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

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A thesis submitted in partial fulfillment of the requirements for the Master of Clinical Science degree in Orthodontics

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

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by

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Abstract

An accurate anteroposterior measurement of jaw relationships is essential in orthodontic diagnosis and treatment planning. The purpose of this longitudinal study was to establish a new cephalometric Wits appraisal using a bisector of the mandibular plane angle, named the Frankfort Mandibular Plane Angle Bisector (FMAB). The FMAB was used to assess the sagittal jaw relationship in a sample of Class I individuals, and compare this measurement to the ANB angle and the Wits appraisal using the Maxillomandibular Bisector (MMB).

The data were collected from pre-treatment (T0), immediate post-treatment (T1) and two year post-retention (T2) lateral cephalograms of 61 male and 60 female Class I subjects. Non-extraction, fixed orthodontic appliance treatment in the permanent dentition was carried out for these patients. Cephalometric data were compared to 19 male and 19 female Class I subjects who had no orthodontic treatment and served as controls.

The FMAB was determined to be a reproducible reference plane which undergoes change in response to growth and treatment, consistent with the changes seen in the ANB angle. A good correlation (r>0.86) was found between the MMB and FMAB Wits appraisal measurements in both the control and treatment groups for all time periods, indicating that the use of either of these measures may be indicated in cephalometric analysis.

Key Words: Wits Appraisal, Frankfort Mandibular Plane Bisector, Anteroposterior Skeletal Discrepancy

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Table of Contents

List of Tables

List of Figures

List of Appendices

Introduction

Evaluation of the sagittal apical base relationship is an essential component of the assessment of an orthodontic patient and the determination of a treatment plan. As a result, a number of linear and angular measurements have been incorporated into cephalometric analyses, with the intention of clarifying the diagnosis of anteroposterior (AP) discrepancies. The most popular of these measurements have been the ANB angle and the Wits appraisal.[1-4]

Riedel[5] introduced the ANB angle, defined as the difference between SNA and SNB angles, to illustrate the AP skeletal relationships of the maxilla and mandible. However, while ANB remains popular and widely used, it has been shown that multiple factors interfere with the ANB angle.[6-11] These factors include: sagittal and vertical dislocations of nasion, the degree of facial prognathism, patient age and rotation of the jaws by either growth or orthodontic treatment. Also, as SNA and SNB become larger and jaws more protrusive, even if their horizontal skeletal relationship remains unchanged, the ANB angle will be excessive.[12]

For these reasons, Jacobson introduced the Wits appraisal to overcome the shortcomings of the ANB angle,[8,9] by relating points A and B to the functional occlusal plane (FOP) and eliminating the use of nasion for cephalometric analysis. The FOP is defined as a line bisecting the overlap of the maxillary and mandibular molars and premolar cusps. However, there are two significant problems that arise with performing the Wits appraisal on the FOP. Firstly, identification of the occlusal plane is not always accurately reproducible nor easily identifiable,[13,14] especially in cases with open bite, missing teeth, skeletal asymmetries, deep curve of Spee or in the mixed dentition. In addition, as the Wits appraisal relies on a dental parameter to describe a skeletal relationship, it has been shown to be profoundly affected by a change in the angulation of the functional occlusal plane, either due to growth or orthodontic treatment.[7,15-17]

In order to mitigate the difficulties in identifying and using the functional occlusal plane in the Wits appraisal, it has been recommended to use the bisected occlusal plane (BOP).

[4,6,18] The BOP is defined as a plane bisecting the overlap of the distobuccal cusps of the first permanent molars and incisor overlap, as described by Downs[19]. In fact, the functional occlusal plane tends to present negative Wits appraisal values, compared to measurements to the bisected occlusal plane or mandibular incisor occlusal plane since FOP rotates more clockwise with respect to a traditional occlusal plane, resulting in less correlation with ANB.[20] Additionally, Thayer[21] compared measurements to the FOP and BOP, and found that either occlusal plane can be used as an adjunct in the assessment of anteroposterior jaw relationships. He found that BOP Wits measurements were related to dental measures, whereas FOP Wits measurements were more related to skeletal measures. However, Palleck et al.[16] showed that the Wits measurement to the BOP was more reproducible than to the FOP, attributed largely to the marked change of FOP inclination with growth in Class I and Class III subjects. Del Santo[3] investigated the effect of occlusal plane inclination on ANB and Wits appraisal to the bisected occlusal plane. His study showed that there was a lack of consistency between ANB and BOP Wits in high occlusal plane angle patients, however in low occlusal plane angle patients, both assessments were found to be consistent.

To overcome these limitations, several new reference planes, linear distances and angles have been proposed. Yang and Suhr[22] measured the FABA angle, defined as the angle between the plane A-B and the Frankfort horizontal plane (shown in Appendix I). While Chang[18] projected the points A and B onto the Frankfort horizontal plane and measured the linear distance between them, which he called AF-BF, which is shown in Appendix II. Neither of these approaches considered the rotational effects of the jaws with growth. In contrast, Hall-Scott[23] projected the points A and B onto the bisector of the angle between the palatal and mandibular plane, which she called the maxillo-mandibular bisector (MMB). Studies have shown that the MMB Wits measurements are more reproducible than Wits measurements to either the FOP or BOP, and that growth and treatment changes in the MMB Wits values reflect changes described by the ANB angle.[16,17] Correlation coefficients between MMB Wits and ANB have been shown to be, on average, 0.66 in Class I subjects, 0.71 in Class II/1 subjects and 0.77 in Class III subjects.[16,17]

However, a concern exists in the utilization of the palatal plane as a reference plane in the MMB Wits appraisal. While the palatal plane has been shown to be stable with age, its inclination is highly variable, requiring additional cephalometric data to ensure a more accurate diagnosis.[24] In addition, while the MMB may present a possible solution for occlusal plane rotation, it does not account for the possible influence of facial type where, the rotation of the palatal plane and mandibular plane will be vary in dolichofacial and brachyfacial subjects.[20] Therefore, a stable cranial reference line to the mandibular plane such as the Frankfort horizontal, may be better at identifying the rotational effects of the jaws. It has been shown that the inclination of the Frankfort horizontal plane remains fairly stable with growth,[25] as a result of the cephalocaudal gradient of growth.

Tanaka et al.[20] assessed the influence of the facial pattern on cephalometric sagittal relationships and classified the facial patterns based on the facial height ratio (FHR) and the mandibular plane angle (FMA). The sagittal relationships investigated were the ANB angle, Wits appraisal and AF-BF. It was found that the ANB angle and AF-BF values varied with the facial pattern, being lower in brachyfacial subjects and higher in dolichofacial subjects. While Tanaka et al. showed that ANB values vary with facial patterns, Nanda[26] showed that there is no statistically significant correlation between ANB and mandibular plane angles. Tanaka et al[20] also found that the correlation for the Wits appraisal and ANB angle in all facial groups was r^2=0.62, indicating that facial type does not influence the correlation between ANB and Wits. Thus, a reference plane utilizing the mandibular plane, an indicator of facial type, is not expected to adversely alter the relationship between the ANB angle and Wits appraisal.

