# Reliability of three reference planes in the assessment of open bite and deep bite subjects.

By

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## Dedication

I dedicate this thesis to my parents, sister, brother and friends. Your love has provided me with the most wonderful life and I thank you for giving me this world.

## ABSTRACT

**Objectives:** A precise sagittal measurement of jaw relationships is crucial in orthodontic diagnosis and treatment planning. The purpose of this retrospective study was to evaluate the reliability and accuracy of three anteroposterior reference planes applied in the Wits analysis.

**Materials and methods:** A retrospective chart review was undertaken on 150 subjects. Subjects were categorized into 3 groups based on the value of pre-treatment overbite; 50 normal (1-3 mm), 50 deep (more than 3mm) and 50 open bite (less than 1 mm) subjects. The maxillomandibular bisector (MMB) was used to evaluate the anteroposterior jaw discrepancy and was compared to the Wits analysis using either the bisecting occlusal plane (BOP) or the functional occlusal plane (FOP) and the ANB angular measurement. Gender as a predictor was also analyzed for the different Wits models. Control subjects with normal overbite were compared to subjects with increased or decreased overbite. In total, 75 male and 75 female were included in the sample.

**Results:** The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to each other were moderate to high ranging from 0.56 to 0.89. The strongest correlations were found between BOP Wits and MMB Wits in the open bite group (r=0.89). Moreover, the correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to the ANB angle were low to moderate ranging from 0.39 to 0.76. The strongest correlation was found between MMB Wits and ANB angle in the open bite group (r=0.74).

**Conclusions**: The Wits appraisal using the MM bisector is a valid indicator of the sagittal discrepancy. The MMB Wits had a higher correlation coefficient to the ANB angle than the FOP Wits, further reinforcing its validity. Caution must be exercised in trying to relate any of Wits appraisal to the gold standard of the ANB angle.



**Key Words:** Wits Appraisal, Maxillomandibular bisector, Anteroposterior Skeletal Discrepancy, Bisected/Functional Occlusal Plane

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# CHAPTER 1

## INTRODUCTION

### 1.1 PREAMBLE

Over the last 50 years, numerous cephalometric measurements have been suggested to assess sagittal jaw discrepancy, and researchers have shown that intrinsic geometric factors influence the validity of the measurements (Taylor 1969, Beatty 1975, Jacobson 1975, Ferrazzini 1976, Jacobson 1976, Freeman 1981, Roth 1982, Hussels and Nanda 1984, Williams, Leighton et al. 1985, Jarvinen 1986, Chang 1987, Jarvinen 1988, Sherman, Woods et al. 1988). The combination utilization of multiple measurements has been advocated for the evaluation of the anteroposterior jaw relationship in individual subjects (Bishara, Fahl et al. 1983, Jacobson 1988, Sherman, Woods et al. 1988). However, no universal consensus for selection of the measurements have been agreed upon.

Assessment of the anteroposterior jaw relationship is a primary component of the evaluation of an orthodontic patient and the establishment of a treatment plan. Hence, various linear and angular parameters have been added into cephalometric analyses, with the purpose of simplifying the diagnosis of sagittal discrepancies. The most commonly used of these analyses have been the Wits appraisal and the ANB angle (Bishara, Fahl et al. 1983, Oktay 1991, Baik and Ververidou 2004, Del Santo 2006).

Wits appraisal has received a mixed response from the orthodontic fraternity ever since it's popularization by Jacobson in 1975 and has been a subject of debate among experts in cephalometrics. Some studies reported good correlation between Wits and ANB angle and therefore considered the Wits analysis as a good estimate of sagittal jaw relationship (Jarvinen 1988, Thayer 1990). However, others reported a weak correlation and found errors in predicting one from the other (Sherman, Woods et al. 1988, Nanda and Merrill 1994, Nanda 2004).

Jacobsen (Jacobson 1976, Jacobson 2003) advocated the utilization of the FOP as a reference line and warned that the ANB angle measure may be arguable if the mandibular plane angle is greater than one standard deviation from the mean. Many authors (Rotberg, Fried et al.

1980, Jarvinen 1981, Rushton, Cohen et al. 1991) however, have found great variations in the Wits measurement calculated to the FOP. Rushton et al (Rushton, Cohen et al. 1991) suggested that the FOP was a challenging line to trace and led to great variations of 1 mm or more in the Wits measure. Nanda et al reported that mild changes in the occlusal plane's cant can cause major variations in Wits analysis (Nanda and Merrill 1994). The Wits analysis has been created to provide the clinicians with a parameter that relates both dental bases, bypassing the problem with cranial base inaccuracy.

Reducing the inaccuracies associated with measuring the Wits parameter can enhance its validity and reinforced its supportive role in the assessment of sagittal jaw relationship. Numerous analyses have been created trying to "correct" the Wits measure with mathematical tables (Hussels and Nanda 1984, Jarvinen 1988), geometric equations to account for skeletal changes (Rotberg, Fried et al. 1980) or new reference lines to which A and B point perpendiculars can be drawn (Freeman 1981, Oktay 1991, Hall-Scott 1994, Foley, Stirling et al. 1997). A new reference line, the maxillomandibular bisector (MMB), has demonstrated that its technique error implied in its construction is far lower compared to the bisecting occlusal plane (BOP) and the functional occlusal plane (FOP) (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001).

Because ANB angle and the Wits appraisal evaluate the same sagittal jaw discrepancy, they should report a good correlation. In fact, the agreement between them is not as accurate as expected; which implies weakness in at least one parameter (Del Santo 2006). Therefore, a need still remains for a sagittal jaw analysis to be created based on the dental bases, but that does not rely on teeth. This analysis should be based on a reference plane for which the inclination does not vary too much with growth or treatment, and is not highly influenced by its cant.

## 1.2 Purpose

The purpose of this investigation was to compare the reliability and validity of the Wits analysis using three different occlusal planes, the FOP, BOP and MMB, and to differentiate between patients exhibiting an increased, normal or reduced overbite. In addition, the correlation between the Wits and ANB values will be analysed in the three situations.

## 1.3 Null hypotheses

The null hypotheses for this study state that:

1. There is no statistically significant difference between the 3 sagittal reference planes (FOP, BOP, MMB) in the Wits value.

2. There is no statistically significant difference between the Wits correlation value when comparing 3 different occlusal planes (FOP, BOP, MMB).

3. There is no statistically significant difference between the Wits and ANB's correlation value when comparing 3 different sagittal occlusal planes (FOP, BOP, MMB).

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION OF CEPHALOMETRY

Hofrath and Broadbent were the first to introduce radiographic cephalometry in orthodontics in 1931 (Damstra, Fourie et al. 2010). Their cephalograms were taken from the lateral side of the patient's head (Leonardi, Annunziata et al. 2008). Nowadays, this method is still employed when taking cephalometric radiographs. Later on, a standardized position was advocated which is defined by the patient's midsagittal plane at a distance of fifteen centimeters from the radiograph and sixty inches (152.4 cm) from the x-ray source. This technique, recommended by the American standard creates similar craniofacial representations on cephalograms (Cohen 2005).

Lateral cephalometric analysis is a valuable assessment tool to diagnose, treatment plan and assess treatment results in orthodontics (Proffit 2013). Traditionally, these analyses have been achieved by way of hand-tracing. Clinically, the sagittal jaw discrepancy is quantitatively determined by the employment of the lateral cephalogram. Analyses have been established to compare each patient to established norms. These data aid to categorize patients based on their soft tissue profile; their skeletal pattern and also their dental pattern. These classifications can then help in deciding on an individualized and appropriate treatment for every patient (Singh and Davies 2011).

The introduction of cephalometry in orthodontics allowed clinicians and researchers to evaluate craniofacial characteristics. The first cephalometric analysis created to assess the dentoskeletal profile was suggested by Downs (Downs 1956). Downs motivated many others to develop cephalometric analyses to assess craniofacial characteristics and help in orthodontic diagnosis and treatment planning. Many soft tissue (Lundström and Lundström 1995, Fushima, Kitamura et al. 1996, Ogawa, Koyano et al. 1996, Ishikawa, Nakamura et al. 1999, Sato, Motoyoshi et al. 2007, Tanaka and Sato 2008), hard tissue (Downs 1956, Steiner 1960), and cephalometric analyses (Holdaway 1983, Arnett and Bergman 1993, Arnett and Bergman 1993, Bergman 1999) attempted to measure the ideal craniofacial characteristics.

Downs in 1956 demonstrated that the Frankfort horizontal plane is considerably variable (+9º to -7º) when he compared it to the natural head position. Lundström et al. have demonstrated that the Frankfort plane as well as the sella-nasion plane show inconsistency as calculated to the sagittal plane in natural head posture and natural head position (Lundström and Lundström 1995). For this reason, natural head position is recommended in cephalometry considering the drawbacks of the intracranial reference planes.

NHP is reproducible, which makes it a great reference plane in cephalometry. Lundström et al assessed the reproducibility of NHP by looking at pre-treatment cephalometric films and lateral photographs (Lundström and Lundström 1992). They evaluated the following internal reference planes: porion-orbitale, basion-nasion and sella-nasion. They concluded that the natural head position is appropriate to determine true horizontal and vertical reference lines (Lundström and Lundström 1992). Their conclusion has been validated by numerous studies showing long-term reproducibility of NHP (Cooke 1990, Peng and Cooke 1999). Thus, NHP is significantly more consistent than that of internal reference planes (Peng and Cooke 1999).

## 2.2 ANB ANGLE AND ITS LIMITATIONS

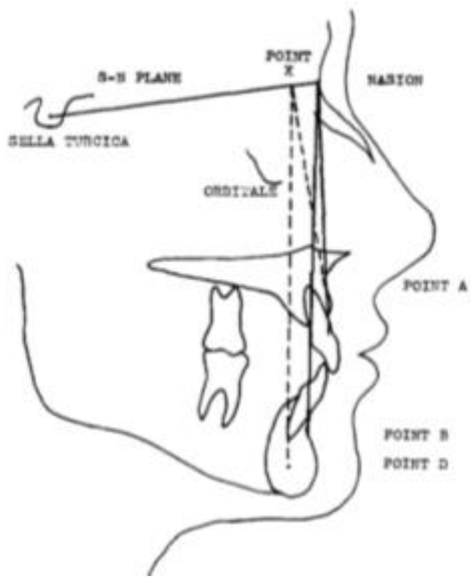
ANB angle was first introduced by Riedel in 1952 (Riedel 1952). It is defined as the difference between SNA and SNB angles, to demonstrate the anteroposterior skeletal relationships. The ANB angle is influenced by the rotations and changes of the anteroposterior and vertical jaw dimensions relative to the cranial base (Holdaway 1956, Ferrazzini 1976, Luder 1978). Therefore, numerous clinicians have been criticizing the validity of the ANB angle as an assessment tool of anteroposterior skeletal discrepancy (Holdaway 1956, Ferrazzini 1976, Luder 1978). Nevertheless, ANB continues to be popular and widely considered as a diagnostic tool.

