The Reliability of 3 Sagittal Reference Planes in the
Assessment of Class I and Class III Treatment

by

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ABSTRACT

The objective of this study was to test the reliability and validity of three sagittal reference planes applied in the Wits analysis. Measurements made to the functional occlusal plane (FOP), the bisected occlusal plane (BOP) and the maxillomandibular bisector (MMB) were compared to each other and to the angular measurement of ANB. The relationship of these reference planes to the pterygomaxillary vertical (PMV) reference plane was also studied. Untreated control subjects were compared to treated subjects in skeletal Class I and Class III samples.

The data were collected from pretreatment (T1), posttreatment (T2) and two year postretention (T3) lateral cephalograms of 35 Class I subjects and 10 Class III subjects. Treatment for these patients was carried out with full fixed orthodontic appliances and was nonextraction in the permanent dentition. Cephalometric data were compared to 39 and 9 controls for the Class I and Class III groups respectively.

The MMB was determined to be an easily identifiable and reproducible reference plane which exhibited greater stability over time with growth and/or treatment than either the FOP or BOP. The MMB Wits increased the reliability and confirmed the validity of the maxillomandibular relationship as expressed by the ANB value. The mean values for the MMB Wits for Class I, II and III populations were distinct or triphasic in distribution and provided a useful clinical tool for patient assessment.

Key Words: Wits Analysis, Maxillomandibular Bisector, Bisected/Functional Occlusal Plane

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INTRODUCTION

The Wits analysis involves projecting perpendiculars from A point and B point to the functional occlusal plane (FOP) and measuring the linear distance between the two. The FOP is defined as a straight line bisecting the overlap of the mesiobuccal cusps of the permanent first molars and the buccal cusps of the first premolars. The original method was proposed by Jacobsen ¹ in 1975 in order to supplement the cephalometric diagnosis of a patient and verify the anteroposterior skeletal discrepancy as described by the ANB angle.

Derived from SNA and SNB, Reidel ² introduced the ANB angle as “a direct comparison of the relationship of the denture bases to each other.” He reported a mean value of approximately 2° in cases with normal occlusion and balanced skeletal relationships, but concluded that an ANB between -1° and 2.5° was acceptable. Jacobsen ^{1,3}, like many other authors ⁴⁻⁹, has identified deficiencies in the ANB angle. Due to variations in the horizontal and/or vertical location of nasion and/or sella, the anterior cranial base can be longer or shorter, or canted in a clockwise or counterclockwise direction. As a result, the ANB can increase or decrease without any change in the actual anteroposterior relationship of the jaws being manifested. Geometric studies have shown that when nasion is retrusive, or more inferiorly positioned, the resultant ANB is higher. Furthermore, rotational growth of the maxilla and/or mandible relative to the anterior cranial base can alter the ANB angle as well.⁴

10, 11

Many researchers have tried to overcome these problems by altering the cranial base landmarks employed in their cephalometric analyses. Beatty ¹⁰ suggested the use of the AXD

angle and the linear measurement of the distance between points A and D projected perpendicular to the SN plane. He reported better correlation of angular and linear measurements with this method than was found between the Wits analysis and ANB. Freeman⁵ proposed the AXB angle and related A point to the Frankfort horizontal. Stoner *et al*¹² and Chang⁴ both used the Frankfort horizontal as a reference plane for measuring the linear distance between A and B point perpendiculars. Although helpful, these approaches did not address the rotational effects of growth of the jaws.

The Wits appraisal is meant to supply the orthodontist with a measurement relating the dental bases to each other without relying on cranial base landmarks at all. However, the FOP Wits does not consider the rotational effects of the occlusal plane with growth and/or treatment. As with its cranial base predecessors, the Wits analysis can be profoundly affected by a change in inclination of its reference plane. Investigators have reported that either the FOP rotated in a random fashion with growth^{6,8} or it rotated in a counterclockwise direction with age.^{15,16} In the search for improvement, the bisected occlusal plane (BOP) has also been advocated as a reference plane in the Wits analysis.^{14,18} Defined by Downs¹⁷ as the plane bisecting the overlap of the distobuccal cusps of the permanent first molars and the incisor overlap, this reference plane was reported to be easier to locate and tended to rotate in the same direction as the jaws with growth.^{14,15,17}

A third reference plane, the maxillomandibular bisector (MMB), was proposed in 1994 by Hall-Scott.¹⁵ The MMB is located by bisecting the anterior angle formed by the intersection of the maxillary and mandibular planes. In contrast to the BOP or FOP, the MMB does not rely on the dentition and therefore eliminated many associated problems with

identification such as: missing teeth, unerupted or malpositioned teeth, mixed dentitions, deep curves of Spee, molar overlap or dental restorations. The MMB had the added advantage of not including cranial base landmarks, thereby eliminating those potential problems associated with them. In her study, Hall-Scott¹⁵ concluded that the MMB was a more reliable and reproducible reference plane for the Wits analysis than the FOP or BOP and that it was better correlated to the ANB as well. She reported that the inclination of the MMB followed the growth rotation of the jaws as they themselves provided the basis for the reference plane. Foley, Stirling and Hall-Scott¹⁹ followed up this study with a population of Class II Division I patients, comparing 36 treated and 15 control subjects using the Wits analysis with three different reference planes. The conclusions of this study were the same; the MMB was a more reliable and reproducible reference plane and was better correlated to the ANB than either the FOP or BOP.

The purpose of this investigation was to compare the reliability and validity of the Wits analysis using the FOP, BOP and MMB reference planes in both Class I and Class III samples. Effects of growth and/or treatment using the three Wits measurements were examined. The mean values of the MMB Wits for Class I and Class III populations were also documented.

