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An Evaluation of the Constructed Frankfort Mandibular Plane Angle Bisector (cFMAB) Wits' Appraisal in the Assessment of Anteroposterior Jaw Relationships

Derek R. Tomson, *The University of Western Ontario*

Supervisor: Dr. Antonios Mamandras, *The University of Western Ontario*
A thesis submitted in partial fulfillment of the requirements for the Master of Clinical Science degree in Orthodontics

AN EVALUATION OF THE CONSTRUCTED FRANKFORT MANDIBULAR PLANE ANGLE BISECTOR (cFMAB) WITS' APPRAISAL IN THE ASSESSMENT OF ANTEROPOSTERIOR JAW RELATIONSHIPS

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by

Derek Richard Tomson

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The School of Graduate and Postdoctoral Studies
The University of Western Ontario
London, Ontario, Canada

Abstract

For proper orthodontic diagnosis and treatment planning, an accurate measurement of the relationship of the maxilla to the mandible in the sagittal plane is required. The ANB measurement has long been the gold standard for explaining this association. The purpose of this longitudinal study was to evaluate three linear measurements of the maxillomandibular anteroposterior relationship and determine which one best correlates with ANB. The constructed Frankfort horizontal-mandibular plane angle bisector (cFMAB-Wits), maxillomandibular bisector (MMB-Wits), and Frankfort-mandibular plane angle bisector (FMAB-Wits) were measured using a Wits'-type analysis and compared to ANB.

Pre-treatment (TO), immediate post-treatment (T1), and two years post-retention (T2) lateral cephalograms were analyzed for 121 Class I patients and 76 Class II Division 1 patients treated at the Graduate Orthodontics Clinic at the University of Western Ontario. 38 Class I and 30 Class II Division 1 untreated individuals from the Burlington Growth Centre served as controls. The data were evaluated using independent samples t-tests and one-way ANOVA to determine statistical differences between groups ($p<0.05$).

Each of the three linear measurements demonstrated modest correlation with ANB, regardless of presenting malocclusion. The difference in correlation with ANB between the three linear measurements was negligible. The cFMAB-Wits measurement produced a positive correlation with ANB, MMB-Wits, and FMAB-Wits. The Wits-type measurements all showed strong correlation amongst one another, suggesting their use may be interchangeable, but none can be used as a reliable surrogate for the gold standard ANB.

Key Words: Anteroposterior skeletal discrepancy, ANB angle, Wits' appraisal, constructed Frankfort mandibular plane angle bisector

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Introduction

In the development of an orthodontic problem list, one of the critical components is an assessment of the anteroposterior (AP) relationship of the maxilla and mandible, both to each other, and to the cranial base.[1] Through the use of lateral cephalograms, the clinician can describe the position of the maxilla and mandible as being either orthognathic, retrognathic (retruded), or prognathic (protruded) with respect to the cranial base. The lateral cephalogram also allows for the description of the sagittal relationship between the jaws as Class I (ideal relationship), Class II (mandible positioned posteriorly relative to the maxilla), or Class III (mandible positioned anteriorly relative to the maxilla). The determination and severity of these relationships are estimated using a number of landmarks which produce corresponding linear planes and angular measurements (Appendix I-II). Based on these points, a wide range of analyses have been created to help describe an individual patient's sagittal jaw relationship.[2-4]

In cephalometric studies, A and B points are representative of the anterior limits of the maxillary and mandibular denture bases, respectively.[5] Downs[6] developed the A-B plane angle to help explain the sagittal relationship of the jaws. In order to relate the maxilla and mandible to each other and to the cranial base, Riedel[7] proposed the use of angular measurements to the sella turcica-nasion line (SN), with the SNA and SNB angles. The difference between these angles, expressed as ANB, has been adopted as the most widely used measure to express sagittal discrepancies between the maxilla and mandible.[3,8,9] According to Riedel, the ideal Class I skeletal relationship will produce an ANB value of +2 degrees +/-2 degrees. Values larger than +4 degrees suggest a Class II discrepancy, while negative values dictate a Class III skeletal relationship.[7]

While the ANB value is the most common measure of sagittal harmony, it must also be interpreted with caution. A number of variables have been shown to significantly affect its value. Owing to the fact that ANB is an angular measurement, as the distance between the vertex of the angle (nasion) and the points change, the angle can too. As the vertex moves closer to the points, the angle increases; as the vertex moves away, the angle decreases. In the vertical plane, length changes from nasion (Na) to A point and from Na to B point have been shown to impact ANB.[10-11] Sagittal changes in the points can occur with growth and orthodontic treatment, which can lead to a rotation of the jaws. This may be expressed as alterations in the degree of facial prognathism, and rotations of the occlusal plane (OP) or the SN line.[1, 12, 13] It has also been shown that rotation of the head to one side or a rotation upwards can affect the ANB reading.[14] Due to this inherent instability of the ANB angle, orthodontists sought different means of describing the sagittal relationships of the jaws based on the lateral cephalogram.

One of the first alternatives to the ANB angle was an extrapolated linear measurement proposed by Jacobson.[15] Termed the Wits' analysis, Jacobson plotted the position of a vertical tangent from A point and B point to a constructed line called the functional occlusal plane (FOP) and measured the linear distance between the two projected points (called AO and BO). The FOP is a line which bisects the overlap of the cusp tips of the molars and premolars, as seen on the cephalometric image (Fig. 1). According to Jacobson,[16] in Class I occlusion cases the AO and BO met at the same point on the FOB in females, corresponding to a Wits' value of 0, while males on average were found to have BO positioned 1 millimeter (mm) anterior to AO, which is read as a Wits' value of -1. In the Wits' analysis, Class II malocclusions present with a positive value owing to the more anterior position of AO relative to BO. In Class III cases, the Wits' value is negative due to the more anteriorly positioned BO.

While the purported benefit of the Wits' analysis is that it relates the maxilla and mandible to each other without the potentially confounding influence of the cranial structures,[15,16] it is not without its criticisms. Unlike the ANB angle, the Wits' analysis is a dental measurement that is used to explain a skeletal relationship and as a result inherent difficulties were quickly identified.[17-22] The FOP can be difficult to identify, making accuracy and reliability an issue. This can be due to excessive overlap of the dentition on the image, such as in skeletal asymmetries, or in cases where there is no distinct line separating the maxillary and mandibular dentition, such as in open bites, with missing teeth, and in the mixed dentition stage.[23] With an inaccurate FOP, the angulation of the plane can be changed, which in turn influences the position of the AO and BO points. This can lead to a misinterpretation of the true sagittal relationship of the jaws.[24] A further criticism of the Wits' analysis is that it does not accurately account for rotation of the jaws, as seen with growth or with orthodontic treatment.[20,23] It has been shown that the FOP does not rotate in a similar fashion so that the linear distance between AO and BO becomes misrepresentative of the position of the maxilla in relation to the mandible.

In order to address the inadequacies of the Wits' analysis, various methods have been suggested to better explain the maxillo-mandibular sagittal relationship. As mentioned earlier, correctly identifying and replicating the FOP can be a challenge. An alternative measure that can be used is the bisector of the occlusal plane (BOP).[6,19,25,26] The BOP is the line which bisects the distobuccal cusps of the first permanent molars and the site of incisal overlap. At this point, it is not clear if there is any benefit in using the BOP in place of the FOP. Previous studies have found no difference in the Wits' measurements when using either plane,[27] while others report that the BOP exhibits higher reproducibility due to less change than FOB in the plane inclination due to growth.[21] Del Santo considered the correlation between the Wits' analysis using the BOP and the ANB angle.[9] His results found that the degree of occlusal plane angulation was a critical factor. In those patients with a high occlusal plane angle, which would rotate the bisector clockwise, the BOP Wits' was poorly correlated with the ANB angle, whereas in patients with a low OP angle the two sagittal assessments produced more consistent findings. While these results can be encouraging for particular patient populations, the criticism of using a dental measurement to explain a skeletal relationship remains, prompting further modifications of the Wits' analysis.

Hall-Scott proposed an alternative plane that could account for discrepancies owing to rotations of the jaws, while at the same time eliminating the difficulties associated with identifying the FOP and BOP.[24] Termed the maxillary-mandibular plane angle bisector (MMB), this new plane was geometrically derived by bisecting the dental base planes themselves, that is, the palatal plane and mandibular plane (Fig. 2). The MMB-Wits' measurement can be used to relate the maxilla and mandible in the sagittal plane in a manner similar to the original Wits' measurement – A point and B point are drawn perpendicularly to MMB and the linear difference between the two is measured. The purported benefits of this method were that the planes cant will not change significantly with growth and if it does, the change will be in a manner and direction so as not to distort the true A point-B point relationship.[24] In addition, the MMB has been shown to be highly reproducible,[28] more so than the FOP and BOP.[29] Correlation coefficients between the Wits' measurements to MMB (MMB-Wits) and ANB measurements suggest that the MMB-Wits can provide a moderate approximation, particularly in Class III subjects ($r = 0.77$).[21,22] However, the MMB relies on the use of the palatal plane, which has been shown to be highly variable in terms of its inclination and as a result can produce distorted anteroposterior readings.[11] A second problem with the MMB-Wits' measurement is that it can be influenced by the patient's facial type.[8,11] Patient's with significantly divergent (dolichofacial) or convergent (brachyfacial) palatal and mandibular planes can produce variable inclinations with growth that can impact the accuracy of the MMB-Wits'. This led to the suggestion that a more stable reference line be used that can still account for the rotational effects of the jaws during growth – the Frankfort horizontal axis.[5]

Despite the inherent difficulties in locating either anatomic or machined porion,[30,31] in a study done by Yang and Suhr[5] examining different cephalometric measurements used to indicate anteroposterior jaw relationships it was shown that the Frankfort horizontal to A-B plane angle (FABA) was a reliable measure (Fig. 3). The FABA angle was also shown to provide an approximation of the expected facial profile of the patient. The authors claim that unlike previous sagittal dysplasia indicators and Wits' appraisals, the FABA angle measures the anteroposterior relationship of the jaws, as opposed to the anteroposterior relationship of the dentition. In addition, unlike the MMB-Wits' measurement, there is less influence due to growth. While the palatal plane may change its inclination in a growing patient, the Frankfort horizontal plane has been shown to be one of the most stable reference planes for cephalometric orientation and growth prediction.[5,13,32] However, as mentioned, the accuracy and reliability of the FABA angle relies on appropriate landmark identification and involves specific landmarks that have been shown to be difficult to locate correctly and consistently.[30,31]

A second method of using the Frankfort horizontal plane to explain the anteroposterior relationship of the maxilla and mandible was proposed by Swoboda and Sangha.[33,34] The bisector of the angle formed between the Frankfort horizontal and mandibular plane was measured (FMAB) and then a vertical relationship to the functional occlusal plane was extrapolated for A point and B point, with the horizontal distance between the two indicative of the sagittal relationship in a manner similar to the Wits' analysis, termed FMAB-Wits' (Fig. 4). The advantage of this bisector is that it is made in close relation to the dental bases, but does not rely on dental measurements. Also, as discussed previously, the Frankfort plane does not experience significant changes to its cant or inclination with growth, as seen with the palatal plane used in the MMB-Wits' analysis. Good correlation with the ANB measurement and MMB-Wits' measurement were found for both Class I[33] and Class II[34] patients. However, the same limitations exist in using the Frankfort horizontal plane, namely the difficulty in accurately locating cephalometric landmarks and doing so in a consistent manner.

In response to the restrictions imposed by the Frankfort horizontal plane, it has been suggested that the ideal line of reference for the anteroposterior relationship of the jaws be extra-cranial, stable, and relate to the true vertical or horizontal perpendicular to it.[35] The Pi analysis purports that because it is independent of cranial reference planes and the dental base, it can produce a true sagittal relationship without the influence of other parameters (Fig. 5). It consists of both a Pi angle and a Pi linear value, which are derived from the tangents of M point (centre of the largest circle placed at a tangent to the anterior, superior, and palatal surfaces of the pre-maxilla) and G point (centre of the largest circle placed at a tangent to the internal anterior, inferior, and posterior surfaces at the mandibular symphysis) to the true horizontal line (THL), which is a line perpendicular to the true vertical line found with the patient in natural head position.[11,35,36] The Pi angle is formed by M point and G point, with G' point serving as the vertex (point of intersection of THL and a perpendicular line drawn from G point to THL). The linear Pi measurement is the distance on the THL between G' and M' (point of intersection of THL and a perpendicular line drawn from M point to THL). While the results of Kumar's study suggest good correlation between the Pi angle and Pi linear, as well as minimal effect of jaw rotation and rotation of the palatal plane on the overall estimate of the anteroposterior relationship, two significant limitations have been identified. The first is the difficulty in identifying the M point and G point. Since these are representative of a point dictated by both horizontal and vertical borders away from the landmark, variability should be expected.[31] The second criticism relates to the use of the true horizontal, which passes through nasion. With growth, nasion can move upward and forward.[37] While this will not significantly impact the Pi linear measurement, it can alter the Pi angle, particularly with growth of nasion in the vertical dimension.[35]

Following the development of the Pi angle and Pi measurement, two further anteroposterior measurement methods have been proposed that make use of similar landmarks. The W angle (Fig. 6) is formed by the perpendicular from point M on the sella turcica-G point line and the M point-G point line.[14] A W angle value between 51-56 degrees can be considered Class I, less than 51 degrees is Class II, and greater than 56 degrees is Class III. While the authors claim that it allows for a reflection of the true changes of the sagittal relationship of the jaws, potentially indicating changes due to growth or orthodontic intervention, it still has inherent difficulties in landmark identification. Tracing the pre-maxilla accurately requires high quality cephalometric images and the W angle relies on landmarks that may not be repeated with high levels of accuracy.[14,30] The YEN angle (Fig. 7) measures the angle formed by the sella turcica-M point line and the M point-G point line.[38] An angle between 117-123 degrees is classified as Class I, less than 117 degrees suggests a Class II relationship, and greater than 123 degrees is Class III. While the YEN angle also requires difficult landmark location, it has also been criticized for failing to account for rotation of the jaw, allowing growth or orthodontic treatment to mask true basal dysplasia.[14] Additionally, at this point in time there are no available studies which have evaluated either the W angle or the YEN angle for the possible effect of growth.

A more recent cephalometric measurement has been proposed with the intention of being independent of reference planes and dental occlusion.[4] The Beta angle (Fig. 8) relies on A point, B point, and the angle they form at the apparent axis of the condyle to measure skeletal dysplasia in the sagittal plane. The head of the condyle is traced and the point approximating its center is used as the landmark. The authors purport that the Beta angle would be most useful for pre-treatment and post-treatment comparison because it will reflect anteroposterior changes due to growth or orthodontic intervention without being influenced by occlusion. However, the position of A point is thought to be influenced by remodeling of the alveolar bone following root movement of the upper incisors[39] and the ability to accurately reproduce the centre of the condyle has been shown to be highly inaccurate.[40,41]

Having a sound means of measuring and comparing the sagittal relationship of the maxilla and mandible is of great import in orthodontics, and yet, to this point there is still no proven means of doing so without some form of inherent error. The ideal measurement would be one that is made close to the dental bases without being directly influenced by the teeth and the occlusion. Furthermore, the ideal anteroposterior measurement would tolerate growth and orthodontic treatment, while still allowing for comparisons of these changes in a temporal manner. In addition, the measurement should correlate well with today's accepted "gold standard" for evaluating sagittal relationships, ANB.[8] A modification of the Wits' analysis that uses stable, accurate, and easily reproducible planes may provide this. While previous studies have looked at the bisector of the Frankfort horizontal plane and mandibular plane,[34,35] identifying Frankfort cephalometrically has inherent issues that may be addressed by using the constructed Frankfort horizontal plane instead.

The constructed Frankfort horizontal plane is oriented at an inferior anterior angle of 6-7 degrees from the SN line, with sella serving as the point of origin of this rotation and nasion acting as the point of orientation.[1] The advantage of the constructed Frankfort compared to the standard Frankfort is the higher reliability and reproducibility of the anatomic landmarks used.[1,30,31] Previous studies have shown that sella turcica and porion produce similar levels of location errors, while more widespread errors in both the vertical and horizontal plane were found when locating orbitale compared with nasion.[30,31] In addition, because the constructed Frankfort horizontal plane relies on the inclusion of nasion, it may be more likely to correlate well with ANB measurements on the same individual. This may hold true through growth as well, with the tendency for nasion to move superiorly and anteriorly with growth being compensated for by the inclusion of nasion.[1] It is thought that in this manner, a modified Wits' measurement using the constructed Frankfort (Fig. 9) may correlate better with ANB than that seen with the FMAB-Wits.[34,35]

The purpose of this study is to evaluate the use of the constructed Frankfort horizontal-mandibular plane angle bisector (cFMAB) as an alternative means to ANB for assessing anteroposterior jaw relationships in a sample of Class I and Class II malocclusions. The bisector of the 2 planes will serve as the reference plane onto which points A and B will be projected and the distance between the two points on the plane will dictate the type of sagittal relationship, in a manner similar to the Wits' analysis.

The primary question to be addressed is:

Which of the three Wits'-type cephalometric analyses (MMB-Wits, FMAB-Wits, cFMAB-Wits) best correlates with the gold standard ANB angle for the assessment of the sagittal relationship between the maxilla and mandible?

The specific secondary objectives of this study are:

1. To evaluate age-related changes in sagittal jaw relationships for males and females over a time period covering pre-pubertal and pubertal development (ages 12, 14, 16 years) using:
    - cFMAB-Wits' analysis
    - FMAB-Wits' analysis
    - MMB-Wits' analysis
    - ANB analysis

2. To evaluate these age-related changes in Class I and Class II patients

3. To evaluate changes between these patients and untreated Class I and Class II controls to assess changes due to treatment and normal growth versus normal growth alone

4. To determine the level of correlation between cFMAB-Wits' and the FMAB-Wits, MMB-Wits linear measurements

Materials and Methods

Subject Selection

This is a retrospective longitudinal study using a population group that has been evaluated in two prior cephalometric studies.[34,35] The treatment group is comprised of patients who were treated with orthodontic therapy at the Graduate Orthodontic Clinic at the University of Western Ontario, London, Ontario, Canada. The control group is comprised of subjects who are part of the Burlington Growth Centre, which is affiliated with the Faculty of Dentistry at the University of Toronto, Canada. The controls were not treated orthodontically and were used as a means of comparison for treatment effects relative to normal growth. For both treatment and control groups, records obtained include dental casts and serial lateral cephalograms. For the control subjects, these records were taken at age 12 years (TO), 14 years (T1), and 16 years (T2). For the treated subjects, records were obtained prior to the start of treatment (T0), at the end of treatment (T1), and at two years post-treatment when retention monitoring was complete (T2). For these individuals, the three time periods approximated the ages 12, 14, and 16 years old.

For both the treatment group and the controls, subjects were divided into the Angle classification of occlusion. For the Class I subgroup, there were 121 treated patients (61 male, 60 female) and 38 untreated controls (19 male, 19 female). In the Class II subgroup, the treated patients consisted of 76 subjects (36 male, 40 female), with 30 corresponding controls (15 male, 15 female).