In the literature, it has been demonstrated that numerous factors influence the ANB value (Taylor 1969, Jacobson 1975, Hussels and Nanda 1984, Jacobson 1988, Jarvinen 1988, Oktay 1991, Hurmerinta, Rahkamo et al. 1997). These factors include: extension and angulation of the anterior cranial base (Jacobson 1975, Ferrazzini 1976, Jacobson 1976), vertical and sagittal positions of nasion, the degree of facial prognathism, direction of the rotation of the maxilla and mandible by either growth or orthodontic treatment and patient age (Nanda 1971, Binder 1979). Moreover, as SNA and SNB become larger and jaws more protrusive, even if their sagittal skeletal relationship stays unchanged, the ANB angle will be increased (Oktay 1991, Proffit 2013).

### 2.3 ANALYSES CREATED TO OVERCOME THE DRAWBACKS OF ANB

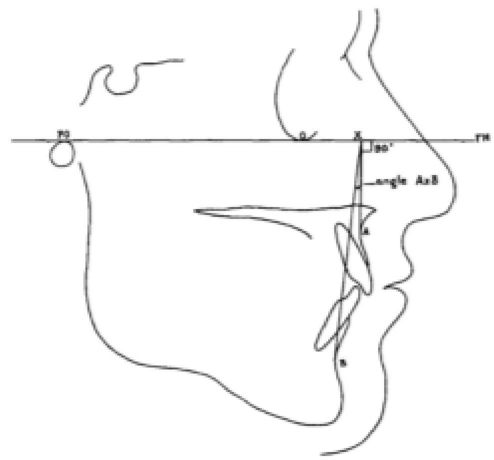
Many authors have created new analysis to overcome the limitations of the ANB angle by changing the cranial base landmarks employed in their cephalometric analyses. Several new reference planes, linear distances and angles have been proposed.

Beatty in 1975 suggested the use of the AXD angle and the linear measurement of the distance between points A and D drawn perpendicular to the SN plane (Beatty 1975). He reported better correlation of angular and linear measurements with this method than was found between the Wits analysis and ANB.



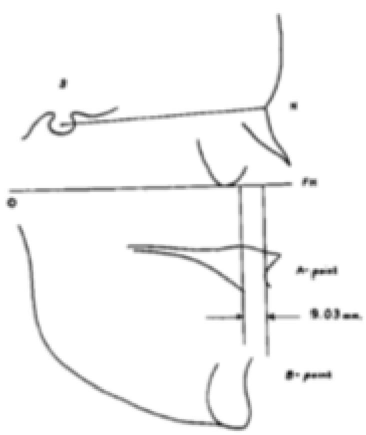

(Beatty 1975)

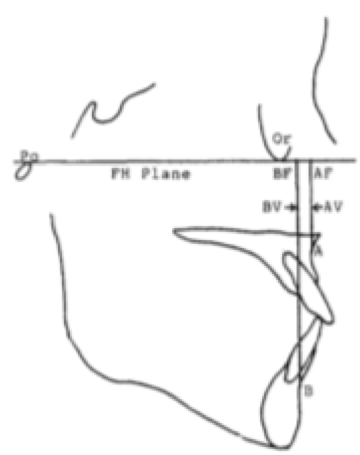
Freeman proposed the AXB angle and related A point to the Frankfort horizontal (Freeman 1981).




(Freeman 1981)

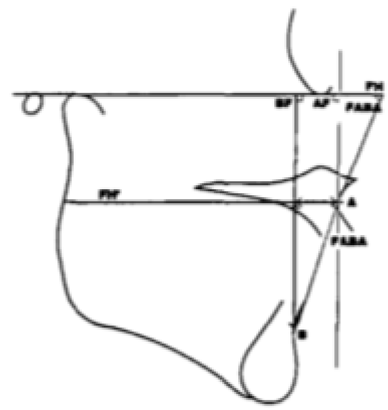
Stoner et al and Chang both used the Frankfort horizontal as a reference line (Stoner, Lindquist et al. 1956, Chang 1987). They projected the points A and B onto the Frankfort horizontal plane and measured the linear distance between them which Chang called AF-BF.



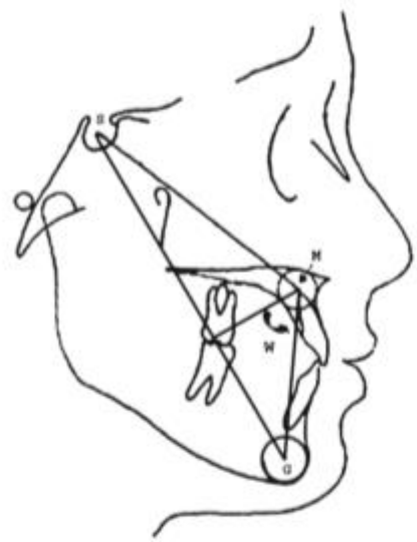

(Stoner, Lindquist et al. 1956) (Chang 1987)

Yang and Suhr measured the FABA angle, defined as “the angle between the plane A-B and the Frankfort horizontal plane” (Yang and Suhr 1995).




(Yang and Suhr 1995)

Bhad et al. introduced W angle to evaluate the sagittal skeletal discrepancy between the maxilla and the mandible (Bhad, Nayak et al. 2013).



(Bhad, Nayak et al. 2013)

Recently, various analyses have been developed to account for the rotational effects of the jaws, which include the Pi analysis (Kumar, Valiathan et al. 2012), the Yen angle (Neela, Mascarenhas et al. 2009) and the W angle (Bhad, Nayak et al. 2013). Kumar et al showed that the Pi analysis had no statistically significant correlations with ANB or Wits (Kumar, Valiathan et al.

2012); while no correlation studies were performed for the Yen or W angles. However, none of these new analyses measurements have been studied with respect to how they vary with growth.

Sachdeva et al. compared the Wits analysis, ANB angle, W angle, Beta angle and Yen angle to assess the most reliable measurement. They concluded that the Beta angle, Yen angle and W angle are valuable angles to assess the anteroposterior jaw discrepancy between maxilla and mandible (Sachdeva 2012). Kannan S et al. evaluated the reliability of sagittal methods utilizing FABA, AXD, MM Bisector, Beta angle, JYD angle, AB plane angle, ANB angle, AXB angle, AF- BF and App-Bpp. They suggested that angular methods such as FABA, AXD, Beta angle and linear measurements such as App-Bpp, MM Bisector could demonstrate superiority for assessing anteroposterior jaw relationship over the methods such as AXB, AB plane, ANB angle and AF-BF(Kannan 2012). Although helpful, few of these new analyses accounted for the rotational effects of growth of the maxilla and mandible.

### 2.4 WITS ANALYSIS AND ITS LIMITATIONS

Jacobson introduced the Wits appraisal to overcome the shortcomings of the ANB angle (Jacobson 1975, Jacobson 1988), by projecting 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 cusp". However, there are two significant problems that arise with performing the Wits appraisal on the FOP. Firstly, tracing of the occlusal plane is hardly reproducible nor easily identifiable (Jacobson 1975, Robertson and Pearson 1980, Rotberg, Fried et al. 1980, Brown 1981, Jarvinen 1981, Richardson 1982, Roth 1982, Hussels and Nanda 1984, Chang 1987, Rushton, Cohen et al. 1991, Haynes and Chau 1995) especially in cases with open bite, skeletal asymmetries, missing teeth, deep curve of Spee or in the mixed dentition.

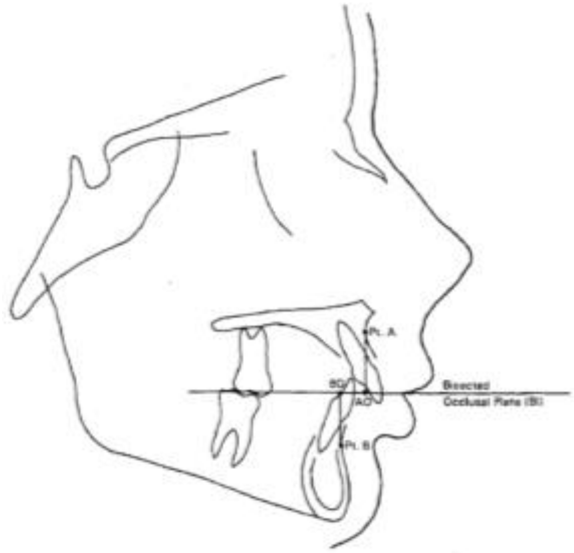
In addition, as the Wits appraisal relies on a dental parameter to describe a skeletal relationship, it has been shown to be profoundly influenced by a change in the inclination of the FOP, either caused by growth or orthodontic treatment (Hussels and Nanda 1984, Sherman, Woods et al. 1988, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). 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 (Hussels and Nanda 1984, Rushton, Cohen et al. 1991) or it rotated in a counterclockwise direction with age (Sherman, Woods et al. 1988, Hall-Scott 1994).

### 2.5 Different reference planes used in the Wits appraisal

In the numerous cephalometric analyses, the definition of the occlusal plane is greatly variable as well as the reference line from which the inclination is measured.  The Wits analysis is a measurement of the sagittal jaw relationship that uses as reference plane the FOP (Jacobson and Jacobson 2006).  Perpendicular lines are drawn from point A and point B onto the occlusal plane.  A linear measure is made by calculating the distance between the intersections of each line on the occlusal plane.  The Wits analysis was created to complement the ANB angle of anteroposterior jaw relationship.


Thayer, 1990

In order to mitigate the difficulties in identifying and using the FOP in the Wits appraisal, it has been recommended to use the bisected occlusal plane (BOP) (Chang 1987, Jarvinen 1988, Oktay 1991, Baik and Ververidou 2004). 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 (Downs 1948).  In fact, the functional occlusal plane tends to present negative Wits appraisal values, compared to measurements to the bisected occlusal plane since FOP rotates more clockwise with respect to a traditional occlusal plane, resulting in less correlation with ANB (Tanaka, Ono et al. 2006).



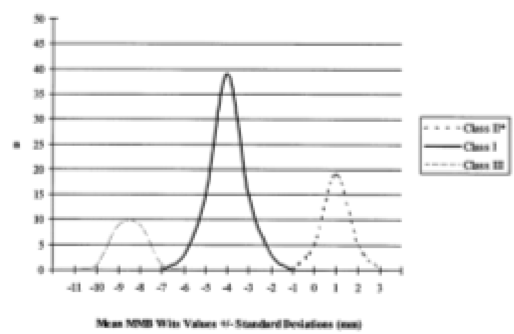

Thayer, 1990

In contrast, Thayer in 1990 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(Thayer 1990). He found that BOP Wits measurements were related to dental measures, whereas FOP Wits values were more related to skeletal measures. However, Palleck et al. 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 (Palleck, Foley et al. 2001). Del Santo investigated the influence of occlusal plane cant on Wits appraisal to the BOP and ANB angle(Del Santo 2006). His study showed a lack of correlation between BOP Wits and ANB measurement in high occlusal plane angle patients, however in low occlusal plane angle patients, both assessments had a high correlation.

