1899)

However, it has been demonstrated that the maxillary first molar can assume a range of possible positions with relation to the facial skeleton (Sassouni, 1971).

In spite of what have become obvious fallacies with the Angle classification system, it remains the predominant classification system utilized by orthodontists and dentists alike when describing the occlusal relationship. With the benefit of decades of research and, notably, the advent of cephalometric radiography, a better and more thorough understanding of skeletal relationships of various malocclusions has emerged. In spite of, or perhaps, because of the additional information gained from the cephalometric film, the distinguishing features of the Class II/2 malocclusion have been rigorously debated in the literature over the past several decades. Despite the emerging details that make the Class II/2 malocclusion distinct, it is troubling that in the investigation of Class II malocclusions, all too often, no distinction is made between Class II/1 and II/2 types. Furthermore, despite all that has been published on the subject of the Class II/2 malocclusion, most oversimplify the definition of the Class II/2 by focusing only on the distocclusion of the molars and canines and the retroclination of the maxillary central incisors.

Early cephalometric investigations of the Class II/2 malocclusion were often plagued by insufficient sample sizes and inconsistent definition of the condition with a somewhat vague distinction between Class II/1 and Class II/2 populations. Yet, it is worthwhile to recognize the conclusions from these early studies, as

they have influenced the evolving understanding and study of the Class II/2 malocclusion.

Some believe the features of the Class II/2 malocclusion to be pathognomonic such that instead of being considered a variation of the Class II malocclusion, it should be considered an entirely separate entity (Brezniak 2002). Wallis compared Class II/2 and Class II/1 subjects and found that the mandibular form in a “typical” Class II/2 demonstrates more acute gonial and mandibular plane angles, excessive overbite and decreased lower anterior face height (1963). These findings agree with the previous work of Hellman, whom like Wallis, found Class II/2 individuals to have more acute gonial and mandibular plane angles (1944). Additionally, Hellman concluded that the effective cranial base length (BaN) was significantly longer and the maxilla was more anteriorly positioned in the typical Class II/2 individual. Robertson and Hilton noted in 1965 that, in addition to the characteristic deep bite and increased interincisal angle, the presentation of the Class II/2 malocclusion was fundamentally based on an underlying Class I or mild Class II skeletal relationship. Peck drew similar conclusions, stating that the mandibular body is sufficiently well-developed and that the relative anterior-posterior relationship of the maxilla and the mandible closely approximates the “normal” Class I relationship (1998).

Other studies have concluded that the Class II/2 presentation is more likely a result of vertical dysplasia rather than a discrepancy in the anteroposterior plane

of space. Maj and Luchesse found that the mandible in the class II/2 malocclusion is characterized by remarkable development in the height of the ramus which they claim is consistent with the typical decreased mandibular plane angle and decreased lower anterior face height often observed in this group (1982). This validates the findings of Strang, who years earlier postulated that the development of the Class II/2 malocclusion is the result of insufficient vertical growth of the face below the nasal area (1958).

Despite conflicting conclusions about the consistency of features of the Class II/2 malocclusion, it is safe to say that grouping all Class II malocclusions together is a diagnostic oversimplification. Though Angle clearly distinguished the two divisions of Class II malocclusion over a century ago, many authors continue to group the two together. The reality is that the skeletal pattern in the Class II/2 population is distinct in its presentation and more closely resembles the Class I malocclusion pattern than II/1 pattern. In addition to distinguishing the two Divisions of Class II malocclusion, Angle astutely recognized a higher prevalence of subdivision malocclusion in the Class II/2 population. By his own estimation, up to 70% of Class II/2 malocclusions may have a subdivision component with over 50% of all Class II malocclusions having a subdivision component (Angle, 1899) . To date, there is little evidence to confirm Angle's assertions regarding the occurrence of subdivision malocclusion.

Subdivision malocclusions present a unique challenge to orthodontists. Determining the etiology of the malocclusion can be of critical importance in determining the best course of treatment for the patient. Failure to recognize the source of the asymmetry can lead to prolonged treatment time in addition to failure to correct the original problem. The etiology of the subdivision may be an underlying skeletal asymmetry or dentoalveolar deviation, or a combination of the two. During development, any number of issues may result in dentoalveolar asymmetry. These include differences in the timing of primary tooth exfoliation (or extraction) on one side of the dental arch versus the other, position and orientation of the developing tooth buds, variations in the timing and direction of permanent tooth eruption, congenitally missing teeth, differences in tooth emergence and sequence, tooth-size asymmetries, position of antagonists and others. Further, skeletal asymmetry may occur for a variety of reasons as well, to include trauma to the condyle and other developing structures, functional shifts secondary to dental interferences and chewing side preference, among others (Sato 2005) (Proffit 1980, 1985). Often times, however, there is no discernible etiology for the existence of skeletal asymmetry (Gato 1966).

Numerous studies have attempted to determine the etiology of the asymmetric occlusal relationships. The majority of studies which used 2-dimensional imaging to investigate Class II subdivision malocclusions have failed to discern a skeletal etiology for the asymmetric occlusal relationship. Alavi et al (1988), using posteroanterior and lateral cephalometric radiographs in addition to models,

reported that the primary contributor to subdivision malocclusion is unilateral distal positioning of the mandibular molar. Further, although asymmetry of both the skeletal bases and dentoalveolar segments was found to be present in both normal occlusion groups and subdivision malocclusions, it was not determined whether the unilateral distal positioning of the mandibular molar occurred due to an asymmetric molar positioning within the alveolus or due to an asymmetric positioning of the mandible itself. Likewise, Rose et al (1994), with the use of submentovertex radiographs, found no significant difference in mandibular asymmetry in those with a subdivision malocclusion, again, reporting that the subdivision malocclusion occurs primarily due to dentoalveolar asymmetry. These studies are supported by the findings of Azevedo et al (2006), who found subdivision malocclusion to be primarily dentoalveolar in nature. More specifically, distal position of the mandibular molar on the Class II side of the malocclusion was the most common etiology of the subdivision and, less commonly, mesial positioning of the maxillary molar on the Class II side. Like Alavi, Rose and numerous others, Azevedo used 2-dimensional radiographs to ascertain dentoalveolar and skeletal asymmetry. 2-dimensional images traditionally used for the study of asymmetry include lateral and posteroanterior cephalograms in addition to submentovertex radiographs. Due to the fact that 3-dimensional structures are being projected onto flat 2-dimensional films, distortion and magnification errors are introduced to the images. With the lateral cephalogram, an object's closer proximity to the film (i.e. on the left side) will be less magnified than its contralateral counterpart located further from the film.

Similarly, with panoramic radiography, various amounts of vertical and horizontal magnification will occur dependent upon the position of structures relative to the focal trough (Larson, 2012). In addition to magnification issues, other reported problems include difficult landmark identification, poor reproducibility of landmark identification and positioning/orientation errors.

Cone-beam computed tomography (CBCT) offers a distinct advantage over 2-dimensional methods for studying asymmetry and other morphological features of the craniofacial skeleton. True anatomic form, without magnification, can be visualized in 3-dimensions (3D), offering a more reliable method for the study of morphology and allowing direct comparison of paired and midline structures (Kwon, 2006). Because of the advantage of 1:1 geometry afforded by CBCT, more accurate and reliable measurements are possible (Berco, 2009). Berco et al also demonstrated that skull orientation does not affect the accuracy and reliability of measurements made using CBCT, thus eliminating positioning/orientation errors frequently seen with conventional two-dimensional imaging methods.

Sanders et al (2010) evaluated dentoalveolar and skeletal asymmetry in patients with Class II subdivision malocclusions using CBCT and found that the primary factor contributing to the subdivision malocclusion is mandibular asymmetry, with a shorter and more posteriorly positioned mandible on the Class II side. This was the first published literature, to date, examining asymmetry in Class II

subdivision malocclusions utilizing CBCT. However, it failed to distinguish or contrast between Class II/1 and Class II/2 types.

In the current study, the hypothesis is that the prevalence of subdivision malocclusions is higher in Class II/2 than in Class II/1 malocclusions and that this can be attributed to greater skeletal asymmetry in the former. Secondly, if there is a difference, a number of mandibular measurements will be made to ascertain where the most common asymmetries occur.

II. OBJECTIVES

A. Overall Objective

The overall objective of this study was to determine if there is a difference in skeletal and/or dentoalveolar asymmetry between patients with Class II Division 1 subdivision and Class II Division 2 subdivision malocclusions. The first goal of the study was to determine the prevalence of subdivision malocclusions within each Division of Class II malocclusion. The second goal of the study was compare asymmetry between Class II/1 and Class II/2 groups, aiming to determine if one group demonstrates more asymmetry than the other. Further, insight regarding the etiology of the subdivision malocclusion between groups will be sought.

B. Specific Hypothesis

There is a higher prevalence of subdivision malocclusion in Class II Division 2 subjects than Class II Division 1 subjects. Furthermore, that there exists a higher occurrence of skeletal (i.e. mandibular) asymmetry in subjects with Class II Division 2 malocclusions.

III. MATERIALS AND METHODS

A. Experimental Design

In accordance with an institution review board (IRB) protocol (retrospective, human-exempt) approved by the Wilford Hall Ambulatory Surgical Center, patient records were obtained from the Tri-Service Orthodontic Residency Program (Air Force Postgraduate Dental School, JBSA-Lackland AFB, San Antonio, TX) that often uses CBCT imaging for diagnostic purposes, particularly when asymmetries are noted. Over 1500 patient records (intraoral photos, clinical examination records, and CBCT scans) were reviewed to select the study sample based on the pre-determined inclusion criteria. The Cone-Beam CT images were taken using the iCat Platinum unit (Imaging Sciences International, Hatfield, PA) with a 17 cm (height) x 23 cm (diameter) field of view at a resolution of 0.3 voxels. All images were collected at 120 kVp and 5mA based on the manufacturer's specifications and recorded as DICOM (digital imaging and communications in medicine) files. The DICOM files were subsequently imported into Dolphin 3D (version 11.5, Dolphin Imaging, Chatsworth, CA).

Intraoral photos, clinical examination records and CBCT scans were utilized to select the study sample. Inclusions criteria for the Class II Division 1 subdivision group included: (1) Complete Class I molar relationship on one side of the dental arch with at least a half-step Class II relationship on the other side; (2) all permanent teeth erupted, including second molars; (3) no malformed or missing teeth, or teeth with extensive restorations or gross decay. Inclusion criteria for

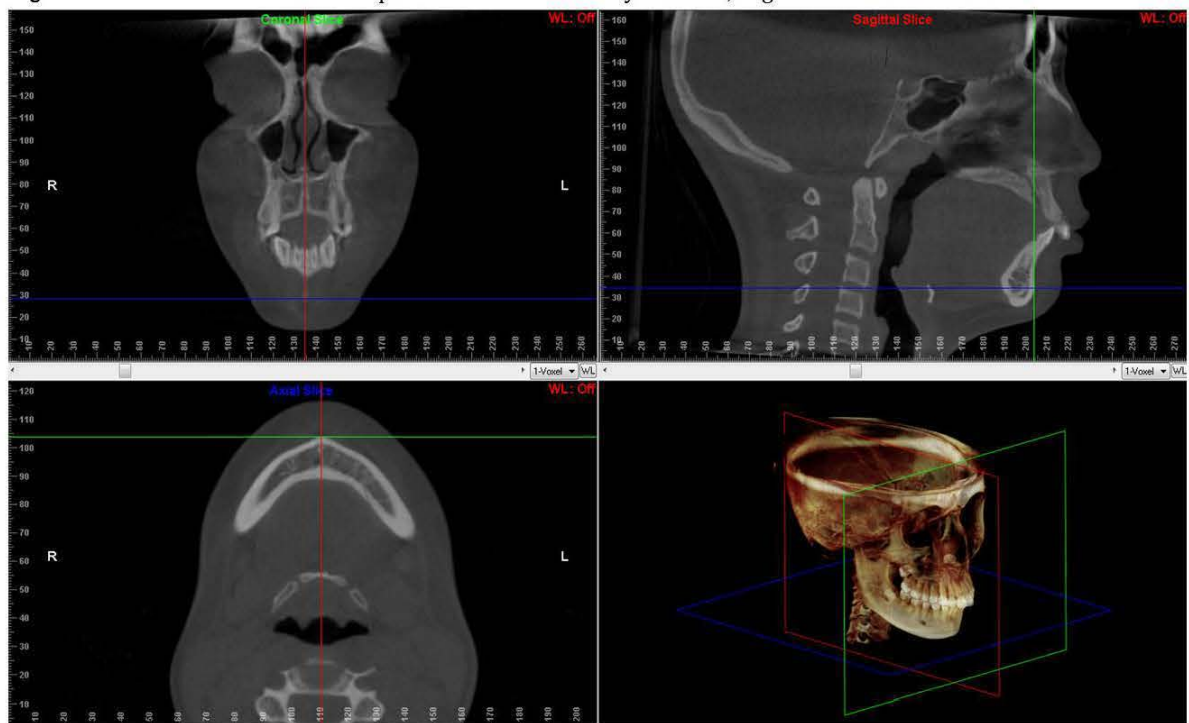
the Class II Division 2 subdivision group included: (1) All of the above criteria as stated for the Class II/1 group; (2) maxillary central incisor to Sella-Nasion line $< 98^\circ$; (3) mandibular plane to Frankfurt horizontal angle $< 24^\circ$; (4) overjet < 3 mm; (5) overbite > 4 mm. No exclusion criteria were established to control for age, gender or race in either group. From the population screened for inclusion in the study, 20 subjects with Class II/2 subdivision malocclusions were identified. Likewise, 20 subjects with Class II/1 subdivision malocclusions were selected for comparison (the first 20 identified that satisfied the inclusion criteria).