Pre-treatment inclusion criteria for all subjects (treated cases and controls) were the following:

i. No congenitally missing or extracted teeth (excluding third molars)
ii. No craniofacial syndromes or anomalies
iii. Minimal crowding of 4.0 mm or less per arch
iv. High quality radiographs allowing for landmark identification

For all of the treated subjects, the following were the inclusion requirements:

i. Non-extraction orthodontic treatment with full fixed appliances

ii. Non-surgical treatment
iii. Obtainment/maintenance of Class I molar occlusion
iv. Passive retention via a fixed lingual retainer and/or removable retainer (upper Hawley, upper/lower Essix)

For the Class I sample, the following were additional pre-treatment inclusion criteria:

i. Class I molar relationship (as measured on dental casts at T0)
ii. Class I skeletal relationship with ANB angle less than 4.0^0 and greater than 0.0º
iii. Overjet less than 4.0 mm and greater than 0.0 mm

For the Class II sample, the following were additional pre-treatment inclusion criteria:

i. Class II Division 1 molar relationship of at least 3.0 mm Class II (approximates half-cusp Class II as measured on dental casts at T0)
ii. Class II skeletal relationship with ANB angle greater than 4.0^0
iii. Overjet greater than 4.0 mm

Additionally, the treated subjects presenting with Class I malocclusion were treated without the use of extra-oral appliances, while the Class II Division 1 treated cases used either cervical or straight-pull headgear at the beginning of treatment and Class II intra-oral elastics from the maxillary anterior segment to the mandibular posterior segment. Subjects who did not satisfy all of the pre-treatment, treatment, and retention criteria were excluded from the study.

Sample Size

The sample size of the groups was determined previously.[34,35] *G*Power Software Version 3* (Dusseldorf University, Dusseldorf, Germany) was used to determine the required sample size that would satisfy 80% power with an alpha value of 0.05. For the Class I sample, the mean values and standard deviations used were derived from a previous study of the MMB-Wits' measurement in treated Class I cases.[21] A minimum of 47 subjects per group was required to provide satisfactory power. The Class II Division 1 values were derived from the Class I FMAB-Wits' study.[34] Based on these values, a minimum of 34 subjects were required in each group. Due to the constraints of the available cases within the Burlington Growth Centre, it was not possible to achieve adequate power for the control group in the Class I sample (n = 38) or the Class II sample (n = 30).

Cephalometric Methods

Each cephalometric film was scanned and digitized using the same *Epson* scanner (Epson, Shinjuku, Tokyo). The cephalometric analysis was conducted using *Dolphin Imaging Software, Version 12* (Dolphin Imaging, Chatsworth, CA, USA) and all cephalograms were traced using this program by the same investigator (DT). The custom analysis consisted of ten skeletal landmarks, four cephalometric angles, and three linear measures. A full description of the landmarks, planes, angular measures, and linear measures is provided in Appendix I and II.

All cephalograms were rendered to 8.0% magnification using the *Dolphin Imaging Software*. Images from the Burlington Growth Centre were enlarged by 9.84%, while the films taken at the University of Western Ontario were enlarged 8.0% prior to 2007 and 9.5% after 2007, owing to a change in radiographic equipment. The decision to standardize all films at 8.0% is based on the previous studies using the same sample.[34,35]

Error Study

An error study was performed three weeks after the final radiograph included in the study sample had been traced by the same individual responsible for the initial tracings (DT). 20 random numbers were selected between 1-159 in the Class I sample and 1-126 in the Class II group, which corresponds to the total number of treated cases and untreated controls in each, using a random number generator (http://www.randomizer.org). The error study included 20 tracings done for each of the occlusal classifications at each of the three time points, resulting in 60 additional tracings for each group. Dahlberg's formula was used to determine the standard deviation of measurement error (SE) for each sample: $\sqrt{[\Sigma(d^2/2N)]}$, where d is the difference between the first and second tracing measurements and N is the sample size of the error study. The reproducibility of measurement (R) was determined using the formula: R = ((S2x – (S2e/2))/S2x, where S2x is the variance found in the first set of tracings and S2e is the variance of the difference found between the initial and error study tracings. The purpose of R is to quantify the reliability of the cephalometric measures used in the study sample.

Statistical Methods

Data was input into the *SPSS Version 20.0* statistical software package (IBM Corp, Armonk, NY,USA). This software was used to calculate and confirm all descriptive statistics.

The data was assessed for normality and the presence of outliers *a priori*, using the Shapiro-Wilk test and boxplots, respectively. The assumption of normality was set at $p > 0.05$. If the data violated this assumption, it was deemed to have a non-normal distribution. In order to identify differences between groups that were not distributed normally, the Mann-Whitney U test was used. All outliers were assessed for their impact through the use of independent samples *t*-test in which the outlier was included and removed. Any significant differences between these tests were identified and reported as separate results. Extreme outliers were defined as those lying more than three box-lengths from the edge of the box and were not included in the analysis if present.

The independent-samples t-test was used to identify statistically significant differences between groups. The accepted *p*-value for statistical significance was set *a priori* at $p < 0.05$. For both the Class I and Class II Division 1 samples, potential differences were assessed between the mean ages of the treatment groups and the controls at each time period, between the ages of the males and females in the treatment groups at each time period, and for each cephalometric measure between the treatment and control groups. The means of each of the cephalometric measures were also compared between this study and the previous studies by Swoboda and Sangha. Levene's test of equality of variances was run concurrently with the independent-samples and any tests that violated the assumption of homogeneity of variances were corrected using the Welch-Satterthwaite correction to the degrees of freedom with non-pooled variances.

A repeated measures analysis of variance (ANOVA) was used to identify statistically significant differences between the mean values in the treated and control subjects for each of the occlusion groups across time periods. The variables measured include treatment received, gender, and stage of treatment. Mauchly's test of sphericity was used to ensure that the variances of the differences between all combinations of levels of the within-subjects factor are equal ($p < 0.05$). For data which did not satisfy this assumption, the Greenhouse-Geisser adjustment for bias was used which adjusted the degrees of freedom of both the within-subjects factor and the error effect. A *post hoc* Bonferroni correction was used to identify statistically significant differences between the three time points as growth of the subjects progressed.

Finally, correlation coefficients were determined for each of the occlusal classifications, as well as for each time period in the treatment and control groups, in order to determine the level of correlation between ANB and the Wits-type analyses (MMB-Wits, FMAB-Wits, cFMAB-Wits). Scatter plots were used to assess for linearity between the variables. If the assumption of linearity was satisfied, the Pearson correlation coefficient was calculated. For those relationships that were not deemed to be linear, the scatter plot was then evaluated to determine if the data were monotonic. For all non-linear monotonic correlations, the Spearman's rank order correlation was used. The Pearson correlation coefficient value (r) or the Spearman's rank order correlation value (r_s) and the two-tailed *p*-values were assessed for significance. These were determined *a priori* as follows:[42]

- +/- 0.90-1.00 = Very strong positive/negative correlation
- +/- 0.70-0.89 = Strong positive/negative correlation
- +/- 0.50-0.69 = Moderate positive/negative correlation
- +/- 0.30-0.49 = Weak positive/negative correlation
- +/- 0.00-0.29 = Negligible correlation

Results

All lateral cepahlograms were traced by the same examiner (DT) over the course of a 48-hour period. The same computer was used for all tracings and the lighting and position of the examiner was static for each tracing. Sixty lateral cephalograms were selected at random using a random number generator (http://www.randomizer.org) and the assigned unique patient numbers. These were retraced by the same examiner 30 days later in the same room and on the same computer. An error study of the reproducibility of four cephalometric angles and three planes is shown in Table 1. Small errors were found, with no angular error larger than 1.17° and no linear error larger than 0.58 mm. The reproducibility (R) values were all 0.91 or larger, suggesting excellent reproducibility of the landmarks used for the cephalometric analyses.

Differences in mean ages between treatment and control groups and between males and females within the treatment group at three different time points are shown in Tables 2 and 3, respectively. An independent-samples t-test was run to identify any significant differences ($p<0.05$). Examination of box plots separated by treatment, gender, and time point revealed that there were few outliers, with control males at time period T1 having the greatest number of outliers with three. Separate t-tests were run with outliers removed and no significant differences were found. The data displayed in tables 2 and 3 include these outliers. No extreme outliers were found. Ages of the males and females within the treatment group were distributed normally, as determined by the Shapiro-Wilk test ($p>0.05$), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ($p>0.05$). The assumption of homogeneity of variances was violated for the control ages and a Welch-Satterthwaite correction of the degrees of freedom was used to produce the means shown in Table 2.

Table 2 displays the mean ages in months at pre-treatment (T0), immediate post-treatment (T1), and at two-years in retention (T2) for the treated individuals. The mean ages for the controls are shown for the corresponding control T0 (approximately 12 years old), T1 (14 years old), and T2 (16 years old) observations. In all three time periods, a significant difference in age was found, with the treated cases older than the control subjects. This discrepancy in age was found to be the smallest at the outset of treatment (4.20 months), while at the two-year retention time the age difference was 9.96 months. It was expected that the treated cases would be older than the controls due to the nature of the selection process. The age at which the radiographs were taken for the treated cases was dependent on their orthodontic treatment while the controls were taken at a pre-determined age. In conjunction with this, the treated group had a much greater amount of variation in age than the controls, as illustrated by the larger standard deviations for each time period.

In Table 3, significant differences were found between the ages of males and females at all three time points. Positive difference in means represents a larger age in months of the treated males than the treated females for the respective observation period. The results show that the average treated male in this study began treatment 5.12 months later than the average female and was seen for two-year retention 6.44 months later.

Cephalometric measurement means and standard deviations at each time period for both treated and control groups are shown in Table 4, separated by the presenting malocclusion of the subject. For the MMB-Wits, FMAB-Wits, and cFMAB-Wits measurements, values are presented in millimeter differences between perpendicular lines drawn from A point and B point to the corresponding line of interest. Positive values indicate that A point is positioned anterior to B point, while negative values indicate a more posteriorly located A point. Table 5 evaluates the differences in these cephalometric measurement means between the present study and the past results presented by Swoboda[33] and Sangha[34] for the Class I and Class II Division 1 samples, respectively. The measurements for cFH-MP and cFMAB-Wits were not found in the Swoboda and Sangha studies and thus were not included in Table 5. There were no significant differences in the cephalometric findings in the Class I treated patients nor in their controls. The FMAB-Wits measurement for the treatment group of the Class II Division 1 sub-analyses was found to be significantly lower in this study than in the Sangha study (-0.82 mm, $p<0.01$). The FMAB-Wits measurement for the treatment and control Class II Division 1 subjects produced the greatest differences between studies for all time periods, ranging in discrepancy from 0.60-0.96 mm. Raw data from this study were re-assessed to eliminate any inaccuracies, but the raw data for the Sangha groups were not available and could not be evaluated for potential errors.

Mean changes across time periods for each of the cephalometric measures were found in Table 6 using the one-way repeated measures ANOVA. All outliers were identified and were not found to have a significant impact and were therefore included in the analyses. The data were also found to satisfy the Shapiro-Wilk test for normality. A *post-hoc* Bonferroni adjustment was used to assess all pair-wise comparisons. Within-subject comparisons were made for the change between T0 and T1, T1 and T2, as well as between T0 and T2. Positive values indicated a decrease in the measurement with time. Significant decreases ($p<0.05$) were found in the Class I treatment group for each of the cephalometric measurements at one of the time periods. Only ANB and FMAB-Wits were found to change significantly between all three time periods. Similar results were found in the control group. The changes found in ANB, FMA, and cFH-MP were statistically significant between each time period. In the Class II Division 1 sample, the treatment group had significant decreases in each of the included cephalometric measurements. The changes in ANB, MMB-Wits, and FMAB-Wits were significant between each time period. In the Class II Divison 1 control subjects, the only significant changes found were in MMA (T0-T1, T0-T2), FMA (T0-T2), and cFH-MP (T0-T1, T0-T2).

Table 7 evaluated the differences in cephalometric measurement values between treated individuals and matched controls at each of the three time periods. In the Class I subjects, the FMA measures were similar for both groups at every time point, while significant differences were found in at least one time period for each of the other measures. For the three bisector measures (MMB-Wits, FMAB-Wits, and cFMAB-Wits), significant differences were found between treated patients and controls at each time point. In the Class II Division 1 group, at pre-treatment the group to be treated was more Class II on average than the controls as measured by ANB (+0.96 degrees, $p<0.05$). Over time, the controls became significantly more Class II compared with the treated group. This was also seen in significant differences in the MMB-Wits (2.02 mm,

$p<0.05$) and FMAB-Wits measurements (2.87 mm, $p<0.05$). The significant differences seen in the Class I cFMAB-Wits values were not found for the Class II Division 1 group.

Differences in cephalometric measurements related to gender were examined in Tables 8-11 for the treatment and control groups. In the Class I treated group, females were found to have a larger FMA and cFH-MP angle, as well as a larger positive FMAB-Wits measurement, while males were found to have a larger negative cFMAB-Wits measurement. Of these, only the FMA difference was found to be significantly different at more than one time point (T1 = 1.80+/-0.84°, $p<0.05$; T2 = 2.92+/-0.84°, $p<0.05$). The only statistically significant difference found between treated Class II Division 1 males and females was in FMAB-Wits at T2 (1.40+/-0.57 mm, $p<0.05$). Amongst the control subjects the MMA at T0 in Class II Division 1 was found to be smaller in females than in males. None of the angular measurements exceeded a difference of 3° and none of the linear measurements were larger than 1.10 mm, suggesting that there were no clinically significant differences between males and females in this study.

The mean changes between each time period were then measured for each variable, separated by presenting occlusion and gender. Table 12 examines the mean changes amongst the female subjects using one-way repeated measures ANOVA. Statistically significant differences were found at all three time points for the FMA value amongst control subjects, though none of these discrepancies were larger than 2° (0.90-1.84°). MMB-Wits, FMAB-Wits, and cFMAB-Wits bisector measurements all produced a statistically significant change with treatment from T0-T1 and from T0-T2, but none of these differences exceeded 1.0 mm. This correlated with the trend seen in ANB amongst treated individuals, decreasing slightly from the initial measurement during the course of orthodontic therapy. For the Class II Division 1 female subset, the control group experienced little or no change (0.11-0.36°). The change was much greater in the treated group, though it still did not exceed 3° (2.14-2.39°). MMB-Wits (2.65-3.01°) and FMAB-Wits (2.53-2.89°) values both decreased significantly with time, while cFMAB-Wits remained relatively unchanged (0.13-0.46°). No significant differences were found across any of the time periods for the Class II Division 1 female control subjects.

Analysis of the male subjects in Table 13 revealed similar patterns to those seen in the female group. In the Class I measurements, ANB decreased over time in the treated group and remained unchanged in the controls. The MMB-Wits, FMAB-Wits, and cFMAB-Wits all produced statistically significant decreases during treatment. The impact of orthodontic treatment on the anteroposterior cephalometric measurements analyzed in this study was most evident in the male subjects in the Class II Division 1 subset. The MMB-Wits and FMAB-Wits both experienced significant decreases from pre-treatment to immediate post-treatment (3.29 mm and 3.13 mm, respectively), as well as from pre-treatment to two years post-retention (4.04 mm and 4.14 mm). This was also reflected in the decrease in ANB amongst the treated males (T0-T1 = 2.35º; T0-T2 = 2.93º) which was statistically significant. The same corresponding change was not apparent in the cFMAB-Wits and remained relatively unchanged following treatment.

The scatter plots for the relationship between ANB and each of the bisectors (MMB-Wits, FMAB-Wits, and cFMAB-Wits) are shown in figures 10-15. Based on the produced scatter plots, the relationships were deemed to be non-linear and thus did not satisfy the assumptions required for the Pearson correlation assessment used previously by Swoboda and Sangha. There did appear to be a monotonic relationship between ANB and each of the bisector variables allowing for the use of the Spearman's rank-order correlation. Tables 14 and 15 present the Spearman correlation coefficients (r_s) for the Class I and Class II Division 1 cases and controls at each of the time periods. The tables also show the statistical significance of each correlation coefficient ($p<0.05$ or $p<0.01$). There was a moderate positive correlation between ANB and both MMB-Wits and FMAB-Wits for all subjects, regardless of occlusal relationship, treatment status, or time of measurement. The highest correlation was ANB with FMAB-Wits amongst Class II Division 1 controls (T0 = 0.63, T1 = 0.69, T2 = 0.73). For the Class I subjects, there was a moderate positive correlation between ANB and cFMAB-Wits that was similar for both treated cases and controls at all time periods. However, this pattern was not found in the Class II Division 1 sample. Some observations suggested a statistically significant positive correlation, while others implied a negligible relationship. The pre-treatment correlation values for the treated cases (r_s = 0.42) and controls (r_s = 0.31) were similar, but following treatment the correlation found with ANB amongst the cases was lower than that found in the control group. None of the *rho* values exceeded 0.52, suggesting that for this sample there is not a strong correlation between ANB and cFMAB-Wits amongst Class II Division 1 patients.

High levels of correlation were found amongst the three bisectors examined in this study. In the Class I subset, the correlation values for MMB-Wits and FMAB-Wits exceeded 0.85 for both treated cases and controls at all time points. A similarly strong relationship was found in the Class II Division 1 subjects, with all Spearman correlations of 0.82 or higher. The Class I cases and controls both produced very strong positive correlations between cFMAB-Wits and both MMB-Wits as well as FMAB-Wits. All time periods were found to be statistically significant with a range of $r_s = 0.79$ to 0.94. However, there were different findings concerning the correlation between cFMAB-Wits and the MMB-Wits and the FMAB-Wits values in the Class II Division 1 dataset. Similar to the relationship seen between cFMAB-Wits and ANB, there was a strong positive correlation prior to treatment ($r_s = 0.68$-0.72). Following orthodontic therapy, there was a statistically significant positive correlation between cFMAB-Wits and both MMB-Wits and FMAB-Wits, though the moderate correlation was not as strong as prior to treatment with *rho* values as low as 0.40 and not greater than 0.57. When there was no orthodontic intervention, there was a low-to-weak correlation across all three time points as seen in the Class II Division 1 controls.

Discussion

The sagittal relationship between the maxilla and mandible is an important diagnostic criterion in evaluating the severity of an individual's malocclusion, as well as the effect of orthodontic treatment in the anteroposterior plane. In order to better evaluate this relationship, lateral cephalograms have been used to describe the position of the maxilla and mandible, as well as how each relates to the other and the cranial base. Through the use of serial lateral cephalograms practitioners have been able to measure orthodontic treatment effects as well as changes owing to the growth of the individual by using established landmarks and comparing their relative position to one another over time. Using these landmarks, numerous planes and landmarks have been proposed to describe the anteroposterior relationship of the maxilla and mandible, the most common of which is the ANB angle first described by Riedel.[3,7, 8,9, 43]

While ANB is the most frequently used measure, it is not without its criticisms. Identification of the necessary landmarks introduces the possibility of error, particularly at A point and B point, which have been shown to be susceptible to tracing errors of greater than 1.50 mm in more than 20% of lateral cephalograms.[30,31] Changes in the axes lengths may also impact the accuracy of ANB,[10,11] which has been shown to occur due to the superior and anterior movement of nasion with growth[37] as well as rotation of the jaws with growth and, most importantly, with orthodontic treatment.[12,13,16,44]

Jacobson proposed a variant for measuring the sagittal relationship of the jaws by extrapolating A point and B point to a line representing the functional occlusal plane (FOP) and creating a linear measurement rather than an angular one.[15] The Wits' analysis eliminated the need for identifying cranial landmarks and was less prone to errors owing to the measured distance from both A and B points. However, a number of inherent difficulties with the analysis were found that can lead to a misinterpretation of the true nature of the skeletal relationship.[17-21,23,24,28] The critical limitation of the Wits' analysis is that it uses dental measurements to try to explain skeletal parameters.