In contrast, Hall-Scott (1994) 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)(Hall-Scott 1994). Studies have shown that the MMB Wits measurements are more reproducible than Wits measurements to either the FOP or BOP in every skeletal pattern, and that growth and treatment changes in the MMB Wits values reflect the ANB angle's changes (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). The MMB does not depend on the teeth and thus eradicated various associated issues with identification such as: mixed dentition, unerupted or crowded teeth, missing teeth, severe curves of Spee, dental restorations or molar overlap. The

MMB had another advantage which is to not include cranial base landmarks, therefore abolishing those potential problems related with them. In addition, Hall-Scott demonstrated that MMB had a greater correlation with the ANB angle than the FOP and BOP in Class I and III subjects (Hall-Scott 1994). Hall-Scott concluded that the cant of the MMB reflected the growth rotation of the maxilla and the mandible as they themselves contributed to the reference plane. Foley, Stirling and Hall-Scott followed up this study with a population of Class II Division I subjects (Foley, Stirling et al. 1997). Their conclusions were the same; the MMB was a more reliable and reproducible reference line and had better agreement with the ANB than either the BOP or FOP.

The validity of the MMB measurement reflects treatment changes and growth similarly demonstrated by the ANB angle. Moreover, a stronger correlation has been detected between the MMB and the ANB angle compared to the FOP or BOP Wits measures in all skeletal patterns which reinforces its validity (Palleck, Foley et al. 2001). The MMB sagittal measure seems to be a more valid and reliable assessment of the skeletal sagittal relationships, particularly during orthodontic treatment, than the Wits analysis measured with either the BOP or FOP, and is a beneficial complement to the cephalometric analysis.




(Palleck, Foley et al. 2001)

## 2.6 Influence of overbite on Wits appraisal

The Wits analysis depends on the occlusal plane angle (Jacobson 1975, Jacobson 1976, Robertson and Pearson 1980, Rotberg, Fried et al. 1980, Brown 1981, Jarvinen 1981, Richardson 1982, Roth 1982, Hussels and Nanda 1984, Williams, Leighton et al. 1985, Chang 1987, Jacobson 1988, Haynes and Chau 1995). Actually, a slight variation on the occlusal plane inclination causes an important effect on the Wits linear value. That variation is greater on the Wits measurement than on the ANB angle.

Since the perpendiculars from points A and B are projected onto the occlusal plane, any change in its inclination is bound to present inconsistencies in Wits analysis (Nanda 2004, Del Santo 2006). Thayer, despite finding good correlations with both occlusal planes (FOP and BOP) warned that in patients with deep bite in a mixed dentition stage, the BOP may vary significantly from the FOP of the permanent and primary molars (Thayer 1990). Deep overbite alone does not seem to introduce major differences in the Wits appraisal with functional and bisecting occlusal planes. However in deep curve of Spee patients, this difference can be clinically significant(Nizam 2014).

### 2.7 Correlation between Wits appraisal and ANB angle

Because the Wits and ANB evaluate the same sagittal jaw discrepancy, they should have good agreement. However, the correlation between these two measurements is not as great as expected with many different results (Rotberg, Fried et al. 1980, Bishara, Fahl et al. 1983, Jarvinen 1988, Hurmerinta, Rahkamo et al. 1997, Polk and Buchanan 2003). This implies weakness in at least one of the measurements. Ishikawa et al found a correlation coefficient of 0.57 with the BOP Wits values in skeletal Class I patients (Ishikawa, Nakamura et al. 2000) which was comparable to the agreement noted by Richardson (r = 0.67) and Jarvinen (r = 0.62) (Richardson 1982, Jarvinen 1988).

More studies have shown an inconsistent agreement between the Wits analysis and the ANB angle ranging from 0.08 to 0.73 (Rotberg, Fried et al. 1980, Williams and Melsen 1982, Bishara, Fahl et al. 1983, Chang 1987, Jarvinen 1988, Thayer 1990, Rushton, Cohen et al. 1991). Rotberg in 1980 extrapolated that the Wits analysis does not describe the anteroposterior jaw relationship only and, as the vertical dimension varies, similar Wits measures do not necessarily suggest identical sagittal jaw discrepancies (Rotberg, Fried et al. 1980, Roth 1982). In contrast, Oktay reported strong correlation (r= 0.76) among the Wits analysis and the ANB angle (Oktay 1991). Moreover, Richardson determined that by controlling the inclination of the BOP she could improve the ANB/Wits correlation from 0.67 to 0.80 (Richardson 1982).

Thayer in 1990 correlated the BOP Wits and the FOP Wits measurements to the ANB value. He obtained correlation values of 0.763 for FOP Wits and ANB, and 0.685 for BOP Wits and ANB angle. According to him, these measurements showed a significant correlation for both occlusal plane Wits measurements compared to the ANB angle (Thayer 1990).

Moreover, Del Santo in 2006 analysed patients with low and high occlusal planes as well as with long and short anterior cranial bases and correlated ANB and Wits values pre and post-treatment. The occlusal plane used to assess the Wits appraisal was defined as a line drawn from the ″mesiobuccal cusp tip of the lower first molar to the overlap of the incisors″. Correlation coefficients ranged between 0.49 to 0.76. The lowest correlations were obtained between Wits and ANB when comparing pre-treatment and post-treatment values. The highest correlations were reported between Wits and ANB prior to treatment. This suggests that with treatment, the value of at least one sagittal assessment tool changed.

A comparison between Wits appraisal and the ANB angle suggests that the jaw discrepancy is greater when evaluated using the ANB than with the Wits analysis in patients with Angle Class III molars (Iwasaki, Ishikawa et al. 2002). Also, it seems that in patients with a flattened occlusal plane, the Wits value underestimated the amount of discrepancy of a skeletal Class III, probably explained by mandibular counter-clockwise (Iwasaki, Ishikawa et al. 2002). In patients with flattened mandibular and occlusal planes, the Wits analysis to evaluate anteroposterior jaw relationship may express no or little skeletal discrepancy even if the individual subject has an evident jaw discrepancy (Iwasaki, Ishikawa et al. 2002). Thus, Iwsasaki et al concluded that the ANB angle is a more accurate cephalometric measurement than the Wits analysis to evaluate the sagittal jaw discrepancy for these patients (Iwasaki, Ishikawa et al. 2002). In contrast, Tanaka et al found that the correlation for the Wits appraisal and ANB angle in all facial groups was r=0.62, indicating that facial type does not affect the agreement between Wits and ANB values (Tanaka, Ono et al. 2006)

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 (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). A stronger correlation has been detected between the MMB and the ANB angle compared to the FOP or BOP Wits values which reinforces its validity (Palleck, Foley et al. 2001). Hall-Scott showed an agreement of 0.83 in the adult group and 0.95 in children between the ANB and the MMB Wits measures. Horowitz and Hixon have declared: "Correlation coefficients of less than r = 0.7 or r = 0.8 have little predictive value when applied to an individual. A correlation coefficient of r = 0.7 means that less than one half of the total variation can be eliminated in prediction (Horowitz, Hixon et al. 1966). "

The low agreement between Wits and ANB measures suggests a mutual independency of the two assessment tools (Rotberg, Fried et al. 1980, Jarvinen 1981). Both measures are influenced by the simultaneous displacement and constant remodeling that occur in craniofacial development. To solve these distorting changes affecting the parameters of these analyses, techniques of geometric correction of both analyses have been created (Freeman 1981, Roth 1982, Hussels and Nanda 1984, Williams, Leighton et al. 1985, Hussels and Nanda 1987, Sherman, Woods et al. 1988) but these involve complicated procedures and are time consuming.

So far, a conjunctive usage of the Wits analysis and the ANB angle has been advocated (Rotberg, Fried et al. 1980, Bishara, Fahl et al. 1983, Jacobson 1988, Sherman, Woods et al. 1988, Ishikawa, Nakamura et al. 2000). Nonetheless, when there is inconsistency in the skeletal relationship evaluation between the two measurements, it is complicated to decide on which measurement to base a selection. This motivates researchers to find assessment tools that correlate strongly together.

### 2.8 Age-related changes in the anteroposterior skeletal relationship and its effects on cephalometrics

Both skeletal and dentoalveolar growth changes have been studied extensively and have been described in the literature; however, some controversy exists. In the literature, there is an agreement on the reduction with age in ANB angle detected in the good occlusion group (Northway, Alexander et al. 1974, Bhatia and Leighton 1993) and is generally due to an age-related decrease of anteroposterior jaw distance (Williams, Leighton et al. 1985, Buschang, LaPalme et al. 1986). Palleck et al showed that the ANB angle diminished 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(Palleck, Foley et al. 2001). These values are consistent with Bishara (Bishara, Fahl et al. 1983), who concluded 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 (Lux, Burden et al. 2005) 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.

On the other hand, Lux et al and Bathia et al 1993 concluded that the Wits measures remained pratically unaltered from age 9 to 15 (Lux, Burden et al. 2005{Bhatia, 1993 #143). Bishara et al. (1983) reported that the Wits suggested no anteroposterior change in the skeletal position of both jaws from age 5 to adulthood (Bishara, Fahl et al. 1983). Lux et al demonstrated that a horizontal rotation of the occlusal plane is noted from age 9 to 15. They described a decrease of the angle between the occlusal plane and the sella-nasion reference line of 3.3 degrees among males, from 18.7 to 15.4, and of 2.3 degrees among females, from 15.4 to 13.1 (Lux, Burden et al. 2005). Therefore, the Wits appraisal in the good occlusion individuals is constant but does not necessarily suggest that a decrease of anteroposterior jaw distance does not happen as we age. Other factors have to be taken into account.

Conversely, Roth (1982) and Sherman et al. (1988) reported an increase in Wits related to growth, which was considered to be influenced by geometric cofactors (Roth 1982, Sherman, Woods et al. 1988). Sherman et al. (1988) described that any variation in the cant of the FOP, generally an age-related counterclockwise rotation, may seriously modify the Wits measure. Roth (1982) demonstrated also that the vertical distance between point A and point B is increased with age which has a “positive summation effect”. This vertical lengthening may increase Wits measure without an actual movement in the anteroposterior position between points A and B. Williams et al. (1985) concluded that if the occlusal plane’s angulation is stable, therefore the Wits appraisal also supports the idea of a decrease of anteroposterior skeletal relationship.