For this study, 7 landmarks (5 bilateral landmarks and 2 midline landmarks) were chosen and used to make 8 bilateral linear measurements (16 total measurements/subject). The five bilateral landmarks chosen were as follows: 1) Condylion (Co), 2) gonion (Go), 3) articular fossa (AF), 4) mesial surface of the maxillary first molar (Mx6), and 5) the mesial surface of the mandibular first molar (Mn6). Midline landmarks were 1) pogonion (Po), and 2) anterior nasal spine (ANS). The following linear measurements were made to determine mandibular skeletal and dentoalveolar asymmetry: 1) Condylion to gonion (Co-Go), 2) gonion to pogonion (Go-Po), 3) pogonion to condylion (Po-Co), 4) condylion to mesial surface of mandibular first molar (Co-Mn6), and 5) mesial surface of mandibular first molar to pogonion (Mn6-Po). The maxillary linear measurements made were as follows: 1) Articular fossa to anterior nasal spine (AF-ANS), 2) mesial of maxillary first molar to anterior nasal spine (Mx6-ANS), and 3) articular fossa to mesial of the maxillary first molar (AF-Mx6). All landmarks were

identified and measurements made solely by the principal investigator using the Dolphin Imaging 11.5 3D software application (Dolphin Imaging and Management, Chatsworth, CA). All landmarks were marked and linear measurements made directly from coronal, axial and sagittal slices taken from the pre-treatment CBCT images for each subject in order to determine skeletal and dentoalveolar asymmetry.

A pilot study was performed to determine intra-rater reliability. All right-sided landmarks were selected and measurements made for the first ten subjects within the Class II Division 1 subdivision group. Said measurements were made three times at separate time intervals (separated by at least one week). Means and standard deviations were calculated and compared using Student's t-tests. Additionally, the Dahlberg formula was applied to determine intra-rater reliability for each measurement.

Fig I. Orientation and reference planes used in this study: coronal, sagittal and axial



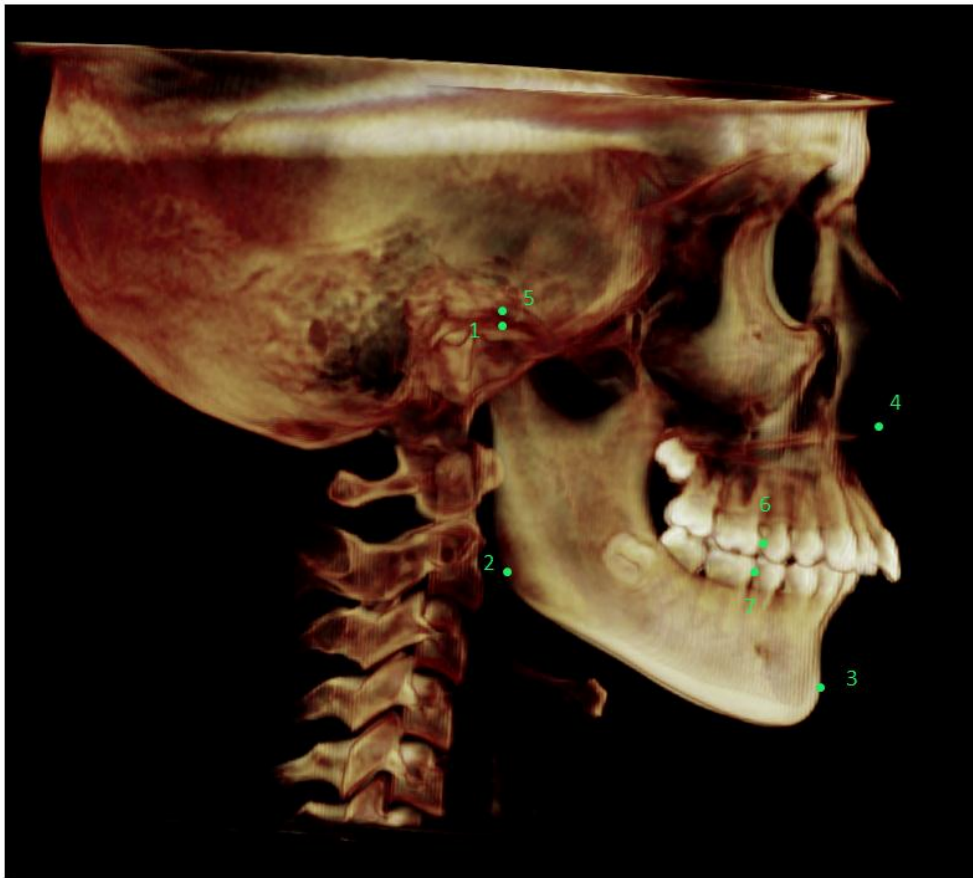


Fig 2. Landmarks used in this study (all measurements were made bilaterally in each subject): 1. condylion (Co) 2. gonion (Go) 3. pogonion (Po) 4. anterior nasal spine (ANS) 5. articular fossa (AF) 6. mesial Mx first molar (Mx6) 7. mesial Mn first molar (Mn6)

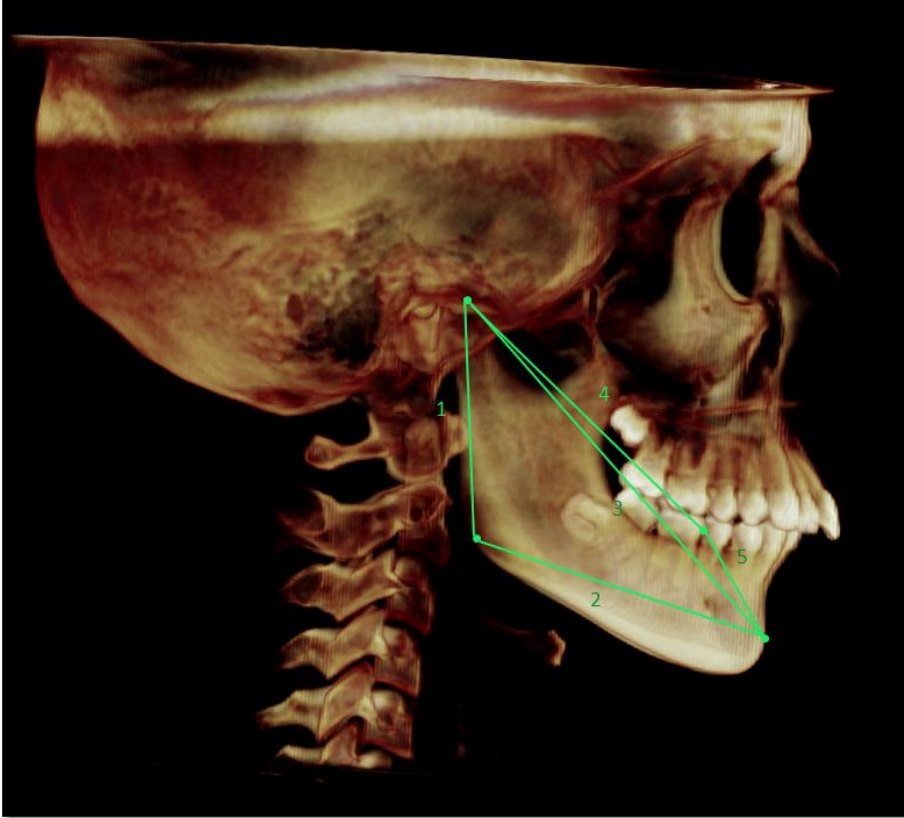


Fig 3. Mandibular measurements (all measurements were made bilaterally in each subject): 1: Co-Go (Condylion-Gonion) 2: Go-Po (Gonion-Pogonion) , 3: Co-Po (Condylion-Pogonion), 4: Co-Mn6 (Condylion-Mesial surface of mandibular first molar), 5: Po-Mn6 (Pogonion-Mesial surface of mandibular first molar)

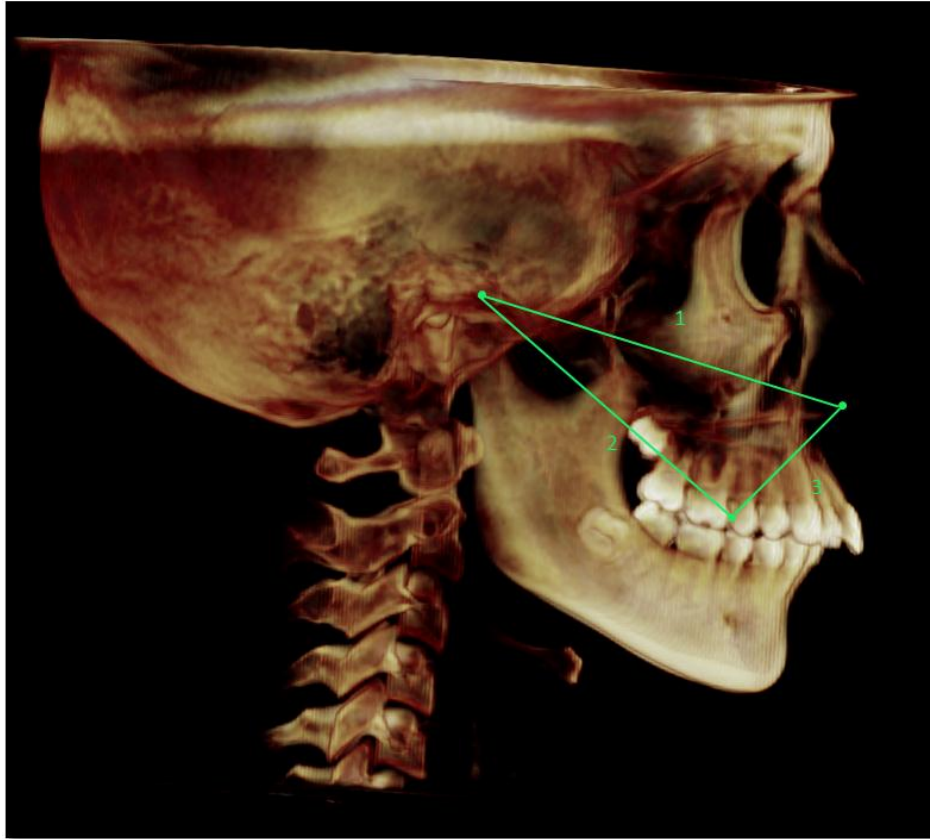


Fig 4. Maxillary measurements (all measurements were made bilaterally in each subject): 1: AF-ANS (Articular fossa-Anterior nasal spine), 2: AF-Mx6 (Articular fossa-Mesial surface of maxillary first molar), 3: ANS-Mx6 (Anterior nasal spine-Mesial surface of maxillary first molar)

B. Statistical Management of Data

A pilot study was conducted to determine intra-rater reliability; eight landmarks (five in the mandible and three in the maxilla) were identified and eight linear measurements were made between said landmarks at two different time points using coronal, axial and sagittal slices from the CBCTs of the first ten subjects in the Class II/1 subdivision group. Mean values and standard deviations were determined from the measurements made on subjects' right sides (chosen arbitrarily). Intra-rater reliability was calculated using the Dahlberg's formula. Based on these results, all linear measures were accepted for inclusion in the study.