METHODS AND MATERIALS

The subjects used in this study were classified, according to Angle, as having either a Class I or Class III occlusion. Records for control data were derived from the Burlington Orthodontic Research Centre. The treated data were obtained from the archives of the University of Western Ontario Graduate Orthodontic Clinic. Case numbers are listed in Appendices IV and V for the Class I subjects and Appendices VI and VII for the Class III subjects. Full records consisted of serial lateral cephalograms taken at approximately 12 years (T1), 14 years (T2) and 16 years (T3) of age. The ages of the controls corresponded to pretreatment (T1), posttreatment (T2) and postretention (T3) cephalograms of the treated group. Table Ia summarizes the ages of the control and treated groups and the interval lengths between time periods for the Class I cases. The same information for the Class III subjects can be located in Table Ib. Plaster dental casts in maximum intercuspation at T1 were also required for inclusion in this study.

The Class I sample consisted of 39 control subjects (19 male, 20 female) and 35 treated subjects (16 male, 19 female). All subjects fulfilled the following inclusion criteria:

1. A Class I molar relationship at T1 as determined by dental casts.
2. An ANB angle less than 4.5° at T1.
3. An overjet less than 5 mm at T1 .
4. A full permanent dentition (excluding 8's).

The treated group met the following additional requirements:

5. Nonextraction orthodontic treatment using full fixed appliances.
6. No extraoral appliances used.
7. Passive retention using a removable maxillary Hawley and either a fixed lower retainer or mandibular Hawley.

The Class III sample consisted of 9 control subjects (4 male, 5 female) and 10 treated subjects (5 male, 5 female). All subjects fulfilled the following inclusion criteria:

1. A Class III molar relationship at T1 as determined by dental casts.
2. An ANB less than 2° at T1.
3. A full permanent dentition (excluding 8's).

The treated group met the additional requirements:

4. Orthodontic treatment using full fixed appliances and nonextraction therapy.
5. Non-surgical treatment approach.
6. No extraoral appliances used.
7. Passive retention with a maxillary Hawley and either a lower fixed retainer or a removable mandibular Hawley.

Each lateral cephalogram was traced by the same investigator under suitably darkened conditions with a 0.05" lead pencil. The tracing is outlined in Figure 1 and the cephalometric landmarks, planes and angles utilized are listed and defined in Appendices I and II. Constructed points are listed in Appendix III. The six angular measurements were made

using a protractor* accurate to 0.5°. Three linear measurements were completed with a digital caliper** accurate to 0.01 mm.

Angular Measurements:

- ANB, MM
- anterosuperior angles of FOP, BOP, MMB and PP to PMV

Linear Measurements:

- FOP, BOP and MMB Wits analyses (Figure 2)

Error Study:

After three months, an error study was carried out using the same format described above on 20 Class I and 15 Class III films. A measure of reliability was then calculated for each sample according to the following formula:

Standard Deviation of Measurement Error (SE) =

$$\sqrt{\frac{\sum d^2}{2n}}$$

where d is the difference between the pairs and n is the number of pairs (Table II).

Statistical Analysis:

There were approximately equal numbers of males and females in both the control and

* Staedtler 568-52-15

** Mitutoyo 500-197, MII Corporation, Japan

treated groups in both the Class I and Class III groups. Statistical analysis included t-tests for sex differences within groups and between time periods for all variables.

The following statistical analyses were carried out for both the Class I and Class III samples. Unpaired t-tests ($p < .05$) were used to evaluate the differences in cephalometric measurements between the control and treated groups within each time period (Tables IV and IX). Paired t-tests ($p < .017$) were then used to test for differences in cephalometric measurements between the three intervals within the control and treated groups. The levels of significance were corrected ($n=3$) using the Bonferroni method for multiple comparisons (Tables V and X).

Pearson product-moment correlation coefficients were calculated to relate the three linear anteroposterior measurements to the OJ, ANB angle, MM angle and PP angle within each time period in both the control and treated groups. Correlation coefficients were also calculated to relate the changes in these measures between each of the time periods.

RESULTS

The standard error of double determination for the various cephalometric measures can be found in Table II. All of the errors, with the exception of the FOP-PMV angle or FOP Wits measurement, fell within acceptable limits. These errors ranged from 0.42° to 1.24° for angular measurements and 0.40 mm to 1.01 mm for linear measurements. The standard error for the FOP-PMV angle was 2.66° and 1.80° for the Class I and Class III groups respectively. The standard error for the MMB-PMV angle was less than 50% compared to the FOP-PMV angle in the Class I group at 1.10° and was approximately 30% in the Class III group at 0.68°. The standard errors for the Class I linear Wits measurements to the MMB and BOP were 0.97 mm and 1.01 mm respectively, approximately half of the standard error of the FOP Wits at 1.99 mm. Similarly, the Class III linear Wits measurements to the MMB and BOP were 0.42 and 0.40 mm respectively, one fifth of the standard error of the FOP Wits at 2.45 mm.

No statistical sex difference was detected within or between the Class I or III control and treated samples. The control and treated data were combined in each of the Class I and Class III samples.

Tables III and VIII outline the mean values and standard deviations for the various cephalometric measurements at T1, T2 and T3 in the Class I and III control and treated groups respectively. Table IV provides the differences between the Class I control and treated group values and their related t-test comparisons. The equivalent data for the Class III sample is outlined in Table IX.

There were no significant differences between the control and treated groups for the

ANB angle or the linear measurements made to either the BOP Wits or the MMB Wits in Class I (Table IV) and Class III (Table IX) subjects. The Class I FOP Wits was affected significantly between time periods with the linear measurement decreasing 1.94 mm ($p < .001$) in the treated group compared to the controls at T2 and 1.68 mm ($p < .01$) at T3. The mean MMB A-P value for this Class I population at T1 was -4.51 ± 1.81 mm for the control group and -4.69 ± 2.19 mm for the treated group. In the Class III group, the corresponding mean MMB Wits values were -8.61 ± 2.18 mm and -9.90 ± 2.88 mm respectively.

Tables V and X (Figures 4 and 5) show the differences in means of the measurements between the time periods and their related t-test comparisons in the Class I and III samples. The ANB angle showed a statistically significant change in both the Class I control and treated groups between T1 and T3, decreasing 0.52° ($p < .017$) and 0.63° ($p < .017$) respectively. Similarly, the MMB Wits showed a statistically significant decrease of 1.05 mm ($p < .0003$) and 1.21 mm ($p < .0003$) for the same control and treated groups which corresponded to the trend observed with the ANB. The BOP Wits value did not change significantly in either of these control or treated groups with growth and/or treatment. Conversely, the FOP Wits measurement of the Class I control group actually showed an increase of 0.73 mm from T1 to T3, with an increase of 0.45 mm occurring in the retention phase.