More recently, various analyses have been developed to account for the rotational effects of the jaws, which include the Pi analysis,[27] the Yen angle[28] and the W angle.[29] The Pi analysis is comprised of a Pi linear and a Pi angle measurement, and shown in Appendix III. It uses the true vertical line, which is obtained in natural head position (NHP), and the true horizontal as reference planes. The true horizontal is a line perpendicular to the true vertical line through nasion. Points defined at the midpoint of the premaxilla (point M) and the center of the largest circle tangent to the internal inferior, anterior and posterior surfaces of the mandibular symphysis (called point G) are then projected onto the true horizontal line. Then, the distance between these projected points (called M` and G`, respectively) on the true horizontal is defined as Pi linear. The Pi angle measures the angle between points M and G at the point G', which is projection of G point onto the true horizontal line. Alternatively, the Yen angle (shown in Appendix IV) measures the inferior posterior angle created by the midpoint of the sella turcica (sella, point S), point M and point G (as previously defined in the Pi analysis). Finally, the W angle (shown in Appendix V) bisects the Yen angle at point M and measures the inferior anterior angle. None of these new analyses measurements have been studied with respect to how they change with growth. Kumar et al.[27] showed that the Pi analysis had no statistically significant correlations with ANB or Wits; while no correlation studies were performed for the Yen or W angles. However, the effects of growth on the ANB angle and MMB Wits appraisal have been investigated. In subjects not receiving orthodontic treatment, Palleck et al.[16] and Foley et al.[17] showed that the MMB Wits measurement tended to decrease from ages 12 to 16 years, on average 1.05mm in Class I subjects, 0.83mm in Class II subjects and 1.22mm in Class III subjects. These same investigators showed that the ANB angle decreased to a lesser extent with growth from ages 12 years to 16 years, on average 0.52° in Class I subjects, 0.53° in Class II subjects and 0.71° in Class III subjects. These values are consistent with Bishara,[1] who found that the ANB angle decreases on average 0.60° with growth from age 12 to 16 years. In untreated subjects with good occlusions, Lux et al[30] showed that between age seven and 15 years, the ANB angle decreased from 4.44° to 2.79° (1.65° decrease) in males, and from 3.41° to 2.11° (1.3° decrease) in females. Both of these changes were found to be statistically significant.

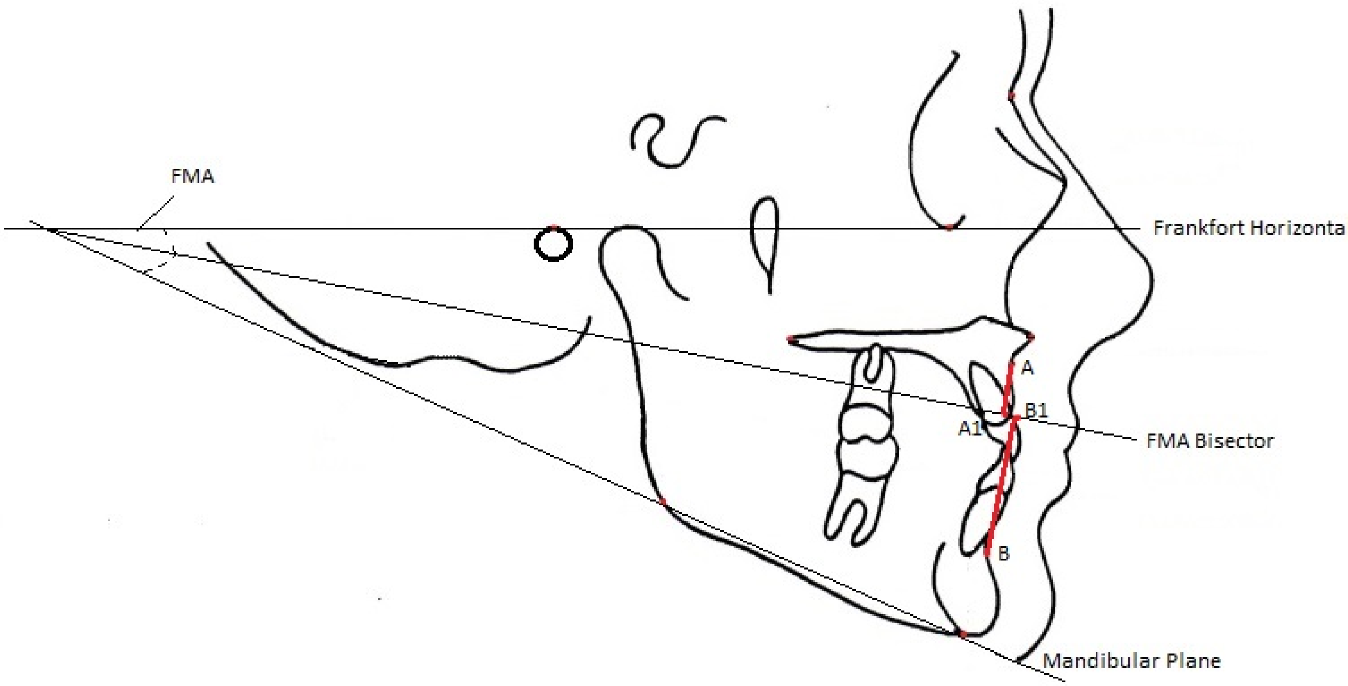
Thus, a need still remains for an anteroposterior jaw measurement to be made close to the dental bases that does not rely on dental measurements. This measurement should be based on a plane for which the cant does not change with growth or treatment, and is not highly variable in its inclination.[23] It is proposed that the bisector of the Frankfort Mandibular Plane Angle be used for this purpose, the FMA Bisector (FMAB). The plane is geometrically derived from the Frankfort horizontal and mandibular plane, to which a

Wits appraisal is performed by extending points A and B to the bisector and measuring the distance between them.

The Frankfort Mandibular Plane Angle Bisector (FMAB) Wits Measurement

The FMAB Wits appraisal assesses the skeletal relationship between the maxilla and the mandible in the sagittal plane. It uses the angle between two skeletal reference planes — The Frankfort Horizontal and Mandibular Plane — to create a bisecting reference plane, to which points A and B are projected onto in a perpendicular fashion. The distance between these projected points is a measure that indicates the severity and the type of skeletal dysplasia in the sagittal dimension (Figure 1).

Figure 1: The Frankfort Mandibular Plane Bisector (FMAB) Anteroposterior Wits Measurement



FMAB Wits = distance between A1 and B1 in mm
A1 anterior to B1 = +
A1 posterior to B1 = -

Study Objectives

The purpose of this study is threefold:

1. Evaluate age-related changes in sagittal jaw relationship over a sufficiently large time interval from pre-pubertal through pubertal development (at ages 12, 14, 16 years) using the FMAB, the ANB angle and the MMB in both males and females with Class I malocclusions;
2. Evaluate changes between Class I treated and control groups to determine any changes in the anteroposterior measurements due to treatment;
3. Determine how the measure FMAB correlates with the well-established angular measure ANB and with an anteroposterior linear measure, the MMB.

Materials and Methods

Prior to performing this cephalometric study investigating a new anteroposterior discrepancy measurement, a preliminary study was performed on 15 subjects, to ensure that the validity of the Frankfort Mandibular Plane Angle Bisector (FMAB) Wits measurement was satisfactory. Initial measurement of the ANB angle, MMB Wits and FMAB Wits was completed then repeated two weeks later. The results of this preliminary investigation are shown in Table 1.

This longitudinal study was composed of both a control and a treatment sample. Records for the control subjects were derived from the Burlington Growth Centre (BGC), located at the Faculty of Dentistry, University of Toronto in Toronto, Canada. The radiographic enlargement of the cephalometric data from BGC is 9.84%. The age groups utilized in this study were age 12 years (T0), age 14 years (T1) and age 16 years (T2). The data for the treatment subjects were obtained from the archives of the Western University Graduate Orthodontic Clinic. Full records consisted of serial lateral cephalograms taken at approximately 12 (pre-treatment [T0]), 14 (post-treatment [T1]) and 16 (post-retention [T2]) years of age. The radiographic enlargement of the cephalometric data from Western University is 8.0% for any cephalograms taken prior to 2007, and 9.5% after and including 2007, due to a change in imaging system. The total study sample consisted of 38 control subjects (19 male, 19 female) and 121 treated subjects (61 male, 60 female). Patient identification numbers are listed in Appendix IX for the control group, and Appendix X for the treatment group.

The criteria for inclusion in this study were:

- Class I molar relationship at T0 as determined from dental casts
- ANB angle less than 4.5° at T0
- Overjet less than 5 mm at T0
- Full permanent dentition (excluding third molars)

The treatment subjects met the following additional inclusion requirements:

- Non-extraction orthodontic treatment with full fixed appliances
- No extraoral appliances
- Passive retention, including either Hawley, fixed or Essix retainers

Subjects who did not meet these criteria were excluded.

Each lateral cephalogram was traced by the same investigator (NAS). Three cephalometric angles and two linear measures were drawn and measured on each tracing using the Dolphin Imaging Software[*] Version 11. Differences in radiographic magnification were calibrated for using the Dolphin Imaging Software. The measurements performed were:

1. the ANB angle (ANB)
2. the Frankfort Mandibular Plane Angle (FMA)
3. the Maxillomandibular angle (MM)
4. the Maxillomandibular Bisector (MMB) Wits appraisal
5. the Frankfort Mandibular Plane Angle Bisector (FMAB) Wits appraisal.