A number of recommendations have been proposed to better identify the true sagittal relationship of the jaws, including changing the method of determining the occlusal plane for the Wits' analysis,[6,13,25,26] using perpendicular tangents of A point and B point to the Frankfort horizontal rather than the occlusal plane,[5,13] and relating cranial structures to an extra-cranial reference line.[35] While there are strengths to each of these proposed measures, they are not without their limitations including intolerance to rotational growth of the jaws and lack of evidence regarding the impact of growth and orthodontic treatment.

The maxillary-mandibular plane angle bisector Wits' analysis (MMP-Wits), first proposed by Hall-Scott,[24] used a geometrically derived plane that eliminated the problems found in correctly identifying the occlusal plane and was purported to not change significantly with growth and rotation of the jaws. Studies have shown that this bisector is highly reproducible and correlates moderately well with ANB.[21,22,28,29] However, changes in the palatal plane lead to significant errors and reduced correlation with other sagittal measurements, which has been shown to occur in treated individuals over time, particularly Class II patients treated with inter-arch elastics and headgear.[34]

In order to eliminate the rotational effects of the palatal plane, the Frankfort horizontal-mandibular plane angle bisector Wits' analysis (FMAB-Wits) was created.[33,34] This bisector utilized the more stable Frankfort horizontal axis and has been shown to be highly reproducible. In separate studies of both Class I[33] and Class II Division 1[34] treated cases and controls, the FMAB-Wits bisector was found to be moderately correlated with ANB. This correlation was higher than that seen between MMB-Wits and ANB. The changes seen in ANB due to growth and orthodontic treatment were also seen in the FMAB-Wits measurements, suggesting that it may be a valid means of assessing the anteroposterior relationship of the jaws. However, none of the correlations exceeded a moderate level (0.50-0.70)[43] and at some time points were found to be considered a low level of correlation (0.30-0.50).

The purpose of this study was to evaluate whether a new bisector would better correlate with the gold standard ANB and thus serve as an alternative method for evaluating the sagittal relationship of the maxilla and mandible, while being tolerant to changes owing to growth and orthodontic treatment. The constructed Frankfort-mandibular plane angle bisector Wits' analysis (cFMAB-Wits) was selected due to the use of more reliable landmarks than the FMAB-Wits[30,31] and to incorporate the potential changes in nasion that would also be reflected in ANB.[1,37] The cFMAB-Wits relies on a constructed horizontal axis which is a surrogate to the Frankfort horizontal, drawn 6° inferior from the sella-nasion line.

In order to assess the reliability of the cephalometric landmarks used for the cFMAB-Wits, an error study was done. Repeat tracings of 60 lateral cephalograms revealed very high rates of reproducibility for both the constructed Frankfort-mandibular plane angle ($R = 0.94$), as well as the Wits'-type measurement to the bisector ($R = 0.96$) using the Dahlberg formula. These results are similar to those found for the MMB-Wits and FMAB-Wits in both this study and previous studies.[33,34] This suggests that the planes used for the measurement are highly reliable and large discrepancies owing to tracing errors are unlikely.

Significant age differences were found between the grouped treated cases and controls prior to orthodontic treatment (T0), immediately after treatment (T1), and at two years retention (T2). Case selection helps to explain this discrepancy. The controls were part of the Burlington Growth Centre study and were assigned to T0, T1, and T2 based on age only, as opposed to the treated individuals who were dependent on their stage of orthodontic treatment. Due to the nature of the graduate orthodontic clinic at the University of Western Ontario where the cases were selected from, patients may start their treatment at a later age. In addition, because the care is being provided by a resident, treatment times may have been extended longer than those seen in private practice, which would further increase the age discrepancy. The ages of the treated participants was also evaluated for any differences owing to gender. At all three time points, the male participants were significantly older than the females, beginning treatment just over five months later than the females and finishing the retention phase more than 6 months later. This is consistent with the differential temporal growth pattern observed in males and females.[1,3,37] Females will undergo puberty earlier than males on average, and as a result, orthodontic treatment is initiated at an earlier age in females in order to capture the advantages of the pubertal growth spurt.[1] This may be particularly advantageous in Class II patients with retrognathic mandibles or prognathic maxillas. Various orthodontic treatment modalities, including elastics, headgear, and fixed functional appliances may be used during this growth spurt to either restrict the forward growth of the maxilla or alter the direction of growth of the mandible more favorably to help correct the Class II malocclusion. As a result, patients presenting with this skeletal relationship may be started at an earlier age than children with little or no maxillomandibular sagittal disharmony in order to ensure that the pubertal spurt is not missed. This differential case selection may explain why the inclusion of all cases (Class I and Class II Division 1) produced a higher mean age at all time periods than that seen by Sangha (restricted to Class II Division 1 participants only).[34]

Each of the study participants were assessed for a number of cephalometric values at each of the three time points (Table 4). The trends observed are consistent with the expected impact of orthodontic treatment and growth.[37] Initial ANB was higher in the Class II Division 1 subset due to the method of case selection (Class I = ANB < 4.0; Class II/1 = ANB > 4.0). The ANB value decreased over time in all groups, regardless of the presence or absence of orthodontic treatment, suggesting that there is greater anterior movement of B point than A point, relative to nasion, with normal growth. The Class II Division 1 treated cases showed that significant improvements in the sagittal relationships of the jaws can be accomplished with orthodontics, as evidenced by their larger change in ANB compared with their matched controls. The relationship between ANB and both MMB-Wits and FMAB-Wits was similar to that found in previous studies,[21,24,33,34] and a similar positive correlation between ANB and cFMAB-Wits was found. This trend was not consistent with the findings in the Class II population, which saw little change in cFMAB-Wits. The implication is that either nasion did not change as appreciably in these individuals as it did in the Class I group or there was greater forward movement of B point. While this could explain the changes seen in the treated individuals, as supported by the decreased ANB values, it does not explain the controls results. Table 5 shows the differences in cephalometric measures found in this study and those found in the previous studies by Swoboda[33] and Sangha[34] using the same participants. A statistically significant difference was found between the T0 FMAB-Wits value for Class II Division 1 cases in this study and the Sangha study, while other measures approached statistical significance as well, including ANB at T0 and FMAB-Wits at T0, T1, and T2 amongst controls. While these may help explain the inconsistent trends seen in the cFMAB-Wits measurements, none of the differences were greater than 1.4° or 1.0 mm and were thus not considered clinically significant. It is possible that the cumulative effects of these small differences may have altered the trend seen, but a new study with a larger number of participants would be necessary to elucidate the cause of this discrepancy.

Each of the study participants were assessed for changes in cephalometric measures over time (Table 6). The change seen in the Class I subjects for ANB closely matches that seen in previous studies looking at growth over similar time intervals.[3,45] While there was statistically significant changes in the Class I cases and controls over time for each of the Wits'-type measurements, in the Class II Division 1 subset, the treated individuals saw a statistically significant change in ANB, MMB-Wits, FMAB-Wits, and cFMAB-Wits, while the controls had no significant changes over time. This supports previous findings by Stahl *et al*[46] and Bishara *et al*[3] which suggested that Class II skeletal relationships do not correct in the absence of orthodontic treatment.

In Table 7, the impact of orthodontics on the sagittal jaw relationship was approximated by calculating the difference in the change due to growth alone and the combination effect of growth and orthodontic treatment. In the Class I sample, the difference between the treated cases and controls for the MMA, FMA, and cFH-MP angles all increased over time. All three of these angles involve the mandibular plane. The likelihood is that the extrusive effects of orthodontic therapy exceeded the compensatory growth of the ramus, resulting in an increased mandibular plane angle.[1] The differences also suggest that, over time, the control group had a less ideal maxillo-mandibular relationship in the antero-posterior plane than the treatment group, but this is not supported by the difference in ANB measurements. While these changes were found to be statistically significant, the largest angular increase from T0 to T2 was 1.12° (cFH-MP) and the largest linear change was 0.66 mm (FMAB-Wits), meaning that the slight differences held little clinical implications. Only the FMAB-Wits measurement produced a consistent difference of more than 2.0 mm (2.13-2.79 mm) that could be viewed as clinically significant. These differences were also seen in the Class II Division 1 sample, though with much larger discrepancies seen due to treatment effects. In particular, the MMB-Wits and FMAB-Wits values changed by 3.38 mm and 3.50 mm, respectively, from T0 to T2. As expected, larger sagittal treatment effects were seen in this population when the treated patient presented with a larger initial sagittal discrepancy (i.e. Class II versus Class I). It was also noted that the Class II Division 1 treated subjects presented with a significantly larger ANB and MMB-Wits value in comparison with the controls. The possible reasoning for this is that the subjects in the Burlington Growth Study voluntarily forego orthodontic treatment and the treated cases may have had a more noticeable sagittal discrepancy and thus actively sought orthodontics.

The potential effect of gender was examined in tables 8-13. No discernible differences were noted in the general trends of any of the cephalometric measurements over time – those that tended to increase/decrease/remain unchanged in females, did the same in males. However, there were statistically significant differences found by gender. In the Class I treated subjects, at two years post-treatment, females had significantly larger FMA (2.92°+/-0.84) and cFH-MP (2.75°+/-0.90) values than the males. This is clinically significant as past research has shown that changes as low as 3° can impact linear extrapolations such as Wits-type analyses.[17] Similarly, the FMAB-Wits was larger for Class I females, and although the difference was not deemed to be clinically significant (1.08mm+/-0.53), it does suggest that the discrepancies may be due to a steeper mandibular plane in the females of this population following orthodontic treatment. As discussed earlier, this could be due to less adaptive growth in ramus height in response to orthodontic extrusion, which would correlate with the fact that females tend to finish growth earlier than males.[1] This is further supported by the fact that there were no significantly differences found between females and males in the Class I controls. This implies that in the absence of orthodontic extrusion, there is less change in the mandibular plane that must be compensated by growth. With a smaller change in the mandibular plane angle, one could expect a smaller change in the Wits-type analyses, regardless if growth has been completed. No statistically significant differences were found in the Class II Division 1 sample, but there were clinically significant differences found by gender, particularly amongst the controls. The MMA (3.32°+/-1.55), FMA (2.23°+/-1.46), and cFH-MP (2.65°+/-1.59) values were all significantly higher in the male controls at T0, suggesting that they had a steeper mandibular plane initially. In all three measurements, the difference between males and females decreased substantially over time, likely due to rotation of the jaws during normal growth.[19,35] However, caution must be exercised in the interpretation of these results due to the small sample size in the control group, particularly when separated by gender and occlusal relationship.

Past studies looking at the sagittal relationships of the jaws have often tried to measure the level of correlation with the gold standard, ANB.[8] Those that correlate well with ANB, whether it be positive (same direction) or negative (opposite direction), could allow orthodontists to use the measure as an adjunct to ANB or as an alternative if ANB cannot be accurately measured. The primary purpose of this study was to evaluate which of the Wits-type bisector measurements - MMB-Wits, FMAB-Wits, or cFMAB-Wits - best correlates with ANB in a sample population of treated Class I and Class II Division 1 subjects, as well as untreated controls. Hall-Scott *et al*[24] examined 36 adults with "normal occlusions" and 43 children with malocclusions (no distinction of Angle classification given) and found that the MMB-Wits measurement showed strong correlation with ANB in children (r = 0.95) and in adults (r = 0.83). A study by Palleck *et al*[21] of Class I subjects found the correlation between ANB and MMB-Wits to be lower in both treated cases (r = 0.69) and controls (r = 0.67) compared with the findings of Hall-Scott. Similar results were found by Foley *et al*[22] when examining Class II Division 1 treated patients (r = 0.63), though they did find stronger correlations to ANB amongst the controls (r = 0.85).

Recently, studies by Swoboda[33] and Sangha[34] have examined the correlation between ANB and both MMB-Wits and FMAB-Wits in Class I and Class II Division 1 cases, respectively. Swoboda found low-to-moderate levels of correlation between ANB and both MMB-Wits (r = 0.19-0.60) and FMAB-Wits (r = 0.25-0.57). Interestingly, for both treated cases and controls, the trend was for the correlation to become less significant with growth (approximated in this study using time intervals). The correlation between the two Wits-type measurements was very high, ranging from 0.86-0.91 for treated cases and 0.91-0.96 for controls. This means that while the MMB-Wits and FMAB-Wits measurements may suggest the same sagittal relationship, it may not necessarily coincide with the finding suggested by ANB. In the Sangha study, similarly moderate levels of correlation were found between ANB and MMB-Wits (r = 0.54-0.63), as well as between ANB and FMAB-Wits (r = 0.58-0.67). There was no trend of decreasing correlation with growth and the correlation between MMB-Wits and FMAB-Wits was lower than the Swoboda findings for both cases (r = 0.80-0.87) and controls (r = 0.80-0.86), though both were considered strong.

In this study, a third Wits-type measurement was introduced, the cFMAB-Wits, for which no previous data could be found for comparison. It was determined that the data did not produce linear relationships using scatter plots and Spearman correlation coefficients were found instead of the Pearson correlation coefficients described above. The r-values were calculated and found to not significantly differ from the Spearman coefficients, but r_s was used in order to maintain validity.

Similar to the Swoboda study, Class I treated cases produced moderate correlation values between ANB and MMB-Wits (r_s = 0.38-0.42) and between ANB and FMAB-Wits (r_s = 0.41-0.47). The controls also exhibited moderate correlation (ANB to MMB-Wits: r_s = 0.38-0.57; ANB to FMAB-Wits: r_s= 0.46-0.54). The trend of decreasing correlation with growth was not found as it had been previously. The Spearman correlation coefficients for ANB and cFMAB were also categorized as moderate (cases: r_s = 0.42-0.48; controls: r_s = 0.51-0.58). High levels of correlation were found for all Class I subjects at all time points between MMB-Wits and FMAB-Wits (r_s = 0.86-0.91), MMB-Wits and cFMAB-Wits (r_s = 0.79-0.94), and FMAB-Wits and cFMAB-Wits (r_s = 0.85-0.94).

The trends found in the Sangha study were also found in this study. Generally, the correlation between ANB and the MMB-Wits and FMAB-Wits were low-to-moderate and did not have a temporal trend, while the correlation between MMB-Wits and FMAB-Wits was high, regardless of treatment status (r_s = 0.82-0.87). What is interesting to note is the variability in correlation between ANB and cFMAB-Wits. As with the Class I subjects, a positive correlation exists, but the correlation values range from a low correlation value of $r_s = 0.42$ for treated cases at T0 to a negligible correlation value of $r_s = 0.10$ at T1. This suggests that any correlation between ANB and cFMAB-Wits in Class II Division 1 patients may diminish or be absent following orthodontic treatment. The same observation was not found amongst the control subjects. There was also a significantly lower level of correlation between MMB-Wits and cFMAB-Wits and between FMAB-Wits and cFMAB-Wits in comparison with the Class I subjects, with all but one of the correlations being considered low or moderate. These findings suggest that cFMAB-Wits may not be a viable measurement method for Class II Division 1 patients if the goal is to compare the finding to ANB or either of the other Wits analyses.

Based on the findings of this study, the general guideline should suggest that caution must be exercised in trying to relate any of MMB-Wits, FMAB-Wits, or cFMAB-Wits to the gold standard of ANB. No measurement exhibited a high level of correlation with ANB and all performed at a very similar moderate level for Class I participants. The results do suggest that cFMAB-Wits is not a viable alternative to ANB for Class II Division 1 subjects. However, this paper supports the ability to interchange MMB-Wits, FMAB-Wits, and cFMAB-Wits as a means of assessing anteroposterior jaw relationships. All three measurements make use of the mandibular plane and produce a bisector which uses varying superior lines of reference. The high level of correlation between the measurements suggests that there is little discrepancy between the position of the bisectors and these differences will likely not produce a discernible difference in a clinical setting.

The ability of this study to measure the correlation between these cephalometric measures depends on good landmark identification and optimal cephalometric imaging. The author acknowledges that difficulty in establishing proper landmark location due to poor lateral cephalogram quality and individual anatomic variation was a potential source of error in this study. Certain landmarks can be more difficult to locate than others[30,31,40] and, as a result, there may have been discrepancies in particular measurements that were not seen in others. In addition, the use of a constructed plane requires that it be drawn at a specified inclination, as opposed to connecting two distinct points. While the use of constructed Frankfort horizontal has been shown to be more reliable and reproducible than the true Frankfort horizontal, it does allow for a reduction in accuracy.[1] The error study done suggested that there was a very high level of reliability for all of the major landmarks used, meaning the potential impact of these errors was likely low.

Another potential source of error in this study was the lack of sufficient power for the control groups in both the Class I and Class II Division 1 groups. Earlier power studies[33,34] deemed the need for 47 subjects and 34 subjects in each group, respectively. The inability to obtain sufficient power of 80% *a priori* means that the risk of type II error is increased. The interpretation is that error may have been introduced into the assessment of the correlation between ANB, MMB-Wits, FMAB-Wits, and cFMAB-Wits – causing for an inference of strong correlation when in fact it was not.

The very nature of the graduate orthodontic program from which the cases were selected introduces selection bias that impacts the ability to extrapolate the findings of this paper to a global scale. Severity of malocclusion, growth patterns, and temporal growth spurts have been shown to vary depending on the ethnic background of the individual.[47] The results found in this population sample may not correlate well with a similar study done in a region of the world that is not predominantly Caucasian.

As the results of this paper have shown, the type of malocclusion can impact the cFMAB-Wits value. Future research could examine the impact that a Class III malocclusion has on cFMAB-Wits and how this affects the correlation coefficient with ANB. In addition, further analysis of a larger sample size will allow for the determination of norms for the cFMAB-Wits measurement, as has been done previously with ANB[7] and the Wits' analysis.[15,16] With a known mean, specific values could correspond to particular occlusal relationships, as has been done with previous measurements (e.g. ANB = 2°+/-2° for Class I). This could facilitate a better understanding of the true correlation between cFMAB-Wits and ANB – does a Class I as determined by ANB always produce a Class I relationship as dictated by cFMAB-Wits? The value in this would be a proven means of confirming cephalometric findings on more than one level regarding the anteroposterior relationship between the maxilla and mandible.

A second potential area for future research should focus on establishing a means of incorporating the rotational effects that are seen with growth in the jaws.[14,35,38] The cFMAB-Wits measurement does account for changes in the position of nasion, but can be impacted by the rotation of the mandible. A clockwise down and backward rotation is common in vertical discrepancies and this would alter the B point extrapolation as well as the bisector itself. If this rotation occurred during normal growth, the linear value would trend to a more negative number, as seen in the negative correlation coefficients found in this study with ANB (as ANB decreases, cFMAB increases). While proposed angles such as the W-angle[14] and the YEN angle[38] seem to address this issue, to date there have not been any published studies which considered the impact of long-term growth on these measurements and questions have been raised regarding the accuracy of the landmarks used. A study using this data set examining the W and YEN angles could further the attempt to identify the best method of correlating the maxillomandibular relationship in the sagittal plane to the current gold standard of ANB. Additionally, these measures may prove to be more reliable across all types of malocclusions and more tolerant of growth, leading to them being accepted as the new gold standard. An alternative study could include considerations of the impact of the vertical nature of growth and treatment effects. Subjects could be separated based on criteria in the vertical plane (e.g. lower face height) and the various measurements could be evaluated for their correlation to ANB – this could lead to the identification of particular patient types for which the Wits-type analyses are a viable substitute for ANB and those in which it is not.