In the Class III sample (Table X), there was an observable increase in the ANB of the treated group, rising from -0.49° to 0.45° from T1 to T3 as compared to the decrease seen in the controls of nearly 0.70° . All 3 linear A-P measures corresponded to the increase in the treated ANB, with the BOP and FOP Wits significantly increased 1.64° and 2.49° ($p < .017$)

respectively. Similar to the control ANB, the MMB Wits measure decreased 1.22 mm while the FOP and BOP Wits measures remained unchanged.

The MM Bisector showed a significant clockwise rotation during growth of the Class I control and treated groups from T1 to T2, followed by a counterclockwise rotation from T2 to T3, resulting in no significant change at the end of T3 (Table V). In the Class I control and treated groups the BOP decreased 1.22° ($p<.0003$) and 0.85° in inclination respectively and the FOP was nearly twice that at 2.07° and 3.11° respectively from T1 to T3 ($p<.0003$). No statistically significant changes in the inclination of the 3 reference planes were documented in the Class III sample.

The correlations of the three Wits appraisals to the one dental measurement (OJ) and the three skeletal measurements (ANB, MM and PP) were generally low in both the Class I and Class III samples. The correlation values are found in Tables VI and VII for the Class I subjects and Tables XI and XII for the Class III subjects. Overall, the best correlation in both samples was demonstrated between the ANB and the three linear anteroposterior measurements. The highest values were consistently found to be the ANB/MMB Wits relationship, especially in the Class I control group at all three time periods ($r= 0.642, 0.738, 0.664$ at T1, T2 and T3 respectively). In Table VI, the ANB/MMB Wits correlation was slightly less than the ANB/FOP Wits in the treated group at T3. The ANB/BOP Wits showed the best correlation at all three time periods in the treated group, but only slightly higher than the MMB Wits at T1 and T2. Statistically significant correlation values between the three linear anteroposterior measurements and the OJ, MM angle and PP angle were few in number and scattered.

DISCUSSION

In determining variations in facial relationships Downs¹⁷ stated "... single readings are not so important, what counts is the manner in which they all fit together and their correlation with type, function and aesthetics." It is, therefore, important that the sum of these single values give the orthodontist an accurate representation of the patient's skeletal pattern at a given time.

The Wits analysis is an adjunct to the ANB angle and was not meant to be considered alone as a defining variable in cephalometric analysis. Jacobsen^{1, 3, 20} recommended using the FOP as a reference plane and cautioned that the ANB reading may be questionable if the mandibular plane angle was greater than one standard deviation from the mean. Many researchers^{7, 8, 16, 19, 21}, however, have reported large variation in the Wits values measured to the FOP. Rushton, Cohen and Linney⁸ commented that the FOP was a difficult plane to locate and caused large deviations of 1 mm or more in the Wits value. They questioned the usefulness of the FOP with such a broad standard deviation ($\pm 5^\circ$) in angulation. Rotberg *et al*²¹ studied Class I and Class II subjects using the FOP Wits. The Wits values varied from -4 mm to +9 mm. Ten of the subjects had Wits values of -0.5 mm to -4 mm with ANB measurements of 1° to 4° . These investigators concluded that if the ANB falls inside this "neutral range", then the positivity or negativity of the Wits value cannot be predicted with more than a 38% accuracy. Jarvinen⁷ studied 42 children with Class I malocclusions and found a mean FOP Wits value of -0.6 mm $\pm$ 2.9 mm which, he said, "...

indicated a considerable inter-individual variation.” Previous studies^{16,19} have shown that the cant of the FOP decreased with age which, in turn, distorted the Wits appraisal. Richardson²² reported a mean BOP Wits value of -0.32 mm (+/- 2.81 mm) in a sample of 25 young adults (7 female, 18 male) with normal occlusions. The range of the Wits measurements in that study was -4.75 mm to 4.25 mm. Oktay¹⁴ reported a mean BOP Wits of 0.445 (+/- 4.24 mm) in a cross-sectional sample of 145 subjects of varying age and skeletal relationships. Thayer¹⁸ looked at both the FOP and BOP Wits and reported mean values of 0.0 mm +/- 2.8 mm and 4.1 mm +/- 3.0 mm respectively.

Reducing the variation and error associated with obtaining the Wits measurement can improve its reliability and strengthen its supportive role in cephalometrics. Various proposals have been put forth to accomplish this: mathematical tables to “correct” the Wits value^{6,13}; geometric equations to account for skeletal variations^{6, 21}; or different reference planes to which A and B point perpendiculars can be projected.^{4, 5, 12, 14, 15, 19}

In the present study, the MM Bisector has shown the lowest measurement error compared to either the BOP or FOP (Table II) which is similar to Hall-Scott¹⁵ and Foley, Stirling and Hall-Scott.¹⁹ The method error involved in the construction of the three reference planes is far less using the MMB or BOP than the FOP. The FOP as measured was not eliminated as all other measurements were within acceptable limits and the large method error was an accurate reflection in this instance of the problems in identification associated with this reference plane.

The ANB angle has been accepted as the standard cephalometric measurement of the sagittal anteroposterior skeletal relationship of the maxilla to the mandible.² Oktay¹⁴

concluded that the ANB was not less reliable than any other cephalometric measurement as a sagittal AP parameter. The present study used the ANB to test the validity of the Wits appraisals using the FOP, BOP or MMB reference planes consistent with Foley, Stirling and Hall-Scott.¹⁹ The ANB angle decreased 0.52° and 0.70° from age 12 to 16 years in the Class I and III control groups respectively which agreed with findings from Foley, Stirling and Hall-Scott¹⁹ (0.53° decrease) and Bishara, Fahl and Peterson²³ (0.60° decrease). The treated Class III ANB, however, increased 0.94° and was likely a favourable response to treatment.