Descriptions of the landmarks, angles, linear measures and constructed points are listed in Appendix VI, VII and VIII. A cephalometric tracing is outlined in Figure 2, depicting all of the measurements of interest.

Sample Size

Calculations using mean values and standard deviations of the MMB Wits measurements in a treated Class I sample, as reported by Palleck et al.[16] were used to determine the desired sample size for this study. Using GPower Software Version 3[31] for sample size calculation, using an alpha value of 0.05 and with 80% power, revealed a minimum sample size of 47 subjects per group was required. Due to limited availability of subjects

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[*] Dolphin Imaging, Chatsworth, CA, USA

from the Burlington Growth Centre that fulfilled the inclusion criteria, only the treatment subjects satisfied the sample size requirements.

Error Study

Three weeks after the final cephalometric radiograph included in the study sample was traced, an error study was performed. Repeated measurements were performed on cephalograms of 20 randomly selected subjects at each time point (i.e. at T0, T1 and T2), resulting in 60 repeated measurements. Random selection was performed by assigning each subject a number from 1 to 159, then generating a string of random numbers via online software (http://www.randomizer.org/), which dictated the chosen subjects based on their assigned number. A Standard Deviation of Measurement Error (SE) was then calculated for each sample according to Dahlberg's formula: $\sqrt{(\Sigma d^2/2n)}$, where d is the difference between the pairs, and n is the number of pairs.

To quantify the reliability of the measures in the study sample, the reproducibility of measurement (called R) was calculated using the formula: $R=((S^2x-(S^2e/2))/S^2x$, where S^2x is the variance of the first set of measurements, and S^2e is the variance of the difference between the initial and repeated measurements.

Statistical Analysis

The data were input into Microsoft Excel® spreadsheet format and uploaded into IBM SPSS® Version 20.0[†] statistical software package.

The data were assessed for normality and the presence of outliers prior to analysis with parametric tests. A Shapiro-Wilk W-Test was applied to determine the distribution of data, and boxplots were plotted in order to determine the presence and location of any outliers. For every outlier detected it was found that the outlier had no significant impact

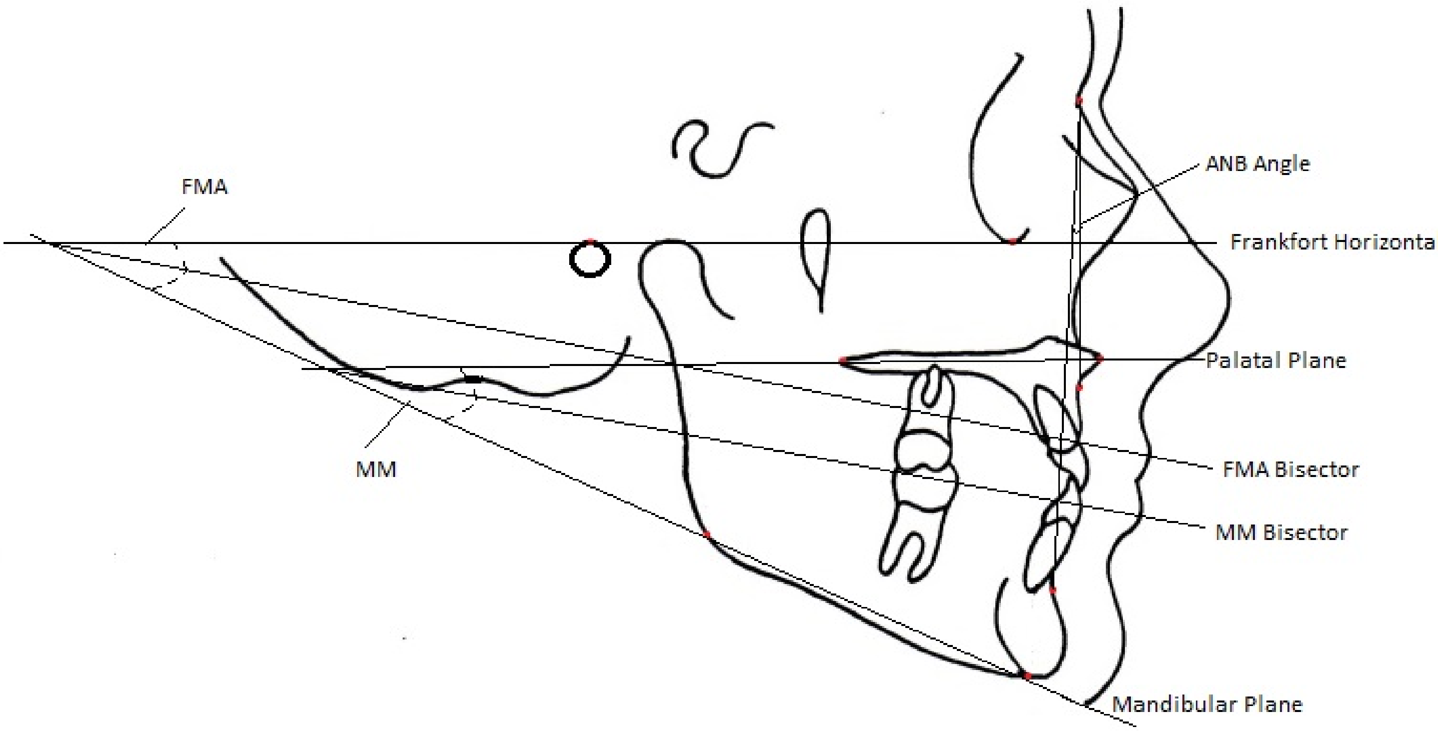
[†] IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp.

on the data given the sample size and the difference with and without the outlier. Thus, all outliers were included in the sample data. To determine the presence of statistically significant differences between males and females, independent sample t-tests ($p<.05$) were performed.

A Repeated Measures ANOVA was used to compare the mean values in the treatment and control groups, and to compare the mean values between males and females within these groups. In the case in which the data were found not to be normally distributed, then a non-parametric test for repeated measures, the Friedman test, was performed. A *post hoc* Bonferroni correction (n=3) was applied to determine differences between the time points as growth proceeded ($p<.017$). Pearson product-moment correlation coefficients were calculated to relate the changes in the ANB angle to the linear anteroposterior Wits appraisal measurements to the maxillomandibular bisector (MMB) and the Frankfort mandibular plane angle bisector (FMAB) between each of the time periods in the control and treatment groups.

In all evaluations, a 20% difference was considered clinically significant.

Figure 2: Cephalometric Measurements Performed



Results

The standard error for the cephalometric measures in the preliminary investigation is shown in Table 1. It was deemed that the error of measurement for the ANB angle, the MMB Wits, and the new cephalometric measurement, the FMAB Wits, were acceptable.

Table 1: Standard Error in the Preliminary Sample (n=15)

Measure	**Standard Error (SE)**
ANB angle	0.31°
MMB Wits	0.81 mm
FMAB Wits	0.77 mm

The standard error and the reproducibility of the measurements (R) for the cephalometric measures for the sample investigated in this study is shown in Table 2. All of the errors fell within acceptable limits and R>0.91 for all measurements, indicating a good reproducibility.

Table 2: Standard Error and Reproducibility in the Study Sample (n=60)

Measure	**Standard Error (SE)**	**Reproducibility (R)**
ANB Angle	0.39°	0.91
MM Angle	1.14°	0.95
FMA Angle	1.09°	0.93
MMB Wits	0.58 mm	0.91
FMAB Wits	0.46 mm	0.96

A significant difference in the ages of the subjects at all time periods was found between the control and treatment groups, as shown in Table 3. Similarly, when considering males and females separately, a significant difference between their ages in both the control and treatment groups, at all time periods was present. These differences are attributed to the large standard deviation of the ages in the treatment group, which is expected as the ages at which radiographs were taken were dependent on orthodontic diagnosis and time of completion of orthodontic treatment, which can be highly variable in an orthodontic residency program. On the other hand, timing of the radiographs performed on the control group subjects were determined solely by their ages.