Previous studies (Sherman, Woods et al. 1988, Foley, Stirling et al. 1997) have concluded that the FOP’s inclination reduced with age which distorted the Wits analysis. The cant of the

BOP and FOP reduced on average with growth in skeletal Class I subjects. The inclination of the FOP was most dramatically affected in both Class I and III subjects compared to BOP (Palleck, Foley et al. 2001). The phenomenon of differential tooth eruption which causes the posterior area of the occlusal plane to move downward and rotate the occlusal plane in a counterclockwise direction has been suggested by Schudy and Creekmore (Creekmore 1967, Schudy 1968). Hussels et al reported that the rotation of the occlusal plane was independent of the palatal and mandibular planes (Hussels and Nanda 1984). The BOP Wits value increased a little overall with craniofacial growth while the FOP Wits value increased with treatment and/or growth. When the occlusal plane rotates in a counterclockwise fashion, it is expected to find an increase in the Wits value.

Sherman et al reported that variations in the Wits analysis happening during growth are not necessarily attributed to changes in the anteroposterior skeletal relationship and are likely to be influenced by variations in the occlusal plane's cant (Sherman, Woods et al. 1988). The Wits analysis utilizes a reference plane that is surely influenced by the vertical alveolar process development and tooth eruption, and this appears to contribute in its somewhat weak prediction accuracy among the parameters (Sherman, Woods et al. 1988, Ishikawa, Nakamura et al. 2000).

Tanaka et al. assessed the influence of the facial pattern on cephalometric sagittal relationships with the mandibular plane angle (FMA) (Tanaka, Ono et al. 2006). The sagittal relationships investigated were the Wits analysis, ANB angle and AF-BF. AF-BF is a measurement representing the linear distance between the projection of points A and B onto the Frankfort horizontal plane. It was found that the AF-BF and ANB angle values varied with the facial pattern, being lower in brachyfacial patients and higher in dolichofacial patients. While Tanaka et al. showed that ANB values vary with facial patterns, Nanda showed that there is no statistically significant correlation between mandibular plane and ANB angles (Nanda 1990). Tanaka et al also found that the correlation for the Wits appraisal and ANB angle in all facial groups was r=0.62, indicating that facial type does not alter the correlation between Wits and ANB (Tanaka, Ono et al. 2006). Thus, a reference plane utilizing the mandibular plane, an indicator of facial type, is not expected to adversely alter the relationship between the Wits analysis and the ANB angle.

Moreover, the growth effects on the MMB Wits analysis have been investigated. In concurrence with Hall-Scott, and Foley et al, the angulation of the MMB did not change significantly (Palleck, Foley et al. 2001{Hall-Scott, 1994 #48). From pre-treatment to post-treatment in both the Class I and Class III treated and control groups, the inclination of the MMB plane did not change significantly. The relationship's changes of A point to B point can thus be due to growth and/or treatment and not the results of alteration in cant of the reference line (Palleck, Foley et al. 2001). In subjects not receiving orthodontic treatment, Palleck et al.(Palleck, Foley et al. 2001) and Foley et al.(Foley, Stirling et al. 1997) 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. Also, according to Bhatia et al, the palatal to mandibular plane angle decreases 3.1º between the ages 4 and 14 years(Bhatia 1971).

## 2.9 NORMAL OVERBITE

In the literature, numerous different measures for "average" overbite have been reported. For example, some researchers calculate the overbite by looking at a certain percentage of overlap of the mandibular incisors' clinical crown. Instances of this consist of: 15-60% of the lower incisor's clinical crown length (Moorrees 1959), 20% of the lower incisor' clinical crown length (Neff 1949), lower incisors occlude with the upper central incisors' middle third (Baume 1950) or incisal third (Strang, Thompson et al. 1958), coverage of up to 1/2 of the lower incisors' crowns (Foster and Day 1974), coverage of up to 1/3 of the lower incisors' clinical crowns but not less than 1 mm (Daniels and Richmond 2000) and overlap in the 2/3 of the lower incisors' clinical crowns (Haynes 1972).

In contrast, other authors have decided to ignore the mandibular incisors' clinical crown length and concentrate on the measure of vertical incisal coverage calculated in millimetres. Instances of this consist of: 0-3 mm (Brunelle, Bhat et al. 1996, Freudenthaler, Celar et al. 2000), 0-4 mm (Björk 1953), 0.5-4 mm (Kim 1974, Beckmann, Kuitert et al. 1998), 1-4 mm (Ceylan and Eroz 2001), 1.5-4 mm (Bjornaas, Rygh et al. 1994), 2-4 mm (Lawton and Selwyn-Barnett 1975, Kinaan 1986), and 2.5-6.5 mm(Prakash and Margolis 1952). Therefore, it is obvious that there is no universal definition of an average overbite yet.

## 2.10 MEASUREMENT OF OVERBITE

Comparable to most craniofacial landmarks and cephalometric measurements, dental overbite can be calculated in numerous ways. The most frequently used technique is to measure the amount of overbite clinically with a periodontal probe. This method is a simple and efficient technique making it convenient for daily private practice, but it is not accurate enough for research purposes. In the literature, most authors prefer to measure overbite more accurately by using either dental casts or cephalometric radiographs.

When calculating overbite from dental models, a method first introduced by (Moorrees 1959) is most commonly used. It implies “placing a fine pencil mark on the labial surface of the mandibular incisors denoting the projection of the incisal edge of the maxillary central incisors”. Moorrees recommended that the “upper side of the pencil’s cone produced by sharpening is held parallel with the occlusal plane”. The same method was used by (Poulton and Aaronson 1961)and (Herness, Rule et al. 1973). Haynes (1972) modified this original method by advocating that authors utilize as reference the Frankfurt Horizontal plane (Haynes 1972).

When calculating overbite on cephalograms, most authors calculate the linear distance between the incisal tips of upper and lower incisors perpendicular to a specific reference plane. The most frequent reference line is the occlusal plane ((Björk 1953, Kim 1974, Lowe 1980, Beckmann, Kuitert et al. 1998, Ceylan and Eroz 2001). Bjork defined occlusal plane as “a tangent line from the incisal edge of the upper incisor to the distobuccal cusp of the upper permanent first molar”. Kim (1974), Lowe (1980) and Ceylan (2001) extended the occlusal plane from “the bisection point of the incisal overlap to the mesial cusp of the upper first molar”. Beckmann et al described the occlusal plane as the bisection point between incisal tips of maxillary and mandibular central incisors and the midpoint between mesiobuccal cusps of maxillary and mandibular first molars (Beckmann, Kuitert et al. 1998). In addition, Palatal Plane (Bergersen 1988), Nasion-Sella plane (Isaacson, Isaacson et al. 1971), Facial Plane (Nasion-Pogonion) (Prakash and Margolis 1952), and Nasion-Menton line (Nahoum, Horowitz et al. 1972) have also been used.

Once the overbite's measuring method has been decided, authors also have the option of noting overbite in either a percentage or a millimetre measure. Neff (1949) preferred the first one, reporting that "a percentage is the only way to have an accurate representation of overbite regardless of tooth length". Some have also proposed calculating overbite as part of the upper central incisor crown's lenght (Björk 1953, Strang, Thompson et al. 1958, Kim 1974, Beckmann, Kuitert et al. 1998). Hence, no universal consensus has been accepted.

## 2.11 DIGITAL RADIOGRAPHY COMPARED TO HAND-TRACED CEPHALOMETRIC MEASUREMENTS

With the fast evolution of computer radiography, digital tracing has eventually taken over the manual tracing techniques (Albarakati, Kula et al. 2012).The utilization of computerized cephalometric analysis eradicated the mechanical errors produced when tracing lines and landmarks as well as those made when calculating the different linear and angular measurements (Chien, Parks et al. 2009).

The current literature reports a high sensitivity when comparing hand traced cephalometric films to manually chosen landmarks on a digital cephalometric image(Forsyth and Davis 1996); Li et al, 2002; Leonardi et al, 200 (Chen, Chen et al. 2004, Gregston, Kula et al. 2004, McClure, Sadowsky et al. 2005, Erkan, Gurel et al. 2012). Sayinsu et al (2007), Erkan et al (2012), Prabhakar et al (2014), Uysal (2009), showed high correlation of validity and reproducibility of digital radiographs in the Dolphin Imaging Software compared to conventional methods (Sayinsu, Isik et al. 2007, Uysal, Baysal et al. 2009, Erkan, Gurel et al. 2012, Prabhakar, Rajakumar et al. 2014).

Sayinsu et al (2007) reported that the validity and reproducibility of the parameters with the Dolphin Imaging$^{TM}$ Software and hand tracing to be greatly correlated. Digital imaging has many advantages such as archiving, transmission and enhancement. Therefore, the digitized technique could be preferred in daily use and for research purposes without loss of quality.

It is generally considered that, despite potential errors of inaccuracy, cephalometrics can be used as a valid assessment tool for assisting orthodontic diagnosis and treatment planning.

However, it is not as a definitive solution and good clinical judgment is also important (Baumrind, Miller et al. 1976).

### 2.12 PURPOSE

The purpose of this investigation was to compare the reliability and validity of the Wits analysis using three different occlusal planes, the FOP, BOP and MMB, and to differentiate between patients exhibiting an increased, normal or reduced overbite. In addition, the correlation between the Wits and ANB values will be analysed in the three situations.

### 2.13 NULL HYPOTHESES

The null hypotheses for this study state that:

1. There is no statistically significant difference between the 3 sagittal reference planes (FOP, BOP, MMB) in the Wits value.

2. There is no statistically significant difference between the Wits correlation value when comparing 3 different occlusal planes (FOP, BOP, MMB).

3. There is no statistically significant difference between the Wits and ANB's correlation value when comparing 3 different sagittal occlusal planes (FOP, BOP, MMB).

# CHAPTER 3

## Materials and Methods

### 3.1 ETHICS

Ethics approval was obtained on September 3th, 2015 from the Human Research Ethics Board (Bannatyne Campus, University of Manitoba) prior to commencement of this retrospective study (Appendix 1).

### 3.2 SAMPLE SELECTION

The retrospective patient sample was acquired from the archives of the University of Manitoba Graduate Orthodontic Clinic. Digital cephalograms were taken by residents and assistants as part of the patients' initial orthodontic records with a Kodak Panoramic/Cephalometric model CS 8000C (Planmeca, Inc. Helsinki, Finland).

Pre-treatment lateral cephalograms were taken between February 2th, 2009 and August 17th, 2015. The chosen sample size comprised 150 subjects and consisted of 75 females and 75 males. Due to the even gender distribution, the sample is considered as gender neutral. The mean age of the subjects was 17.13 (SD 6.91). A summary of the sample is shown in Table 3.1.

| *Parameter* | *Mean* | *Min.* | *Max.* | *SD* |
|---|---|---|---|---|
| **Age of patients** | 17.13 | 11.89 | 48.33 | 6.91 |

*Table 3.1. Summary statistics for the sample.*

***Inclusion criteria***

- All skeletal patterns
- All Angle molar classifications
- All growth patterns
- Fully erupted permanent dentition excluding third molars;
- No missing teeth in either arches;
- No impacted teeth;
- Accurate plaster dental models in maximum intercuspation.