The inclination of the FOP and BOP measured to the PMV decreased on average with growth in the Class I control group, while, in agreement with Hall-Scott¹⁵, and Foley, Stirling and Hall-Scott¹⁹, the inclination of the MMB from T1 to T3 did not change significantly (Table V). A similar, though not statistically significant trend was seen in the Class III control and treated subjects (Table VIII). The inclination of the FOP was most dramatically affected in both Class I and III groups. The phenomenon of differential tooth eruption which causes the posterior part of the occlusal plane to drop and rotate the occlusal plane in a counterclockwise fashion has been described by Schudy²⁴ and Creekmore.²⁵ Hussels and Nanda⁶ reported that the rotation of the occlusal plane was unrelated to the palatal and mandibular planes. The flattening of the FOP and BOP with growth corresponded to the Class I Wits values made to these two planes. The BOP Wits increased slightly overall with growth while the FOP Wits increased with growth and/or treatment. When the occlusal plane rotates counterclockwise, one expects to see an increase in the linear Wits measurement (Figure 6). If B point is ahead of A point, as in the MMB Wits value (Figure 3), then an absolute increase in the linear distance between the 2 points will result in a more negative

number or a mathematical decrease in the Wits value. This value corresponded to a decrease in ANB or a “Class III” Wits. In the present study, the MMB Wits decreased 1 mm (became more negative) from T1 to T3 with growth. With the BOP and FOP Wits measurements, a counterclockwise rotation of the occlusal plane will also increase the linear distance between the 2 points but because A point is usually ahead of B point, this change yields a more “Class II” Wits value. This finding was supported by Sherman, Woods and Nanda¹⁶ who found that the traditional Wits value increased and suggested that the changes in B point and the FOP Wits appraisal cannot always be detected clinically due to growth of the chin. From T1 to T3 in both the Class I and Class III control and the treated groups, the inclination of the MMB plane did not change significantly. Alterations in the relationship of A point to B point can therefore be attributed to growth and/or treatment and not the effects of change in inclination of the reference plane.

Treated Class I patients chosen for this study had balanced skeletal patterns and were treated for what amounted to mostly dental malocclusions. The Class I subjects comprised an ideal longitudinal sample to evaluate the effects of orthodontic treatment on the Wits appraisal due to the lack of significant differences between ANB, BOP, FOP, or MMB Wits in the control and treated groups at T1. The pattern of change demonstrated by the ANB was supported by the MMB Wits and the BOP Wits. Neither one of these measurements differed significantly between the control and treated groups at T2 or T3 however, the FOP was altered at these time periods. The MMB Wits and, to a lesser extent, the BOP Wits, were a better representation of the sagittal skeletal relationship as related to ANB because they were not affected to a great degree by treatment that did not effect a skeletal change. If the

goal of treatment was to alter the skeletal relationship, as in the Class III population, then the Wits value should correspond to appropriate changes in the ANB. The change in the Class III MMB Wits measurements from T1 to T3 corresponded to both the control and treated ANB changes recorded, whereas the FOP and BOP Wits remained relatively unchanged in the control group.

Many researchers have examined the corollary relationship between the Wits analysis and the ANB angle with mixed results. Foley, Stirling and Hall-Scott ¹⁹ found a relatively high correlation between the ANB and MMB Wits (0.852 at T3 in controls, 0.631 in treated subjects). Hall-Scott ¹⁵ found a correlation of 0.95 in children and 0.83 in the adult group between the two variables. Richardson ²² determined that by controlling for the inclination of the BOP she could improve the ANB/Wits correlation from 0.67 to 0.80. This study found the MMB Wits correlated with the ANB in the Class I control group better at all time periods than either the FOP or BOP Wits (Table VI). The BOP Wits correlated best in the treated sample at all time periods but the MMB Wits was significant at T1 and T2. At T3, the BOP Wits had a 0.57 correlation with the ANB which was similar to findings reported by Richardson ²² ($r = 0.67$) and Jarvinen ¹³ ($r = 0.62$). One would expect high correlation values for the BOP in the Class I samples since incisor overlap was consistent and significant dental compensations were not present.

The overall correlations to ANB were varied and ranging from 0.261 to 0.738 in the Class I sample which was in agreement with Foley, Stirling and Hall-Scott. ¹⁹ The highest consistent correlations were recorded between the ANB and the MMB Wits in the Class III treated group between the 3 time periods while the correlation values for the BOP and FOP

Wits paralleled those of the Class I sample. No statistical relationship could be established between the OJ and the 3 A-P measures in the Class III sample. The findings pertaining to the correlations of MM angle or PP angle to the three Wits appraisals were of little value in either sample. The positive associations were sporadic and did not denote a strong relationship which was true both within and between the 3 time periods for the Class I and Class III groups.

The palatal plane angle was demonstrated to be a reliable component of the MM angle itself. The inclination of the PP remained stable throughout growth +/- treatment. Measured to the PMV, a mean of $83.71^{\circ} \pm 3.87^{\circ}$ was determined at T3 in the Class I control subjects. Nanda and Merrill ¹¹ reported a mean measurement of the same angle of approximately $80^{\circ} \pm 4^{\circ}$ in a sample of 445 adults with different malocclusions and concluded that the inclination of the PP is stable throughout growth. In the present study, the only significant finding was a difference in the inclination of the treated group PP angle at T1. By the end of treatment, and maintained through the end of retention, no significant difference in inclination could be found between the Class I and III control and treated subjects. Sato-Tsuji ²⁶ has published research relating to the USP projection that is similar to the MMB Wits except instead of the palatal plane, a maxillary plane PNS-P^o is used, where P^o is a constructed point. This point was determined by the intersection of the NA line with the anatomic structure located between the incisive foramen and ANS. The landmark was advocated to avoid using ANS. However, the palatal plane (ANS-PNS) has been suggested as an acceptable reference plane to determine the MM angle.