After establishing intra-rater reliability of the primary investigator, linear measurements, as described previously, were made bilaterally for each subject at three time intervals. Average values and standard deviations were obtained for each measure and the data were analyzed. Absolute differences between right side and left side linear measurements were calculated for each subject in each of the two groups, averaging the measurements from the three time points. From this data, mean absolute differences between right side and left side measurements were calculated for each of the eight linear measures. This provided a measure of overall asymmetry for each linear measure. Right and left side mean values were then compared using Student's t tests. Values of $p < 0.05$ were considered statistically significant. The data was then organized to

allow comparison of linear measures taken from the Class I side of the asymmetric malocclusion to the Class II side.

IV. RESULTS

The pilot study, consisting of the first ten subjects in the Class II/1 subdivision group and all eight bilateral linear measurements, showed that the intra-rater reliability of all linear measurements was acceptable (Table IV). All measurements were made at three separate time points by one examiner. Condylion-Gonion (Co-Go) was determined to have an accuracy level of 0.513 mm by the Dahlberg formula, which was the lowest level of reliability of all of the measurements. This is likely due to the difficulty in reliably identifying a point gonion along the convex structure at the junction of the ramus and body of the mandible. It was difficult to consistently identify where along this curvature the ramus ended and the body began, made more difficult by the anatomic variation common to this region. Still, the point Gonion was considered acceptably accurate for the purposes of the study and all linear measurements proposed initially were used for the remainder of the study.

Statistically significant ($p < .05$) side-to-side differences existed between Class II/1 subdivision subjects and Class II/2 subdivision subjects in two of the eight measures (Table V). Additionally, all mandibular measures exhibited increased side-to-side differences in the Class II/2 subdivision group versus the Class II/1 subdivision group. Measurements Co-Po and Co-Mn6 exhibited significantly more asymmetry in the Class II/2 subdivision group than in Class II/1 subjects. The mean difference in left-right measurements for Co-Po in the CI II/2 subdivision group was 2.36 mm +/- 1.26 versus 1.36mm +/- 0.98 in the CI II/1 subdivision group. For the measurement Co-Mn6, the mean left-right difference

was measured at 2.11 mm +/- 1.36 versus 1.23 mm +/- 1.05 for the Class II/1 group. Though both measures of asymmetry proved statistically significant, it must be noted that standard deviations for these measurements and the others made in this study, were high enough to call into question the strength of statistical significance. There were no statistically significant differences in maxillary left-right measures between the CI II/1 subdivision group and the CI II/2 subdivision group.

The data was then analyzed to compare differences in linear measurements between the Class I and Class II sides for each of the two groups (Figure 7). Means and standard deviations were collected for this data set. Paired Student's t tests were applied to compare each linear measure for the two groups. The amount of Class I versus Class II side asymmetry was statistically significant ($p < .05$) for the measurement Co-Po. The measurement Co-Po was 2.17 mm +/- 1.57 greater on the Class I side in the Class II/2 group versus 0.98 mm +/- 1.36 for the Class II/1 group. Though no other measurements proved statistically significant, there was an obvious trend identified, with each of the mandibular measures showing greater Class I to Class II side asymmetry in the Class II/2 group. That is, in Class II/2 subdivision malocclusions, there were greater differences in linear measures when comparing the Class I side of subjects to the Class II side than in the Class II/1 group. Again, it must be mentioned that standard deviations were high for all measures, thus diminishing the strength of statistically significant findings.

Fig 5. Prevalence of A) Division 1 and Division 2 malocclusion in study Class II population, B) non-subdivision and subdivision in study Class II Division 1 population, C) non-subdivision and subdivision in study Class II Division 1 population

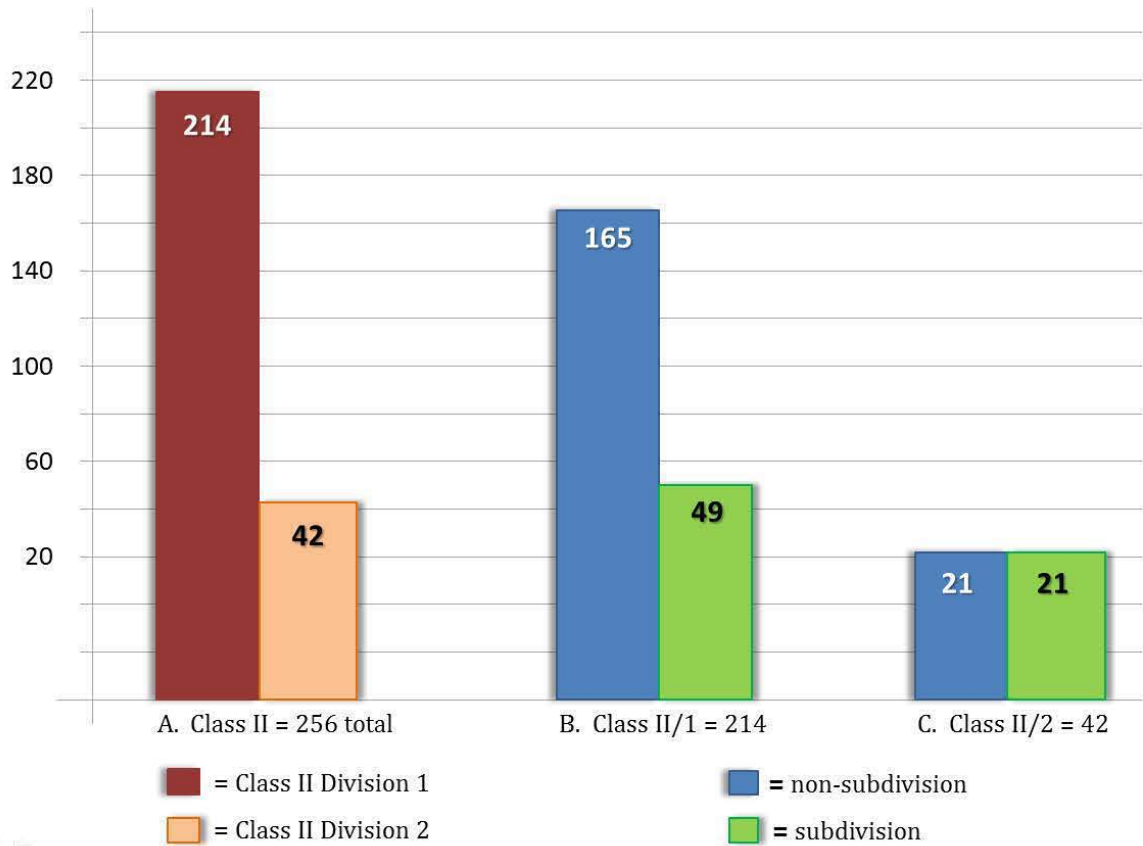
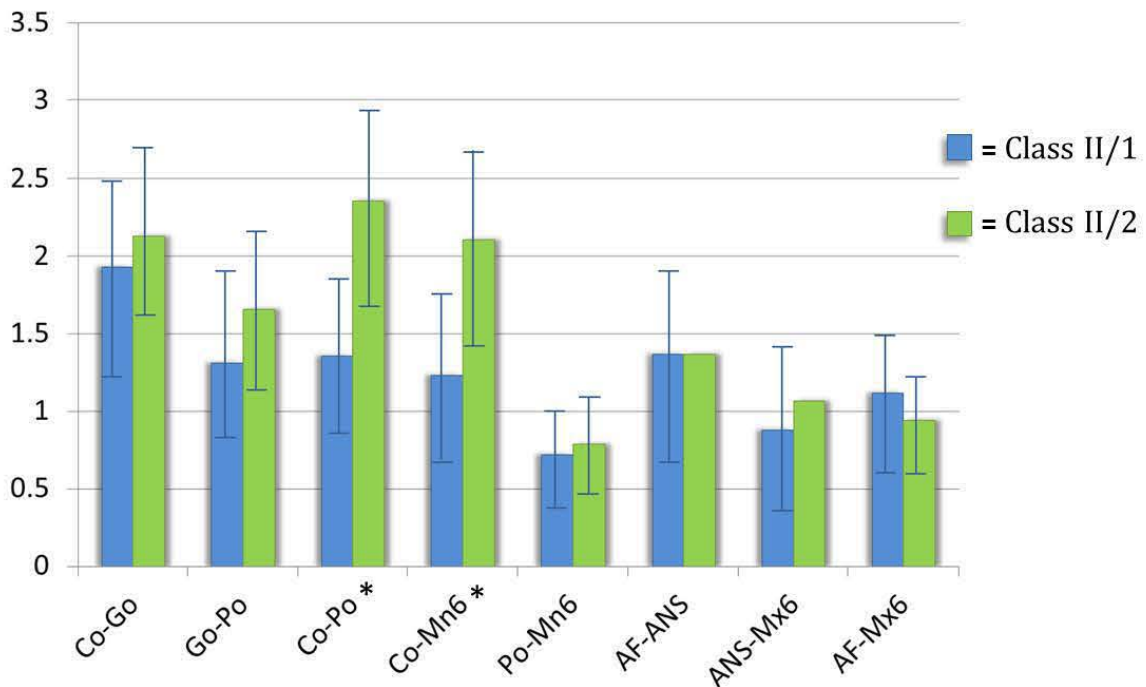
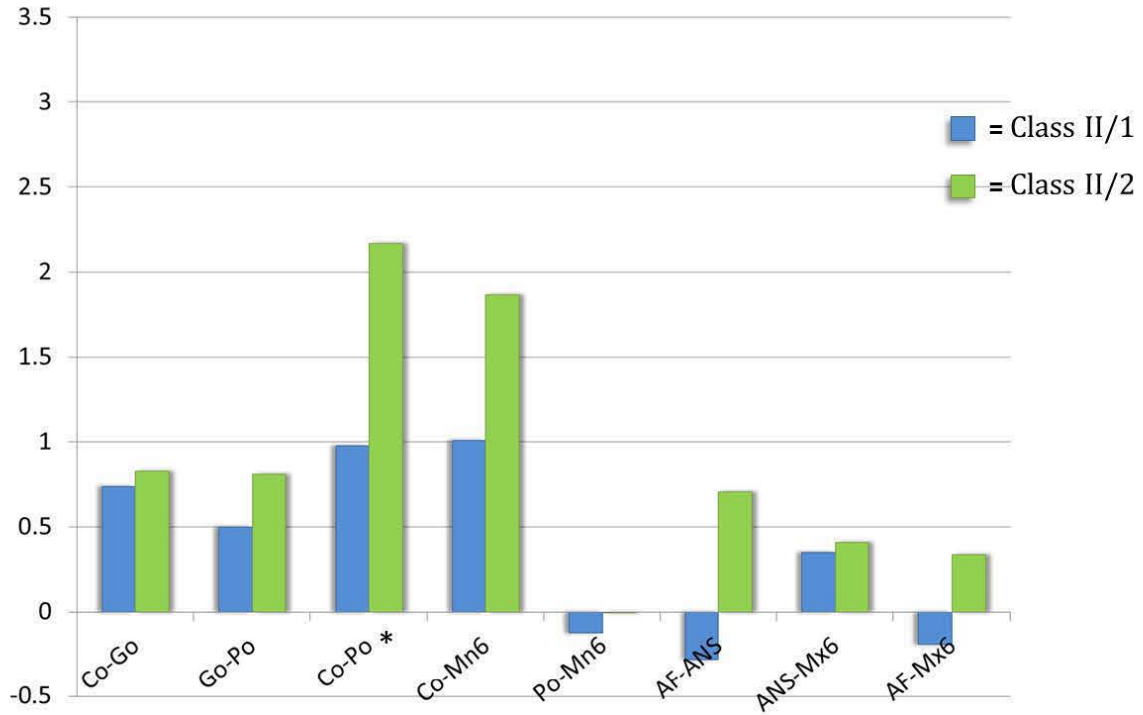


Fig 6. Comparison of absolute differences in left-right linear measurements (in mm) between Class II Division 1 subdivision and Class II Division 2 subdivision malocclusion groups.