The patients included in this research were categorized as having either an openbite, a deepbite or a normal overbite. Therefore, patients were classified as follow:

- Control group: overbite between 1-3 mm;
- Deep bite group: overbite more than 3 mm;
- Open bite group: overbite less than 1 mm.

***Exclusion criteria:***

- Missing one or more teeth in either arches
- Impacted teeth (except third molars)
- Craniofacial deformities
- Inaccurate or missing dental casts

The chosen sample comprised 150 subjects (75 males, 75 females), which consisted of 75 patients presenting with a pretreatment Class I skeletal relationship (ANB = 0-4°), 54 patients with a Class II jaw relationship (ANB > 4°), and 21 patient with a Class III skeletal pattern (ANB < 0°). As per the Angle classification, 71 subjects had a pretreatment molar relationship of Class I, 53 subjects with a Class II and 26 presenting with a Class III. A summary of the groups is shown in Table 3.2.

| Group | Gender | Angle classification | ANB angle | Overjet |
|---|---|---|---|---|
| Control | 25 F, 25 M | I: 34<br>II: 11<br>III: 5 | I: 30<br>II: 14<br>III: 6 | 1-2 mm : 16<br>>2 mm : 33<br><1 mm : 1 |
| Deep bite | 25 F, 25 M | I: 14<br>II: 36<br>III: 0 | I: 22<br>II: 26<br>III: 2 | 1-2 mm : 8<br>>2 mm : 42<br><1 mm : 0 |
| Open bite | 25 F, 25 M | I: 23<br>II: 6<br>III: 21 | I: 23<br>II: 14<br>III: 13 | 1-2 mm : 13<br>>2 mm : 20<br><1 mm : 17 |

*Table 3.2. Characteristics of the three groups*

## 3.3 DATA COLLECTION

### 3.3.1 Calibration

The lateral cephalograms were labeled with a unique participant code for blinding purposes. No information on the radiographs indicated the gender or age. All of the lateral cephalometric radiographs were digitally traced by the primary examiner (Virginie Provencal) using the Dolphin™ 11.7 imaging software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). Film magnification was standardized for each film, which matched an actual 30 mm ruler included in each film view.

Intra-rater and inter-rater reliability of the lateral cephalometric radiographs and dental cast measurements were calculated utilizing the Interclass Correlation Coefficient test (ICC). 10% of the sample were randomly selected to be re-measured by a second independent examiner (Antoine Beaudet). Each of the 15 lateral cephalometric radiographs and dental cast were re-measured for intra-rater and inter-rater reliability at a second time at intervals 4 weeks apart from the initial measurement to identify landmark identification error.

### 3.3.2 Defining overbite categories

Patients were classified into three overbite groups depending on two pre-treatment variables; overbite measured on the dental casts and overbite calculated on the lateral cephalometric radiographs. Subjects within 1-3 mm were categorized as the control group, more than 3 mm were in the deep bite group and less than 1 mm were classified as the open bite group.

## 3.4 Statistical analysis

### 3.4.1 Sample size calculation

Calculations using mean values and standard deviations of the MMB Wits measurements in a treated Class I sample, as reported by Palleck et al. in 2001 were used to calculate the necessary sample size for this research. Using S.A.S Version 9.4 for sample size calculation, using $\alpha<0.05$ and with 80% power, dictated a minimum sample size of 47 subjects per group. Therefore, 50 subjects per group were included.

### 3.4.2 Error study

Four weeks after the cephalograms and dental models included in the study sample were completed being measured, an error study was calculated. Repeated measurements were performed on cephalometric radiographs and dental casts of 15 randomly selected subjects. Random selection was performed by assigning each patient a number from 1 to 150, then generating a string of random numbers via online software (http://www.randomizer.org/), which dictated the chosen subjects based on their assigned number. Finally, a Standard Deviation of Measurement Error (SE) was measured for every sample using the Dahlberg's formula:

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

To quantify the reliability of the measures in the study sample, the reproducibility of measurement (called R) was calculated using the formula: R= ((S2x-(S2e/2))/S2x, where S2x is the variance of the first set of measurements, and S2e is the variance of the difference between the initial and repeated measurements.

### 3.4.3 General statistics

For *intra and inter-examiner reliability*: measurements were assessed using an interclass correlation coefficient (ICC) test on 10% of the sample included in the study.

*For overbite type definition*: The data were assessed for normality and the presence of outliers prior to analysis with parametric tests. For every outlier detected it was found that the outlier had no significant impact on the data given the sample size and the difference with and without the outlier. Thus, all outliers were included in the sample data. Statistical analysis will include an unpaired t-test for gender differences within groups. A paired t-test ($p<0.05$) was calculated to evaluate the mean values of the different Wits measurements. Spearman correlation coefficients were assessed to relate the ANB angle to the Wits values in every group. The p-value was considered significant at $\alpha<0.05$. Intraclass Correlation Coefficient was used to correlate the three Wits measurements to each other.

*For all statistical tests:* statistical software SAS 9.4 was utilized to evaluate the data.

## 3.5 Cephalometric analysis

### 3.5.1 Image quality

All of the digital radiographs met the criteria for good to excellent radiographic diagnosis. The radiographic technique established in the Graduate Orthodontic clinic assumed the following requirements:

- Natural head position with the Frankfort horizontal parallel to the floor
- Correct orientation in cephalostat
- Correct exposure dosage and time

Natural head position is a concept first established by Moorrees and Kean (1958) to standardize the orientation of the head within the cephalostat and uses extracranial reference lines. Literature supports that the variance of natural head position and extracranial reference line reproducibility over a 15-year period is significantly less than using intracranial reference lines. (Peng and Cooke 1999). A technique adapted by Solow and Tallgren (1976) established 'orthoposition' as the natural head position. The patient positions themselves by standing and using a mirror to look into their own eyes.

### 3.5.2 Digitized cephalometric radiography

The lateral cephalometric radiograph's data was transferred in JPEG format into Dolphin Imaging™ 11.5. The images were then digitally traced. Digitization is defined as "the conversion of landmarks on a radiograph or tracing to numerical values on a two dimensional coordinate system, usually for the purpose of computerized cephalometric analysis" (Jacobson and Jacobson 2006). This technique permits automatic measurement of landmark relationships. Once digitized, manual landmark identification was carried out a single examiner.

### 3.5.3 Cephalometric Landmarks and Measurements

A cephalometric landmark is a "recognizable, and repeatable point on a tracing that represents a hard or soft tissue anatomical structure" (Phulari 2013). A line or plane may be drawn between two landmarks, and subsequently linear or angular measurements may be taken between two or more landmarks or planes (Phulari 2013). These measurements in turn may then be used to analyze cephalometric radiographs (Phulari 2013). Therefore, this study utilized hard tissue landmarks that have been proven (Phulari 2013) and analyses that are recognized in the literature (Riedel 1952, Jacobson 1976, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001).

The cephalometric landmarks, as well as the linear and angular measurements, used in this study are illustrated in Figures 3-2. The definitions of the landmarks and measurements used in this study are provided in Tables 3-2, 3-3, and 3-4.

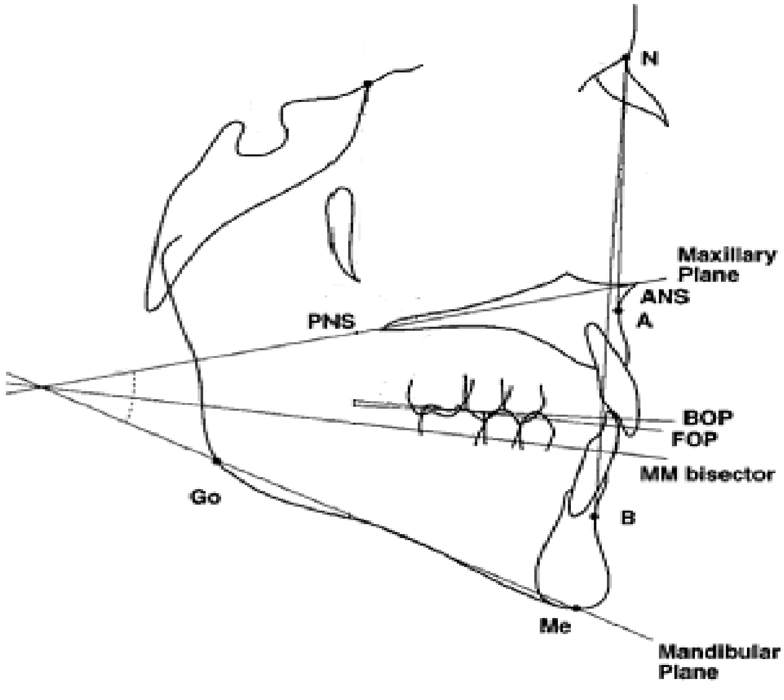



***Figure 3.1 Cephalometric tracing***

| *Landmarks* | *Definitions* | *References* |
|---|---|---|
| **Nasion (Na)** | Junction of the nasal and frontal bones. | (Broadbent. 1975, Phulari 2013) |
| **Anterior nasal spine (ANS)** | Tip of bony anterior nasal spine in the midline or median plane.<br>The most anterior point on the maxilla at the level of the palate. | (Phulari 2013)<br>(Moyers and Moyers 1988) |
| **Posterior nasal spine (PNS)** | Intersection of a continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose.<br>Most posterior point at the | (Broadbent. 1975)<br>(Riolo 1974) |

| | | |
|---|---|---|
| | sagittal plane on the bony hard palate. | |
| **A-point (Subspinale)** | Deepest, most posterior midline point on the curvature between the ANS and prosthion. | (Broadbent. 1975, Phulari 2013) |
| **B-point (supramentale)** | Deepest, most posterior midline point on the bony curvature of the anterior mandible, between infradentale and pogonion. | (Broadbent. 1975, Phulari 2013) |
| **Incision superius (UI)** | Incisal tip of the most labially placed maxillary central incisor. | (Broadbent. 1975, Jacobson and Jacobson 2006) |
| **Incision inferius (Li)** | Incisal tip of the most labially placed mandibular incisor. | (Broadbent. 1975, Jacobson and Jacobson 2006) |
| **Gonion (Go)** | Point midway between the point representing the middle of the curvature at the left and right angles of the mandible; if each side of the mandible was obviously visible on the radiograph, the midpoint between the right and left Go was used. | (Broadbent. 1975, Phulari 2013) |
| **Menton (Me)** | Point most inferior on mandibular symphysis. | (Broadbent. 1975, Phulari 2013) |
| **Lower First Premolar Cusp Tip** | The cusp tip of the mandibular first bicuspid. | (Jacobson 1975) |
| **Upper First Premolar Cusp tip** | The cusp tip of the maxillary first bicuspid. | (Jacobson 1975) |

| | | |
|---|---|---|
| **Upper first molar mesiobuccal cusp tip** | The mesiobuccal cusp tip of the maxillary first molar. | (Jacobson 1975) |
| **Lower first molar mesiobuccal cusp tip** | The mesiobuccal cusp tip of the mandibular first molar. | (Jacobson 1975) |
| **Upper first molar distobuccal cusp tip** | The distobuccal cusp tip of the maxillary first molar. | (Björk 1953) |
| **Lower first molar distobuccal cusp tip** | The distobuccal cusp tip of the mandibular first molar. | (Downs 1948) |