Conclusions

The conclusions that can be derived from this investigation are as follows:

1. Similar correlation values were found between the gold standard ANB and the three Wits-type analyses (MMB-Wits, FMAB-Wits, cFMAB-Wits) used in this population sample. The difference between the three was negligible and none achieved more than a moderate level of correlation.

2. Males in the treatment group were significantly older than females prior to starting orthodontic therapy, at the end of treatment, and at the end of retention. These results suggest that females generally begin correction of Class I and Class II Division 1 malocclusions earlier than males, likely due to earlier maturation and timing of the pubertal growth spurt.

3. Gender does not act as a significant determinant of ANB, MMB-Wits, FMAB-Wits, or cFMAB-Wits within each malocclusion classification at the start of treatment or at the end of active orthodontic therapy. Significant differences between males and females exist at the end of retention for cFMAB-Wits in Class I individuals and in both classes for FMAB-Wits.

4. MMB-Wits, FMAB-Wits, and cFMAB-Wits are all strongly correlated with one another in the Class I sample population. For Class II Division 1 participants, the level of correlation is only weak to moderate.

Table 1: Measurement Error and Reproducibility of Cephalometric Variables (n=60)

Cephalometric Measure	Measurement Error (SE)	Reproducibility (R)
ANB (°)	0.38	0.93
MMA (°)	1.17	0.92
FMA (°)	1.09	0.93
cFH-MP (°)	1.17	0.94
MMB-Wits (mm)	0.58	0.91
FMAB-Wits (mm)	0.49	0.96
cFMAB-Wits (mm)	0.47	0.96

Table 2: Mean Ages at T0, T1, and T2 for Treatment and Control Groups and Differences Across Time Periods (Subtraction of Means: Treatment – Control)

Treatment Group	Age at T0 (months)	Age at T1	Age at T2
	Mean +/- s.d.	Mean +/- s.d.	Mean +/- s.d.
Treatment	148.59 +/- 12.16	177.23 +/- 13.73	202.38 +/- 13.94
Control	144.39 +/- 1.30	168.55 +/- 1.72	192.42 +/- 0.98
Difference	4.20 +/- 1.47* 95% C.I. (1.31,7.09)	8.68 +/- 1.66* 95% C.I. (5.42,11.95)	9.96 +/- 1.68* 95% C.I. (6.65,13.27)

**p<0.05*

Table 3: Mean Ages at T0, T1, and T2 for Males and Females in the Treatment Group and Differences Across Time Periods (Subtraction of Means: Males – Females)

Gender	Age at T0 (months)	Age at T1	Age at T2
	Mean +/- s.d.	Mean +/- s.d.	Mean +/- s.d.
Male	151.18 +/- 11.42	180.53 +/- 12.63	205.53 +/- 13.65
Female	146.06 +/- 12.40	174.01 +/- 14.06	199.09 +/- 13.99
Difference	5.12 +/- 1.70* 95% C.I. (1.76, 8.47)	6.52 +/- 1.91* 95 C.I. (2.75, 10.83)	6.44 +/- 1.97* 95% C.I. (2.54, 10.33)

**p<0.05*

Table 4: Cephalometric Measurement Means and Standard Deviations in the Treatment and Control Groups for Class I and Class II Division 1 Population Samples

Class	Ceph. Meas.	Treatment Group			Control Group		
		T0	T1	T2	T0	T1	T2
I	ANB (°)	2.97+/-1.08	2.52+/-1.22	2.39+/-1.34	2.55+/-1.08	2.25+/-1.07	1.99+/-1.40
	MMA (°)	28.72+/-4.56	28.84+/-4.85	28.36+/-5.02	27.36+/-4.77	26.33+/-4.53	25.92+/-5.07
	FMA (°)	26.43+/-4.16	26.56+/-4.69	25.65+/-4.78	26.35+/-4.48	25.40+/-4.48	24.34+/-4.89
	cFH-MP (°)	29.85+/-4.58	30.03+/-4.93	29.46+/-5.10	28.86+/-5.06	28.15+/-5.39	27.35+/-5.61
	MMB-Wits (mm)	-3.60+/-2.32	-4.31+/-2.51	-4.58+/-2.79	-2.12+/-1.07	-2.49+/-1.30	-2.52+/-1.30
	FMAB-Wits (mm)	-4.43+/-2.35	-5.16+/-2.54	-5.60+/-2.92	-2.30+/-1.11	-2.66+/-1.31	-2.81+/-1.23
	cFMAB-Wits (mm)	-3.31+/-2.14	-4.05+/-2.20	-4.27+/-2.68	-1.86+/-1.01	-2.16+/-1.17	-2.30+/-1.17
II/1	ANB (°)	5.75+/-1.54	3.51+/-1.72	3.11+/-1.82	4.79+/-1.15	4.77+/-1.27	4.64+/-1.57
	MMA (°)	28.47+/-4.16	28.14+/-4.84	27.38+/-4.72	25.53+/-4.50	24.26+/-4.73	23.84+/-4.47
	FMA (°)	25.07+/-3.91	25.38+/-4.03	24.36+/-4.12	24.23+/-4.09	23.55+/-4.78	23.05+/-4.65
	cFH-MP (°)	28.72+/-4.55	29.15+/-4.89	28.49+/-5.20	27.24+/-4.50	26.41+/-4.64	25.77+/-4.52
	MMB-Wits (mm)	1.62+/-1.97	-1.34+/-2.15	-1.88+/-2.38	0.26+/-1.78	0.12+/-1.77	0.14+/-1.87
	FMAB-Wits (mm)	0.47+/-2.07	-2.35+/-2.20	-3.02+/-2.57	-0.16+/-2.35	-0.10+/-2.18	-0.15+/-2.17
	cFMAB-Wits (mm)	2.20+/-1.57	-1.98+/-1.50	-2.47+/-1.87	1.85+/-1.28	1.74+/-1.24	1.85+/-1.23

Table 5: Difference in Cephalometric Measurement Means Between Tomson and Swoboda/Sangha Studies in the Treatment and Control Groups for Class I and Class II Division 1 Population Samples (Subtraction of Means: Tomson – Swoboda/Sangha)

Class	Ceph. Meas.	Treatment Group			Control Group		
		T0	T1	T2	T0	T1	T2
I	ANB (°)	-0.01 (p=0.94)	-0.14 (p=0.36)	0.01 (p=0.95)	0.02 (p=0.94)	0.18 (p=0.49)	0.15 (p=0.63)
	MMA (°)	0.06 (p=0.92)	0.18 (p=0.77)	0.02 (p=0.98)	0.83 (p=0.46)	0.44 (p=0.68)	0.31 (p=0.79)
	FMA (°)	-0.03 (p=0.96)	-0.19 (p=0.76)	-0.51 (p=0.42)	0.60 (p=0.57)	0.07 (p=0.95)	-0.08 (p=0.94)
	MMB-Wits (mm)	0.23 (p=0.43)	0.19 (p=0.55)	0.29 (p=0.41)	0.05 (p=0.84)	0.24 (p=0.40)	0.21 (p=0.46)
	FMAB-Wits (mm)	0.12 (p=0.69)	0.05 (p=0.88)	0.07 (p=0.85)	0.02 (p=0.94)	0.15 (p=0.60)	0.12 (p=0.67)
II/1	ANB (°)	-0.11 (p=0.66)	-0.19 (p=0.49)	-0.20 (p=0.49)	-0.41 (p=0.15)	-0.31 (p=0.34)	-0.40 (p=0.29)
	MMA (°)	0.88 (p=0.22)	0.21 (p=0.77)	0.43 (p=0.58)	0.17 (p=0.89)	-0.22 (p=0.86)	-0.22 (p=0.85)
	FMA (°)	-0.34 (p=0.59)	-0.29 (p=0.66)	-0.59 (p=0.38)	-1.30 (p=0.24)	-1.34 (p=0.27)	-1.28 (p=0.29)
	MMB-Wits (mm)	0.01 (p=0.98)	0.11 (p=0.75)	-0.03 (p=0.94)	-0.26 (p=0.55)	-0.25 (p=0.56)	-0.25 (p=0.58)
	FMAB-Wits (mm)	**-0.82 (p<0.01)**	-0.60 (p=0.10)	-0.78 (p=0.07)	-0.96 (p=0.09)	-0.80 (p=0.14)	-0.91 (p=0.09)

Table 6: Mean Change Between Time Periods in Cephalometric Measurement Values in the Treatment and Control Groups for Class I and Class II Division 1 Population Samples

Class	Ceph. Meas.	Treatment Group			Control Group		
		T0-T1	T1-T2	T0-T2	T0-T1	T1-T2	T0-T2
I	ANB (°)	0.45* (SE=0.08)	0.13* (SE=0.07)	0.58* (SE=0.09)	0.31* (SE=0.11)	0.26* (SE=0.14)	0.56* (SE=0.20)
	MMA (°)	-0.13 (SE=0.19)	0.49* (SE=0.17)	0.36 (SE=0.23)	1.02* (SE=0.30)	0.41 (SE=0.31)	1.44* (SE=0.30)
	FMA (°)	-0.13 (SE=0.20)	0.92* (SE=0.16)	0.78* (SE=0.20)	0.95* (SE=0.25)	1.06* (SE=0.22)	2.01* (SE=0.29)
	cFH-MP (°)	-0.18 (SE=0.18)	0.57* (SE=0.15)	0.39 (SE=0.21)	0.71* (SE=0.27)	0.80* (SE=0.24)	1.51* (SE=0.31)
	MMB-Wits (mm)	0.72* (SE=0.12)	0.27 (SE=0.12)	0.99* (SE=0.15)	0.37* (SE=0.13)	0.03 (SE=0.17)	0.40* (SE=0.15)
	FMAB-Wits (mm)	0.74* (SE=0.14)	0.44* (SE=0.13)	1.18* (SE=0.15)	0.36* (SE=0.13)	0.15 (SE=0.17)	0.51* (SE=0.14)
	cFMAB-Wits (mm)	0.74* (SE=0.12)	0.23 (SE=0.12)	0.97* (SE=0.15)	0.30* (SE=0.11)	0.14 (SE=0.15)	0.44* (SE=0.15)
II/1	ANB (°)	2.24* (SE=0.13)	0.40* (SE=0.10)	2.64* (SE=0.15)	0.03 (SE=0.12)	0.13 (SE=0.16)	0.15 (SE=0.18)
	MMA (°)	0.32 (SE=0.23)	0.77* (SE=0.19)	1.09* (SE=0.26)	1.29* (SE=0.35)	0.42 (SE=0.29)	1.71* (SE=0.35)
	FMA (°)	-0.30 (SE=0.23)	1.02* (SE=0.22)	0.72* (SE=0.28)	0.68 (SE=0.28)	0.50 (SE=0.27)	1.18* (SE=0.35)
	cFH-MP (°)	-0.43 (SE=0.22)	0.66* (SE=0.19)	0.23 (SE=0.30)	0.82* (SE=0.27)	0.64 (SE=0.28)	1.47* (SE=0.36)
	MMB-Wits (mm)	2.96* (SE=0.19)	0.54* (SE=0.16)	3.50* (SE=0.23)	0.14 (SE=0.24)	-0.02 (SE=0.22)	0.12 (SE=0.28)
	FMAB-Wits (mm)	2.82* (SE=0.20)	0.67* (SE=0.16)	3.49* (SE=0.24)	-0.06 (SE=0.26)	0.05 (SE=0.21)	-0.01 (SE=0.27)
	cFMAB-Wits (mm)	0.22 (SE=0.26)	0.49* (SE=0.12)	0.27 (SE=0.30)	-0.12 (SE=0.21)	0.12 (SE=0.19)	-0.01 (SE=0.24)

** = $p < 0.05$*

Table 7: Differences in Cephalometric Measurement Values Between Treatment and Control Groups for Class I and Class II Division 1 Population Samples (Subtraction of Means: Treatment – Control)

Class	Ceph. Meas.	T0	T1	T2
I	ANB (°)	0.42+/-0.20*	0.27+/-0.22	0.40+/-0.25
	MMA (°)	1.36+/-0.85	2.51+/-0.88*	2.44+/-0.93*
	FMA (°)	0.08+/-0.78	1.16+/-0.85	1.31+/-0.89
	cFH-MP (°)	0.99+/-0.87	1.87+/-0.93*	2.11+/-0.96*
	MMB-Wits (mm)	-1.48+/-0.38*	-1.82+/-0.42*	-2.06+/-0.46*
	FMAB-Wits (mm)	-2.13+/-0.39*	-2.51+/-0.42*	-2.79+/-0.48*
	cFMAB-Wits (mm)	-1.45+/-0.36*	-1.89+/-0.37*	-1.97+/-0.44*
II/1	ANB (°)	0.96+/-0.31*	-1.25+/-0.35*	-1.53+/-0.38*
	MMA (°)	2.91+/-0.92*	3.88+/-1.04*	3.53+/-1.00*
	FMA (°)	0.84+/-0.85	1.82+/-0.92*	1.30+/-0.92
	cFH-MP (°)	1.48+/-0.98	2.74+/-1.04*	2.72+/-1.08*
	MMB-Wits (mm)	1.36+/-0.41*	-1.46+/-0.44*	-2.02+/-0.48*
	FMAB-Wits (mm)	0.63+/-0.46	-2.24+/-0.47*	-2.87+/-0.53*
	cFMAB-Wits (mm)	0.34+/-0.32	-0.24+/-0.44	-0.62+/-0.37

*$p < 0.05$

Table 8: Cephalometric Measurement Means and Standard Deviations in the Treatment Group for Class I and Class II Division 1 Population Samples by Gender

Class	Ceph. Meas.	Females			Males		
		T0	T1	T2	T0	T1	T2
I	ANB (°)	3.00+/-1.09	2.52+/-1.21	2.58+/-1.25	2.95+/-1.08	2.53+/-1.23	2.21+/-1.41
	MMA (°)	28.85+/-4.72	29.24+/-4.47	29.07+/-4.57	28.59+/-4.43	28.46+/-5.20	27.67+/-5.37
	FMA (°)	27.18+/-4.66	27.48+/-5.00	27.13+/-4.85	25.71+/-3.50	25.68+/-4.21	24.21+/-4.28
	cFH-MP (°)	30.43+/-4.95	30.88+/-4.91	30.85+/-4.82	29.29+/-4.15	29.20+/-4.86	28.11+/-5.04
	MMB-Wits (mm)	-3.52+/-2.23	-4.33+/-1.94	-4.36+/-2.44	-3.67+/-2.42	-4.30+/-2.97	-4.79+/-3.09
	FMAB-Wits (mm)	-4.14+/-2.12	-4.95+/-2.04	-5.06+/-2.38	-4.70+/-2.54	-5.37+/-2.94	-6.13+/-3.29
	cFMAB-Wits (mm)	-3.05+/-2.10	-3.80+/-1.95	-3.75+/-2.35	-3.56+/-2.17	-4.29+/-2.40	-4.78+/-2.89
II/1	ANB (°)	5.67+/-1.67	3.53+/-1.92	3.30+/-1.98	5.84+/-1.39	3.50+/-1.48	2.91+/-1.63
	MMA (°)	28.45+/-4.34	28.03+/-5.14	27.19+/-4.93	28.48+/-4.02	28.27+/-4.56	27.59+/-4.54
	FMA (°)	25.12+/-4.29	25.19+/-4.62	24.48+/-4.33	25.02+/-3.51	25.58+/-3.31	24.22+/-3.92
	cFH-MP (°)	29.11+/-4.95	29.50+/-5.44	29.20+/-5.69	28.29+/-4.09	28.77+/-4.24	27.70+/-4.54
	MMB-Wits (mm)	1.63+/-1.94	-1.02+/-2.03	-1.38+/-2.21	1.60+/-2.04	-1.69+/-2.25	-2.44+/-2.46
	FMAB-Wits (mm)	0.54+/-1.90	-2.00+/-2.11	-2.36+/-2.41	0.39+/-2.27	-2.74+/-2.26	-3.75+/-2.56
	cFMAB-Wits (mm)	2.27+/-1.60	-1.81+/-1.46	-2.14+/-1.61	2.11+/-1.56	-2.16+/-1.54	-2.83+/-2.08

Table 9: Cephalometric Measurement Means and Standard Deviations in the Control Group for Class I and Class II Division 1 Population Samples by Gender

Class	Ceph. Meas.	Females			Males		
		T0	T1	T2	T0	T1	T2
I	ANB (°)	2.37+/-1.19	2.14+/-1.00	1.81+/-1.22	2.75+/-0.93	2.36+/-1.16	2.18+/-1.59
	MMA (°)	26.87+/-4.39	26.14+/-4.33	25.62+/-5.44	27.86+/-5.21	26.54+/-4.85	26.24+/-4.78
	FMA (°)	26.18+/-4.17	25.29+/-3.96	24.34+/-4.90	26.52+/-4.89	25.52+/-5.09	24.33+/-5.01
	cFH-MP (°)	26.88+/-4.83	28.78+/-5.19	28.21+/-5.87	28.84+/-5.43	27.49+/-5.65	26.48+/-5.32
	MMB-Wits (mm)	-2.36+/-1.04	-2.79+/-1.37	-2.75+/-1.15	-1.86+/-1.08	-2.17+/-1.17	-2.27+/-1.43
	FMAB-Wits (mm)	-2.48+/-1.01	-2.93+/-1.34	-2.98+/-1.15	-2.11+/-1.21	-2.37+/-1.24	-2.63+/-1.31
	cFMAB-Wits (mm)	-1.98+/-0.96	-2.24+/-1.21	-2.29+/-1.07	-1.75+/-1.05	-2.08+/-1.15	-2.32+/-1.30
II/1	ANB (°)	4.72+/-1.28	4.61+/-1.27	4.37+/-1.65	4.86+/-1.05	4.92+/-1.30	4.91+/-1.50
	MMA (°)	23.89+/-4.23	23.09+/-4.27	22.66+/-3.97	27.21+/-4.26	25.43+/-5.02	25.02+/-4.75
	FMA (°)	23.11+/-4.20	22.50+/-4.69	22.26+/-4.24	25.35+/-3.79	24.60+/-4.80	23.85+/-5.04
	cFH-MP (°)	25.91+/-4.52	25.37+/-4.41	25.11+/-4.28	28.56+/-4.21	27.45+/-4.79	26.43+/-4.81
	MMB-Wits (mm)	0.10+/-1.73	-0.29+/-1.54	-0.42+/-1.80	0.41+/-1.87	0.53+/-1.93	0.69+/-1.83
	FMAB-Wits (mm)	-0.15+/-2.26	-1.36+/-1.62	-0.56+/-1.96	-0.17+/-2.52	0.25+/-2.63	0.26+/-2.35
	cFMAB-Wits (mm)	1.92+/-1.12	1.38+/-0.88	1.73+/-1.09	1.79+/-1.46	2.09+/-1.47	1.98+/-1.39