Class II Division 1 subdivision mean differences in symmetry represented by blue bars; Class II Division 2 subdivision mean differences in symmetry represented by green bars; whiskers indicate Standard Deviation for each variable; * Statistically significant ($p < 0.05$)

Fig 7. Comparison of symmetry between Class I and Class II sides for the two groups (Class II Division 1 subdivision and Class II Division 2 subdivision)



Positive values indicate a greater linear measurements on the Class I side (i.e. non-subdivision side); * statistically significant ($p < 0.05$)

Table I. iCat CBCT unit: technical parameters and settings

<i>Technical parameter</i>	<i>Value</i>
Manufacturer	Imaging Sciences
X-ray source voltage	120 kVp
X-ray source current	5 mA
Focal spot size	0.5 mm
X-ray beam size	0.5 x 0.5 to 8 x 10 in
Scanning time	17.8 seconds
Image acquisition	Single 360° rotation
Image detector	Amorphous silicon flat panel
Gray scale	12 bit
Field of view	17.0 cm (diameter) x 13.2 cm
Voxel size (mm)	0.3 mm
Primary reconstruction time	About 60 seconds
Secondary reconstruction time	Real time
Radiation exposure (mSV)	135-193 μ Sv
Patient positioning	Seated with flat occlusal plane

Table II. Inclusion Criteria for the Sample Selection

<i>Class II Division 1 Subdivision group</i>	<i>Class II Division 2 Subdivision group</i>
Class II side being at least a 1/2 step Class II All permanent teeth up to 2nd molar present anomalies	Class II side being at least a 1/2 step Class II All permanent teeth up to 2nd molar present anomalies Max central incisor to sella-nasion line < 98° Mandibular plane to Frankfurt horizontal plane < Overjet < 3 mm mandibular incisors

Table III. Description of Landmarks

<i>Landmark</i>	<i>Definition</i>
condylion (Co)	Most superior, posterior point on the mandibular condyles (bisected)
gonion (Go)	The point at the middle of the curvature at the angle of the mandible. Represents junction of the ramus and body of the mandible at its posterior inferior aspect (bisected)
pogonion (Po)	The most anterior point on the anterior curvature of Mandibular symphysis
articular fossa (AF)	The most superior point in the concavity of the fossa; the deepest point in the concavity
anterior nasal spine (ANS)	The most anterior midpoint on the anterior nasal spine of the maxilla
mesial surface of mandibular first molar	The point on the mesial surface of the mandibular first molar at the height of contour
mesial surface of maxillary first molar	The point on the mesial surface of the maxillary first molar at the height of contour

Table IV. Accuracy Statistics (in mm) of Linear Measurements from First Ten Subjects in Class II Division 1 Subdivision Group

Class II Division 1 Subdivision Pilot Group (n=10)				
Location	Variables	Mean	Mean range	Accuracy
MANDIBLE	Co-Go	56.71	1.21	0.469
	Go-Po	82.3	0.85	0.513
	Co-Po	116.21	0.52	0.374
	Co-Mn6	77.97	0.58	0.36
	Po-Mn6	39.76	0.48	0.297
MAXILLA	AF-ANS	99.11	0.66	0.329
	ANS-Mx6	41.73	0.63	0.499
	AF-Mx6	75.93	0.51	0.413

Accuracy determined using Dahlberg's formula

All measurements were made at two separate timepoints bilaterally. Right/left side accuracy was averaged to determine the mean intra-rater reliability for each linear measure

Table IV. Descriptive Statistics and Statistical Comparisons of Right-Left Measurements (in mm) in Class II Division 1 Subdivision and Class II Division 2 Subdivision Groups

Variable	Class II Division 1 Subdivision Group				Class II Division 2 Subdivision Group				Cl II/Div1 subd vs. Class II/Div 2 subdiv
	Mean	SD	Min	Max	Mean	SD	Min	Max	
Co-Go	1.93	1.32	0.3	5.37	2.13	1.17	0	5.13	NS
Go-Po	1.31	1.01	0.1	4.07	1.66	0.97	0.27	3.27	NS
Co-Po	1.36	0.98	0.27	3.8	2.36	1.26	0.67	5.33	*
Co-Mn6	1.23	1.05	0	3.97	2.11	1.36	0.03	5.47	*
Po-Mn6	0.72	0.57	0.13	1.7	0.79	0.57	0.07	1.97	NS
AF-ANS	1.37	1.2	0.1	5.47	1.37	1.07	0.07	2.7	NS
ANS-Mx6	0.88	1.09	0	4.73	1.07	0.89	0.03	3.33	NS
AF-Mx6	1.12	0.8	0.03	2.57	0.94	0.54	0.03	1.7	NS

SD indicates standard deviation; Min, minimum; Max, maximum; NS, not significant

*P < 0.05

V. DISCUSSION

Given the often stark morphological differences between a Class II/1 and Class II/2 malocclusion, it is a diagnostic oversimplification to group the two together as one in the same under the heading 'Class II malocclusion.' Much has been written about the development of a Class II subdivision malocclusion but this is the first study, to the author's knowledge, to compare skeletal morphological differences between a Class II Division 1 subdivision malocclusion to that of a Class II Division 2 subdivision malocclusion. In his study of subdivision malocclusion, Sanders concluded that posteriorly positioned and shorter mandibles on the Class II side are the primary etiological factors in the occurrence of subdivision malocclusion. The results of this study indicate the same, at least in regard to mandibular length, as there was an identifiable trend of decreased mandibular length on the Class II side in both Division 1 and Division 2 subdivision malocclusions. No comment could be made in regard to the antero-posterior positioning of the mandible itself, as in this study's design, reference planes were not established.

The first objective of this study was to determine whether there is a higher prevalence of subdivision malocclusion in the Class II/2 type. Based on the population studied, the results indicate that, in fact there is. The results indicate that a subdivision malocclusion was present in 50% of subjects with Class II/2 malocclusion (21 out of 42). In the Class II/1 group, on the other hand, 22.9% (42/256) were found to have a subdivision malocclusion. These results suggest that asymmetry may be one of the constellation of features that commonly

characterize the Class II/2 malocclusion, albeit less common than other features which may be considered pathognomonic. More common morphological features, as discussed previously, include upright maxillary central incisors, deep bite, decreased mandibular plane angle, maxillomandibular hypodivergence and decreased lower face height (Brezniak 2002, Peck 1998). The higher prevalence of subdivision malocclusions found in Class II/2 subjects supports this initial hypothesis, which was based on clinical observation. It is noteworthy that Edward Angle, over a century ago, thought there to be a higher instance of asymmetric occlusal relationships in Class II/2 malocclusion yet, to the authors' knowledge, there was no prior or subsequent literature to support or refute his claim. As stated previously, Angle estimated that up to 70% of Class II/2 patients present with a subdivision malocclusion. Larger population studies would be needed to better estimate the true prevalence of subdivision in Class II/1 and Class II/2 populations.

Having found a higher prevalence of subdivision malocclusion in the Class II/2 group, the second objective was to determine if this may be due to greater skeletal and/or dentoalveolar asymmetry. The results of this study indicate that there is greater mandibular asymmetry in the Class II/2 malocclusion population (versus Class II/1 malocclusion). Two of five measures of mandibular asymmetry proved significantly greater ($p < 0.05$) in the Class II/2 malocclusion group. These were Co-Po and Co-Mn6. The results from the remaining three mandibular measures also indicate greater asymmetry in the Class II/2 malocclusion group, though not to a statistically significant degree. Of the linear measurements

chosen for use in this study, Co-Po is most indicative of total mandibular length and therefore, the most logical measurement to use when comparing mandibular length between sides. The landmark Pogonion was chosen for its relative ease in identification. Other authors have used various points to define mandibular length, including McNamara, who used condylion-gnathion to measure “effective mandibular length” in his widely-accepted cephalometric analysis (1984).

The development of a Class II subdivision malocclusion is multifactorial, as is the development of Class II malocclusions in general. Although there is agreement that a confluence of factors may lead to the development of subdivision malocclusion, it remains difficult to pinpoint the precise cause of the asymmetric occlusion in most cases (Fischer 1953). In regards to the development of the Class II/2 malocclusion, Ricketts found that the condyles rest in a more posterior and superior position. This may be due to the upright nature of the maxillary incisors and in essence, a restricted forward positioning of the mandible. Ricketts defined this scenario as a “posterior functional shift.” It is thought by some that by proclining the maxillary incisors to a more normal inclination, you may restore the ability for the condyles and the mandible to move forward closer to a Class I relationship, sometimes referred to as “unlocking the mandible.” It is generally accepted that functional shifts, lateral and otherwise, may affect symmetric growth of the mandible. It is possible that a posterior functional shift, if assumed to be occurring in the Class II/2 population, may have the same effect therefore leading to greater mandibular asymmetry in this population. This is merely speculation but merits further investigation on this subject.

Proper diagnosis and treatment planning in cases of asymmetric malocclusion, be it of true skeletal or dental etiology, is one of the more challenging elements that we deal with in orthodontic practice. The results of this study indicate that mandibular asymmetry is a common feature of Class II/2 malocclusion. It cannot be assumed that non-subdivision Class II/2 malocclusions would demonstrate more asymmetry than their Division 1 counterparts since only subdivision malocclusions were investigated in this study. Further, it is true that some degree of skeletal asymmetry is considered normal. As normative data, the differences in symmetry, even in those variables found to be statistically significant in this study, may be small enough to be considered not clinically significant. That said, it is prudent for the orthodontist to look closely for both dental and skeletal asymmetry prior to initiating definitive treatment. This is especially true given the fact that the deep bite, a feature common to the Class II/2 phenotype, may mask dental midline discrepancies. Early recognition of asymmetry, be it dental or skeletal in nature, will help the clinician to formulate the most efficient treatment plan to correct the patient's malocclusion. Special treatment considerations in the correction of subdivision malocclusion may include asymmetric extractions and/or surgery in addition to specific anchorage concerns.

When comparing absolute differences in bilateral linear measurements between groups, one other measurement proved statistically significant ($p < 0.05$); that was, Co-Mn6. It is impossible to say whether this was due to an overall increase in effective mandibular length (i.e. skeletal asymmetry) or due to distal

positioning of the mandibular molar on the Class II side. In other studies, reference planes were established, thereby allowing mesio-distal position of the molar to be better assessed. Since reference planes were not established in this study, no definitive conclusions could be drawn regarding the mesiodistal position of maxillary and mandibular molars. Furthermore, when the data was studied to compare Class I versus Class II sides of subdivision malocclusion, the differences between sides of Co-Mn6 did not prove significant. The only significant finding when analyzing the data in this manner was, as previously stated, Co-Po.

Although the methods described in this study were found to be sufficiently accurate in the determining the existence of mandibular asymmetry, it would be impractical to apply routinely in the diagnostic process. There are some inherent weaknesses that must be recognized as well. Without the establishment of reference planes, it is impossible to determine whether the molar is mesially or distally positioned in craniofacial complex. For example, if it were determined that there is significant differences in the measurement Co-Mn6 between sides, it could be due to the asymmetry in the molar position itself or due to mandibular asymmetry. Without reference planes, it is impossible to determine. Therefore, this study could not draw conclusions about the mesio-distal position of the maxillary or mandibular first molar. According to Sanders (2010), a mesially positioned maxillary molar and a distally positioned mandibular molar on the Class II side were minor contributing factors in the etiology of subdivision malocclusions.

Another limitation of this study was that no second evaluator was used to verify the linear measurements made, making the determination of inter-rater reliability impossible. Previous studies, however, indicate that inter-rater reliability while admittedly not as strong as intra-rater reliability is, in fact considered acceptable (Goldenberg 2007, Lagrevere 2009). The intra-rater reliability reported here showed good reproducibility of measurements and therefore it was concluded that little information would be gained from an additional evaluator. That said, CBCT imaging offers distinct advantage over conventional radiographic techniques for making linear measurements in the assessment of skeletal morphology. One of the main advantages of CBCT over conventional radiography for the purposes of making linear measurements is that it is not subject to magnification error. Ludlow et al showed that skull orientation did not significantly affect accuracy of linear measurements the way that it potentially does with cephalometric and panoramic techniques (2007).

It must be stated that with all measurements made in this study, there existed high standard deviations thus diminishing the strength of statistical significance. Each of the two groups of subdivision malocclusions included twenty subjects. The occurrence of Class II/2 malocclusion has been found to be between 3-4% in the United States with Class II/2 subdivision malocclusions occurring significantly less (at one half the rate according to the result of this study) (Massler 1951). The strength of this study would have been greater had there been more suitable subjects. Another factor may be the broadness of the inclusion criteria utilized in the selection of the study sample. The inclusion criteria for the subdivision

groups specified that there must be at least a half-step Class II molar relationship on one side. If a more stringent inclusion criteria had been selected, perhaps the asymmetry detected in this study (in mandibular length, condylion-pogonion) would be more pronounced or demonstrate a higher degree of statistical significance.