Hall-Scott's cross-sectional study ¹⁵ reported a mean MMB Wits value of

approximately -4 mm for children and -4.5 mm for adults with normal occlusion. Comparatively, this longitudinal study found a mean MMB Wits of approximately -4.5 mm for children (aged 12 years) and -5.5 mm for older adolescents (aged 16 years) with Class I malocclusions which did not coincide with a “normal” Wits value of 0 mm for females and -1 mm for males. In a Class I occlusion, B point was projected ahead of A point and as a result, a negative anteroposterior value in the sagittal relationship was “normal”. In the Class III sample, a mean MMB Wits of approximately -8.5 mm for children and -9.8 mm for older adolescents was established. The standard deviations for the Class I and Class III mean MMB Wits values were less than 50% and 30% of those mean values respectively, whereas the standard deviations for the mean BOP and FOP Wits values ranged from approximately 30% to greater than 100% of the mean values. The distribution of the mean MMB Wits values for all 3 Angle skeletal base classifications can be found in Figure 7. The MMB Wits resolved the Class II¹⁹, Class I and Class III populations into distinct and identifiable subgroups without significant overlap of standard deviations for easier classification.

CONCLUSIONS

The conclusions that can be drawn from this study of Class I and Class III subjects are:

1. The MM Bisector is more easily reproduced and shows less variation than either the BOP or FOP.
2. The inclination of the MM Bisector is stable with growth +/- treatment and shows no significant change compared to the BOP and FOP.
3. The validity of the MMB Wits is supported by the fact that it reflects growth and treatment changes described by the ANB angle. The stronger correlations detected between the ANB angle and the MM Bisector compared to the BOP or FOP Wits measures reinforces its validity.
4. The MM Bisector A-P measure provides a more reliable and valid indicator of the skeletal anteroposterior relationships of the jaws, especially during treatment, than the Wits appraisals made with either the FOP or BOP, and is a useful adjunct to the cephalometric assessment of a patient.
5. The mean MMB Wits values for Class I, Class II and Class III populations were distinct and displayed a triphasic distribution for easy classification.

Table I

**Ages at T1, T2, T3; and Interval Lengths Between Time Periods
for the Control and Treated Groups
(All Values in Months)**

a.) Class I

	Age at T1		Age at T2		Age at T3		Interval Length T1-T2	Interval Length T2-T3
	Mean	SD	Mean	SD	Mean	SD	Mean	Mean
Control	144.7	1.1	169.0	1.6	192.8	1.0	24.3	23.8
Treated	147.5	9.1	171.5	11.2	197.8	12.0	24.0	26.3

b.) Class III

	Age at T1		Age at T2		Age at T3		Interval Length T1-T2	Interval Length T2-T3
	Mean	SD	Mean	SD	Mean	SD	Mean	Mean
Control	134.3	16.4	163.7	15.5	193.9	22.0	29.4	30.2
Treated	144.3	17.5	164.6	17.8	193.9	19.1	20.3	29.3

Table II

**Standard Deviations of Measurement Errors for Class I and Class III
Double Measures**

Standard Deviation of Measurement Error (SE) =

$$\sqrt{\frac{\sum d^2}{2n}}$$

Class I , n = 20; Class III, n = 15

Measure	Class I SE	Class III SE
ANB Angle	0.45°	0.42°
MM Angle	1.01°	0.68°
PP Angle	1.24°	1.17°
BOP Wits	1.01 mm	0.40 mm
FOP Wits	1.99 mm	2.45 mm
MMB Wits	0.97 mm	0.42 mm
BOP-PM Vert ANGLE	1.18°	1.05°
FOP-PM Vert ANGLE	2.66°	1.80°
MMB- PM Vert ANGLE	1.10°	0.68°

Table III
Means and Standard Deviations at Each Time Period In the
Class I Control and Treated Groups

	Control						Treated					
	T1		T2		T3		T1		T2		T3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ANB°	2.54	1.17	2.13	1.47	2.02	1.52	2.16	1.31	1.84	1.19	1.53	1.35
OJ mm	2.83	1.03	2.60	0.69	2.35	0.90	3.08	1.90	2.06	0.65	2.05	0.85
MM°	27.36	4.17	26.42	4.15	26.31	4.61	28.53	4.91	28.32	5.22	27.87	4.96
PP°	82.35	3.76	83.83	3.94	83.71	3.87	84.14	3.38	84.65	3.57	84.56	3.62
BOP-PM Vert°	92.44	3.68	92.20	3.79	91.22	3.50	93.82	4.24	94.11	3.76	92.96	3.69
FOP-PM Vert°	93.95	4.60	93.50	4.09	91.88	4.24	94.66	4.43	92.46	4.43	91.56	4.08
MMB-PM Vert°	96.13	3.34	97.02	3.35	96.57	3.59	98.43	3.46	99.05	3.31	98.66	3.64
BOP WITS mm	-2.08	1.48	-1.68	2.13	-1.61	2.30	-1.61	2.61	-2.16	2.04	-1.77	2.13
FOP WITS mm	-3.13	2.23	-2.85	2.54	-2.40	2.81	-2.02	3.58	-0.92	2.33	-0.72	2.60
MMB WITS mm	-4.51	1.81	-5.04	2.27	-5.56	2.50	-4.69	2.19	-5.46	1.80	-5.90	1.91

Table IV
Differences Between Class I Control and Treated Groups
and Their t-Values in Each Time Period

	T1		T2		T3	
	Difference	t	Difference	t	Difference	t
ANB°	0.38	1.32	0.29	0.93	0.48	1.46
OJ mm	-0.24	-0.70	0.54	3.47~	0.30	1.47
MM°	-1.17	-1.12	-1.90	-1.75	-1.56	-1.41
PP°	-1.78	-2.15*	-0.82	-0.94	-0.85	-0.98
BOP-PM Vert°	-1.38	-1.51	-1.91	-2.19*	-1.75	-2.10*
FOP-PM Vert°	-0.71	-0.68	1.04	1.06	0.32	0.34
MMB-PM Vert°	-2.30	-2.93^	-2.03	-2.63^	-2.09	-2.51*
BOP WITS mm	-0.47	-0.98	0.48	1.00	0.15	0.30
FOP WITS mm	-1.11	-1.63	-1.94	-3.43~	-1.68	-2.69^
MMB WITS mm	0.18	0.39	0.42	0.89	0.34	0.66