***Table 3.2 Definitions of hard tissue and dental landmarks***

| *Plane* | *Description* | *Reference* |
|---|---|---|
| **Functional occlusal plane** | Line drawn through the region of the overlapping cusps of the first premolars and first molars. | (Jacobson 1975, Athanasiou 1995) |
| **Bisected occlusal plane** | Line drawn bisecting the overlap of the distobuccal cusps of the first permanent molars and incisor overlap | (Downs 1948) |
| **Bjork's occlusal plane** | Tangent line from the incisal edge of the upper incisor to the distobuccal cusp of the upper permanent first molar | (Björk 1953) |
| **Palatal plane** | A line passing through the anterior nasal spine and the posterior nasal spine | (Athanasiou 1995) |
| **Mandibular plane** | A line passing through the mandibular borders (bilaterally) joining points gonion and menton. | (Athanasiou 1995, Jacobson and Jacobson 2006) |
| **Maxillo-mandibular bisector** | Bisector of the angle between the palatal and mandibular plane | (Hall-Scott 1994) |

***Table 3.3 Definitions of planes***

| Angular and linear measurements | Definition | Reference |
|---|---|---|
| **Wits to functional occlusal plane (FOP Wits) mm** | Linear measurement between A point and B point projected onto the functional occlusal plane. | (Jacobson 1975, Athanasiou 1995) |
| **Wits to bisecting occlusal plane (BOP Wits) mm** | Linear measurement between A point and B point projected onto the bisecting occlusal plane. | (Chang 1987, Jarvinen 1988, Oktay 1991, Baik and Ververidou 2004) |
| **Wits to maxillo-mandibular bisector (MMB Wits) mm** | Linear measurement between A point and B point projected onto the maxillo-mandibular bisector. | (Hall-Scott 1994, Foley, Stirling et al. 1997) (Palleck, Foley et al. 2001) |
| **ANB angle** | Angle formed by A point, nasion and B point which describes the anteroposterior position of the two jaws to one another. | (Steiner 1960, Athanasiou 1995) |
| **Overbite mm** | Linear distance between the incisal tips of upper and lower incisors perpendicular to Bjork's occlusal plane | (Björk 1953) |

***Table 3.4 Definitions of angular and linear measurements***

### 3.5.4 Hand-traced cephalometric radiographs

10% of the sample randomly chosen was hand-traced to verify the accuracy of the dolphin system$^{TM}$ tracing. One cephalometric angle (ANB) was drawn and measured on each tracing with the use of a protractor that is accurate to 0.5°, and 4 linear measurements were calculated with dial caliper that is accurate to 0.1 mm; 3 Wits measurements as well as the overbite. However, numerous studies showed that digital computerized tracings with Dolphin software™ were as reliable as the hand-traced method (Erkan, Gurel et al. 2012, Prabhakar, Rajakumar et al. 2014).

## 3.6 Plaster model analysis

Plaster models from pre-treatment records were verified to ensure that the dates they were taken matched the dates of the corresponding cephalometric radiographs. Once this was confirmed, each set of models was carefully inspected for damage. If there were any broken or chipped teeth that would be used in any of the measurements described below, the subject was excluded from the study.  Moreover, it was to ensure that the dental casts were an accurate representation of the subject's dentition and occlusal relationships by comparing them to their radiographs and their intra-oral photos.

To determine the intra-examiner and inter-examiner cast measurement error, the same 15 subjects who were randomly selected from the original sample for the cephalometric error calculation were uuencoded and their models retrieved and re-measured by the same operator four weeks later as well as by a second investigator, without reference to the previous measurements.

### 3.6.1 Plaster Model Measurements

The following measurement was performed on the plaster models:

Overbite (mm): the amount of vertical incisor overlap, measured as a linear distance from the maxillary central incisors to the mandibular incisors. First, the incisal edges of the right and left maxillary central incisors were projected onto the labial surface of the mandibular incisors using a mechanical pencil (Fig. 3.2). The pencil's lead was oriented parallel to the functional occlusal plane and was extended so that it contacted both the incisal edge and the labial surface simultaneously (Fig. 3.3). Next, the distance from these two pencil markings (i.e. one for each upper central incisor) to the mandibular incisal edges was measured with the Boley gauge to the nearest 0.1 mm, holding the gauge parallel to the labial surface of the lower incisors (Fig 3.4). If there was a discrepancy in overbite between the two measurements of up to 2 mm, the greater of the two measurements was recorded. If this discrepancy was greater than 2 mm, the tooth that was deemed to be more malpositioned in relation to the other maxillary anterior teeth was excluded.

*Figure 3.2: The incisal edges of the right and left maxillary central incisors were projected onto the labial surface of the mandibular incisors using a mechanical pencil.*

*Figure 3.3 The pencil's lead was oriented parallel to the functional occlusal plane and was extended so that it contacted both the incisal edge and the labial surface simultaneously.*

*Figure 3.4 The distance from these two pencil markings to the mandibular incisal edges was measured with the Boley gauge to the nearest 0.1 mm, holding the gauge parallel to the labial surface of the lower incisors.*

# CHAPTER 4

## Results

### 4.1 Sample Group Statistics

Group 1 represents the deep bite group with a mean overbite of 5.64 mm ± 1.37mm.

Group 2 represents the open bite group with a mean overbite of -1.29 mm ± 1.49 mm.

Group 3 represents the control/normal group with a mean overbite of 2 mm ± 0.57 mm.

A summary of the three groups prior to treatment is described in Table 4-1.

| *Groups* | *Mean* | *Min.* | *Max.* | *SD* |
|---|---|---|---|---|
| **1. Deep bite** | 5.64 | 3.5 | 9.6 | 1.38 |
| **2. Open bite** | -1.29 | -6.4 | 0.7 | 1.49 |
| **3. Control** | 2 | 1 | 3 | 0.57 |

*Table 4.1. Differences in overbite between groups.*
*Group 1 – deep bite, Group 2 – open bite, Group 3 – control.*

### 4.2 Reliability

In order to determine reliability and reproducibility of the measurements of the results, 10% of the selected sample size was re-measured. The primary investigator (Virginie Provencal) and a second independent investigator (Antoine Beaudet) evaluated the subjects at two separate time points. The level of reliability was assessed based on Intraclass Correlation Coefficient (ICC) values which ranged from 0 (no agreement) to 1 (perfect agreement). Each of the 15 patients pre-treatment lateral cephalometric radiographs and dental casts were measured one month apart.

### *4.2.1 Intra-rater reliability*

To quantify the intra-rater reliability, an Intraclass Correlation Coefficient (ICC) was used. The intra-examiner results showed a high consistency in the repeated measurements; all ICC values were greater or equal to 0.98 (average of 0.99). The ICC values for both the lateral cephalometric radiographs and dental models indicate extremely high reliability. Based on these results we can be confident that the reproducibility of the dental model measurements and cephalometric radiograph measurements are reliable within the one-month time lapse period.

| **INTRA-RATER RELIABILITY** | |
|---|---|
| **Variables examined** | **Intraclass Correlation** |
| Overbite on cephalogram | 0.99 |
| Overbite on models | 0.98 |
| FOP Wits | 0.99 |
| BOP Wits | 0.99 |
| MMB Wits | 1 |
| ANB angle | 0.99 |
| **Average** | **0.99** |

*Table 4.2. ICC values for the intra-examiner reliability*

### *4.2.2 Inter-rater reliability*

Inter-examiner ICC values had a wider reliability interval (0.88 - 0.97) and overall lower average correlation (0.93). However, there was still strong agreement of the values with correlation coefficients greater than 0.88 (Table 4.3). Based on these results, we can be confident that the reproducibility of the cephalometric variables are reliable within a one month time lapse period.

| INTER- RATER RELIABILITY | |
|---|---|
| **Variables examined** | **Intraclass Correlation** |
| Overbite on cephalogram | 0.93 |
| Overbite on models | 0.90 |
| FOP Wits | 0.88 |
| BOP Wits | 0.94 |
| MMB Wits | 0.97 |
| ANB angle | 0.97 |
| **Average** | 0.93 |

*Table 4.3. ICC values for the inter-examiner reliability.*

### *4.2.3 Hand-traced reliability*

Hand-traced ICC values had a narrow reliability interval (0.97 -0.98) and excellent overall great average correlation (0.98). Thus, there was strong agreement of the values with correlation coefficients greater than 0.97 (Table 4.4). Based on these results, we can be confident that the reproducibility of the hand-traced cephalometric variables and the digitized measurements are reliable.

| HAND-TRACED RELIABILITY | |
|---|---|
| **Variables examined** | **Intraclass Correlation** |
| Overbite | 0.98 |
| FOP Wits | 0.97 |
| BOP Wits | 0.97 |
| MMB Wits | 0.99 |
| ANB angle | 0.98 |
| **Average** | 0.98 |

*Table 4.4. ICC values for the hand-traced measurements reliability.*

## 4.3 Differences within the groups

### *4.3.1 Age*

The ANOVA F-test was used to calculate the difference in age between the control group, the deep bite and the open bite groups. No significant difference ($p>0.05$) in the age of the subjects was found between the three groups, as shown in Table 4.5 ($p=0.17$). Similarly, when considering males and females separately, no significant difference ($p>0.05$) was found between their age ($p=0.32$). An unpaired t-test was used to evaluate the level of significance which is shown in Table 4.6. However, the standard deviations are large, which is expected, as the age at which the radiographs were taken, were dependent on the orthodontic diagnosis, which can be highly variable in an orthodontic residency program or in private practice.

| ***Groups*** | ***Mean*** | ***Min.*** | ***Max.*** | ***SD*** |
|---|---|---|---|---|
| Control | 18.33 | 12 | 42 | 7.13 |
| Deep bite | 16.84 | 12 | 44 | 5.85 |
| Open bite | 19.49 | 12 | 59 | 7.99 |
| **Average** | 18.22 | 12 | 48.33 | 6.99 |
| **P value = 0.17** P<0.05 is statistically significant | | | | |

*Table 4.5. Means and Standard Deviations in the three groups for age.*

| ***Groups*** | ***Mean*** | |
|---|---|---|
| | **M** | **F** |
| Control | 16.92±6.43 | 19.43±7.43 |
| Deep bite | 17.13±7.07 | 16.40±4.29 |
| Open bite | 19.20±6.72 | 19.45±9.13 |
| **Average** | 17.75±6.74 | 18.43±6.95 |
| **P value = 0.32** P<0.05 is statistically significant | | |

*Table 4.6. Means and Standard Deviations in the three groups for age per gender.*

### *4.3.2 Analysis of Covariance by group and by gender*

Prior to assessing the differences between each group with a repeated measures ANOVA test, the data were assessed for the presence of outliers via boxplots. The presence of outliers in the data was minimal (between none and three outliers per group). The two groups that had the most outliers were the control group with the FOP Wits and the open bite group with the MMB Wits. The boxplots demonstrating these outliers are shown in Figure 4.1, 4.2, 4.3 and 4.4.