VI. CONCLUSION

1. In the population studied, 256 patients met the inclusion criteria determined for Class II malocclusion. Of these, 83.6% (214 of 256) had Class II Division 1 malocclusion. The other 16.4% (42 of 256) had Class II Division 2 malocclusion.
2. The prevalence of unilateral Class II malocclusion (i.e. subdivision malocclusions) was greater in Class II Division 2 patients than in Class II Division 1 patients by almost twofold.
3. Bilateral linear measurements using selected maxillary and mandibular skeletal and dental landmarks reveal a trend of greater mandibular asymmetry in patients with Class II Division 2 subdivision malocclusion. Every mandibular variable measured indicated a greater degree of mandibular asymmetry in the Class II Division 2 subdivision malocclusion group, with the measure Co-Po proving statistically significant.
4. Linear measurements using the seven landmarks selected in this study can be made accurately, with good intra-rater reliability and would be acceptable for further studies. However, with recent advances in the use of 3D volumetric analysis via CBCT, it is possible that newer methods may enable more accurate assessment of skeletal morphology, including skeletal asymmetries.

Appendix A. Raw data. Class II Division 2 Subdivision Group. Mandibular measurement

subject	co-go			go-po			co-po			co-mn6			po-mn6			
	right	left	r-l	right	left	r-l	right	left	r-l	right	left	r-l	right	left	r-l	
2-0001	1	52.2	50.3	1.9	84.6	87.6	-3	118.3	120.9	-2.6	79	81	-2	38.5	40.2	-1.7
	2	53	53.3	-0.3	83.6	88	-4.4	118.9	120.4	-1.5	79.3	81.2	-1.9	39.7	40.8	-1.1
	3	52.3	51.6	0.7	85.6	88	-2.4	118.2	120.2	-2	78.8	81.5	-2.7	40.2	39.9	0.3
	mean	52.5	51.73	0.767	84.6	87.87	-3.27	118.5	120.5	-2.03	79.03	81.23	-2.2	39.47	40.3	-0.83
SD			0.899			0.838			0.45			0.356			0.838	
2-0002	1	66.6	66.6	0	91.5	88.8	2.7	130.2	126.9	3.3	87.1	84	3.1	44.6	43.7	0.9
	2	66.4	65.2	1.2	92.8	90.7	2.1	130.3	126.4	3.9	87.3	83.5	3.8	43.8	43.7	0.1
	3	66.3	66.4	-0.1	92.5	87.9	4.6	129.3	126	3.3	85.7	84.4	1.3	43.4	43.6	-0.2
	mean	66.43	66.07	0.367	92.27	89.13	3.133	129.9	126.4	3.5	86.7	83.97	2.733	43.93	43.67	0.267
SD			0.591			1.066			0.283			1.053			0.464	
2-0003	1	60.7	56.6	4.1	80.7	81.8	-1.1	115.6	113.9	1.7	77.3	76.1	1.2	39.5	38.4	1.1
	2	59.8	56.8	3	80.2	80.5	-0.3	115.4	113.9	1.5	77.1	76	1.1	37.9	37.7	0.2
	3	59.1	58.2	0.9	80.8	80.2	0.6	116.4	113.9	2.5	76.8	76.4	0.4	38.9	37.5	1.4
	mean	59.87	57.2	2.667	80.57	80.83	-0.27	115.8	113.9	1.9	77.07	76.17	0.9	38.77	37.87	0.9
SD			1.327			0.694			0.432			0.356			0.51	
2-0004	1	57.1	57.3	-0.2	87.4	85.3	2.1	116	114.5	1.5	79.7	77.5	2.2	37.3	37.5	-0.2
	2	58.9	57.4	1.5	87.5	84.3	3.2	116	113.4	2.6	79.9	77.3	2.6	36.6	37.3	-0.7
	3	59.4	56.2	3.2	87.7	85.4	2.3	116.1	113.9	2.2	80.3	77.7	2.6	36.5	36.5	0
	mean	58.47	56.97	1.5	87.53	85	2.533	116	113.9	2.1	79.97	77.5	2.467	36.8	37.1	-0.3
SD			1.388			0.478			0.455			0.189			0.294	
2-0005	1	60.4	57	3.4	82.6	85.5	-2.9	111.6	112.6	-1	72.6	72.6	0	40.5	40.3	0.2
	2	60.8	59	1.8	82.1	82.8	-0.7	110.6	112	-1.4	71.8	73.2	-1.4	39.3	39.3	0
	3	61	60.1	0.9	81.5	82.1	-0.6	110.4	110.8	-0.4	70.7	73.2	-2.5	38.7	38.4	0.3
	mean	60.73	58.7	2.033	82.07	83.47	-1.4	110.9	111.8	-0.93	71.7	73	-1.3	39.5	39.33	0.167
SD			1.034			1.061			0.411			1.023			0.125	
2-0006	1	57.6	58.3	-0.7	94.9	93.5	1.4	122.9	123.1	-0.2	89.1	87.6	1.5	38.5	39.2	-0.7
	2	58.1	57.7	0.4	95	93.7	1.3	121.3	120.1	1.2	89.2	87.3	1.9	34.6	36.1	-1.5
	3	58	57.7	0.3	94.8	93.7	1.1	121.6	120	1.6	89.3	87.3	2	35.1	36	-0.9
	mean	57.9	57.9	0	94.9	93.63	1.267	121.9	121.1	0.867	89.2	87.4	1.8	36.07	37.1	-1.03
SD			0.497			0.125			0.772			0.216			0.34	
2-0007	1	67.9	67.1	0.8	94.8	94.8	0	127.4	127.3	0.1	85	85.3	-0.3	43.8	42.7	1.1
	2	69.8	65.7	4.1	93	94.2	-1.2	125.6	124.2	1.4	84.6	84.6	0	41.1	40.5	0.6
	3	70	66.1	3.9	92.9	94.1	-1.2	125.5	125	0.5	84.8	84.4	0.4	41	40.9	0.1
	mean	69.23	66.3	2.933	93.57	94.37	-0.8	126.2	125.5	0.667	84.8	84.77	0.033	41.97	41.37	0.6
SD			1.511			0.566			0.544			0.287			0.408	
2-0008	1	59.8	57.3	2.5	85.3	83.3	2	117.8	113.1	4.7	80.2	73.5	6.7	36.3	36	0.3
	2	57.4	55.5	1.9	80	82	-2	111.6	111.2	0.4	77.4	76.5	0.9	35.7	35.5	0.2
	3	57.9	55.4	2.5	79.8	82.7	-2.9	111.4	110.6	0.8	77.9	76.8	1.1	35.4	35.7	-0.3
	mean	58.37	56.07	2.3	81.7	82.67	-0.97	113.6	111.6	1.967	78.5	75.6	2.9	35.8	35.73	0.067
SD			0.283			2.13			1.94			2.688			0.262	
2-0009	1	64.9	62.9	2	89.6	86.3	3.3	127	126.2	0.8	86.8	84.7	2.1	41.7	42.8	-1.1
	2	65.7	63.2	2.5	89.2	86.1	3.1	129.6	128.1	1.5	89.7	87.7	2	41.4	41.4	0
	3	64.8	63.3	1.5	90.1	85.7	4.4	129.9	128.1	1.8	89.3	89.5	-0.2	42	40.7	1.3
	mean	65.13	63.13	2	89.63	86.03	3.6	128.8	127.5	1.367	88.6	87.3	1.3	41.7	41.63	0.067
SD			0.408			0.572			0.419			1.061			0.981	

2-0010	1	54.2	55.5	-1.3	81.6	81.3	0.3	110.6	112.6	-2	72.6	74.4	-1.8	38.7	38.9	-0.2
	2	59.1	61.2	-2.1	81.1	82.6	-1.5	113	113.4	-0.4	75	76.1	-1.1	39.2	39.4	-0.2
	3	59.3	61.4	-2.1	81.3	82.3	-1	113.4	114	-0.6	74.9	75.5	-0.6	39.1	39.2	-0.1
	mean	57.53	59.37	-1.83	81.33	82.07	-0.73	112.3	113.3	-1	74.17	75.33	-1.17	39	39.17	-0.17
	SD			0.377			0.759			0.712			0.492			0.047
2-0011	1	68.3	66.2	2.1	96	95.3	0.7	127.9	126.8	1.1	83.9	83.8	0.1	43.9	43.2	0.7
	2	68	66.4	1.6	95.5	91.3	4.2	126.8	125.4	1.4	83.8	83.6	0.2	42.7	41.9	0.8
	3	68.6	66	2.6	95.6	90.4	5.2	126.9	125.1	1.8	84.5	83.2	1.3	43.2	41.9	1.3
	mean	68.3	66.2	2.1	95.7	92.33	3.367	127.2	125.8	1.433	84.07	83.53	0.533	43.27	42.33	0.933
	SD			0.408			1.929			0.287			0.544			0.262
2-0012	1	60.5	56.5	4	87.3	88.5	-1.2	119.8	117.2	2.6	78.5	76.3	2.2	41.7	40.7	1
	2	61.1	57.4	3.7	87	88.3	-1.3	119.8	117	2.8	79	76.2	2.8	41.3	40.7	0.6
	3	60.1	57.5	2.6	86.7	87.9	-1.2	120	117	3	78.1	76.3	1.8	41.4	41	0.4
	mean	60.57	57.13	3.433	87	88.23	-1.23	119.9	117.1	2.8	78.53	76.27	2.267	41.47	40.8	0.667
	SD			0.602			0.047			0.163			0.411			0.249
2-0013	1	64.5	62.7	1.8	92.5	94.1	-1.6	129.7	127.6	2.1	92.1	87.4	4.7	38.4	40.3	-1.9
	2	65.1	64.2	0.9	92.1	92.4	-0.3	129.8	124.7	5.1	91.8	86	5.8	38.2	39.3	-1.1
	3	66.3	63.9	2.4	92.2	93.2	-1	129.6	125.6	4	92.2	87.8	4.4	38	39.4	-1.4
	mean	65.3	63.6	1.7	92.27	93.23	-0.97	129.7	126	3.733	92.03	87.07	4.967	38.2	39.67	-1.47
	SD			0.616			0.531			1.239			0.602			0.33
2-0014	1	59.5	63	-3.5	86.5	88.2	-1.7	118.5	123	-4.5	76.7	80	-3.3	43.2	44.1	-0.9
	2	60	61.3	-1.3	85.9	88	-2.1	116.4	122	-5.6	77.5	79.3	-1.8	43.4	43.9	-0.5
	3	60.1	62	-1.9	86	87.5	-1.5	116.9	122.8	-5.9	77.4	78.9	-1.5	42.9	44.4	-1.5
	mean	59.87	62.1	-2.23	86.13	87.9	-1.77	117.3	122.6	-5.33	77.2	79.4	-2.2	43.17	44.13	-0.97
	SD			0.929			0.249			0.602			0.787			0.411
2-0015	1	52.2	51	1.2	93.9	91.2	2.7	121.7	123.2	-1.5	82.6	83.2	-0.6	40.6	40.5	0.1
	2	52.9	51.1	1.8	93	92.3	0.7	121.9	122.9	-1	82	83.4	-1.4	40.4	40.9	-0.5
	3	52.8	51.5	1.3	93.4	91.9	1.5	122.1	122.7	-0.6	81.9	83.2	-1.3	40.9	41.2	-0.3
	mean	52.63	51.2	1.433	93.43	91.8	1.633	121.9	122.9	-1.03	82.17	83.27	-1.1	40.63	40.87	-0.23
	SD			0.262			0.822			0.368			0.356			0.249
2-0016	1	64.9	67.8	-2.9	88.6	89.3	-0.7	123	126.6	-3.6	83	87.4	-4.4	41.5	41.6	-0.1
	2	65.5	66.9	-1.4	88.2	89.4	-1.2	123.3	125.5	-2.2	83.3	87.2	-3.9	41.1	42	-0.9
	3	65.3	67.4	-2.1	88	89.9	-1.9	122.9	125.9	-3	83.2	87.1	-3.9	41	41.9	-0.9
	mean	65.23	67.37	-2.13	88.27	89.53	-1.27	123.1	126	-2.93	83.17	87.23	-4.07	41.2	41.83	-0.63
	SD			0.613			0.492			0.573			0.236			0.377
2-0017	1	64.8	60.1	4.7	82.7	82.8	-0.1	123	126.6	-3.6	80.1	82.1	-2	40	37.8	2.2
	2	64	60.9	3.1	82.9	83.9	-1	122.2	126.6	-4.4	80.3	82.3	-2	40.1	38.1	2
	3	64.3	60.4	3.9	82.5	86.2	-3.7	122.4	127	-4.6	80.3	82.1	-1.8	39.9	38.2	1.7
	mean	64.37	60.47	3.9	82.7	84.3	-1.6	122.5	126.7	-4.2	80.23	82.17	-1.93	40	38.03	1.967
	SD			0.653			1.53			0.432			0.094			0.205
2-0018	1	66.7	60.1	6.6	87.9	87.4	0.5	124.3	126.3	-2	86.3	87.1	-0.8	40.9	42.2	-1.3
	2	65.5	61.1	4.4	88	87.7	0.3	122.9	126	-3.1	86.1	87.3	-1.2	40.3	42	-1.7
	3	65.7	61.3	4.4	88.1	87.5	0.6	121.2	125.9	-4.7	86.4	87.6	-1.2	40.5	42.1	-1.6
	mean	65.97	60.83	5.133	88	87.53	0.467	122.8	126.1	-3.27	86.27	87.33	-1.07	40.57	42.1	-1.53
	SD			1.037			0.125			1.109			0.189			0.17