Table 3: Ages at T0, T1, T2 for the Control and Treatment Groups and the t-values for their Difference in Each Time Period

	Age at T0 (months)		Age at T1 (months)		Age at T2 (months)	
	Mean	**t**	**Mean**	**t**	**Mean**	**t**
Control	144±2.21	4.99*	169±1.65	9.18*	192±1.03	10.27*
Treatment	150±13.0		180±13.16		205±13.66	

* p< .05

The mean values and standard deviations for the investigated cephalometric measurements pre-treatment (T0), post-treatment (T1) and post-retention (T2), in the control and treatment groups, for both males and females are shown in Tables 4, 5 and 6. Differences in each of the values of interest between the control and treatment groups are shown in Table 7, with their related t-test comparisons. A positive difference indicates a larger value in the treatment group; whereas a negative value is indicative of a greater value at that time period in the control group.

Table 4: Means and Standard Deviations at Each Time Period In the Control and Treatment Groups

	Control			Treatment		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB (°)	2.53±1.17	2.07±1.23	1.84±1.36	2.98±1.07	2.66±1.16	2.38±1.28
MM (°)	26.53±4.99	25.89±4.84	25.61±5.36	28.66±4.47	28.79±4.89	28.34±4.88
FMA (°)	25.75±4.71	25.33±4.76	24.42±4.96	26.46±4.32	26.75±4.80	26.16±4.92
MMB Wits (mm)	-2.17±1.07	-2.53±1.04	-2.73±1.21	-3.83±2.22	-4.50±2.36	-4.87±2.71
FMAB Wits (mm)	-2.32±1.10	-2.63±1.09	-2.93±1.25	-4.55±2.35	-5.21±2.49	-5.67±2.83

Table 5: Means and Standard Deviations at Each Time Period In the Control Group for Males and Females

	Males			Females		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB (°)	2.95±1.03	2.41±1.18	2.25±1.38	2.10±1.12	1.72±1.14	1.43±1.16
MM (°)	26.78±5.34	26.16±4.91	25.75±5.08	26.28±4.60	25.63±4.75	25.47±5.63
FMA (°)	25.67±5.22	25.51±5.14	24.55±4.96	25.82±4.13	25.15±4.34	24.28±4.96
MMB Wits (mm)	-1.88±1.09	-2.31±1.18	-2.47±1.26	-2.46±0.97	-2.75±0.82	-2.99±1.11
FMAB Wits (mm)	-2.09±1.13	-2.43±1.22	-2.66±1.27	-2.55±1.01	-2.84±0.90	-3.20±1.17

Table 6: Means and Standard Deviations at Each Time Period Treatment Group for Males and Females

	Males			Females		
	T0	**T1**	**T2**	**T0**	**T1**	**T2**
ANB (°)	2.94±1.10	2.59±1.19	2.17±1.34	3.02±1.02	2.74±1.10	2.60±1.16
MM (°)	28.75±4.40	28.55±5.30	27.96±5.35	28.57±4.54	29.03±4.42	28.74±4.32
FMA (°)	25.59±3.56	25.65±4.32	24.71±4.47	27.35±4.82	27.87±5.00	27.63±4.93
MMB Wits (mm)	-3.83±2.36	-4.56±2.62	-5.12±2.96	-3.84±2.06	-4.44±2.05	-4.61±2.40
FMAB Wits (mm)	-4.87±2.57	-5.51±2.79	-6.31±3.11	-4.24±2.04	-4.89±2.09	-5.02±2.33

Table 7: Differences Between Control and Treatment Groups and Their t-Values in Each Time Period (Subtraction of Means: Treatment – Control)

Treatment-Control:	T0		T1		T2	
	Difference	t	Difference	t	Difference	t
ANB Angle (°)	0.45±0.10	2.23*	0.60±0.06	2.74*	0.54±0.06	2.24*
MM Angle (°)	2.13±0.52	2.47*	2.89±0.05	3.17*	2.73±0.48	2.92*
FMA (°)	0.71±0.38	0.86	1.42±0.04	1.59	1.74±0.04	1.89
MMB Wits (mm)	-1.66±1.15	-6.19*	-1.98±1.32	-7.18*	-2.13±1.47	-6.73*
FMAB Wits (mm)	-2.23±1.25	-7.96*	-2.57±1.39	-8.88*	-2.74±1.57	-8.31*

* $p < .05$

The results in Table 7 show that significant differences were found for all measurements, between the control and treatment groups, except for the Frankfort mandibular plane angle (FMA) for all time periods. The ANB angle was significantly larger in the treatment group subjects, ranging from 0.45°±0.10° at T0 ($p<.05$), to 0.60°±0.06° at T1 ($p<.01$), to a difference of 0.54°±0.06° ($p<.05$) at T2. Similarly, the maxillomandibular (MM) angle was significantly greater in subjects of the treatment group for all time periods, demonstrating the largest discrepancy post-treatment (T1), with a value of 2.89mm±0.5mm ($p<.05$). In addition, both the Wits appraisal measurements to MMB and FMAB demonstrated a significant difference at T0, T1 and T2, at significance level of $p<0.001$. While a statistical significant difference was detected for most of the values, they are not deemed clinically significant.

Prior to assessing the differences between each time period with a repeated measures ANOVA test, the data were assessed for the presence of outliers via boxplots. While the presence of outliers in the majority of the data was minimal (between none and two outliers), the palatal plane inclination (PP-FH) for the female treatment group was marked, demonstrating the presence of 7 outliers in the data. The boxplot demonstrating these outliers is shown in Figure 3. In comparison, the mandibular plane (MP-FH) measurements in the female treatment group demonstrated the presence of only a single outlier, shown in a boxplot in Figure 4. Such a discrepancy between the quantity of outliers was not seen in any of the other groups

Figure 3: Outliers Detected in the Palatal Plane Inclination (PP-FH) for the Female Treatment Group

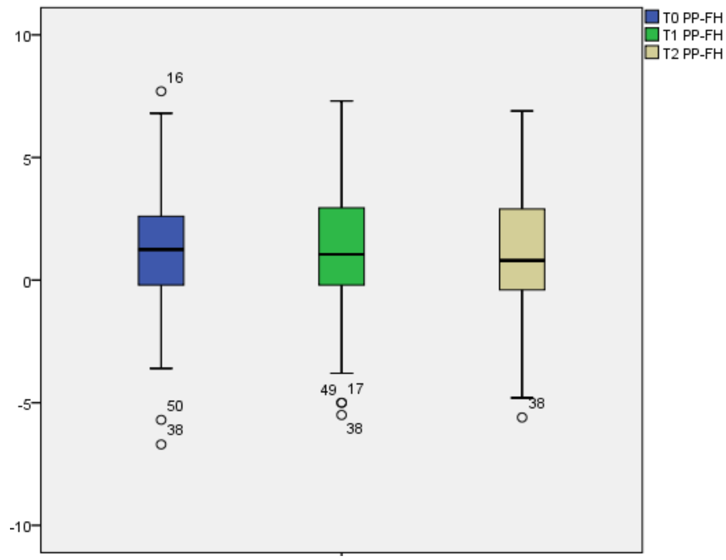
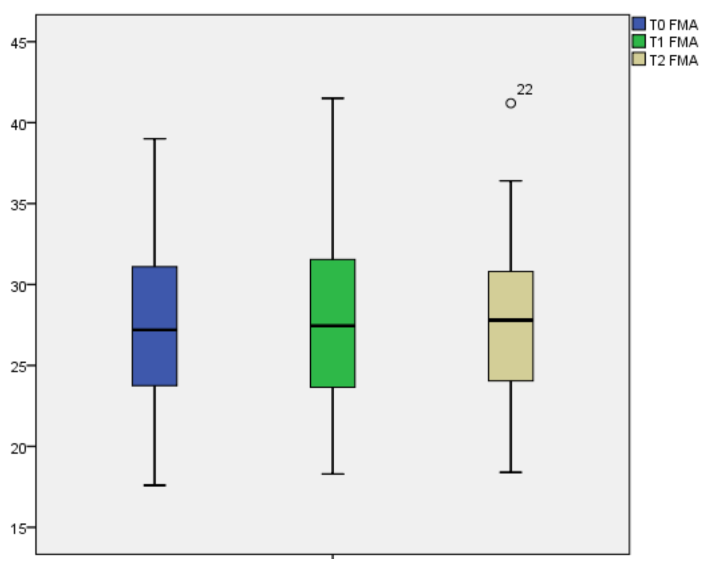


Figure 4: Outliers Detected in the Mandibular Plane Inclination (MP-FH, a.k.a. FMA) for the Female Treatment Group



Tables 8 to 10 illustrate how the values of interest (ANB angle, MM angle, FMA, MMB Wits, FMAB Wits) change between each time period. Table 8 investigates the differences between the control and treatment groups for the entire sample, which includes both males and females. In general, all values decreased from T0 to T2 significantly (p<.017), with the exception of the maxillomandibular (MM) angle and mandibular plane angle (FMA) in the treatment group.