*Figure 4.1 Box plot of the FOP Wits distributions*

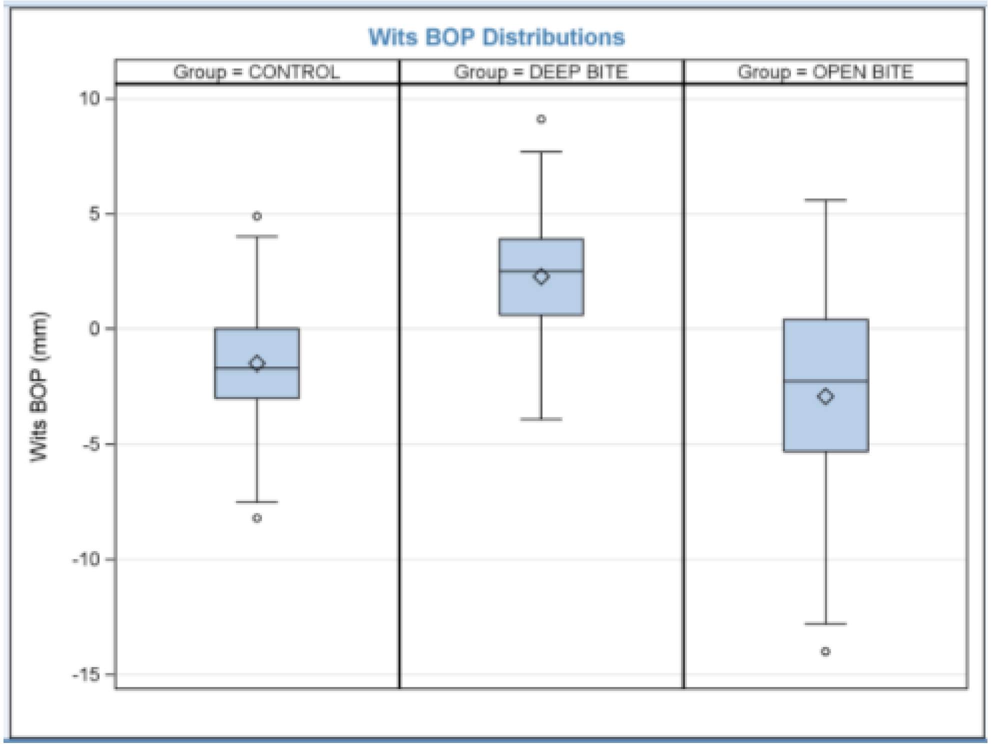



*Figure 4.2 Box plot of the BOP Wits distributions*

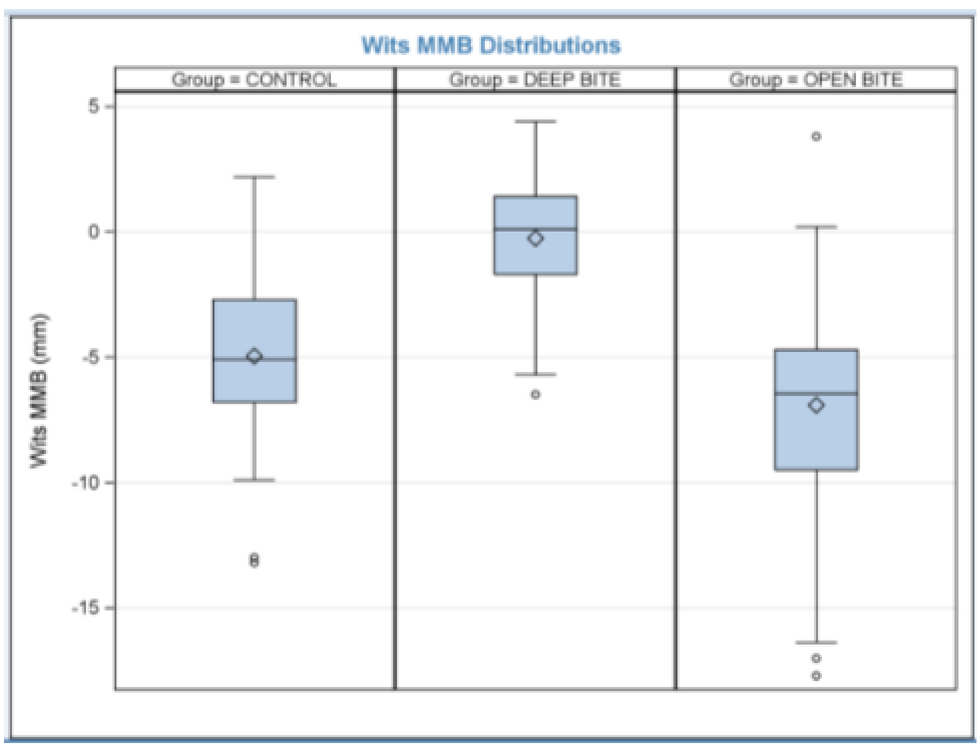



*Figure 4.3 Box plot of the MMB Wits distributions*

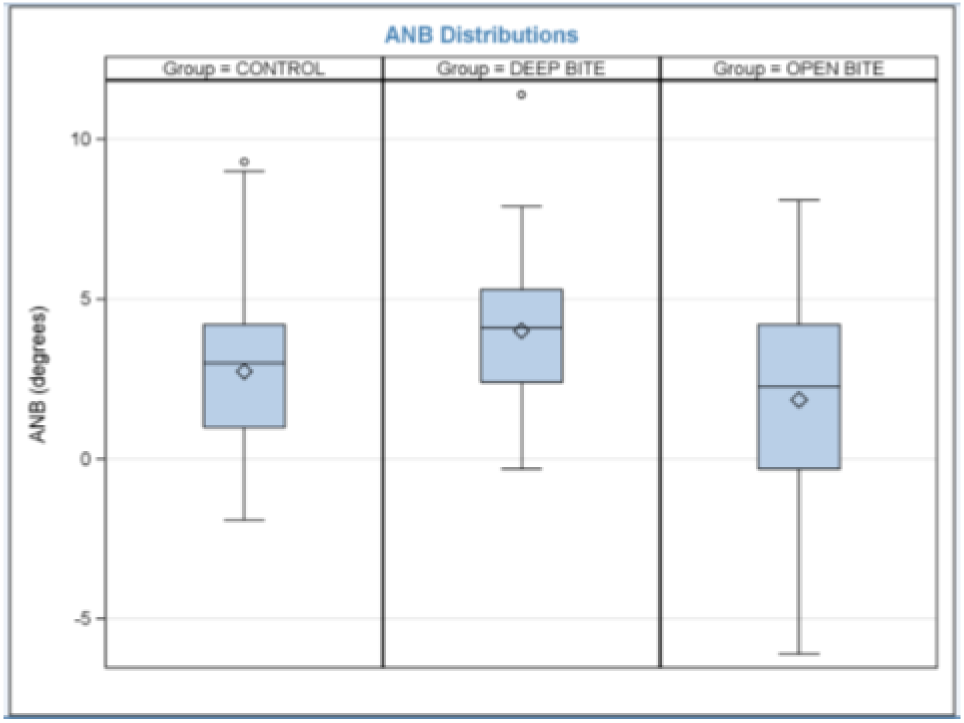



*Figure 4.4 Box plot of the ANB angle distributions*

The mean values and standard deviations for the investigated pretreatment cephalometric measurements in the three groups are shown in Table 4.7.

| | **Control** | **Deep bite** | **Open bite** | **Averages** |
|---|---|---|---|---|
| Overbite (mm) | 2.00±0.57 | 5.64±1.38 | -1.29±1.49 | 2.12 ± 1.15 |
| FOP Wits (mm) | -1.11±3.21 | 2.17±3.57 | -3.83±5.24 | -0.19 ± 4.00 |
| BOP Wits (mm) | -1.48±2.75 | 2.27±2.79 | -2.92±4.70 | -2.12 ± 3.41 |
| MMB Wits (mm) | -4.96±3.37 | -0.26±2.59 | -6.91±4.51 | -2.21 ± 3.49 |
| ANB angle (deg) | 2.74±2.54 | 4.01±2.20 | 1.86±3.30 | 2.87 ± 2.68 |

*Table 4.7. Means and Standard Deviations in the three groups.*

The mean values and standard deviations for the investigated pretreatment cephalometric measurements in the three groups, for both males and females are shown in Table 4.8.

| | **Control** | | **Deep bite** | | **Open bite** | |
|---|---|---|---|---|---|---|
| | **M** | **F** | **M** | **F** | **M** | **F** |
| Overbite (mm) | 1.96±0.56 | 2.05±0.60 | 5.76±1.37 | 5.53±1.40 | -1.6±1.68 | -0.98±1.22 |
| FOP Wits (mm) | -1.72±3.23 | -0.50±3.13 | 1.89±3.26 | 2.45±3.90 | -5.07±5.95 | -2.59±4.16 |
| BOP Wits (mm) | -2.18±2.86 | -.079±2.50 | 2.03±2.55 | 2.51±3.03 | -4.60±4.97 | -1.24±3.79 |
| MMB Wits (mm) | -6.16±3.42 | -3.76±2.93 | -0.64±2.63 | 0.12±2.54 | -8.65±4.86 | -5.17±3.41 |
| ANB angle (deg) | 1.76±2.47 | 3.72±2.24 | 3.27±1.64 | 4.76±2.47 | 0.6±3.50 | 3.13±2.57 |

*Table 4.8: Means and Standard Deviations in the three groups for Males and Females*

ANOVA was used to compare the mean values between the three different groups for the same Wits measurement as well as the mean values of the males and females within these groups. For the FOP Wits, the average mean value is -0.19 mm ranging from -3.83 to 2.17. For the BOP Wits, the average mean value is -2.12 mm ranging from -2.91 to 2.27. In addition, for the MMB Wits, the average measurement is -2.21 mm ranging from -6.91 to -0.26. The lowest measurements are found in the open bite group and the highest measurements are found in the deep bite group. Results are shown in table 4.7 and 4.8.