* p < .05
^ p < .01
~ p < .001

Table V
Mean Changes and Paired t Values Between Each Time Period
In the Class I Control and Treated Groups

	Control						Treated					
	T1 - T2		T2 - T3		T1 - T3		T1 - T2		T2 - T3		T1 - T3	
	Diff.	t	Diff.	t	Diff.	t	Diff.	t	Diff.	t	Diff.	t
ANB°	0.40	2.77*	0.12	0.82	0.52	2.82*	0.31	2.01	0.31	2.30	0.63	3.05*
OJmm	0.23	2.01	0.25	2.14	0.48	3.91~	1.01	3.30^	1.39	0.11	1.03	3.60^
MM°	0.94	3.67^	0.11	0.40	1.05	3.17^	0.22	0.75	0.45	1.89	0.67	1.71
PP°	-1.48	-5.22~	0.12	0.44	-1.36	-3.63^	-0.51	-1.87	0.09	0.44	-0.43	-1.40
BOP-PM Vert°	0.24	0.71	0.98	3.44^	1.22	3.98~	-0.29	-0.71	1.14	4.09~	0.85	2.23
FOP-PM Vert°	0.45	0.80	1.61	3.92~	2.07	4.59~	2.21	4.68~	0.90	2.11	3.11	5.50~
MMB-PM Vert°	-0.89	-3.51^	0.45	1.39	0.44	-1.24	-0.62	-2.37	0.39	2.36	-0.23	-0.83
BOP WITSmm	-0.40	-1.59	-0.69	-0.27	-0.47	-1.67	0.56	1.77	-0.40	-2.08	0.16	0.42
FOP WITSmm	-0.28	-0.73	-0.45	-1.25	-0.73	-1.54	-1.10	-2.24	-0.20	-0.59	-1.30	-2.38
MMB WITSmm	0.53	2.52*	0.52	2.62*	1.05	3.81~	0.77	3.57^	0.44	2.39	1.21	4.72~

* $p < .017$
^ $p < .003$
~ $p < .0003$

Table VI
Correlation Coefficients Within the Time Periods for the
Class I Control and Treated Groups

	Control			Treated		
	T1	T2	T3	T1	T2	T3
ANB-BOP WITS	0.552^	0.699^	0.570^	0.597^	0.441^	0.568
ANB-FOP WITS	0.261	0.544^	0.601^	0.486^	0.292	0.448^
ANB-MMB WITS	0.642^	0.738^	0.664^	0.551^	0.335^	0.274
OJ-BOP WITS	0.299	0.356*	0.347*	0.458^	0.062	0.380*
OJ-FOP WITS	-0.116	0.293	0.176	0.337*	-0.337*	0.178
OJ-MMB WITS	0.192	0.332*	0.368*	0.353*	0.158	0.264
MM-BOP WITS	-0.051	-0.169	-0.205	-0.388*	-0.411*	-0.352*
MM-FOP WITS	-0.690	-0.303	-0.235	-0.244	-0.345*	-0.128
MM-MMB WITS	-0.123	-0.261	-0.306	-0.281	-0.303	-0.267
PP-BOP WITS	-0.091	0.045	0.050	0.149	0.066	0.092
PP-FOP WITS	-0.102	0.228	0.264	0.272	-0.005	0.002
PP-MMB WITS	-0.058	0.092	0.072	0.028	-0.191	-0.264

* p < .05
^ p < .01
~ p < .001

Table VII
Correlation Coefficients Between the Time Periods for
the Class I Control and Treated Groups

	Control			Treated		
	T1 - T2	T2 - T3	T1 - T3	T1 - T2	T2 - T3	T1 - T3
ANB- BOP WITS	0.532^	0.592^	0.718^	0.343*	0.424*	0.610^
ANB-FOP WITS	0.219	0.293	0.360*	0.482^	0.222	0.456^
ANB-MMB WITS	0.687^	0.537^	0.666^	0.675^	0.674^	0.691^
OJ-BOP WITS	0.546^	0.424^	0.224	0.586^	0.199	0.644^
OJ-FOP WITS	0.077	0.266	-0.225	0.372*	0.113	0.486^
OJ-MMB WITS	0.576^	0.532^	0.499^	0.319	-0.052	0.625^
MM-BOP WITS	-0.106	-0.134	-0.131	0.037	-0.033	-0.152
MM-FOP WITS	0.001	-0.099	-0.033	0.042	0.161	0.018
MM-MMB WITS	-0.056	-0.099	0.087	0.105	0.122	0.017
PP-BOP WITS	0.153	0.046	0.367*	0.137	-0.095	0.241
PP-FOP WITS	0.198	0.302	0.405*	0.405*	-0.151	0.284
PP-MMB WITS	0.123	-0.121	-0.025	0.119	-0.290	-0.016

*p < .05

^p < .01

~p < .001

Table VIII
Means and Standard Deviations at Each Time Period In the
Class III Control and Treated Groups

	Control						Treated					
	T1		T2		T3		T1		T2		T3	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
ANB°	0.91	1.57	1.04	1.80	0.20	1.22	-0.49	1.54	0.44	1.76	0.45	1.84
OJ mm	1.62	0.98	1.56	0.92	1.85	1.27	-0.19	2.71	1.37	1.19	0.90	0.92
MM°	28.57	4.62	28.91	4.93	26.73	4.22	29.68	5.85	31.24	6.27	31.09	6.32
PP°	83.66	4.87	85.12	4.23	85.05	3.18	84.95	4.32	84.56	4.27	84.98	4.02
BOP-PM Vert°	93.33	5.71	94.42	5.53	92.50	4.42	94.90	5.18	94.47	4.87	93.75	5.04
FOP-PM Vert°	92.84	3.23	93.26	4.60	91.46	3.49	98.39	6.82	96.41	5.53	95.85	4.05
MMB-PM Vert°	97.67	4.70	99.38	5.04	98.56	3.90	99.76	4.99	100.24	4.76	100.28	4.52
BOP WITS mm	-5.69	1.81	-6.21	2.20	-5.64	1.35	-6.69	2.64	-5.40	1.29	-5.05	2.03
FOP WITS mm	-5.15	1.81	-5.38	2.90	-4.96	2.88	-9.02	3.04	-6.85	1.73	-6.53	1.73
MMB WITS mm	-8.61	2.18	-9.56	1.96	-9.83	2.29	-9.90	2.88	-9.62	2.03	-9.69	2.08