Table 8: Mean Change Between Each Time Period in the Control and Treatment Groups for Both Males and Females

	Control Group			Treatment Group		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB Angle (°)	0.46±0.52*	0.22±0.71	0.68±1.03*	0.32±0.81	0.28±0.70*	0.60±0.96*
MM Angle (°)	0.64±1.26*	0.28±1.71	0.92±1.70*	-0.13±2.18	0.44±1.96	0.32±2.59
FMA (°)	0.42±1.23	0.91±1.18*	1.33±1.42*	-0.29±1.99	0.60±1.56*	0.30±2.06
MMB Wits (mm)	0.35±0.48*	0.21±0.60	0.56±0.81*	0.67±1.17*	0.37±1.15	1.04±1.49*
FMAB Wits (mm)	0.31±0.51*	0.29±0.69	0.61±0.83*	0.65±1.30*	0.47±1.31	1.12±1.53*

* p< .017

Table 9: Mean Change Between Each Time Period in the Control and Treatment Groups for Males

	Control Group			Treatment Group		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB Angle (°)	0.54±0.59*	0.16±0.51	0.70±0.92*	0.35±0.81	0.42±0.77*	0.77±1.02*
MM Angle (°)	0.63±1.42	0.41±1.64	1.04±1.44	0.21±2.32	0.59±2.14	0.79±3.08
FMA (°)	0.17±0.93	0.95±1.06*	1.12±1.00*	-0.07±2.24	0.94±1.74*	0.87±2.29*
MMB Wits (mm)	0.42±0.45*	0.17±0.53	0.59±0.63*	0.73±1.21*	0.56±1.23*	1.29±1.54*
FMAB Wits (mm)	0.34±0.53	0.23±0.65	0.56±0.76	0.65±1.31*	0.80±1.40*	1.45±1.55*

* p< .017

Table 10: Mean Change Between Each Time Period in the Control and Treatment Groups for Females

	Control Group			Treatment Group		
	T0-T1	**T1-T2**	**T0-T2**	**T0-T1**	**T1-T2**	**T0-T2**
ANB Angle (°)	0.38±0.43	0.29±0.86	0.67±1.13*	0.28±0.81	0.14±0.60	0.42±0.87*
MM Angle (°)	0.66±1.08	0.15±1.77	0.81±1.92	-0.46±1.98	0.29±1.75	-0.17±1.86
FMA (°)	0.67±1.43	0.87±1.29	1.54±1.71*	-0.52±1.67	0.25±1.26	-0.27±1.60
MMB Wits (mm)	0.28±0.51	0.24±0.66	0.53±0.96	0.61±1.13*	0.17±1.03	0.78±1.39*
FMAB Wits (mm)	0.28±0.48	0.36±0.72	0.65±0.90	0.66±1.29*	0.13±1.13	0.79±1.44*

* p< .017

The changes in the cephalometric measurements of interest were then investigated separately for males and females, as shown in Table 9 and Table 10, respectively. While no significant trend was noted in the male control group subjects (likely due to lack of power and small sample size), it was found that, with the exception of the MM angle, a significant overall change occurred from pre-treatment to post-retention for males in the treatment group. In these males, the change was significantly greater between T1 and T2 time periods, coinciding with an age range of 15.2 years to 17.3 years. The female subjects in the control group also did not show a definable trend, while the females in the treatment group demonstrated an overall significant increase (with the exception of the MM angle and FMA) from T0 to T2. In contrast to the male subjects, any significant change that occurred was seen in the T0 to T1 time interval, corresponding to an age range of 12.4 years to 14.75 years. The Maxillomandibular and the Frankfort mandibular plane angles in the female treatment group were the only values that were shown to decrease from T0 to T2.

The presence of differences in the amount of change of the cephalometric parameters for males compared to females was investigated. Statistically significant changes ($p<.05$) were present in the treatment group only. For all of the significant changes present, the male subjects demonstrated a greater change than the females. Specifically, a statistically larger decrease in the ANB angle, the MM angle, the FMA, and FMAB Wits was seen from pre-treatment to post-retention. In addition, a statistically significant decrease in only ANB, FMA and FMAB Wits was seen in the time period from post-treatment to post-retention in males.

The correlations of the two (MMB and FMAB) Wits appraisals to the three skeletal measurements (ANB, MM and FMA) were generally low. The correlation values are depicted in Table 11. Overall, the strongest correlations were found between MMB Wits and FMAB Wits for all time periods ($r>0.86$).

Table 11: Pearson Correlation Coefficients Within the Time Periods for the Control and Treatment Groups

	Control Group			Treatment Group		
	T0	T1	T2	T0	T1	T2
ANB-MMB Wits	0.60	0.52	0.32	0.39	0.30	0.19
ANB-FMAB Wits	0.57	0.46	0.26	0.42	0.30	0.25
MMB Wits-FMAB Wits	0.93	0.91	0.96	0.86	0.86	0.91
FMA-ANB	0.10	0.13	0.16	0.17	0.10	0.21
FMA-MMB Wits	-0.45	-0.38	-0.42	-0.34	-0.32	-0.38
FMA-FMAB Wits	-0.41	-0.38	-0.43	-0.17	-0.20	-0.22
MM-ANB	0.10	0.09	0.16	0.11	0.43	0.15
MM-MMB Wits	-0.40	-0.37	-0.35	-0.19	-0.23	-0.28
MM-FMAB Wits	-0.52	-0.52	-0.45	-0.36	-0.38	-0.40

Discussion

Among the criteria that the orthodontist requires for diagnosis and treatment planning, the sagittal relationship between maxilla and mandible is critical to specifically address whether a skeletal malocclusion exists, and if so, to what degree. Many parameters to evaluate the intermaxillary relationship have been described in the literature, but the ANB angle suggested by Reidel[5] is the most popular and, therefore, the most used.[32]

As a complement to the ANB angle, the Wits appraisal was introduced by Jacobson in 1975.[9] Jacobson explained that a high ANB angle in a person with an excellent occlusion could be caused by forward position of the maxilla in relation to nasion and/or by clockwise rotation of the maxilla with regard to the anterior cranial base. In these cases, he reports differences in the ANB angle and Wits appraisal may result. Furthermore, Jacobson asserts that the ANB angle is only reliable if the mandibular plane angle is normal. An increased mandibular plane angle would indicate a divergent pattern, and in many of these cases, an anterior cranial base with a higher inclination reduces the SNA angle and provides less reliable information. Zamora et al.[33] investigated the relationship between the ANB angle and Wits appraisal (to the bisected occlusal plane) utilizing CBCT imaging. They found that in the 45 patients in whom the ANB angle and BOP Wits appraisal did not coincide, 49% of these individuals had a mandibular plane angle that was considered to be within the range of normal (i.e. a mesofacial pattern). This same study did not find a correlation between the mandibular plane angle and the ANB angle (r=.04), similar to findings from Hussels[7] and Nanda,[34] nor did they find a significant correlation between the Wits appraisal and the mandibular plane angle (r=0.24). Similarly, in this study, the correlation found between the ANB angle and the Frankfort mandibular plane angle (FMA) was very small (r=0.10 to 0.21), while the MMB Wits appraisal correlation to FMA was somewhat larger (r=-0.45 to -0.32).