2-0019	1	57.2	58.3	-1.1	82.9	83.6	-0.7	114.5	118.3	-3.8	76.8	81.8	-5	40.4	38.7	1.7
	2	58	59.2	-1.2	82.7	84.2	-1.5	114.9	118.6	-3.7	76.5	82	-5.5	40.7	39	1.7
	3	58.4	59.3	-0.9	82.3	83.9	-1.6	114.7	118.6	-3.9	76.4	82.3	-5.9	40.7	38.9	1.8
	mean	57.87	58.93	-1.07	82.63	83.9	-1.27	114.7	118.5	-3.8	76.57	82.03	-5.47	40.6	38.87	1.733
	SD			0.125			0.403			0.082			0.368			0.047
2-0020	1	65.5	62	3.5	91.5	92	-0.5	127.8	125.2	2.6	94.2	92.3	1.9	38.8	40.1	-1.3
	2	65.3	62.4	2.9	93.9	92.1	1.8	127.3	125.7	1.6	94.3	92.3	2	38.4	39.9	-1.5
	3	65.1	62.2	2.9	96	92.4	3.6	127.8	124.9	2.9	94.5	92.8	1.7	38.4	39.5	-1.1
	mean	65.3	62.2	3.1	93.8	92.17	1.633	127.6	125.3	2.367	94.33	92.47	1.867	38.53	39.83	-1.3
	SD			0.283			1.678			0.556			0.125			0.163

Appendix B. Raw data. Class II Division 2 Subdivision Group. Maxillary measurements.

subject	af-ans			ans-mx6			af-mx6			
	right	left	r-l	right	left	r-l	right	left	r-l	
2-0001	1	103.4	105.3	-1.9	46.3	45.9	0.4	75.6	77	-1.4
	2	103.3	104.1	-0.8	45.5	45.7	-0.2	76.5	77.4	-0.9
	3	104.4	104.4	0	46	45.3	0.7	76.8	77.9	-1.1
	mean	103.7	104.6	-0.9	45.93	45.63	0.3	76.3	77.43	-1.133
	SD			0.779			0.374			0.205
2-0002	1	107	104.8	2.2	44.9	40.5	4.4	81.8	82.5	-0.7
	2	104.9	105.6	-0.7	43.1	40.9	2.2	83.1	82.8	0.3
	3	107.8	106.5	1.3	44.6	41.2	3.4	82	83.4	-1.4
	mean	106.6	105.6	0.933	44.2	40.87	3.333	82.3	82.9	-0.6
	SD			1.212			0.899			0.698
2-0003	1	95.2	93.3	1.9	40.5	39.4	1.1	73.4	73.6	-0.2
	2	94.1	92.9	1.2	40.9	39.2	1.7	73.3	73.3	0
	3	93.7	92.5	1.2	40.5	39.3	1.2	73.9	73.5	0.4
	mean	94.33	92.9	1.433	40.63	39.3	1.333	73.53	73.47	0.067
	SD			0.33			0.262			0.249
2-0004	1	102.2	100.8	1.4	44.7	43.2	1.5	75.9	77.1	-1.2
	2	102.4	99	3.4	44.1	42.6	1.5	76.1	76.8	-0.7
	3	102.2	98.9	3.3	44.2	43.3	0.9	76.6	76.9	-0.3
	mean	102.3	99.57	2.7	44.33	43.03	1.3	76.2	76.93	-0.733
	SD			0.92			0.283			0.368
2-0005	1	95.1	95.1	0	43.1	40.2	2.9	70	69.8	0.2
	2	93.7	93.9	-0.2	41.3	40.2	1.1	69.8	70	-0.2
	3	93.3	95.2	-1.9	41.3	40	1.3	69.9	70.7	-0.8
	mean	94.03	94.73	-0.7	41.9	40.13	1.767	69.9	70.17	-0.267
	SD			0.852			0.806			0.411
2-0006	1	109.6	109.8	-0.2	41.8	40.4	1.4	85.2	86.7	-1.5
	2	109.5	109.5	0	41.9	40.8	1.1	85.3	86.6	-1.3
	3	108.7	108.7	0	42.1	40.9	1.2	86	86.6	-0.6
	mean	109.3	109.3	-0.067	41.93	40.7	1.233	85.5	86.63	-1.133
	SD			0.094			0.125			0.386
2-0007	1	109.5	110.8	-1.3	44.6	45.3	-0.7	83.2	82.4	0.8
	2	108.9	109.2	-0.3	44.3	45.1	-0.8	83.7	81.7	2
	3	108.5	110.2	-1.7	44.6	45.3	-0.7	84.1	81.9	2.2
	mean	109	110.1	-1.1	44.5	45.23	-0.733	83.67	82	1.667
	SD		0.66	0.589			0.047			0.618
2-0008	1	99.4	98.4	1	42.7	41.5	1.2	75.8	74.5	1.3
	2	92.8	94	-1.2	40.2	40.4	-0.2	75.3	74.8	0.5
	3	93	94.1	-1.1	39.9	41.5	-1.6	75.2	75.2	0
	mean	95.07	95.5	-0.433	40.93	41.13	-0.2	75.43	74.83	0.6
	SD			1.014			1.143			0.535

2-0009	1	102.4	103.5	-1.1	40	38.5	1.5	83.3	85.8	-2.5
	2	104.3	103.2	1.1	40.9	38.8	2.1	84.2	85.2	-1
	3	104.3	103.5	0.8	40.7	39.4	1.3	84.6	85.4	-0.8
	mean	103.7	103.4	0.267	40.53	38.9	1.633	84.03	85.47	-1.433
	SD			0.974			0.34			0.759
2-0010	1	94.4	92.7	1.7	39.7	39.6	0.1	70.6	69.9	0.7
	2	96.4	94.4	2	40	38.8	1.2	72.4	72.2	0.2
	3	96.1	93.3	2.8	40.1	38	2.1	72.5	72.4	0.1
	mean	95.63	93.47	2.167	39.93	38.8	1.133	71.83	71.5	0.333
	SD			0.464			0.818			0.262
2-0011	1	105.5	104.3	1.2	42.2	44.5	-2.3	80.3	78.8	1.5
	2	105.5	104.9	0.6	42.5	45.8	-3.3	80.4	78.4	2
	3	105.7	105	0.7	42.9	46	-3.1	80	78.4	1.6
	mean	105.6	104.7	0.833	42.53	45.43	-2.9	80.23	78.53	1.7
	SD			0.262			0.432			0.216
2-0012	1	99	97.7	1.3	37.9	38.4	-0.5	76.1	75.5	0.6
	2	99.3	98.2	1.1	37.4	38.6	-1.2	76.8	75.3	1.5
	3	99.7	97.9	1.8	38.1	38.7	-0.6	76.8	75.8	1
	mean	99.33	97.93	1.4	37.8	38.57	-0.767	76.57	75.53	1.033
	SD			0.294			0.309			0.368
2-0013	1	107.4	105.3	2.1	37.8	39.4	-1.6	86.4	84.5	1.9
	2	103.9	105.7	-1.8	38.2	38.3	-0.1	86.1	84.6	1.5
	3	104.5	105.2	-0.7	37.9	38.6	-0.7	85.9	84.3	1.6
	mean	105.3	105.4	-0.133	37.97	38.77	-0.8	86.13	84.47	1.667
	SD			1.642			0.616			0.17
2-0014	1	94.1	96.6	-2.5	40.8	42.7	-1.9	75.9	77.2	-1.3
	2	94.3	95.5	-1.2	41	43	-2	76.4	75.9	0.5
	3	93.9	95.1	-1.2	41.2	43.4	-2.2	75.6	76.2	-0.6
	mean	94.1	95.73	-1.633	41	43.03	-2.033	75.97	76.43	-0.467
	SD			0.613			0.125			0.741
2-0015	1	100.6	103	-2.4	39.4	39.2	0.2	79.9	81.8	-1.9
	2	100.1	102.9	-2.8	39.3	39.4	-0.1	79.9	81	-1.1
	3	100.4	102.9	-2.5	39.9	39.7	0.2	80.4	81.4	-1
	mean	100.4	102.9	-2.567	39.53	39.43	0.1	80.07	81.4	-1.333
	SD			0.17			0.141			0.403
2-0016	1	101	103.8	-2.8	41.8	41.6	0.2	81.3	82.7	-1.4
	2	101.2	104	-2.8	41.8	41.8	0	81.4	82.2	-0.8
	3	101.4	103.8	-2.4	41.4	41.7	-0.3	81	82.1	-1.1
	mean	101.2	103.9	-2.667	41.67	41.7	-0.033	81.23	82.33	-1.1
	SD			0.189			0.205			0.245
2-0017	1	98	97.2	0.8	35.8	36.8	-1	77.6	76	1.6
	2	97.9	97.4	0.5	36	36.4	-0.4	77.2	76.3	0.9
	3	97.8	97.7	0.1	36.2	36.2	0	77.5	76.2	1.3
	mean	97.9	97.43	0.467	36	36.47	-0.467	77.43	76.17	1.267
	SD			0.287			0.411			0.287

2-0018	1	108.2	107.6	0.6	39.5	40.2	-0.7	85.5	84.3	1.2
	2	108	108.1	-0.1	39.9	40	-0.1	85	84.9	0.1
	3	108.6	108.4	0.2	39.8	39.9	-0.1	85.3	84.9	0.4
	mean	108.3	108	0.233	39.73	40.03	-0.3	85.27	84.7	0.567
	SD			0.287			0.283			0.464
2-0019	1	97.5	98.3	-0.8	38.2	39.1	-0.9	77.7	77.5	0.2
	2	97.8	98	-0.2	38.5	38.7	-0.2	77.2	77.9	-0.7
	3	97.9	97.9	0	38.6	38.2	0.4	77.3	76.9	0.4
	mean	97.73	98.07	-0.333	38.43	38.67	-0.233	77.4	77.43	-0.033
	SD			0.34			0.531			0.478
2-0020	1	104.4	105.3	-0.9	37.8	39.4	-1.6	86.4	84.5	1.9
	2	104.3	105	-0.7	38.2	38.3	-0.1	86.1	84.6	1.5
	3	105	104.8	0.2	37.9	38.6	-0.7	85.9	84.3	1.6
	mean	104.6	105	-0.467	37.97	38.77	-0.8	86.13	84.47	1.667
	SD			0.478			0.616			0.17

Appendix C. Raw data. Class II Division 1 Subdivision Group. Mandibular measurements.