Table 10: Differences in Cephalometric Measurement Values Between Females and Males in the Treatment Group of the Class I and Class II Division 1 Population Sample at T0, T1, and T2 (Subtraction of Means: Females - Males)

Class	Ceph. Meas.	T0	T1	T2
I	ANB (°)	0.05+/-0.20	-0.01+/-0.22	0.38+/-0.24
	MMA (°)	0.25+/-0.84	0.78+/-0.89	1.40+/-0.91
	FMA (°)	1.47+/-0.75	1.80+/-0.84*	2.92+/-0.84*
	cFH-MP (°)	1.14+/-0.83	1.69+/-0.89	2.75+/-0.90*
	MMB-Wits (mm)	0.14+/-0.43	-0.03+/-0.46	0.43+/-0.51
	FMAB-Wits (mm)	0.56+/-0.43	0.42+/-0.46	1.08+/-0.53*
	cFMAB-Wits (mm)	0.50+/-0.39	0.49+/-0.40	1.03+/-0.48*
II/1	ANB (°)	-0.17+/-0.36	0.03+/-0.40	0.38+/-0.42
	MMA (°)	-0.03+/-0.96	-0.24+/-1.12	-0.41+/-1.10
	FMA (°)	0.09+/-0.91	-0.40+/-0.93	0.26+/-0.95
	cFH-MP (°)	0.83+/-1.05	0.73+/-1.13	1.50+/-1.19
	MMB-Wits (mm)	0.03+/-0.46	0.67+/-0.49	1.06+/-0.54
	FMAB-Wits (mm)	0.14+/-0.48	0.74+/-0.50	1.40+/-0.57*
	cFMAB-Wits (mm)	-0.16+/-0.36	0.34+/-0.34	0.69+/-0.42

*$p < 0.05$

Table 11: Differences in Cephalometric Measurement Values Between Females and Males in the Control Group of the Class I and Class II Division 1 Population Sample at T0, T1, and T2 (Subtraction of Means: Females - Males)

Class	Ceph. Meas.	T0	T1	T2
I	ANB (°)	-0.38+/-0.34	-0.21+/-0.35	-0.37+/-0.45
	MMA (°)	-0.99+/-1.54	-0.40+/-1.47	-0.62+/-1.64
	FMA (°)	-0.34+/-1.45	-0.23+/-1.46	0.01+/-1.59
	cFH-MP (°)	0.04+/-1.64	1.28+/-1.74	1.76+/-1.80
	MMB-Wits (mm)	-0.50+/-0.34	-0.62+/-0.41	-0.48+/-0.41
	FMAB-Wits (mm)	-0.37+/-0.36	-0.56+/-0.41	-0.36+/-0.39
	cFMAB-Wits (mm)	-0.23+/-0.32	-0.17+/-0.38	-0.03+/-0.38
II/1	ANB (°)	-0.12+/-0.43	-0.31+/-0.47	-0.55+/-0.58
	MMA (°)	-3.32+/-1.55*	-2.34+/-1.70	-2.36+/-1.60
	FMA (°)	-2.23+/-1.46	-2.10+/-1.73	-1.59+/-1.70
	cFH-MP (°)	-2.65+/-1.59	-2.08+/-1.68	-1.31+/-1.66
	MMB-Wits (mm)	-0.31+/-0.66	-0.81+/-0.64	-1.11+/-0.66
	FMAB-Wits (mm)	0.02+/-0.87	-0.71+/-0.80	-0.82+/-0.79
	cFMAB-Wits (mm)	0.13+/-0.48	-0.71+/-0.44	-0.25+/-0.46

*$p < 0.05$

Table 12: Mean Change Between Time Periods in Cephalometric Measurement Values in the Treatment and Control Groups for Females in the Class I and Class II Division 1 Population Samples

Class	Ceph. Meas.	Treatment Group			Control Group		
		T0-T1	T1-T2	T0-T2	T0-T1	T1-T2	T0-T2
I	ANB (°)	0.48* (SE=0.12)	-0.07 (SE=0.09)	0.42* (SE=0.12)	0.22 (SE=0.11)	0.33 (SE=0.22)	0.56 (SE=0.25)
	MMA (°)	-0.39 (SE=0.28)	0.17 (SE=0.23)	-0.22 (SE=0.26)	0.74 (SE=0.32)	0.52 (SE=0.40)	1.26* (SE=0.47)
	FMA (°)	-0.30 (SE=0.26)	0.17 (SE=0.23)	-0.22 (SE=0.26)	0.90* (SE=0.29)	0.95* (SE=0.30)	1.84* (SE=0.42)
	cFH-MP (°)	-0.45 (SE=0.24)	0.03 (SE=0.20)	-0.42 (SE=0.22)	0.11 (SE=0.28)	0.56 (SE=0.28)	0.67 (SE=0.36)
	MMB-Wits (mm)	0.80* (SE=0.16)	0.03 (SE=0.16)	0.84* (SE=0.21)	0.43 (SE=0.22)	-0.04 (SE=0.32)	0.39 (SE=0.23)
	FMAB-Wits (mm)	0.81* (SE=0.18)	0.11 (SE=0.17)	0.92* (SE=0.20)	0.45 (SE=0.22)	0.06 (SE=0.32)	0.51 (SE=0.20)
	cFMAB-Wits (mm)	0.75* (SE=0.18)	-0.05 (SE=0.16)	0.69* (SE=0.20)	0.27 (SE=0.17)	0.45 (SE=0.27)	0.32 (SE=0.21)
II/1	ANB (°)	2.14* (SE=0.18)	0.24 (SE=0.14)	2.39* (SE=0.19)	0.11 (SE=0.21)	0.25 (SE=0.25)	0.36 (SE=0.25)
	MMA (°)	0.42 (SE=0.32)	0.84* (SE=0.25)	1.27* (SE=0.36)	0.80 (SE=0.46)	0.43 (SE=0.30)	1.23 (SE=0.47)
	FMA (°)	-0.07 (SE=0.38)	0.71* (SE=0.28)	0.64 (SE=0.38)	0.61 (SE=0.44)	0.24 (SE=0.42)	0.85 (SE=0.53)
	cFH-MP (°)	-0.39 (SE=0.34)	0.30 (SE=0.24)	-0.09 (SE=0.41)	0.54 (SE=0.34)	0.26 (SE=0.33)	0.80 (SE=0.50)
	MMB-Wits (mm)	2.65* (SE=0.25)	0.36 (SE=0.19)	3.01* (SE=0.28)	0.39 (SE=0.37)	0.13 (SE=0.34)	0.52 (SE=0.37)
	FMAB-Wits (mm)	2.53* (SE=0.27)	0.36 (SE=0.21)	2.89* (SE=0.28)	0.31 (SE=0.44)	0.10 (SE=0.31)	0.41 (SE=0.40)
	cFMAB-Wits (mm)	-0.46 (SE=0.33)	0.33 (SE=0.16)	-0.13 (SE=0.34)	-0.54 (SE=0.27)	0.35 (SE=0.25)	-0.19 (SE=0.36)

*$p < 0.05$

Table 13: Mean Change Between Time Periods in Cephalometric Measurement Values in the Treatment and Control Groups for Males in the Class I and Class II Division 1 Population Samples

Class	Ceph. Meas.	Treatment Group			Control Group		
		T0-T1	T1-T2	T0-T2	T0-T1	T1-T2	T0-T2
I	ANB (°)	0.42* (SE=0.11)	0.32* (SE=0.10)	0.74* (SE=0.14)	0.39 (SE=0.19)	0.17 (SE=0.16)	0.56 (SE=0.32)
	MMA (°)	0.13 (SE=0.27)	0.79* (SE=0.23)	0.92* (SE=0.37)	1.33 (SE=0.53)	0.30 (SE=0.48)	1.63* (SE=0.30)
	FMA (°)	0.03 (SE=0.31)	1.47* (SE=0.22)	1.50* (SE=0.30)	1.01 (SE=0.42)	1.18* (SE=0.32)	2.19* (SE=0.42)
	cFH-MP (°)	0.09 (SE=0.26)	1.09* (SE=0.22)	1.18* (SE=0.34)	1.34* (SE=0.44)	1.05 (SE=0.40)	2.39* (SE=0.44)
	MMB-Wits (mm)	0.63* (SE=0.19)	0.50* (SE=0.17)	1.13* (SE=0.22)	0.31 (SE=0.15)	0.10 (SE=0.11)	0.41 (SE=0.20)
	FMAB-Wits (mm)	0.66* (SE=0.20)	0.76* (SE=0.18)	1.43* (SE=0.23)	0.26 (SE=0.14)	0.26 (SE=0.12)	0.52* (SE=0.19)
	cFMAB-Wits (mm)	0.73* (SE=0.18)	0.49* (SE=0.17)	1.23* (SE=0.22)	0.33 (SE=0.13)	0.24 (SE=0.11)	0.57* (SE=0.21)
II/1	ANB (°)	2.35* (SE=0.21)	0.58* (SE=0.15)	2.93* (SE=0.22)	-0.06 (SE=0.14)	0.01 (SE=0.21)	-0.05 (SE=0.24)
	MMA (°)	0.21 (SE=0.32)	0.68 (SE=0.29)	0.89 (SE=0.39)	1.78* (SE=0.53)	0.41 (SE=0.51)	2.19* (SE=0.51)
	FMA (°)	-0.56 (SE=0.25)	1.36* (SE=0.34)	0.81 (SE=0.41)	0.75 (SE=0.35)	0.75 (SE=0.35)	1.50* (SE=0.45)
	cFH-MP (°)	-0.48 (SE=0.28)	1.07* (SE=0.28)	0.58 (SE=0.44)	1.11 (SE=0.41)	1.03 (SE=0.45)	2.13* (SE=0.49)
	MMB-Wits (mm)	3.29* (SE=0.27)	0.74* (SE=0.25)	4.04* (SE=0.34)	-0.11 (SE=0.30)	-0.17 (SE=0.29)	0.28 (SE=0.40)
	FMAB-Wits (mm)	3.13* (SE=0.29)	1.01* (SE=0.22)	4.14* (SE=0.36)	-0.43 (SE=0.28)	-0.01 (SE=0.31)	-0.43 (SE=0.35)
	cFMAB-Wits (mm)	0.04 (SE=0.41)	0.67* (SE=0.22)	0.72 (SE=0.50)	0.31 (SE=0.29)	-0.11 (SE=0.27)	0.19 (SE=0.33)

*$p < 0.05$

Table 14: Spearman's Rank-Order Correlation Coefficients by Time Period for Treatment and Control Groups in the Class I Population Sample

Ceph. Meas. Correlation	Treatment			Control		
	T0	T1	T2	T0	T1	T2
ANB-MMA	0.10	0.06	0.03	0.18	0.03	0.17
ANB-FMA	0.11	0.11	0.16	0.22	0.14	0.17
ANB-cFH/MP	0.12	0.13	0.17	0.09	0.14	0.20
ANB-MMB Wits	**0.38^**	**0.42^**	**0.41^**	**0.57^**	**0.38***	**0.54^**
ANB-FMAB Wits	**0.41^**	**0.45^**	**0.47^**	**0.54^**	**0.46^**	**0.54^**
ANB-cFMAB Wits	**0.42^**	**0.44^**	**0.48^**	**0.58^**	**0.51^**	**0.58^**
MMA-FMA	0.75^	0.74^	0.77^	0.88^	0.84^	0.91^
MMA-cFH/MP	0.78^	0.76^	0.79^	0.88^	0.79^	0.83^
MMA-MMB Wits	-0.08	-0.07	-0.19*	-0.16	-0.40*	-0.29
MMA-FMAB Wits	-0.29^	-0.27^	-0.37^	-0.36*	-0.52^	-0.41^
MMA-cFMAB Wits	0.21*	0.22*	0.30^	0.27	0.38*	0.34*
FMA-cFH/MP	0.84^	0.86^	0.88^	0.89^	0.87^	0.88^
FMA-MMB Wits	-0.28^	-0.25^	-0.30^	-0.28	-0.50^	-0.42^
FMA-FMAB Wits	-0.18	-0.13	-0.18*	-0.30	-0.37*	-0.42^
FMA-cFMAB Wits	0.22*	0.20	0.21*	0.30	0.28	0.38*
cFH/MP-MMB Wits	-0.22*	-0.21*	-0.27^	-0.26	-0.46^	-0.33*
cFH/MP-FMAB Wits	-0.25^	-0.19*	-0.25^	-0.35	-0.39^	-0.37*
cFH/MP-cFMAB Wits	0.08	0.08	0.13	0.24	0.08	0.19
MMB Wits-FMAB Wits	**0.86^**	**0.87^**	**0.89^**	**0.91^**	**0.87^**	**0.91^**
MMB Wits-cFMAB Wits	**0.87^**	**0.88^**	**0.91^**	**0.94^**	**0.79^**	**0.88^**
FMAB Wits-cFMAB Wits	**0.90^**	**0.91^**	**0.94^**	**0.93^**	**0.85^**	**0.91^**

* *$p < 0.05$*

^ *$p < 0.01$*

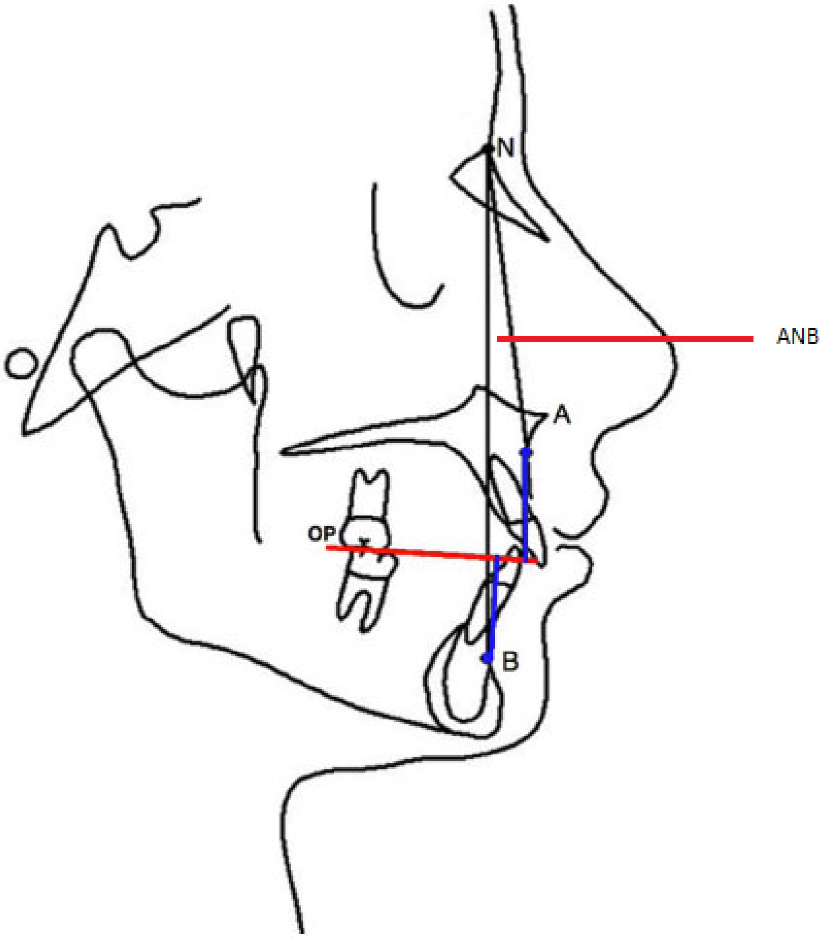
Table 15: Spearman's Rank-Order Correlation Coefficients by Time Period for Treatment and Control Groups in the Class II Division 1 Population Sample

Ceph. Meas. Correlation	Treatment			Control		
	T0	T1	T2	T0	T1	T2
ANB-MMA	0.24*	0.26*	0.27*	-0.13	0.01	0.27
ANB-FMA	0.42^	0.46^	0.45^	0.25	0.28	0.44*
ANB-cFH/MP	0.43^	0.41^	0.50^	0.25	0.25	0.48^
ANB-MMB Wits	**0.51^**	**0.38^**	**0.55^**	**0.52^**	**0.54^**	**0.66^**
ANB-FMAB Wits	**0.57^**	**0.50^**	**0.60^**	**0.63^**	**0.69^**	**0.73^**
ANB-cFMAB Wits	**0.42^**	**0.10**	**0.30^**	**0.31**	**0.40^**	**0.52^**
MMA-FMA	0.69^	0.77^	0.73^	0.68^	0.72^	0.71^
MMA-cFH/MP	0.74^	0.74^	0.76^	0.77^	0.77^	0.72^
MMA-MMB Wits	0.07	0.18	0.10	-0.31	-0.21	0.24
MMA-FMAB Wits	-0.16	-0.10	-0.16	-0.46^	-0.30	0.04
MMA-cFMAB Wits	-0.02	0.09	0.14	-0.18	0.06	0.05
FMA-cFH/MP	0.75^	0.80^	0.82^	0.74^	0.83^	0.80^
FMA-MMB Wits	-0.03	0.07	-0.01	-0.17	-0.15	0.17
FMA-FMAB Wits	0.10	0.14	0.08	-0.01	0.02	0.33
FMA-cFMAB Wits	-0.03	-0.03	0.03	-0.15	-0.05	0.16
cFH/MP-MMB Wits	0.02	0.06	0.07	-0.21	-0.20	0.20
cFH/MP-FMAB Wits	-0.02	-0.01	0.01	-0.19	-0.08	0.25
cFH/MP-cFMAB Wits	0.16	-0.09	0.01	-0.01	0.16	0.17
MMB Wits-FMAB Wits	**0.86^**	**0.82^**	**0.86^**	**0.85^**	**0.87^**	**0.84^**
MMB Wits-cFMAB Wits	**0.72^**	**0.40^**	**0.51^**	**0.28**	**0.40***	**0.40***
FMAB Wits-cFMAB Wits	**0.68^**	**0.46^**	**0.57^**	**0.38***	**0.42***	**0.50^**