In this study, the correlation between the FMAB Wits appraisal and FMA had a large range over the investigated time periods, but was generally better than the correlation to the ANB angle, and ranged from r=-0.43 to -0.17. The highest correlations with the ANB angle were between the ANB angle and MMB Wits appraisal at time T0 in the control group (r=0.60), but this correlation gradually decreased to r=0.32 at time T2. This differs from the findings of Palleck et al.[16], in which the correlation between the ANB angle and MMB Wits appraisal was more consistent in the Class I sample, ranging from r=0.54 to r=0.69 in the control group. However, in this investigation, the overall strongest correlations were found between MMB Wits and FMAB Wits appraisals ranging from r=0.91 to r=0.96 in the control group, and from r=0.86 to r=0.91 in the treatment group. Horowitz and Hixon[35] stated that a correlation coefficient better than 0.8 may be used in clinical predictions, such that these pairs may be considered highly interchangeable in the assessment of anteroposterior jaw relationships. While the correlations between the ANB angle and the Wits appraisal measurements tended to gradually decrease, those between the MMB Wits and FMAB Wits appraisals were generally strong for all time points. Aside from the correlations between FMAB Wits and MMB Wits, the results show low correlation coefficients of less than r=0.8, indicating a lack of interchangeability in their use in clinical assessment. In theory, as the ANB angle and Wits appraisal evaluate the same skeletal discrepancy, they must have a high correlation. A weak correlation between the ANB angle and Wits appraisal has been shown in several studies,[1,6,18,21,36,37] suggesting that differing assessments of jaw discrepancies frequently occur with these pairs, likely attributed to a weakness in at least one of the measures. Because of the high correlation between the Wits appraisal measurements, which are independent of nasion, it is postulated that the poor correlations seen with the ANB angle may at least be attributed to the location of nasion, which tends to change throughout growth adopting a more forward and upward position.[38]

To assess the validity of the Wits appraisal measurements in diagnosing anteroposterior jaw relationships and their ability to reflect growth and treatment changes, the ANB angle was used as a standard to which to compare these values. Despite its shortcomings, the ANB angle acts as a useful reference point, and has been shown not to be any less reliable than any other cephalometric measurements as a sagittal anteroposterior parameter.[4]

The changes in the cephalometric measures with growth, with or without treatment, were investigated and shown in Table 8. In the control group, the ANB angle demonstrated a statistical significant ($p<.017$) decrease from pre-treatment (at approximately age 12 years) to post-retention (at approximately 16 years), by 0.68°±1.03°. In a longitudinal study by Lux et al.,[30] the change in ANB in Class I subjects between the ages of 11 years and 15 years was found to be 0.75°±3.05° in males, and 0.51°±3.99° in females. Similarly, Bishara et al[1] found that the ANB angle decreased by 0.60°±0.57° from ages 12 years to 16 years. The MMB Wits appraisal value showed a statistically significant decrease ($p<.05$) in each time interval, with an overall decrease from T0 to T2 of 0.56mm±0.81mm. The FMAB Wits value demonstrated a decrease of similar magnitude to the MMB Wits from pre-treatment to post-retention of 0.61mm±0.83mm. Generally, all of the values in the control group decreased between the time periods.

In the treatment group, the ANB angle demonstrated a similar decrease to the control group, by an amount of 0.60°±0.96° from pre-treatment to post-retention. Similarly, the ANB angle in the Class I treatment group decreased by 0.63°±1.88° in the study by Palleck et al.[16] In this study, the MMB Wits value showed a statistically significant decrease ($p<.001$) in each time interval, with a decrease of 1.04mm±1.49mm from T0 to T2. This decrease was slightly smaller than that found in the Class I sample from Palleck et al.[16] of 1.21mm±2.91mm. The FMAB Wits value demonstrated a decrease of similar magnitude to the MMB Wits from pre-treatment to post-retention of 1.12mm±1.53mm. Only the maxillomandibular angle and mandibular plane angle in the time period during orthodontic treatment (T0 to T1) showed an increase between time intervals, being 0.13°±2.18° and 0.29°±1.99°, respectively. These mild increases were attributed to the extrusive effect of orthodontics, causing the mandible to tip down and back. With growth, the maxillomandibular and mandibular plane angles returned to normal values as the growth of the ramus compensated for these changes.[12]

Ultimately, while many of the values decreased with statistical significance between the time periods, these changes do not carry clinical significance due to their small magnitudes.

The data was then assessed by separating the cephalometric measurements based on gender, as seen in Tables 9 and 10. The cephalometric measures tended to decrease with time, with a couple of exceptions. Only for the females in the treatment group did the maxillomandibular angle and mandibular plane angle show an overall increase from pre-treatment to post-retention, with values of 0.17°±1.86° and 0.27°±1.60°, respectively. This suggests that despite ramal growth occurring post-orthodontics, the mandibular plane never fully recovered from the down and back rotation from orthodontic extrusion in the female subjects. Interestingly, this overall increase is not seen in the male sample, demonstrating a 0.79°±3.08° overall decrease in the maxillomandibular plane angle and 0.87°±2.29° decrease in the mandibular plane angle, which may be attributed to ramal growth occurring later and lasting longer in males[12] as compared to females, who peak, and thus complete, growth earlier. However, given the broad standard deviations of the changes, it is not possible to make conclusive statements in regards to treatment effects. Changes secondary to growth were reflected not only in the ANB angle, but also in the MMB Wits and FMAB Wits appraisal measurements. The change from T0 to T2 in the ANB angle in the treated male group was 0.77°±1.02°, and in the treated female group was 0.42°±0.87°. Similarly, the change of the MMB Wits over the same time interval in the treated males was 1.29mm±1.54mm and in treated females was 0.78mm±1.39mm. Finally, the change from pre-treatment to post-retention of the FMAB Wits demonstrated a similar trend, with a value of 1.45mm±1.55mm in the treatment male group, and 0.79mm±1.44mm in the treatment female group. Therefore, both Wits appraisal measurements reflect similar growth and treatment changes with the ANB angle.

Gender differences in the amount of change of the cephalometric parameters occurred between the time periods. Only a statistical significant change ($p \leq .05$) was seen in the treatment group, and in all cases in which a statistical change was evident, it was due to a larger change in the male group. Specifically, a statistically larger decrease in the ANB angle, the MM angle, the FMA, and FMAB Wits was seen from pre-treatment to post-retention in the males. In addition, a statistically significant decrease in only the ANB angle, FMA and FMAB Wits was seen in the time period from post-treatment to post-retention in males. These larger changes were consistent with a later growth spurt in males, and reflect a normal pattern of growth. Whether the magnitude of change is also attributed to treatment effects is unclear, due to a smaller sample size of the control group, limiting the ability to detect statistical significance.

Another method of determining how well an anteroposterior parameter will be able to diagnose a sagittal skeletal discrepancy is how reliable it is. In this study, repeat tracings of 60 radiographs designed to test the reliability of the MMB and FMAB Wits measurements, showed that while the error in the FMAB Wits was smaller, the difference between them is not clinically significant. Similarly, the error between the landmarks that comprise these Wits appraisal measurements, the MM and FMA angles, were shown to have errors of 1.14° and 1.09°, respectively, also presenting an insignificant clinical difference. The reproducibility of the measurements was also demonstrated via the calculated reproducibility of measurement, which demonstrated values of $R>0.91$ for all measurements.

Ultimately, the difference between the Wits appraisal measurements may be better appreciated when considering identification of the landmarks themselves. While on average the error of measurement of the maxillomandibular angle and Frankfort mandibular plane angle is low, when considering the individual angular measurements of the mandibular plane and palatal plane with respect to Frankfort Horizontal, differences associated to the spread of the data is evident. Within the treated female group, there were 7 outliers when identifying the palatal plane in the 60 female subjects, equivalent to approximately 10% of the sample being an outlier. However, the measurements of the mandibular plane in the treated female group identified only a single outlier. Interestingly, such a discrepancy with respect to the quantity of outliers was not seen in any other groups. While these results are not entirely conclusive, it does suggest that on a case-by-case basis, as is encountered on a daily basis with orthodontic treatment planning, utilizing the mandibular plane, rather than the palatal plane, may be a more reliable reference plane.