subject		co-go			go-po			co-po			co-mn6			po-mn6		
		right	left	r-l	right	left	r-l	right	left	r-l	right	left	r-l	right	left	r-l
1-0001	1	58.7	55.4	3.3	87.6	87.6	0	120.2	117	3.2	80.9	79.3	1.6	41.8	39.9	1.9
sub L	2	58	55.3	2.7	88	88.1	-0.1	120.4	117.1	3.3	81.2	79.2	2	41.8	39.7	2.1
	3	58.3	56	2.3	88.2	86.8	1.4	120.5	116.9	3.6	81.4	79.4	2	41.3	40.3	1
	mean	58.33	55.57	2.767	87.93	87.5	0.433	120.4	117	3.367	81.17	79.3	1.867	41.63	39.97	1.667
	st dev			0.411			0.685			0.17			0.189			0.478
1-0002	1	53.3	52	1.3	77.3	77	0.3	111.5	109.3	2.2	74.9	73.8	1.1	37.6	36.6	1
sub R	2	53.9	53	0.9	77.9	77.1	0.8	111	110.1	0.9	75	74	1	38	36.2	1.8
	3	54.8	52.9	1.9	78.3	77.1	1.2	110.8	109.8	1	74.3	73.4	0.9	38.4	36.1	2.3
	mean	54	52.53	1.367	77.83	77.07	0.767	111.1	109.7	1.367	74.73	73.73	1	38	36.3	1.7
	st dev			0.411			0.368			0.591			0.082			0.535
1-0003	1	59.1	53.1	6	90.3	91.1	-0.8	122.4	121.2	1.2	85.7	84.7	1	38.8	38.5	0.3
sub L	2	58.9	53.3	5.6	89.9	91.9	-2	123	121.9	1.1	85	84.3	0.7	38.4	37.7	0.7
	3	58.4	53.9	4.5	91.1	91	0.1	122.1	121.2	0.9	85.9	85	0.9	39.1	38.6	0.5
	mean	58.8	53.43	5.367	90.43	91.33	-0.9	122.5	121.4	1.067	85.53	84.67	0.867	38.77	38.27	0.5
	st dev			0.634			0.86			0.125			0.125			0.163
1-0004	1	63.2	61.3	1.4	85.3	86	-0.7	120.4	122.5	-2.1	82.1	84.3	-2.2	41	40.3	0.7
sub R	2	63.4	63.3	0.1	85.3	85.3	0	121.2	122.9	-1.7	81.3	84.5	-3.2	40.2	40.9	-0.7
	3	65.6	63.2	2.4	85	86.7	-1.7	120.9	122.1	-1.2	81.7	85	-3.3	40.4	41	-0.6
	mean	64.07	62.77	1.3	85.2	86	-0.8	120.8	122.5	-1.667	81.7	84.6	-2.9	40.53	40.73	-0.2
	st dev			0.942			0.698			0.368			0.497			0.638
1-0005	1	56.5	56.5	-0.1	84.1	81.2	2.9	120.1	118.8	1.3	81.6	82.1	-0.5	39.9	38.6	1.3
sub R	2	56.8	56.3	0	83.3	82.9	0.4	119.2	119.8	-0.6	82.2	82.8	-0.6	40.2	38.3	1.9
	3	56	57.3	-1.3	84.2	82.8	1.4	119.8	118.4	1.4	81.3	81.1	0.2	39.8	37.8	2
	mean	56.43	56.9	-0.467	83.87	82.3	1.567	119.7	119	0.7	81.7	82	-0.3	39.97	38.23	1.733
	st dev			0.591			1.027			0.92			0.356			0.309
1-0006	1	48.9	44.4	4.5	75.8	77.4	-1.6	104.6	105.4	-0.8	68.9	69.7	-0.8	35.9	36.3	-0.4
sub R	2	46.3	44.3	1.5	76	77	-1	105	104.9	0.1	68.3	70	-1.7	36	35.8	0.2
	3	45.3	44.3	1	76.3	77.3	-1	104.5	105.8	-1.3	68.3	69.3	-1	36.4	35.8	0.6
	mean	46.83	44.5	2.333	76.03	77.3	-1.267	104.7	105.4	-0.667	68.5	69.67	-1.167	36.1	35.97	0.133
	st dev			1.546			0.285			0.579			0.386			0.411
1-0007	1	58.1	54.5	3.5	82.7	82.2	0.5	119.3	117.5	1.8	82.1	81.1	1	41.1	40.5	0.6
sub L	2	58.4	55.1	3.3	82.1	82.2	-0.1	119.3	117.6	1.7	82.5	81.4	1.1	40.9	40.2	0.7
	3	58.3	55.9	2.4	82.2	82.4	-0.2	119.1	117.8	1.3	82.3	81.3	1	40.8	40.3	0.5
	mean	58.27	55.2	3.067	82.33	82.27	0.067	119.2	117.6	1.6	82.3	81.27	1.033	40.93	40.33	0.6
	st dev			0.478			0.309			0.216			0.047			0.082
1-0008	1	57.3	58	-0.7	79.4	77.6	1.8	112.3	111.1	1.2	73.7	73.5	0.2	39.9	39.1	0.8
sub L	2	58.6	57.3	1.3	78.4	77.7	0.7	112.4	111.3	1.1	73.3	73.2	0.1	40	38.9	1.1
	3	57.4	57.1	0.3	78.2	78.2	0	112	111.4	0.6	73.2	73.3	-0.1	40.1	39.2	0.9
	mean	57.77	57.47	0.3	78.67	77.83	0.833	112.2	111.3	0.967	73.4	73.33	0.067	40	39.07	0.933
	st dev			0.816			0.741			0.262			0.125			0.125
	st dev			0.816			0.741			0.262			0.125			0.125
1-0009	1	56.7	54.3	2.4	81.1	82.9	-1.8	115	116.3	-1.3	77.4	76.9	0.5	40.5	40.7	-0.2
sub R	2	57.5	53.4	4.1	81	83.4	-2.4	115.4	116.7	-1.3	77.1	77.3	-0.2	40.4	41	-0.6
	3	56.8	55.9	0.9	81.5	83.2	-1.7	115.1	116.7	-1.6	77.6	77.1	0.5	40.7	40.6	0.1
	mean	57	54.53	2.467	81.2	83.17	-1.967	115.2	116.6	-1.4	77.37	77.1	0.267	40.53	40.77	-0.233
	st dev			1.307			0.309			0.141			0.33			0.287
1-0010	1	55.5	54.9	0.6	79.1	80.3	-1.2	116.3	115.8	0.5	73.3	74	-0.7	41	41.3	-0.3
sub L	2	55.4	55	0.4	79.8	80.3	-0.5	116.3	115.6	0.7	73.2	73.6	-0.4	41	41.6	-0.6
	3	55.9	54.3	1.6	79.7	80.4	-0.7	116.4	115.8	0.6	73.4	73.8	-0.4	41.3	41.4	-0.1
	mean	55.6	54.73	0.867	79.53	80.33	-0.8	116.3	115.7	0.6	73.3	73.8	-0.5	41.1	41.43	-0.333
	st dev			0.525			0.294			0.082			0.141			0.205
1-0011	1	63.3	59.2	4.1	82	80.9	1.1	121.7	121.2	0.5	80.3	79.1	1.2	43.7	43.4	0.3
sub L	2	63.5	60.3	3.2	82.2	82	0.2	121.3	121.5	-0.2	80.4	78.8	1.6	43	43.9	-0.9
	3	63.6	59.4	4.2	82.4	80.2	2.2	120.9	120.4	0.5	80.4	78.5	1.9	43.3	44	-0.7
	mean	63.47	59.63	3.833	82.2	81.03	1.167	121.3	121	0.267	80.37	78.8	1.567	43.33	43.77	-0.433
	st dev			0.45			0.818			0.33			0.287			0.525

1-0012	1	58.6	55.9	2.7	85.9	81.6	4.3	119.7	115.4	4.3	79.6	77.5	2.1	41.1	39.4	1.7
sub L	2	57	56	1	83.4	81.5	1.9	119.4	115.8	3.6	79.5	77.6	1.9	41	39.7	1.3
	3	58.6	55.7	2.9	84.6	81.7	2.9	119.4	115.9	3.5	79.8	77.4	2.4	41	39.5	1.5
	mean	58.07	55.87	2.2	84.63	81.6	3.033	119.5	115.7	3.8	79.63	77.5	2.133	41.03	39.53	1.5
	st dev			0.852			0.984			0.356			0.205			0.163
1-0013	1	63.8	66.3	-2.5	88	83.4	4.6	120.7	121.4	-0.7	83.1	81.2	1.9	39	40.6	-1.6
sub L	2	64.7	66	-1.3	87.7	83.8	3.9	120.9	121.3	-0.4	83.2	81.3	1.9	39.3	40.3	-1
	3	65.4	66	-0.6	87.6	83.9	3.7	121	121.7	-0.7	82.9	81.1	1.8	39.6	40.8	-1.2
	mean	64.63	66.1	-1.467	87.77	83.7	4.067	120.9	121.5	-0.6	83.07	81.2	1.867	39.3	40.57	-1.267
	st dev			0.785			0.386			0.141			0.047			0.249
1-0014	1	51.4	54.4	-3	88	87.6	0.4	115.8	116.6	-0.8	81.8	81.5	0.3	37.8	37.4	0.4
sub R	2	52.3	53.2	-0.9	88.1	88.7	-0.6	116	115.9	0.1	81.5	81.2	0.3	37.6	37.2	0.4
	3	52.4	53.9	-1.5	88.3	87.8	0.5	115.9	116.3	-0.4	81.6	81.6	0	37.5	37.5	0
	mean	52.03	53.83	-1.8	88.13	88.03	0.1	115.9	116.3	-0.367	81.63	81.43	0.2	37.63	37.37	0.267
	st dev			0.883			0.497			0.368			0.141			0.189
1-0015	1	52.5	51.4	1.1	79	81.4	-2.4	114.4	110.5	3.9	70.5	69.7	0.8	41.8	42	-0.2
sub L	2	52.5	51.3	1.2	79.4	81.1	-1.7	113.7	111	2.7	70	69.9	0.1	42.3	42.3	0
	3	52.3	51.8	0.5	79.6	82.1	-2.5	113.1	111.2	1.9	70.9	70.3	0.6	42.4	42.7	-0.3
	mean	52.43	51.5	0.933	79.33	81.53	-2.2	113.7	110.9	2.833	70.47	69.97	0.5	42.17	42.33	-0.167
	st dev			0.309			0.356			0.822			0.294			0.125
1-0016	1	57.9	58.1	-0.2	82.7	83.3	-0.6	115.4	116.2	-0.8	77.2	77.3	-0.1	40.1	39.7	0.4
sub L	2	57	57.8	-0.8	84.8	82.9	1.9	115.4	116.3	-0.9	77.4	77.5	-0.1	40.8	40.3	0.5
	3	58	58.2	-0.2	83.4	82.9	0.5	115.1	116.9	-1.8	77.1	77.6	-0.5	40.3	40.1	0.2
	mean	57.63	58.03	-0.4	83.63	83.03	0.6	115.3	116.5	-1.167	77.23	77.47	-0.233	40.4	40.03	0.367
	st dev			0.283			1.023			0.45			0.189			0.125
1-0017	1	58.9	58.1	0.8	82.7	83.3	-0.6	115.4	116.2	-0.8	77.2	77.3	-0.1	40.1	39.7	0.4
sub R	2	58.3	58	0.3	84.8	83.4	1.4	115.4	115.8	-0.4	77	76.9	0.1	39.9	39.9	0
	3	58	58.3	-0.3	83.5	83.9	-0.4	115.1	115.6	-0.5	77.4	77.4	0	40.4	40.1	0.3
	mean	58.4	58.13	0.267	83.67	83.53	0.133	115.3	115.9	-0.567	77.2	77.2	0	40.13	39.9	0.233
	st dev			0.45			0.899			0.17			0.082			0.17
1-0018	1	62.2	59.3	2.9	83.4	85.8	-2.4	120.4	121.5	-1.1	78.1	79.7	-1.6	43.2	42.7	0.5
sub R	2	62	59.1	2.9	82.7	86.5	-3.8	120.3	121	-0.7	78.4	80	-1.6	43.4	42.7	0.7
	3	62.5	61.4	1.1	84.6	85.8	-1.2	121	121.6	-0.6	77.7	79.4	-1.7	43.4	42.9	0.5
	mean	62.23	59.93	2.3	83.57	86.03	-2.467	120.6	121.4	-0.8	78.07	79.7	-1.633	43.33	42.77	0.567
	st dev			0.849			1.062			0.216			0.047			0.094
1-0019	1	52	50.5	1.5	83.4	81.1	2.3	112.6	109.4	3.2	77.5	73.4	4.1	35.8	36.2	-0.4
sub L	2	50.8	49.5	1.3	83	82.4	0.6	111.9	110.1	1.8	77.2	73	4.2	36	35.9	0.1
	3	50.5	49.5	1	83.2	81.8	1.4	112.5	110.2	2.3	77.5	73.9	3.6	36.1	36.3	-0.2
	mean	51.1	49.83	1.267	83.2	81.77	1.433	112.3	109.9	2.433	77.4	73.43	3.967	35.97	36.13	-0.167
	st dev			0.205			0.694			0.579			0.262			0.205
1-0020	1	64.6	59.8	4.8	81.4	83.5	-2.1	119.7	118.6	1.1	79.9	77.1	2.8	41.4	42.7	-1.3
sub L	2	63.8	60.1	3.7	81.6	83.3	-1.7	120	119	1	79.4	77	2.4	41.4	42.8	-1.4
	3	63	60.2	2.8	81.7	82.8	-1.1	119.4	118.7	0.7	79.8	77.3	2.5	41.3	42.7	-1.4
	mean	63.8	60.03	3.767	81.57	83.2	-1.633	119.7	118.8	0.933	79.7	77.13	2.567	41.37	42.73	-1.367
	st dev			0.818			0.411			0.17			0.17			0.047