Table IX
Differences Between Class III Control and Treated Groups
and Their t-Values in Each Time Period

	T1		T2		T3	
	Difference	t	Difference	t	Difference	t
ANB°	1.40	1.97	0.60	0.74	-0.25	-0.33
OJ mm	1.81	1.89	0.19	0.38	0.95	1.85
MM°	-1.11	-0.46	-2.33	-0.89	-4.37	-1.67
PP°	-1.29	-0.61	0.56	0.29	0.07	0.04*
BOP-PM Vert°	-1.57	-0.63	-0.05	-0.02*	-1.25	-0.56
FOP-PM Vert°	-5.55	-2.22	-3.15	-1.34	-4.39	-2.42
MMB-PM Vert°	-2.09	-0.94	-0.86	-0.38	-1.71	-0.84
BOP WITS mm	0.99	0.95	-0.81	-0.99	-0.59	-0.71
FOP WITS mm	3.87	3.33	1.47	1.36	1.57	1.43
MMB WITS mm	1.28	1.09	0.06	0.06	-0.14	-0.14

* p < .05
^ p < .01
~ p < .001

Table X
Mean Changes and Paired t Values Between Each Time Period
In the Class III Control and Treated Groups

	Control						Treated					
	T1 - T2 Diff. t		T2 - T3 Diff. t		T1 - T3 Diff. t		T1 - T2 Diff. t		T2 - T3 Diff. t		T1 - T3 Diff. t	
ANB°	-0.13	-0.42	0.84	1.31	0.71	1.06	-0.93	-1.93	-0.01	-0.03	-0.94	-2.31
OJmm	0.07	0.26	-0.29	-0.53	-0.23	-0.49	-1.56	-1.85	0.47	1.16	-1.09	-1.37
MM°	-0.34	-0.70	2.18	1.96	1.84	1.01	-1.56	-2.74	0.15	0.30	-1.41	-1.92
PP°	-1.47	-1.75	0.07	0.27	-1.39	-0.61	0.39	0.88	-0.42	-1.06	-0.03	-0.05
BOP-PM Vert°	-1.09	-0.93	1.92	1.03	0.83	0.78	0.43	1.11	0.72	1.67	1.15	2.14
FOP-PM Vert°	-0.41	-0.26	1.80	0.48	1.38	1.16	1.98	1.70	0.56	0.66	2.54	1.66
MMB-PM Vert°	-1.71	-2.45	-0.89	0.39	-0.89	-0.99	-0.48	-1.16	-0.04	-0.11	-0.52	-0.93
BOP WITSmm	0.52	0.91	-0.57	-0.47	-0.05	0.02	-1.29	-1.86	-0.35	-0.66	-1.64	-3.20*
FOP WITSmm	0.24	0.22	-0.42	0.40	-0.19	-0.06	-2.17	-2.96	-0.33	-0.44	-2.49	-2.33*
MMB WITSmm	0.95	2.01	0.27	0.95	1.22	2.33	-0.28	-0.53	0.07	0.13	-0.21	-0.41

* p < .017
^ p < .003
~ p < .0003

Table XI
Correlation Coefficients Within the Time Periods for the
Class III Control and Treated Groups

	Control			Treated		
	T1	T2	T3	T1	T2	T3
ANB-BOP WITS	0.133	-0.110	0.407	0.229	-0.205	0.190
ANB-FOP WITS	0.297	-0.472	0.330	-0.359	-0.588	0.565
ANB-MMB WITS	-0.085	-0.224	0.434	0.115	-0.347	0.077
OJ-BOP WITS	0.404	0.862^	0.849^	0.574	0.333	0.245
OJ-FOP WITS	-0.094	0.561	0.398	0.346	0.392	-0.231
OJ-MMB WITS	0.525	0.760*	0.810*	0.711*	0.049	0.245
MM-BOP WITS	-0.593	-0.756*	-0.124	-0.360	-0.407	-0.425
MM-FOP WITS	-0.162	-0.454	0.378	-0.516	-0.177	-0.066
MM-MMB WITS	-0.575	-0.783*	0.045	-0.471	-0.545	-0.532
PP-BOP WITS	-0.352	-0.484	-0.441	-0.528	-0.356	-0.359
PP-FOP WITS	0.593	0.372	0.010	-0.383	-0.331	-0.109
PP-MMB WITS	-0.134	-0.390	-0.288	-0.452	-0.258	-0.215

* p < .05

^ p < .01

~ p < .001

Table XII
Correlation Coefficients Between the Time Periods for
the Class III Control and Treated Groups

	Control			Treated		
	T1 - T2	T2 - T3	T1 - T3	T1 - T2	T2 - T3	T1 - T3
ANB- BOP WITS	0.321	0.368	0.633	0.835^	0.879^	0.754*
ANB-FOP WITS	0.353	0.641	0.827*	0.125	0.466	0.368
ANB-MMB WITS	0.401	0.809*	0.785*	0.973^	0.849^	0.819^
OJ-BOP WITS	0.447	-0.166	0.603	0.644*	-0.288	0.300
OJ-FOP WITS	0.399	0.328	0.703	0.042	-0.476	-0.168
OJ-MMB WITS	0.358	0.654	0.641	0.753*	-0.483	0.476
MM-BOP WITS	-0.149	0.448	0.330	-0.113	0.819^	0.205
MM-FOP WITS	0.423	0.502	0.197	-0.078	0.455	0.530
MM-MMB WITS	0.160	0.941^	0.452	0.090	0.898^	0.332
PP-BOP WITS	-0.191	-0.576	-0.192	0.459	-0.786^	0.112
PP-FOP WITS	-0.305	0.295	0.126	-0.068	-0.118	-0.362
PP-MMB WITS	-0.063	-0.071	-0.250	0.203	-0.869^	-0.105

* p < .05
^ p < .01
~ p < .001

Figure 1

Cephalometric Landmarks, Planes and Angles Utilized

Angles:

- ① MM
- ② FOP to PMV
- ③ BOP to PMV
- ④ MMB to PMV
- ⑤ PP to PMV
- ⑥ ANB

MM Bisector A-P Measure

A3 = intersection of perpendicular projected from A Point with MM Bisector

B3 = intersection of perpendicular projected from B Point with MM Bisector

The linear distance between **A3** and **B3** is measured to within 0.01 mm.