The presence of a broad spread of the data should be noted in Tables 4, 5 and 6, especially of the ANB angle, MMB Wits and FMAB Wits measurements. The standard deviations of these values are nearly half of the average value, suggesting the reliability of the measured values is questionable. Sources of potential error in the measurement of these values may be: difficulty in identifying landmarks in cephalometric radiographs of poor quality, large anatomical variations in the inclinations of the planes investigated, and the individual anatomical variation.

Future studies may consider investigating how the FMAB Wits appraisal measurement changes in Class II and Class III samples. Alternatively, the results of this study may be compared to Wits appraisal measurements performed to a bisector of the mandibular plane angle using a constructed Frankfort Horizontal plane.

Conclusion

The conclusions that can be drawn from this study are as follows:

1. The Wits appraisal using the FMA bisector is a valid indicator of the anteroposterior skeletal discrepancy, as its changes with growth and treatment reflect those changes seen in the gold standard ANB angle.
2. A good correlation (r>0.86) was found between the MMB and FMAB Wits appraisal in both the control and treatment groups for all time periods, indicating that the use of either of these measures may be interchangeable.
3. Individual measures of the palatal plane (PP-FH) with respect to the mandibular plane (MP-FH) demonstrated a larger number of outliers, indicating that assessment of the anteroposterior skeletal discrepancy may be more reliable when using the mandibular plane instead of the palatal plane as a reference plane. For extreme or controversial cephalometric interpretations, visual inspection provides an essential aid in diagnosis and skeletal classification.

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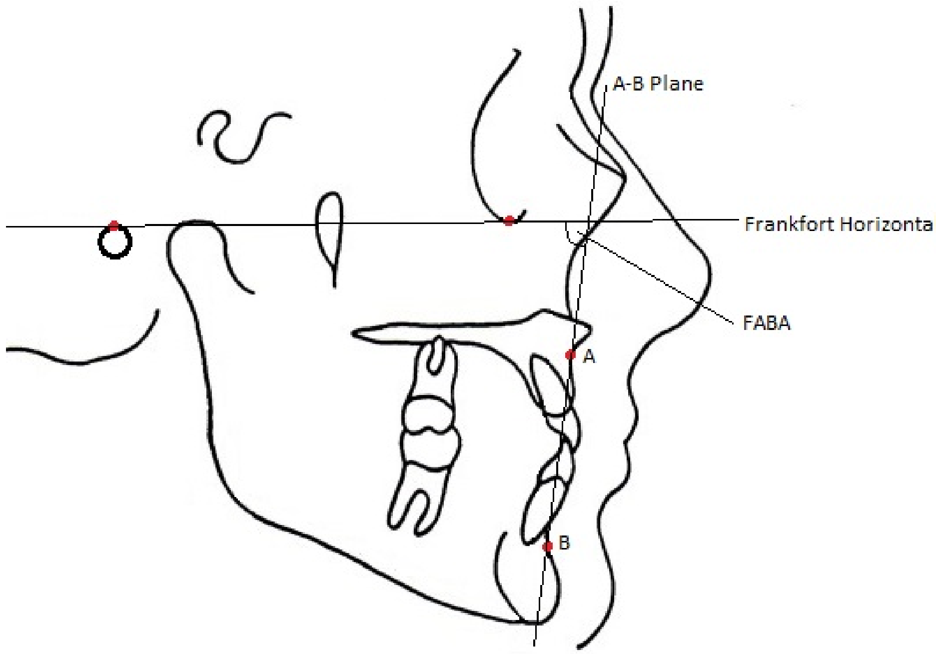
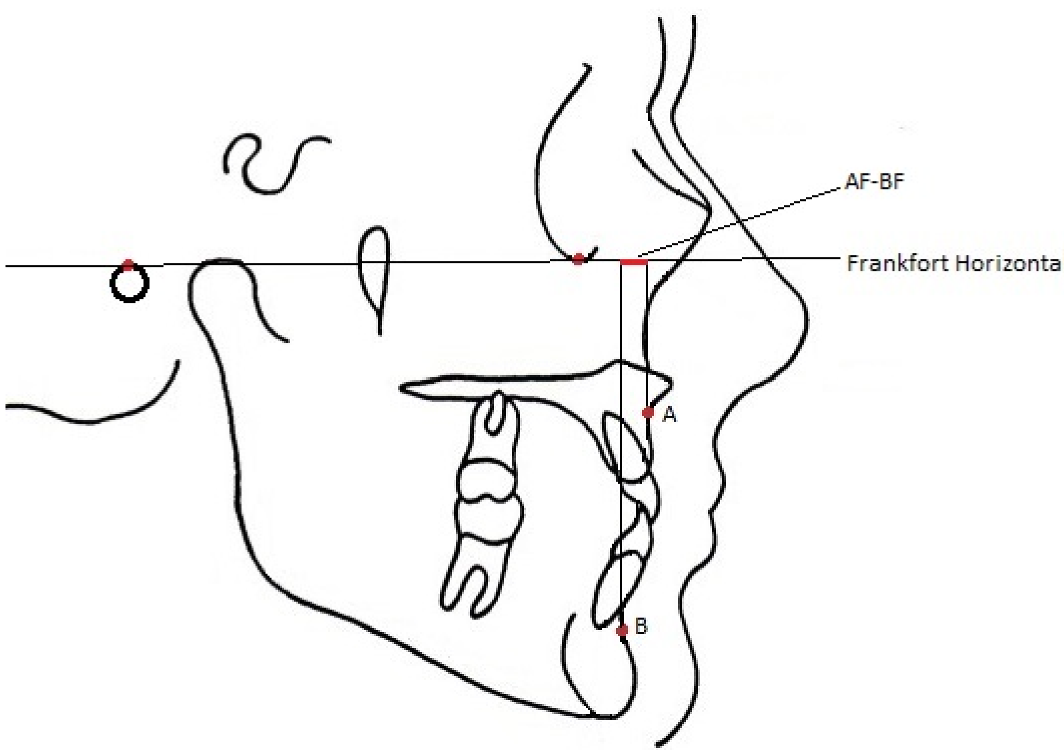
Appendices

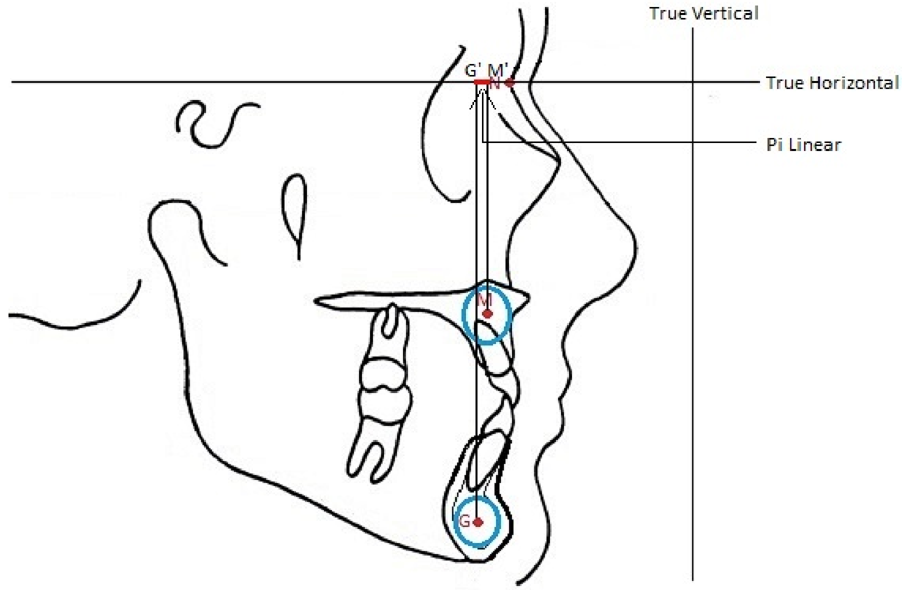
Appendix I: FABA Angle, as proposed by Yang and Suhr (1995)[22]