Appendix D. Raw data. Class II Division 1 Subdivision Group. Maxillary measurements.

af-ans		ans-mx6		af-mx6				
	r-l	right	left	r-l	right	left	r-l	
2-0001	1							
	2	1.5	43.5	44	-0.5	77	76.7	0.3
	3	1	43.9	43	0.9	76.5	77.5	-1
	mean	0.8	43	43.8	-0.8	76.9	77.1	-0.2
	SD	1.1	43.47	43.6	-0.13	76.8	77.1	-0.3
2-0002	1	0.294			0.741		0.535	
	2	0.7	40.9	38.6	2.3	72.3	71.7	0.6
	3	0.6	41.9	39	2.9	72	72.3	-0.3
	mean	-0.1	40.4	38.7	1.7	73	71.1	1.9
	SD	0.4	41.07	38.77	2.3	72.43	71.7	0.733
2-0003	1	0.356			0.49		0.903	
	2	1.2	45.7	41.5	4.2	82.7	85	-2.3
	3	1.4	46	40.3	5.7	83.3	85	-1.7
	mean	-0.1	45.3	41	4.3	82.4	86.1	-3.7
	SD	0.833	45.67	40.93	4.733	82.8	85.37	-2.57
2-0004	1	0.665			0.685		0.838	
	2	-1.3	41.3	41.6	-0.3	80	80.4	-0.4
	3	-0.3	41	41.8	-0.8	80.4	81	-0.6
	mean	0.6	41.3	41.2	0.1	79.9	80.2	-0.3
	SD	-0.33	41.2	41.53	-0.33	80.1	80.53	-0.43
2-0005	1	0.776			0.368		0.125	
	2	2.3	39.8	39	0.8	82.1	79.7	2.4
	3	1.1	39.3	41.3	-2	82.8	80.3	2.5
	mean	3.5	40.3	40.9	-0.6	82.3	80.3	2
	SD	2.3	39.8	40.4	-0.6	82.4	80.1	2.3
2-0006	1	0.98			1.143		0.216	
	2	-0.2	38	38.5	-0.5	69.7	69.6	0.1
	3	0.1	38.4	38.4	0	69.3	69.4	-0.1
	mean	-0.5	38.5	38.7	-0.2	69.8	69.5	0.3
	SD	-0.2	38.3	38.53	-0.23	69.6	69.5	0.1
2-0007	1	0.245			0.205		0.163	
	2	0.1	41.8	41.3	0.5	80.5	80.4	0.1
	3	0.7	41.9	41.1	0.8	80.3	80	0.3
	mean	-0.5	42	41.3	0.7	80.1	80.4	-0.3
	SD	0.1	41.9	41.23	0.667	80.3	80.27	0.033
2-0008	1	0.49			0.125		0.249	
	2	1.3	43.7	42.3	1.4	71.2	72.9	-1.7
	3	1.3	44	42.5	1.5	71.5	73	-1.5
	mean	1.4	44.1	42.2	1.9	71.6	72.5	-0.9
	SD	1.333	43.93	42.33	1.6	71.43	72.8	-1.37

2-0009	1	0.047			0.216			0.34
	2	-0.8	41.1	41.4	-0.3	72.3	72.8	-0.5
	3	-1.6	41.3	41.8	-0.5	72.3	72.5	-0.2
	mean	-1.1	41.5	41.3	0.2	72.4	72.9	-0.5
	SD	-1.17	41.3	41.5	-0.2	72.33	72.73	-0.4
2-0010	1	0.33			0.294			0.141
	2	-2.4	40.9	40.1	0.8	71	71	0
	3	-2.1	40.4	39.9	0.5	71.2	70.9	0.3
	mean	-2.3	40.6	40.3	0.3	71.2	70.8	0.4
	SD	-2.27	40.63	40.1	0.533	71.13	70.9	0.233
2-0011	1	0.125			0.205			0.17
	2	-0.5	40.8	40.7	0.1	81	79	2
	3	-0.1	40.4	40.8	-0.4	80.8	79.3	1.5
	mean	0.1	40.8	41	-0.2	80.7	79.3	1.4
	SD	-0.17	40.67	40.83	-0.17	80.83	79.2	1.633
2-0012	1	0.249			0.205			0.262
	2	-2.6	43	40.8	2.2	75.4	77.5	-2.1
	3	-2	42.6	40.9	1.7	75.8	77.2	-1.4
	mean	-2.1	42.7	41	1.7	75.9	77.3	-1.4
	SD	-2.23	42.77	40.9	1.867	75.7	77.33	-1.63
2-0013	1	0.262			0.236			0.33
	2	-6	41.9	41.5	0.4	79	80.8	-1.8
	3	-5.6	41.9	41.4	0.5	79.3	81	-1.7
	mean	-4.8	41.4	41.4	0	79.2	80.9	-1.7
	SD	-5.47	41.73	41.43	0.3	79.17	80.9	-1.73
2-0014	1	0.499			0.216			0.047
	2	-0.1	36.7	35.9	0.8	77.1	78.5	-1.4
	3	-0.4	37	36	1	76.9	78.4	-1.5
	mean	-0.3	36.5	35.7	0.8	77.4	78.7	-1.3
	SD	-0.27	36.73	35.8	0.933	77.13	78.53	-1.4
2-0015	1	0.125			0.1			0.082
	2	1.2	38.4	38.8	-0.4	69	67.4	1.6
	3	1	38.8	38.9	-0.1	69.8	67.6	2.2
	mean	1.3	38.5	38.9	-0.4	69.3	67.8	1.5
	SD	1.167	38.57	38.87	-0.3	69.37	67.6	1.767
2-0016	1	0.125			0.141			0.309
	2	-2.5	46.3	47.2	-0.9	75.5	75.5	0
	3	-1.9	45.9	47.3	-1.4	75.6	75.8	-0.2
	mean	-1.5	45.8	47	-1.2	75.3	75.4	-0.1
	SD	-1.97	46	47.17	-1.17	75.47	75.57	-0.1
2-0017	1	0.411			0.205			0.082
	2	-2.5	45.6	47.2	-1.6	75.5	75.5	0
	3	-1.8	46	46.8	-0.8	74.5	75.4	-0.9
	mean	-2.7	45.8	46.9	-1.1	74.6	75.3	-0.7
	SD	-2.33	45.8	46.97	-1.17	74.87	75.4	-0.53

2-0018	1	0.386			0.33			0.386
	2	2.3	44.5	44.1	0.4	78	75.8	2.2
	3	1	44.3	44.2	0.1	78.3	76	2.3
	mean	1.6	44.9	44.8	0.1	78.3	76	2.3
	SD	1.633	44.57	44.37	0.2	78.2	75.93	2.267
2-0019	1	0.531			0.141			0.047
	2	1.5	38	38.2	-0.2	73.8	71.9	1.9
	3	0.2	38	38.1	-0.1	73.4	72	1.4
	mean	1.3	38.4	38.3	0.1	73.5	71.9	1.6
	SD	1	38.13	38.2	-0.07	73.57	71.93	1.633
2-0020	1	0.572			0.125			0.205
	2	0.7	41.6	41.6	0	76.1	74.6	1.5
	3	0.7	41.3	41.4	-0.1	75.6	74.5	1.1
	mean	1.7	41.5	41.4	0.1	75.7	74.8	0.9
	SD	1.033	41.47	41.47	0	75.8	74.63	1.167
		0.471			0.082			0.249

Literature Cited

1. Ackerman J, Proffit W. The characteristics of malocclusion: a modern approach to classification and diagnosis. *Am J Orthod* 1969;56:443-54.
2. Alavi D et al. Facial and dental arch asymmetries in Class II subdivision malocclusion. *Am J Orthod Dentofacial Orthop* 1988;93:38–46.
3. Angle E. Classification of malocclusion. *Dent Cosmos* 1899;4h248-64, 350-7.
4. Azevedo A et al. Evaluation of asymmetries between subjects with Class II subdivision and apparent facial asymmetry and those with normal occlusion. *Am J Orthod Dentofacial Orthop* 2006; 129:376–383.
5. Berco M et al. Accuracy and reliability of linear cephalometric measurements from cone-beam computed tomography scans of a dry human skull. *Am J Orthod Dentofacial Orthop* 2009;136:17.e1-17.e9)
6. Blair E. A cephalometric roentgenographic appraisal of the skeletal morphology of Class I, Class II, Div. 1, and Class II, Div. 2 (Angle) malocclusions. *The Angle Orthod* 1954 24:2, 106-119.
7. Brezniak N et al. Pathognomonic cephalometric characteristics of Angle Class II Division 2 malocclusion. *Angle Orthod* 2002;72:251–257.
8. Case CS. *Technics and principles of dental orthopedia*. Chicago: CS Case 1921:15-20.
9. Fischer B. Asymmetries of the Dentofacial Complex. *Angle Orthod*. Oct 1954, Vol. 24, No. 4 (October 1954) pp. 179-192.
10. Goldenberg DC, Alonso N, Goldenberg FC, Gebrin ES, Amaral TS, Scanavini MA, Ferrerira MC. Using Computed Tomography to evaluate maxillary changes after surgically assisted rapid palatal expansion. *J Craniofacial Surg* 2007;18:302-311.

11. Hellman, M.: Diagnosis in orthodontia and the method I use in practice, *Angle Orthodontist* 13: 3-14, 1944.
12. Kwon T et al. A comparison of craniofacial morphology in patients with and without facial asymmetry - a three-dimensional analysis with computed tomography. *Int. J. Oral Maxillofac. Surg.* 2006; 35: 43–48.
13. Lagravere MO, Gordon J, Guedes Ines, Flores-Mir C. Reliability of traditional cephalometric landmarks as seen in three-dimensional analysis in maxillary expansion treatments. *Angle Orthod* 2009;79:1047-56.
14. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007; 103:534-42.
15. Maj G. A cephalometric appraisal Of Class II And Class III malocclusions. *Angle Orthod* 1960 30:1, 26-34.
16. Massler M, Frankel JM. Prevalence of malocclusion in children aged 14 to 18 years. *Am J Orthod* 1951;37:751-68.
17. Peck S et al. Class II Division 2 malocclusion: a heritable pattern of small teeth in well-developed jaws. *Angle Orthod* 1998;68:9-20.
18. Proffit, WR, Vig KW, Turvey TA. Early fracture of the mandibular condyles: frequently an unsuspected cause of growth disturbances. *Am J Orthod.* 1980;78:1–24.
19. Proffit, WR. On the aetiology of malocclusion. The Northcroft lecture, 1985 presented to the British Society for the Study of Orthodontics, Oxford, April 18, 1985. *Br J Orthod.* 1986; 13:1–11.

20. Renfroe E. A study of the facial patterns associated with class I, class II, div. 1, and class II, div. 2 malocclusion. *Angle Orthod* 18: 12-15, 1948.
21. Ricketts RM: A study of change in temporomandibular relations associated with the treatment of Class II malocclusion. *Am J Orthod* 38:918-933, 1952
22. Robertson NRW, Hilton R. Features of upper central incisors in Class II, Division 2. *Angle Orthod.* 1965;35:51–53
23. Rose JM, Sadowsky C, Begole EA, Moles R. Mandibular skeletal and dental asymmetry in Class II subdivision malocclusions. *Am J Orthod Dentofacial Orthop.* 1994;105: 489–495.
24. Sanders, DA, Rigali PH, Neace WP, Uribe F, Nanda R. Skeletal and dental asymmetries in Class II subdivision malocclusions using cone-beam computed tomography. *Am J Orthod Dentofacial Orthop.* 2010;138:542e1–542e20.
25. Sassouni, V., Forrest, E.J.: *Orthodontics in Dental Practice.* St. Louis: The C.V. Mosby Co, 1971.
26. Sato, H, Kawamura A, Yamaguchi M, Kasai K. Relationship between masticatory function and internal structure of the mandible based on computed tomography findings. *Am J Orthod Dentofacial Orthop.* 2005;128:766–773.
27. Siegel, M. A matter of Class: interpreting subdivision in a malocclusion. *Am J Orthod Dentofacial Orthop.* 2002; 122:582-6.
28. Strang R. Class II, Division 2 Malocclusion. *Angle Orthod* 1958 28:4, 210-214.
29. US Department of Health, Education, and Welfare. An assessment of the occlusion of the teeth of youths 12-17 years – National Center for Health Statistics, DHEW no (HRA) 77-1644, 1977: Rockville, Maryland: United States
30. Wallis SF. Integration of certain variants of the facial skeleton in Class II division 2 malocclusion. *Angle Orthod.* 1963;33:60–67.