* $p < 0.05$

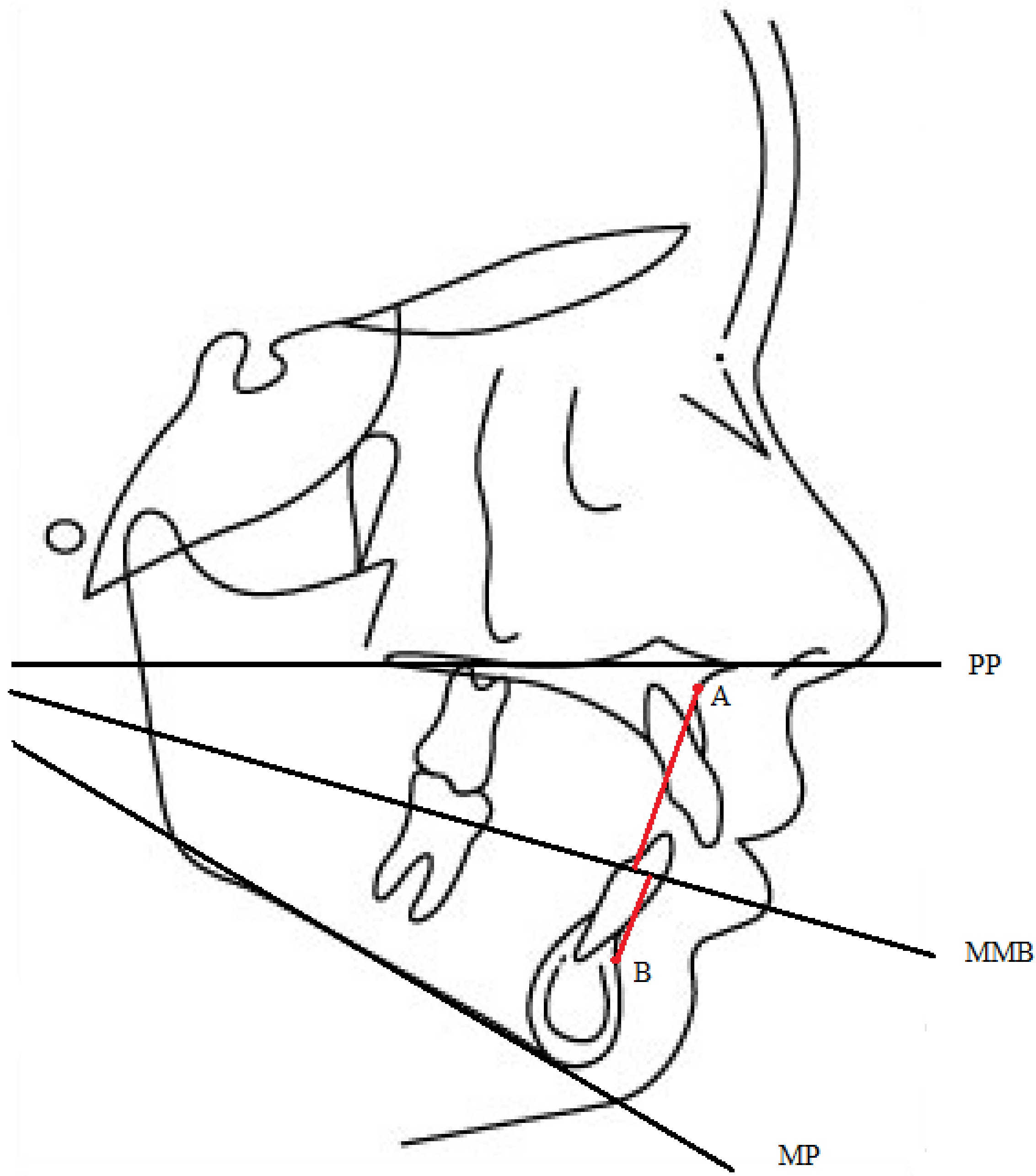
^ $p < 0.01$

Figure 1: ANB Angle (Reidel)[7] and Wits' Measurement (Jacobson)[15]



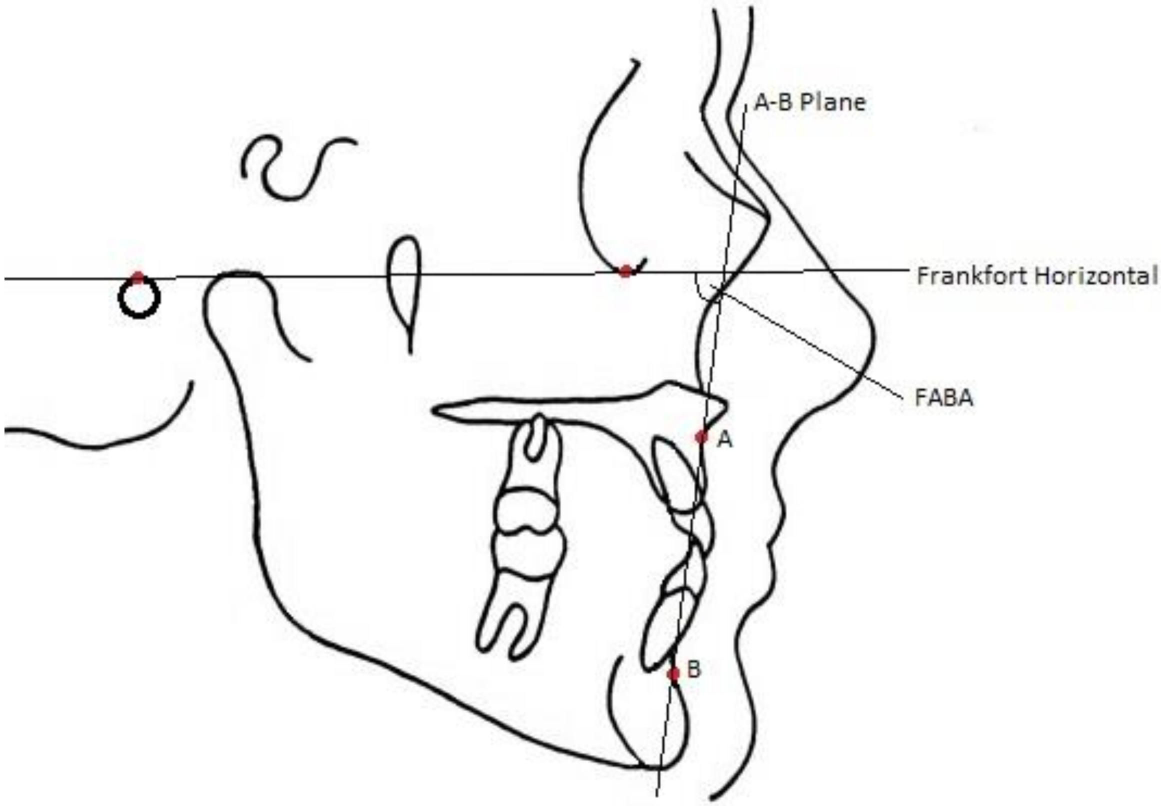
The Wits' measurement is the difference in anterior position between A point and B point on the functional occlusal plane (OP) in millimetres.

Figure 2: MMB-Wits' Measurement (Hall-Scott)[24]



The MMB-Wits' measurement is the difference in anterior position between A point and B point on the bisector of the palatal plane and mandibular plane.

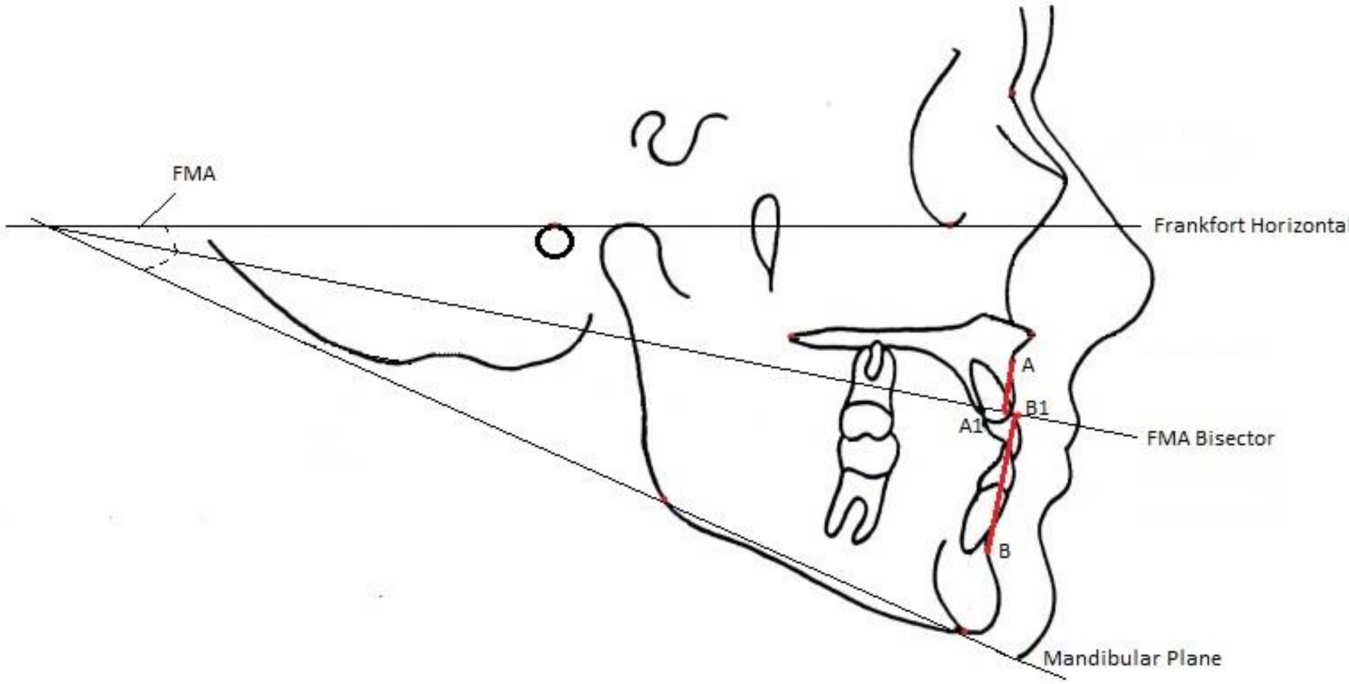
Figure 3: FABA Angle (Yang & Suhr)[5]



The FABA angle is formed by the inferior and posterior angle of the intersection of Frankfort horizontal and the A-B plane.

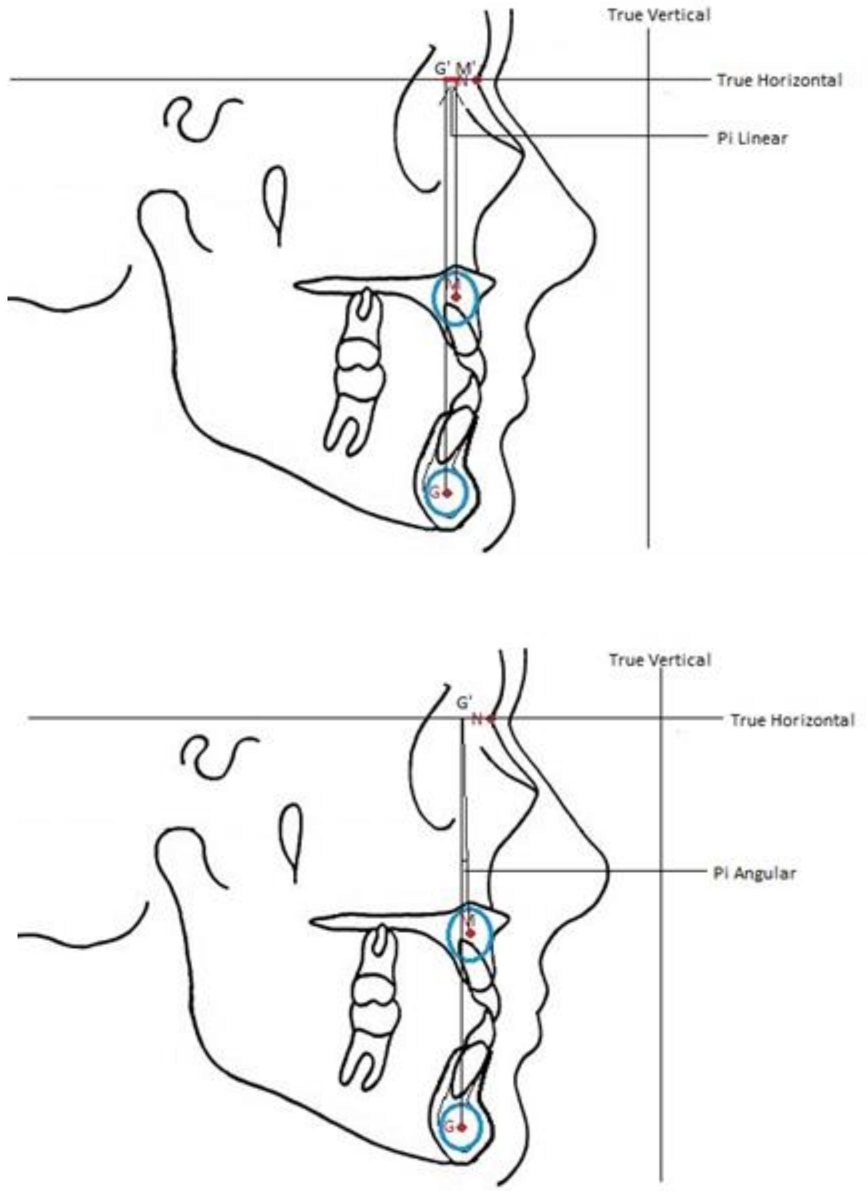
Referenced from Swoboda et al[33]

Figure 4: FMAB-Wits' Measurement (Swoboda)[33]



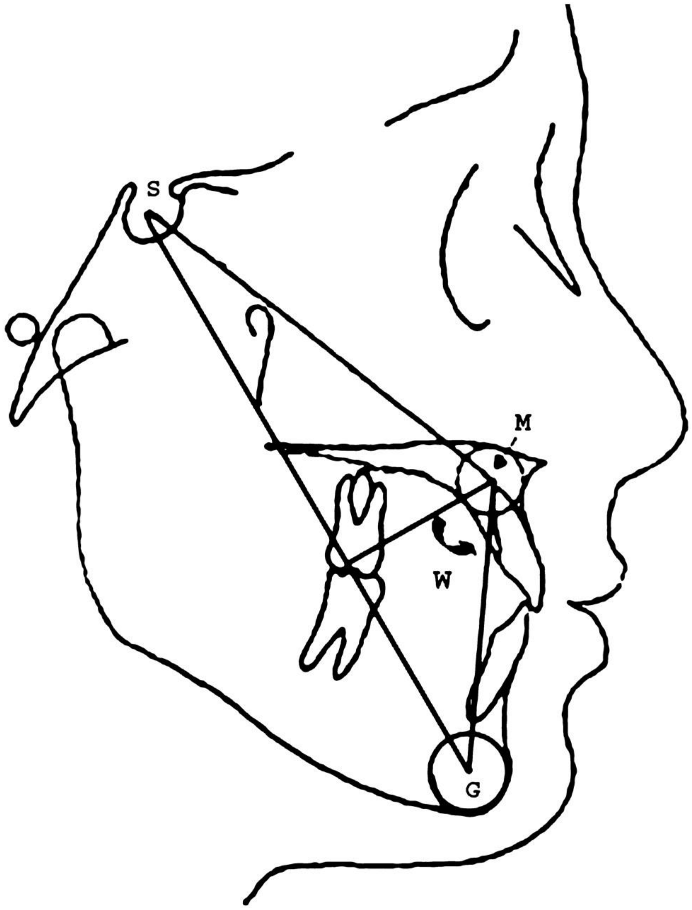
The FMAB-Wits' measurement is the difference in anterior position between A point and B point on the bisector of Frankfort horizontal and the mandibular plane.

Figure 5: Pi Linear and Pi Angle (Kumar)[35]



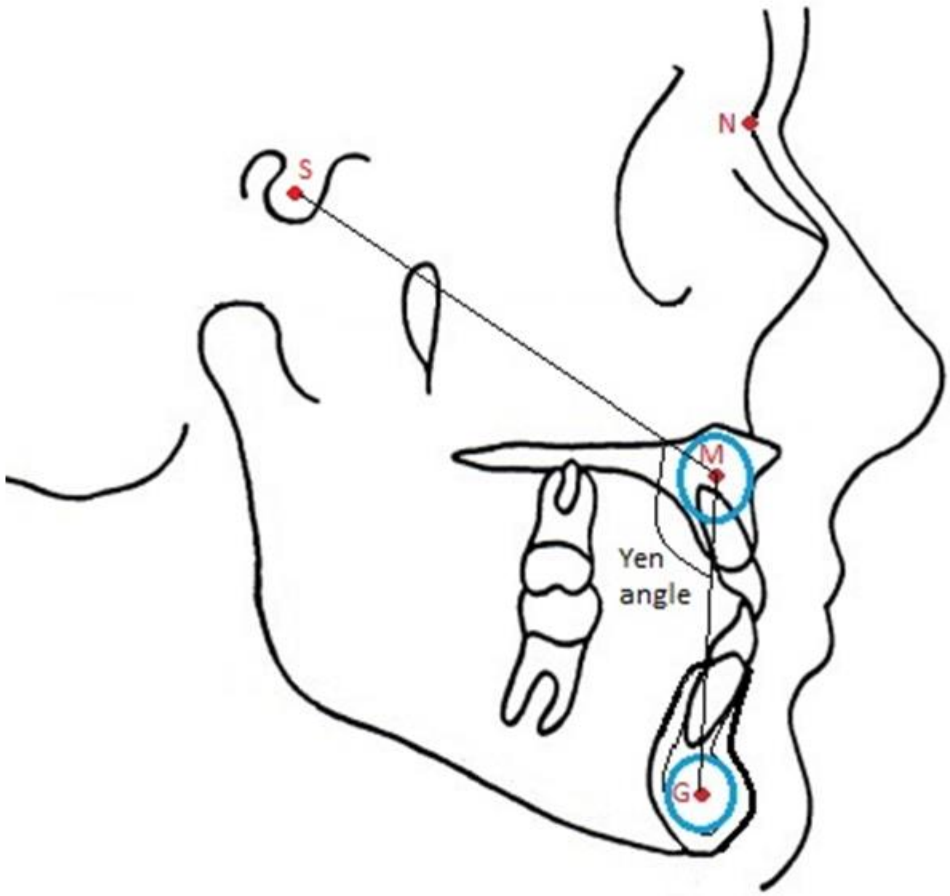
The Pi linear measurement is the distance between M point and G point drawn perpendicularly to the true horizontal line. The Pi angle is formed by M point and G point to G' point, which is where a perpendicular line from G point meets the true horizontal line.

Figure 6: W-angle (Bhad)[14]



The W-angle is formed by the perpendicular from point M on the S-G point line and the M point-G-point line.

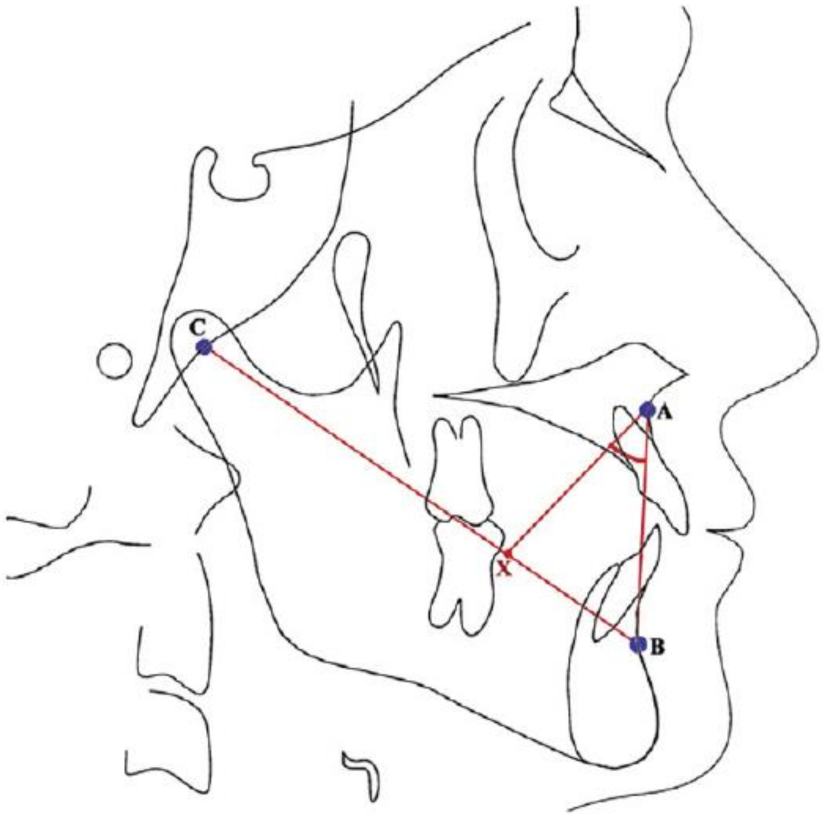
Figure 7: YEN angle (Neela)[38]



The YEN angle measures the angle formed by the S-M point line and the M point-G point line.