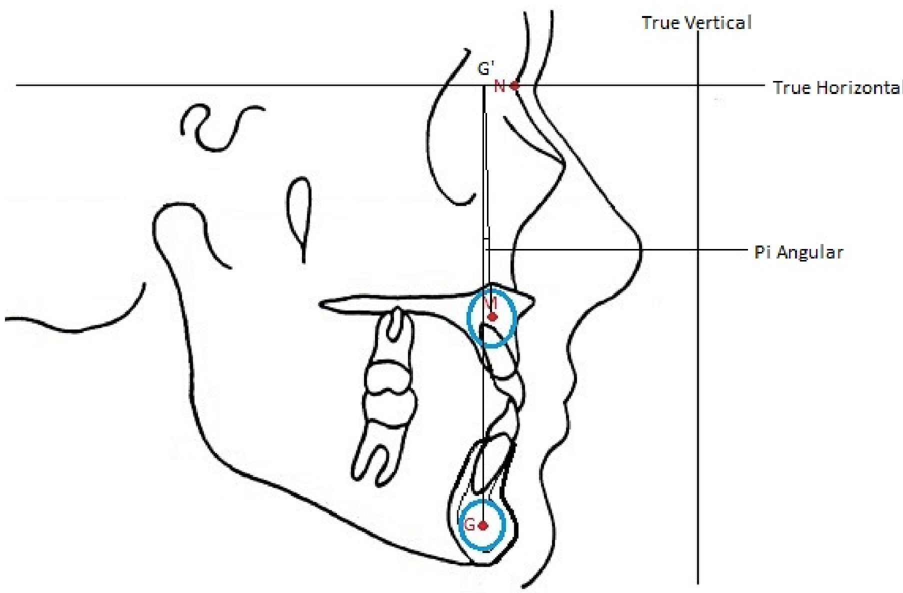


Appendix II: AF-BF, as proposed by Chang (1987)[18]

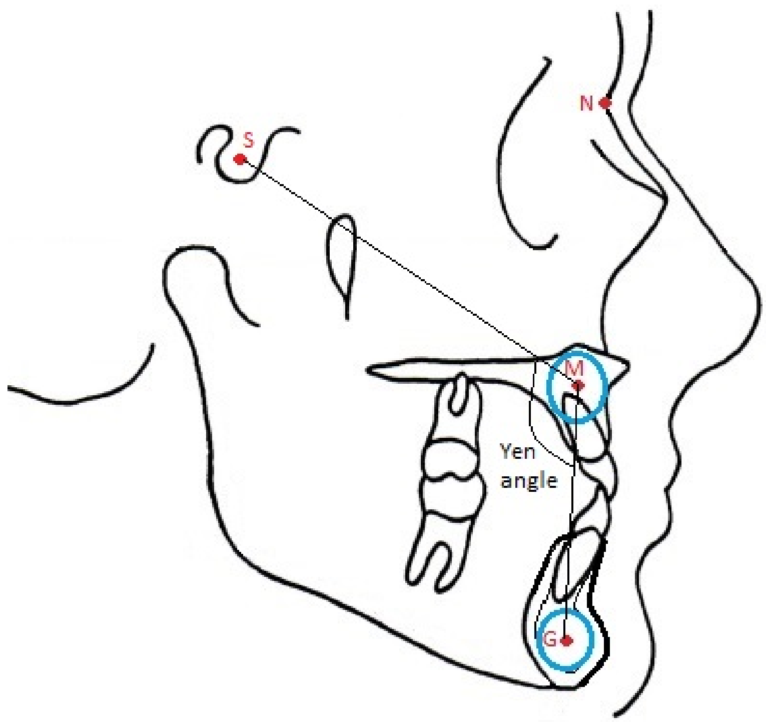


Appendix III: Pi analysis, as proposed by Kumar (2012)[27]

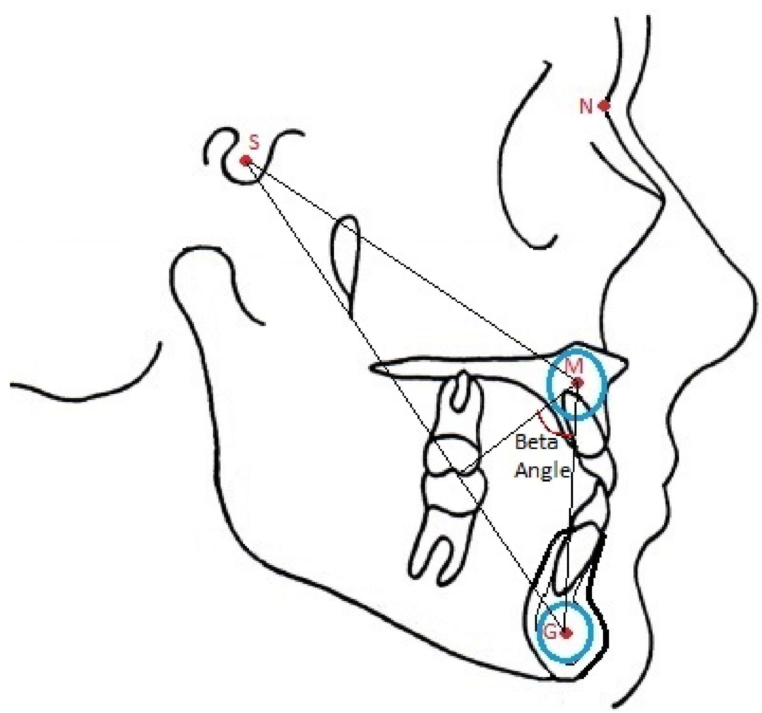




Appendix IV: Yen Angle, as proposed by Neeta et al. (2009)[28]



Appendix V: W Angle, as proposed by Bhad et al. (2013)[29]



Appendix VI: Definition of Cephalometric Landmarks

Landmark	Abbreviation	Definition
Nasion	N	The junction of the frontonasal suture at the most posterior point of the curve at the bridge of the nose
Anterior Nasal Spine	ANS	The most anterior point on the maxilla at the level of the palate
Posterior Nasal Spine	PNS	The most posterior point on the maxilla at the level of the bony hard palate
A Point (subspinale)	A	The most posterior point on the concave outline of the maxilla labial to the upper incisors
B Point (supramentale)	B	The most posterior point on the concave outline of the mandibular symphysis labial to the lower incisors
Menton	Me	The lower point on the outline of the bony chin
Gonion	Go	The lowest most posterior point at the angle of the mandible
Porion	Po	The uppermost margin of the external auditory meatus; anatomic porion
Orbitale	Or	The lowest point on the lower margin of the bony orbit

Appendix VII: Definition of Cephalometric Planes and Angles

Planes	Abbreviation	Definition
Palatal Plane	PP	A line joining ANS and PNS
Mandibular Plane	MP	A line joining Me to Go
Maxillomandibular Bisector	MMB	The bisector of the maxillomandibular angle
Frankfort Horizontal Plane	FH	A line joining porion and orbitale
Frankfort Mandibular Angle Bisector	FMAB	The bisector of the Frankfort mandibular angle
Angle	**Abbreviation**	**Definition**
ANB angle	ANB	The angle formed from point A, to nasion, to point B
Maxillomandibular angle	MM	The angle formed by the intersection of the palatal plane and mandibular plane
Frankfort Mandibular Plane Angle	FMA	The angle formed by the intersection of Frankfort Horizontal and the mandibular plane

Appendix VIII: Constructed Cephalometric Points

A1	A point projected in a perpendicular fashion onto the FMAB
B1	B point projected in a perpendicular fashion onto the FMAB
A2	A point projected in a perpendicular fashion onto the MMB
B2	B point projected in a perpendicular fashion onto the MMB

A Wits assessment using the MMB and FMAB reference planes is calculated by measuring the linear distance between constructed points A and B, respectively.

Figure 2 outlines an example of the Wits assessment using FMAB. Using this reference plane, the distance between A2 and B2 is measured. B anterior to A in the sagittal plane has a negative value; B posterior to A has a positive value.

Appendix IX: Control Subjects from the Burlington Orthodontic Research Centre

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 X: Treated Subjects from the Western University Graduate Orthodontic Clinic

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 X (continued): Treated Subjects from the Western University Graduate Orthodontic Clinic

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

Curriculum Vitae

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