B3 anterior to **A3** has a negative value.

B3 posterior to **A3** has a positive value.

Figure 3

**T2 Comparisons of the Mean Anteroposterior Measurements Between
the Class I Control and Treated Groups**

Figure 4
Comparisons of the Mean Anteroposterior Measurements at Each Time Period
in the Class I Control and Treated Groups

CONTROL GROUP

TREATED GROUP

Figure 5

**Comparisons of the Mean Anteroposterior Measurements at Each Time Period
In the Class I and Class III Control Groups**

CLASS I CONTROLS

CLASS III CONTROLS

Figure 6
Effect of Change In Cant of the Reference Plane
on the Wits Value

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As the reference plane is canted counterclockwise, the linear distance between projected points A1 and B1 is increased. The positions of points A and B have not changed, however, the cant of the occlusal plane indicates a more positive Class II Wits value.

Figure 7
Distribution of Class I, II and III MMB Wits Values

*data derived from Foley, Stirling and Hall-Scott¹⁹

APPENDIX I
Definitions of Cephalometric Landmarks

Landmark	Code	Definition
Sella Turcica	S	The centre of the pituitary fossa of the sphenoid bone. Determined by inspection.
Nasion	N	The junction of the frontonasal suture at the most posterior point of the curve at the bridge of the nose.
Sphenoethmoidal	SE	The junction of the sphenoethmoidal suture with the anterior skull base.
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	A	The most posterior point on the concave outline of the maxilla labial to the upper incisors.
B Point	B	The most posterior point on the concave outline of the mandibular symphysis labial to the lower incisors.
Pterygomaxillary Fissure	PTM	A bilateral, upside-down, teardrop-shaped radiolucent area, the anterior surfaces of which represent the posterior surfaces of the maxilla. The point itself is taken at the most anterior and inferior confluence of the curvatures.
Menton	Me	The lowest point on the outline of the bony chin.
Gonion	Go	The lowest most posterior point at the angle of the mandible.

APPENDIX II

Definitions of Planes and Angles

Planes	Code	Definition
Sella-Nasion	SN	A line joining Nasion and Sella-turcica.
Maxillary/Palatal	MxP/PP	A line joining ANS to PNS.
Mandibular	MdP	A line joining Me to Go.
PM Vertical	PMV	A line joining SE to PTM.
Functional Occlusal	FOP	A line bisecting the molar and premolar overbite, excluding the incisors
Bisected Occlusal	BOP	A line bisecting the overlap of the distobuccal cusps of the first permanent molars and incisor overlap.
Maxillomandibular Bisector	MMB	The bisector of the maxillomandibular angle.
Angles	Code	Definition
ANB	ANB	Angle formed by the points A, Nasion and B.
Maxillomandibular	MM	Angle formed by the intersection of the Maxillary and Mandibular planes.
PP	PP	Anterosuperior angle formed by the intersection of the PP and PMV.
FOP	FOP	Anterosuperior angle formed by the intersection of the FOP and PMV.
BOP	BOP	Anterosuperior angle formed by the intersection of the BOP and PMV.
MMB	MMB	Anterosuperior angle formed by the intersection of the MMB and PMV.

APPENDIX III

Constructed Points

- A1** A point projected in perpendicular fashion onto the FOP
- B1** B point projected in perpendicular fashion onto the FOP
- A2** A point projected in perpendicular fashion onto the BOP
- B2** B point projected in perpendicular fashion onto the BOP
- A3** A point projected in perpendicular fashion onto the MMB
- B3** B point projected in perpendicular fashion onto the MMB

A Wits assessment using each of the three 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 the MMB.

Using this reference plane, the distance between **A3** and **B3** is measured.

B anterior to A in the sagittal plane has a negative value; B posterior to A has a positive value.

APPENDIX IV
Class I Control Subjects Utilized
Burlington Orthodontic Research Centre
I.D. Numbers

<u>Number</u>	<u>Sex</u>	<u>Number</u>	<u>Sex</u>
135	M	334	F
875	M	368	F
858	M	861	F
296	M	336	F
1013	M	108	F
871	M	159	F
106	M	114	F
490	M	537	F
544	M	60	F
196	M	469	F
1321	M	613	F
1110	M	487	F
1320	M	713	F
563	M	312	F
120	M	1039	F
157	M	1360	F
786	M	1173	F
831	M	1361	F
1367	M	674	F
		1310	F

APPENDIX V
Class I Treated Subjects Utilized

Graduate Orthodontic Clinic, University of Western Ontario
I.D. Numbers

<u>Number</u>	<u>Sex</u>	<u>Number</u>	<u>Sex</u>
442	M	554	F
1037	M	593	F
1205	M	1023	F
1358	M	1035	F
1547	M	1359	F
1563	M	1360	F
1564	M	1594	F
1600	M	1724	F
1641	M	1748	F
1661	M	1778	F
1701	M	1809	F
1939	M	1873	F
1889	M	1874	F
1956	M	1876	F
1893	M	1681	F
1823	M	1835	F
		1963	F
		1964	F
		1965	F

APPENDIX VI
Class III Control Subjects Utilized

Burlington Orthodontic Research Centre
I.D. Numbers

<u>Number</u>	<u>Sex</u>
75	M
361	M
830	M
1126	M
317	F
948	F
1199	F
1018	F
918	F

APPENDIX VII
Class III Treated Subjects Utilized

Graduate Orthodontic Clinic, University of Western Ontario
I.D. Numbers

<u>Number</u>	<u>Sex</u>
364	M
953	M
992	M
1106	M
1575	M
426	F
439	F
669	F
1020	F
1975	F

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