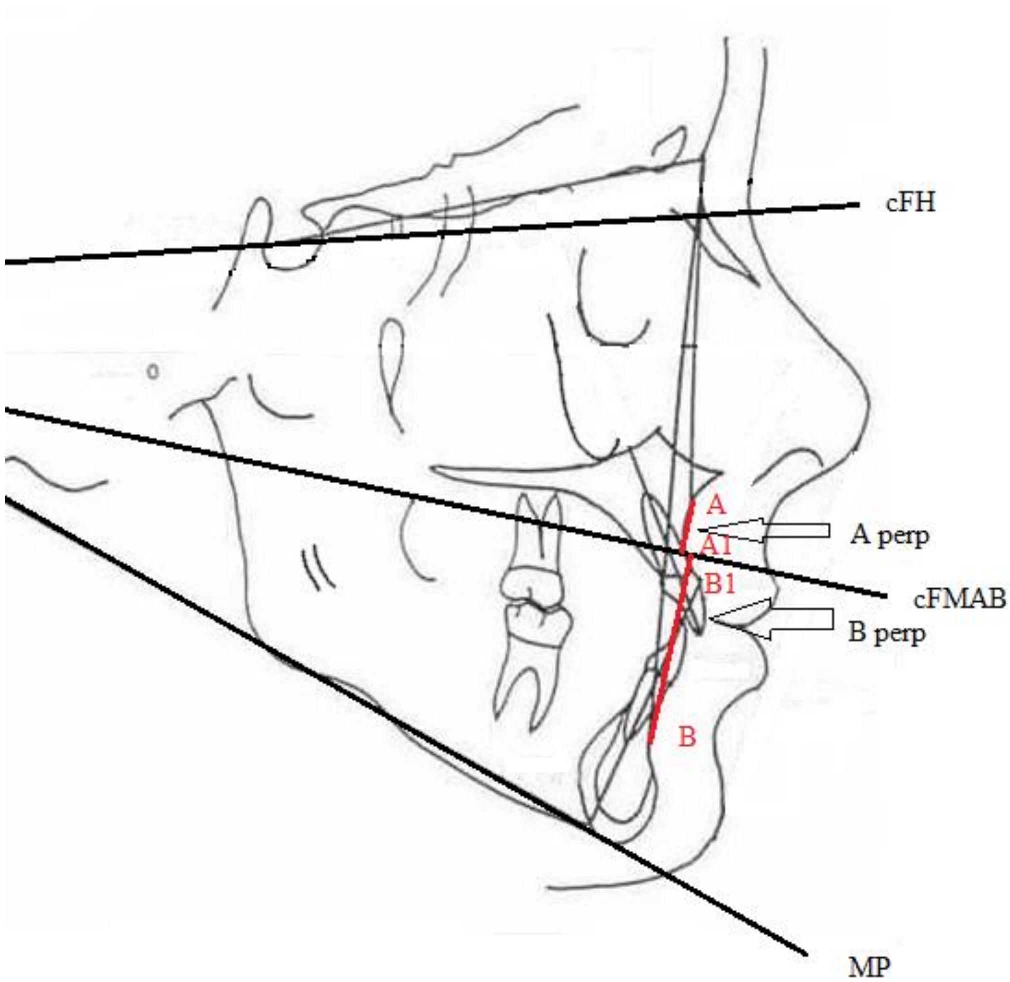
Referenced from Swoboda et al[33]

Figure 8: Beta angle (Baik & Ververidou)[4]



The beta angle measures the angle formed by the A-B plane and a perpendicular line drawn from A point to the line connecting B point and the centre of the condyle.

Figure 9: cFMAB-Wits' measurement



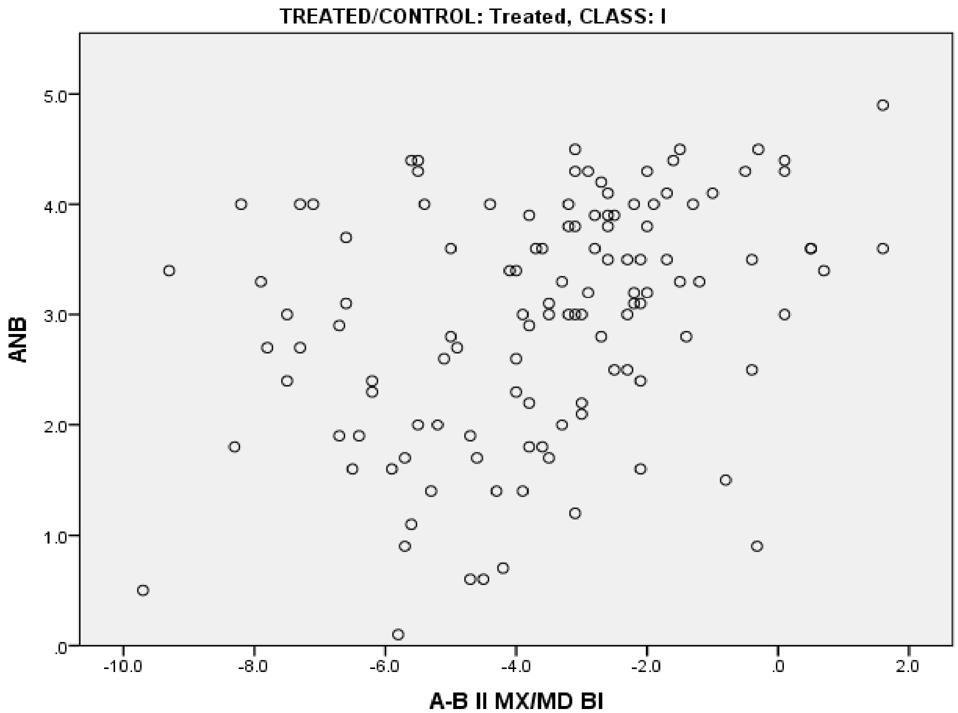
The cFMAB-Wits' measurement is the difference in anterior position between A point and B point on the bisector of constructed Frankfort horizontal (SN-6°) and the mandibular plane (cFMAB).

cFMAB-Wits Measurement = distance (mm) between A1 and B1

A1 anterior to B1 = Positive integer

A1 posterior to B1 = Negative integer

Figure 10: Scatter plot for assessment of correlation between ANB and MMB-Wits in treated cases (Class I and Class II/1)



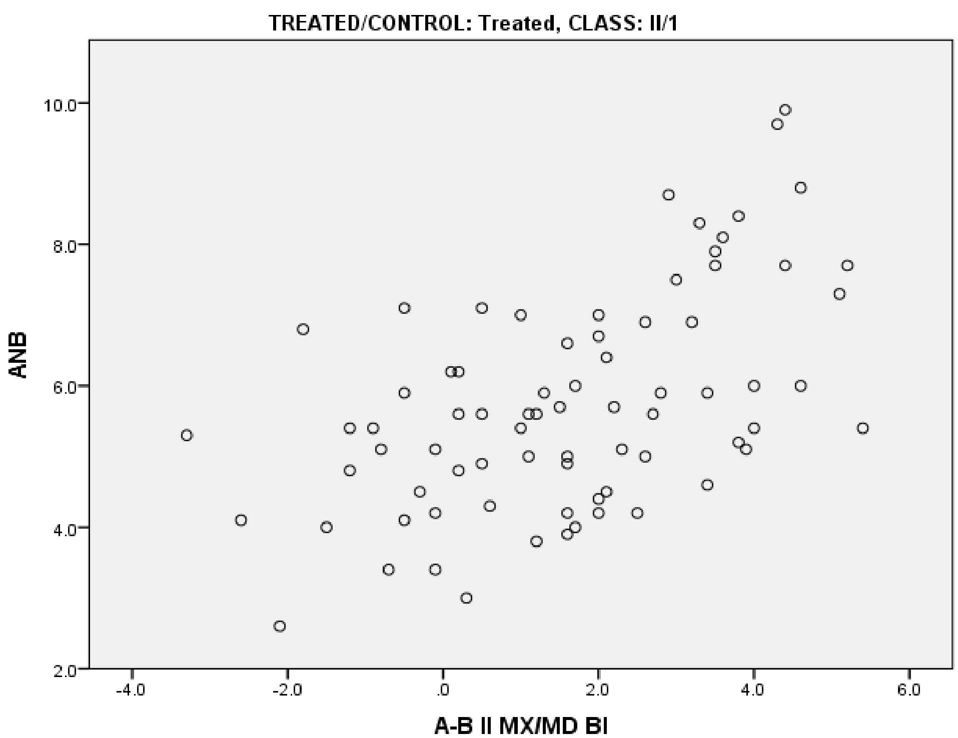
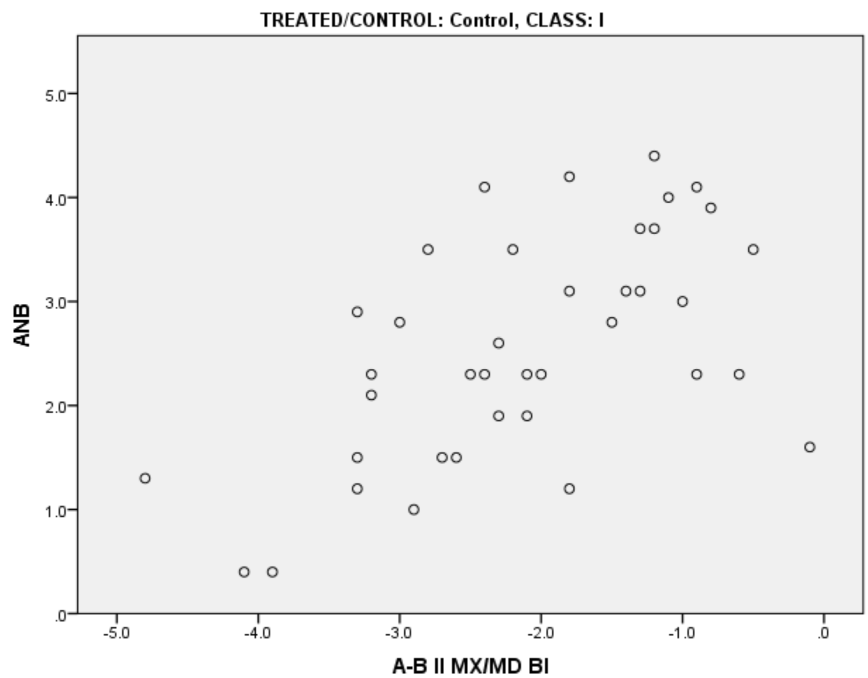


Figure 11: Scatter plot for assessment of correlation between ANB and MMB-Wits in controls (Class I and Class II/1)



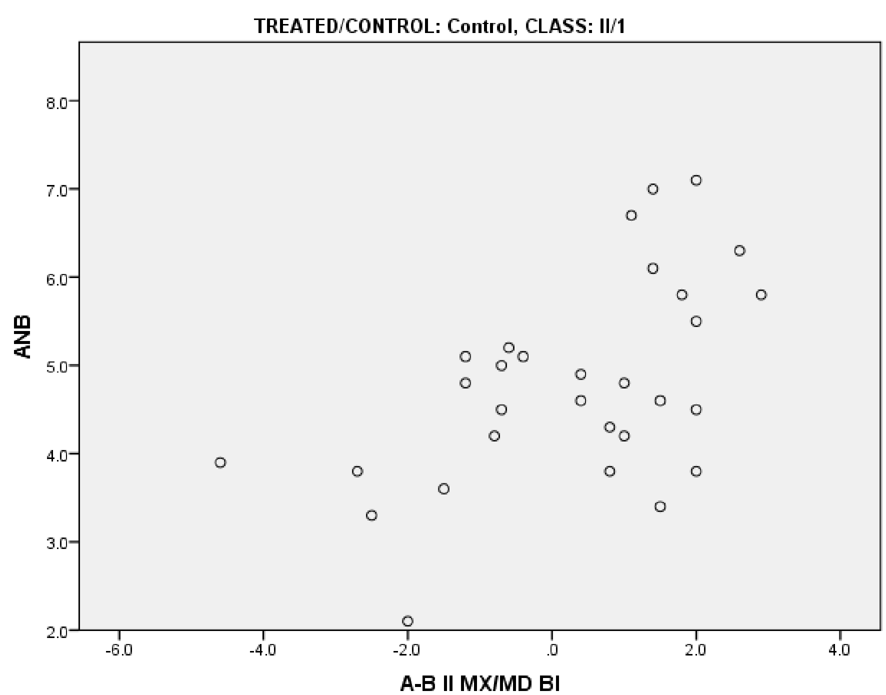
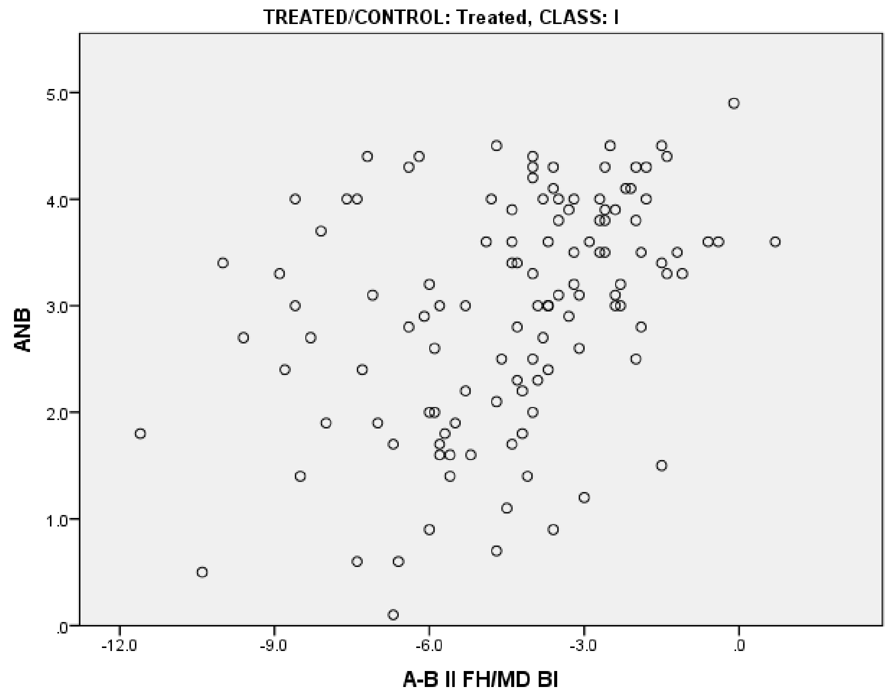


Figure 12: Scatter plot for assessment of correlation between ANB and FMAB-Wits in treated cases (Class I and Class II/1)



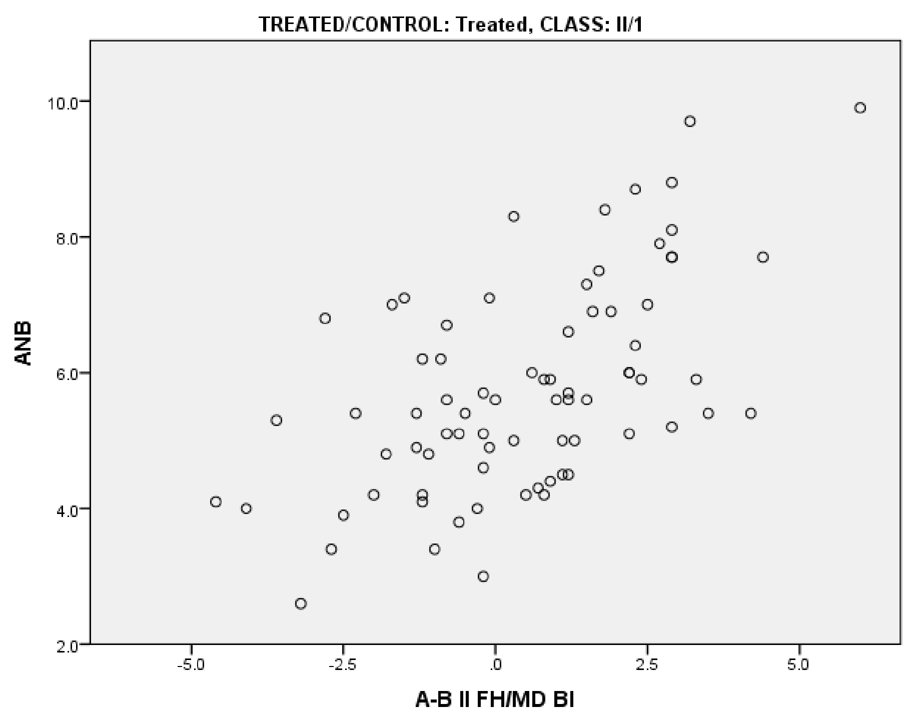
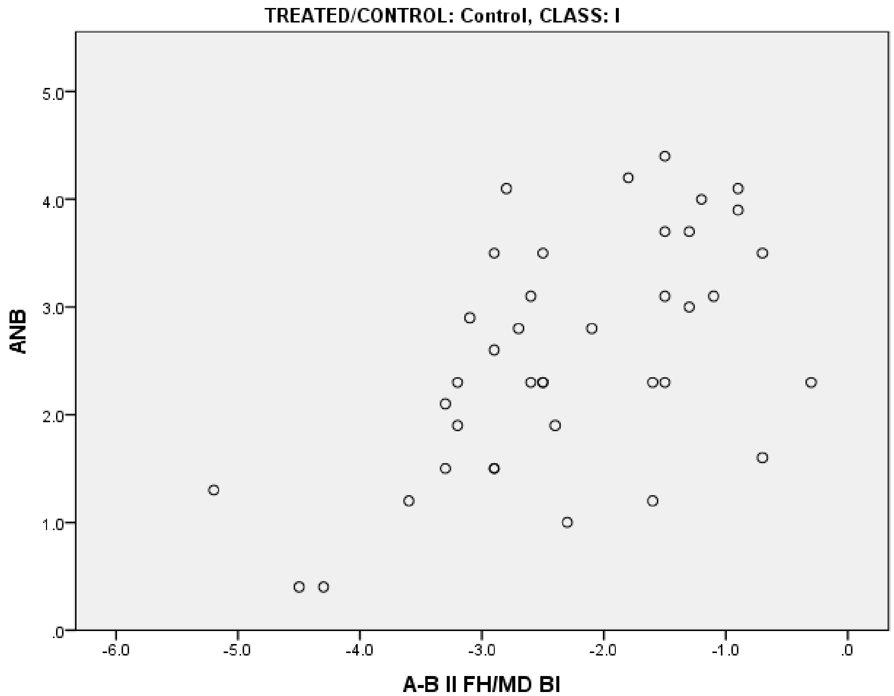


Figure 13: Scatter plot for assessment of correlation between ANB and FMAB-Wits in controls (Class I and Class II/1)



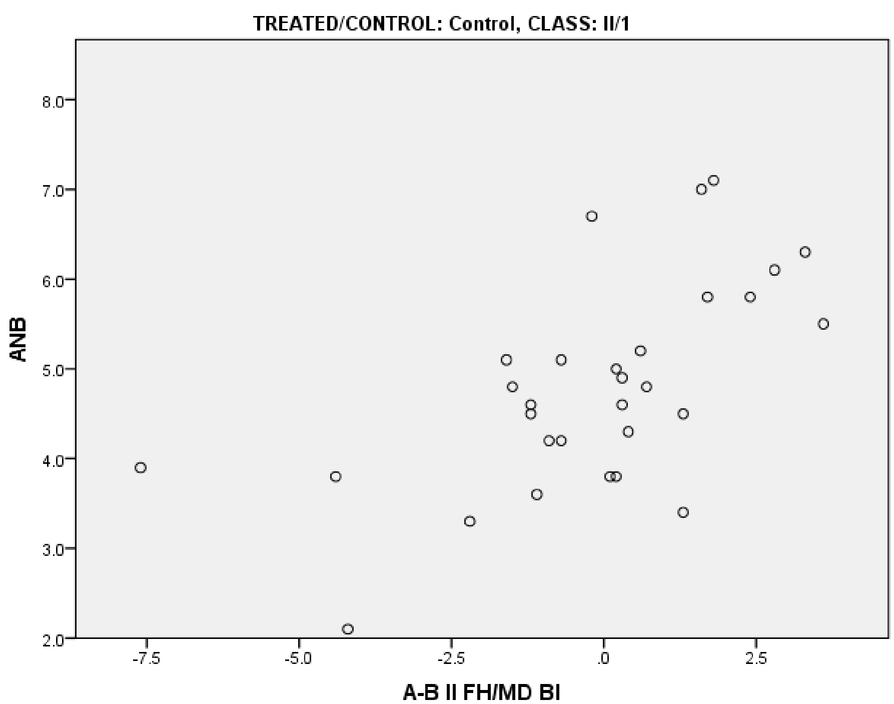
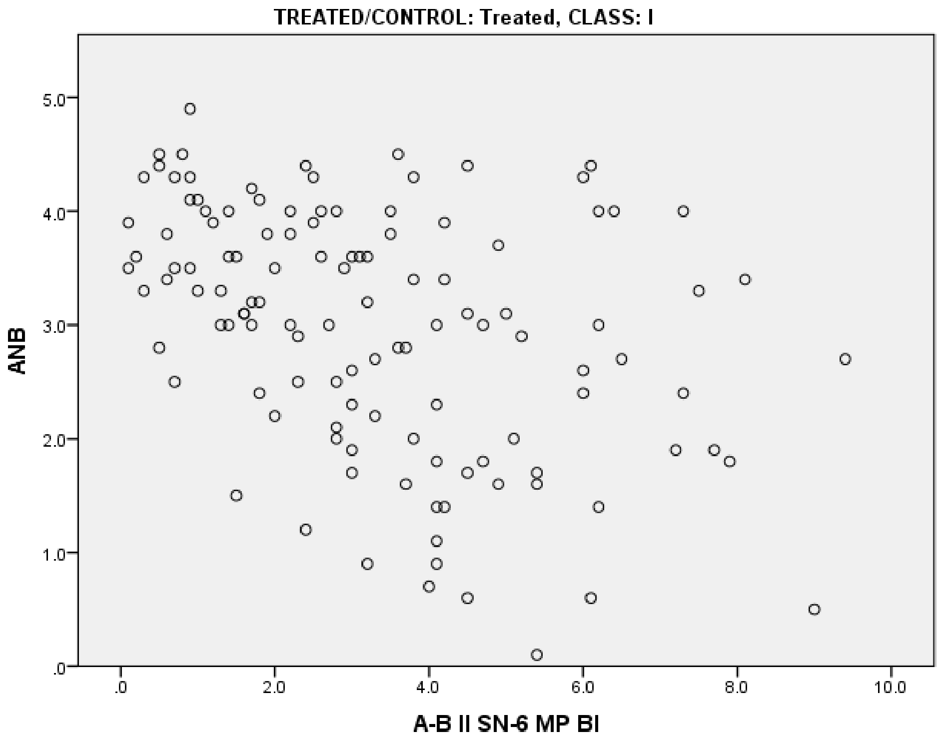


Figure 14: Scatter plot for assessment of correlation between ANB and cFMAB-Wits in treated cases (Class I and Class II/1)



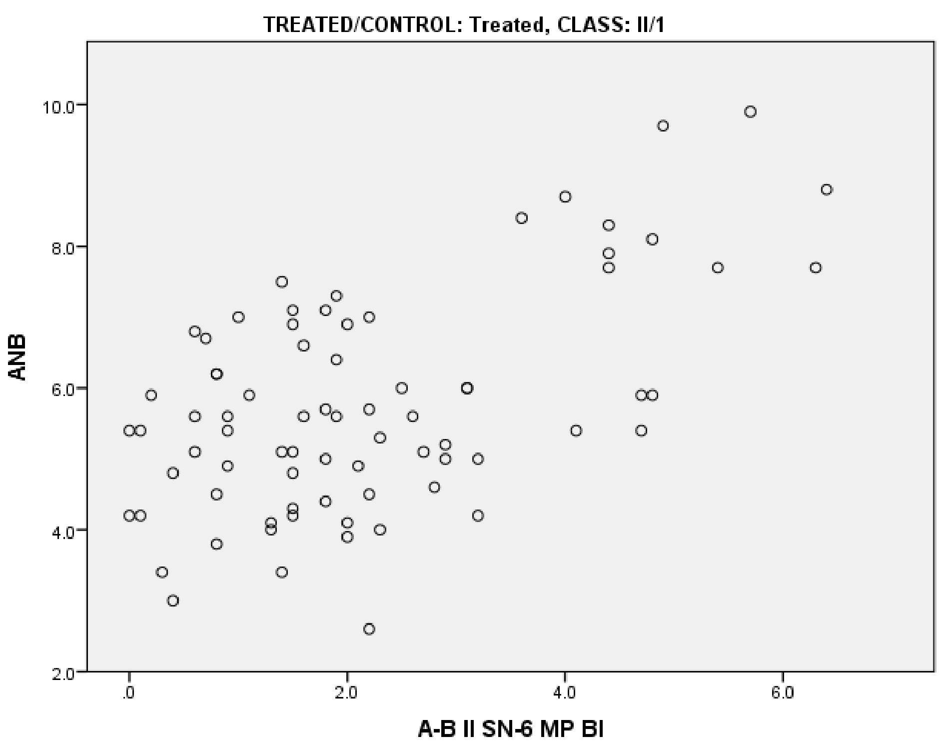
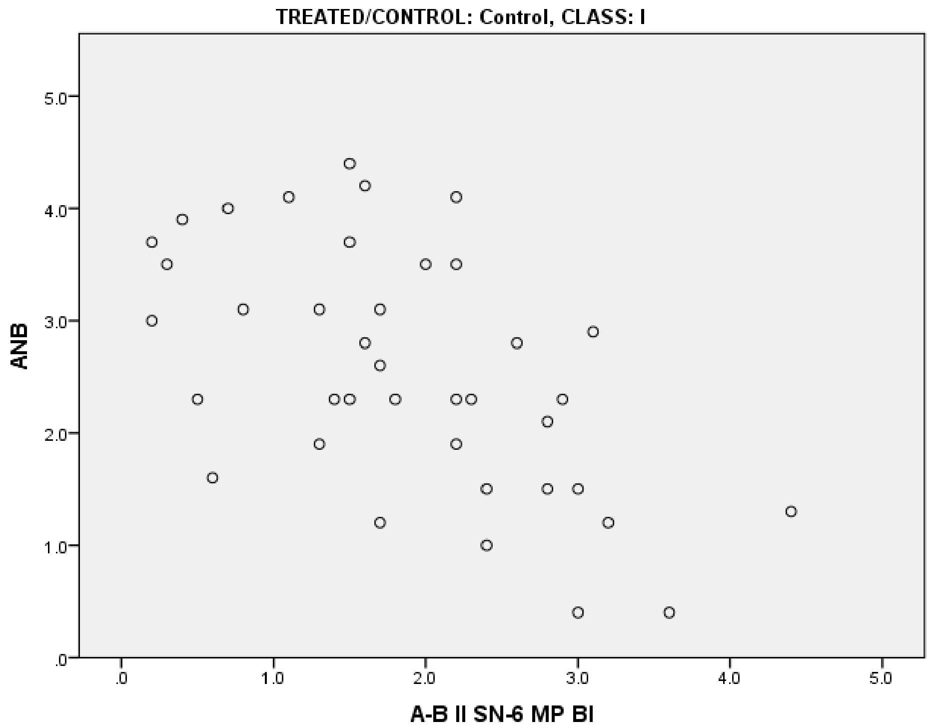
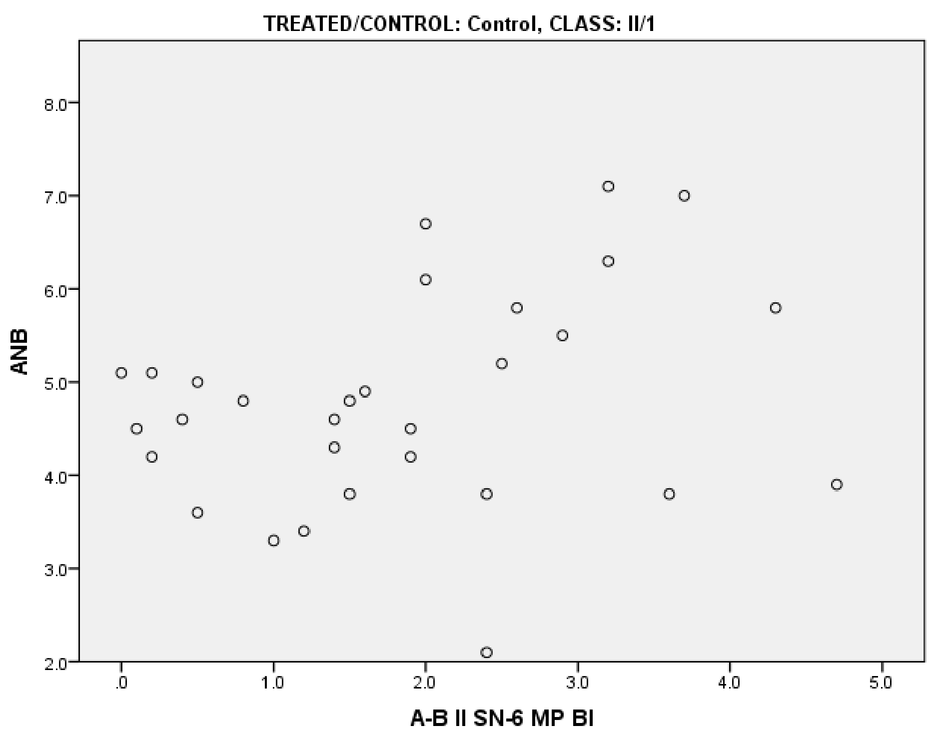


Figure 15: Scatter plot for assessment of correlation between ANB and cFMAB-Wits in controls (Class I and Class II/1)





APPENDIX I

Definition of Cephalometric Landmarks (**PROFFIT text**)

Landmark (Abbreviation)	Definition
A point (A)	The innermost point on the contour of the premaxilla between the anterior nasal spine and maxillary incisor
Anterior Nasal Spine (ANS)	The most anterior point on the maxilla at the level of the bony hard palate
B point (B)	The innermost point on the concave contour of the mandibular symphysis between the mandibular incisor and gnathion
G point (G)	The centre point of a circle placed at the internal anterior, inferior, and posterior surfaces of the mandibular symphysis
Gonion (Go)	The lowest most posterior point at the angle of the mandible
M point (M)	The centre point of a circle placed at the tangent to the anterior, superior, and palatal surfaces of the pre-maxill
Menton (Me)	The most inferior point on the mandibular symphysis
Nasion (Na)	The most anterior point at the intersection of the frontal bone and nasal bone

APPENDIX I (continued)

Definition of Cephalometric Landmarks (**PROFFIT text**)

Landmark (Abbreviation)	Definition
Orbitale (Or)	The lowest point on the inferior margin of the bony orbit
Porion (Po)	The midpoint of the uppermost margin of the external auditory meatus (*anatomic porion*)
Posterior Nasal Spine (PNS)	The most posterior point on the maxilla at the level of the bony hard palate
Sella (S)	The midpoint of the cavity of the sella turcica

APPENDIX II

Definition of Cephalometric Planes and Angles

Planes (Abbreviation)	Definition
Constructed Frankfort Horizontal (cFH)	A constructed line 6° inferior to the sella-nasion line
Constructed Frankfort Horizontal Mandibular Bisector Plane (cFMAB)	The bisector of the constructed Frankfort mandibular angle
Frankfort Horizontal (FH)	A line joining porion and orbitale
Frankfort Mandibular Bisector Plane (FMAB)	The bisector of the Frankfort mandibular angle
Mandibular Plane (MP)	A line joining menton and gonion
Maxillomandibular Bisector (MMP)	The bisector of the maxillomandibular bisector plane
Palatal Plane (PP)	A line joining anterior nasal spine and posterior nasal spine
Sella-Nasion Line (SN)	A line joining sella and nasion

Angles (Abbreviation)	Definition
ANB Angle (ANB)	The angle formed by the points A point – nasion – B point
Constructed Frankfort Mandibular Angle (cFMA)	The angle formed by the intersection of the constructed Frankfort horizontal and the mandibular plane

APPENDIX II (continued)

Definition of Cephalometric Planes and Angles

Angles (Abbreviation)	Definition
Maxillomandibular Angle (MMA)	The angle formed by the intersection of the palatal plane and mandibular plane
Frankfort Mandibular Angle (FMA)	The angle formed by the intersection of the Frankfort horizontal and the mandibular plane

APPENDIX III

Treated Class I Subjects from Western University Graduate Orthodontic Department
UWO Computer ID Numbers
(n = 121)

Identification Number	Gender	Identification Number	Gender
137	F	90	M
217	F	442	M
554	F	1205	M
593	F	1600	M
1023	F	10018	M
1035	F	10031	M
1037	F	10045	M
1166	F	10052	M
1963	F	10076	M
10024	F	10117	M
10059	F	10174	M
10098	F	20034	M
20060	F	20037	M
20084	F	20041	M
20100	F	20091	M
20192	F	20115	M
20200	F	20116	M
30023	F	20168	M
30082	F	20183	M
30134	F	30029	M
30183	F	30074	M
30188	F	30096	M
30195	F	30161	M
40019	F	30171	M
40025	F	40109	M
40066	F	40122	M
40085	F	40157	M
40094	F	40175	M
40105	F	50021	M
40116	F	50039	M
40124	F	50091	M
40126	F	50134	M
40148	F	50221	M
40183	F	50244	M
50016	F	50281	M
50028	F	50299	M
50043	F	50306	M
50095	F	50314	M
50193	F	50320	M
50280	F	50343	M
50289	F	50345	M
50327	F	50378	M

APPENDIX III (continued)

Treated Class I Subjects from Western University Graduate Orthodontic Department
UWO Computer ID Numbers
(n = 120)

Identification Number	Gender	Identification Number	Gender
70090	F	50381	M
70112	F	70066	M
70170	F	70141	M
80048	F	80045	M
80132	F	80056	M
920049	F	80084	M
920090	F	80087	M
920094	F	920008	M
920104	F	920209	M
920247	F	920256	M
920515	F	920317	M
920559	F	920460	M
920560	F	920486	M
930102	F	930029	M
960142	F	930086	M
970168	F	930116	M
980113	F	960126	M
990032	F	980080	M
		980094	M

APPENDIX IV

Control Class I Subjects from Burlington Growth Study Computer ID Numbers
(n = 38)

Identification Number	Gender	Identification Number	Gender
334	F	196	M
368	F	1321	M
861	F	1110	M
1039	F	135	M
336	F	831	M
1360	F	1320	M
1173	F	563	M
1361	F	875	M
674	F	1367	M
1310	F	786	M
159	F	858	M
114	F	120	M
537	F	296	M
60	F	157	M
469	F	1013	M
613	F	871	M
487	F	106	M
713	F	490	M
312	F	544	M

APPENDIX V

Treated Class II Division 1 Subjects from Western University Graduate Orthodontic Department
UWO Computer ID Numbers
(n = 76)

Identification Number	Gender	Identification Number	Gender
40114	F	815	M
20083	F	1367	M
1082	F	577	M
848	F	2147	M
1993	F	40118	M
1166	F	40013	M
3201	F	30048	M
3202	F	2333	M
40146	F	2546	M
20096	F	810	M
3210	F	108	M
1196	F	1217	M
1333	F	1218	M
2923	F	1012	M
10171	F	50301	M
50143	F	50246	M
40080	F	2794	M
30132	F	1457	M
30093	F	479	M
2800	F	30163	M
70135	F	30020	M
1101	F	180	M
1104	F	40138	M
1739	F	3307	M
50347	F	830	M
1118	F	20090	M
1128	F	20133	M
20048	F	1615	M
20159	F	976	M
709	F	981	M
2522	F	1496	M
40037	F	746	M
838	F	40023	M
30111	F	1011	M
1364	F	80006	M
50064	F	604	M
40070	F		
40171	F		
30017	F		
30006	F		

APPENDIX VI

Control Class II Division 1 Subjects from Burlington Growth Study Computer ID Numbers
(n = 30)

Identification Number	Gender	Identification Number	Gender
1056	F	2557	M
288	F	849	M
1024	F	492	M
170	F	1312	M
2538	F	1336	M
847	F	897	M
849	F	1068	M
2601	F	1144	M
134	F	231	M
118	F	1378	M
1202	F	1306	M
2588	F	2573	M
482	F	1397	M
806	F	825	M
494	F	2602	M

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Curriculum Vitae

Name:	Derek Richard Tomson
Post-secondary Education and Degrees:	University of Guelph Guelph, Ontario, Canada 1999-2003 Bachelor of Science (Honours)
	University of Ottawa Ottawa, Ontario, Canada 2004-2006 Master of Science (Epidemiology)
	The University of Western Ontario London, Ontario, Canada 2006-2010 Doctor of Dental Surgery
	The University of Western Ontario London, Ontario, Canada 2013-2016 Master of Clinical Dentistry (Orthodontics)
Related Work Experience	Eastbridge Dental Care Waterloo, Ontario, Canada 2010-2013
	King Street Dental Hamilton, Ontario, Canada 2012-2013

Publications:

Tomson, D. *Evaluating the association between primary brain tumors and a family history of cancer.* University of Ottawa – Electronic Thesis and Dissertation Repository, 2006.