The following interaction plots illustrate the different Wits models by group and gender as predictors. As demonstrated in Figure 4.5, the FOP Wits mean values in the three groups show statistically significant differences ($p<0.05$) for gender ($p=0.03$) and groups ($p<0.0001$). The mean values for the control group, the deep bite and open bite groups are respectively -1.1 mm ± 3.2, 2.2 mm ± 3.6 and -3.8 mm ± 5. Moreover, females have on average mean values of 1.4 mm higher than the males which is statistically significant ($p=0.03$).

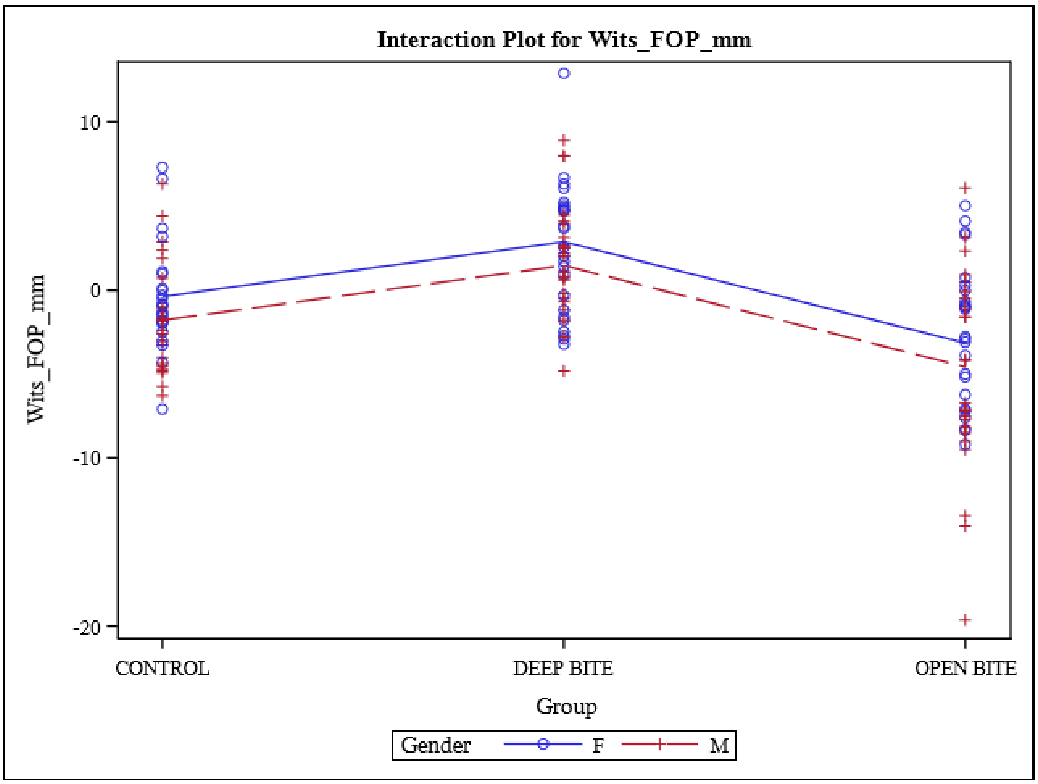



*Figure 4.5. Interaction plot for FOP Wits – Group and Gender as predictors*

As illustrated in Figure 4.6, the BOP Wits mean values in the three groups show statistically significant differences ($p<0.05$) for gender ($p=0.002$) and groups ($p<0.0001$). The mean values for the control group, the deep bite and open bite groups are respectively -1.4 mm ± 2.7, 2.3 mm ± 2.8 and -2.9 mm ± 4.7. Moreover, females have on average mean values of 1.7 mm higher than the males which is statistically significant ($p=0.002$).

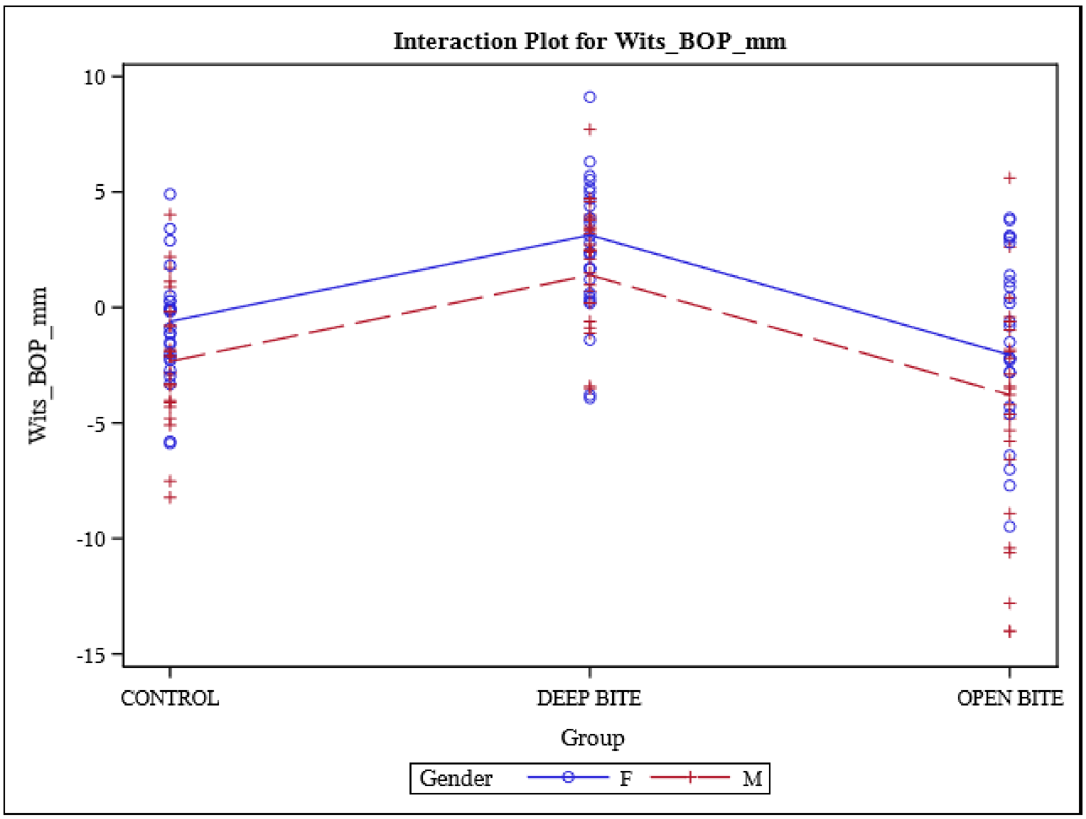



*Figure 4.6. Interaction plot for BOP Wits – Group and Gender as predictors*

As illustrated in Figure 4.7, the MMB Wits mean values in the three groups show statistically significant differences ($p<0.05$) for gender ($p=0.0001$) and groups ($p<0.0001$). The mean values for the control group, the deep bite and open bite groups are respectively -5.0 mm ± 3.4, -0.3 mm ± 2.6 and -6.9 mm ± 4.5. Moreover, females have on average mean values of 2.2 mm higher than the males which is statistically significant ($p=0.0001$).

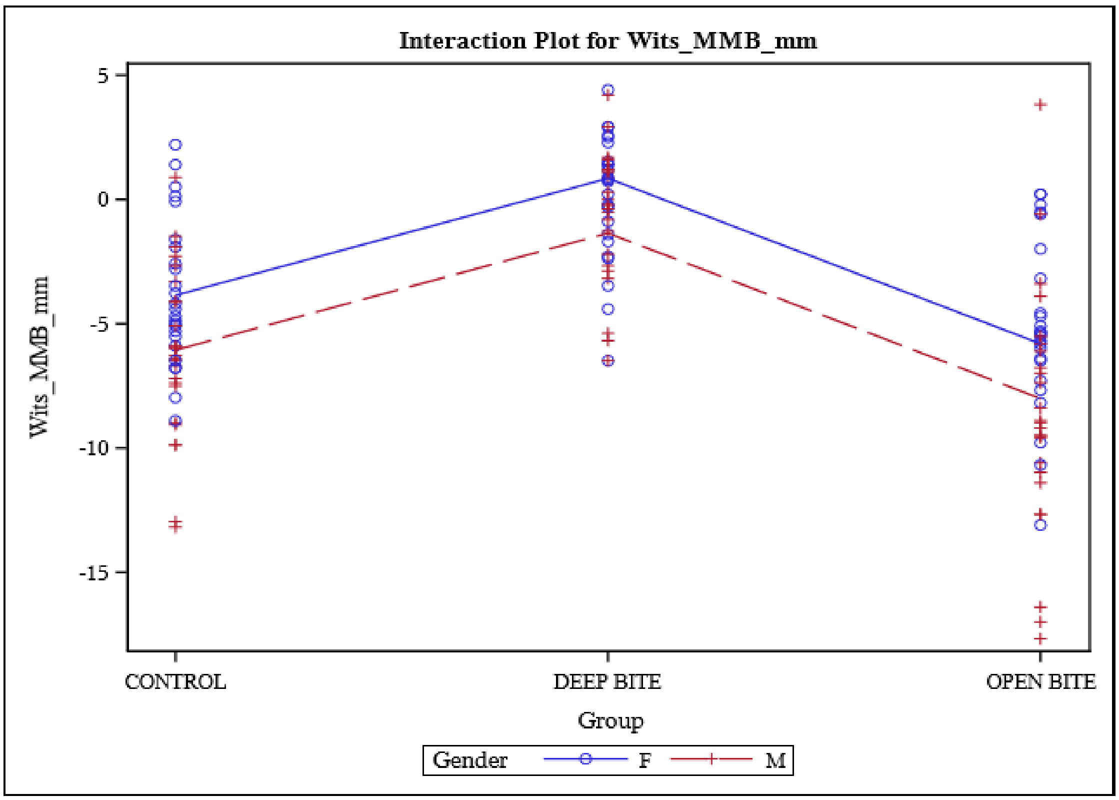



*Figure 4.7. Interaction plot for MMB Wits – Group and Gender as predictors*

As illustrated in Figure 4.8, the ANB angle mean values in the three groups show statistically significant differences ($p<0.05$) for gender ($p=0.0001$) and groups ($p=0.0002$). The mean values for the control group, the deep bite and open bite groups are respectively 2.7° ± 2.5, 4.0° ± 2.2 and 1.9° ± 3.3. Moreover, females have on average mean values of 2.0° higher than the males which is statistically significant ($p=0.0001$).

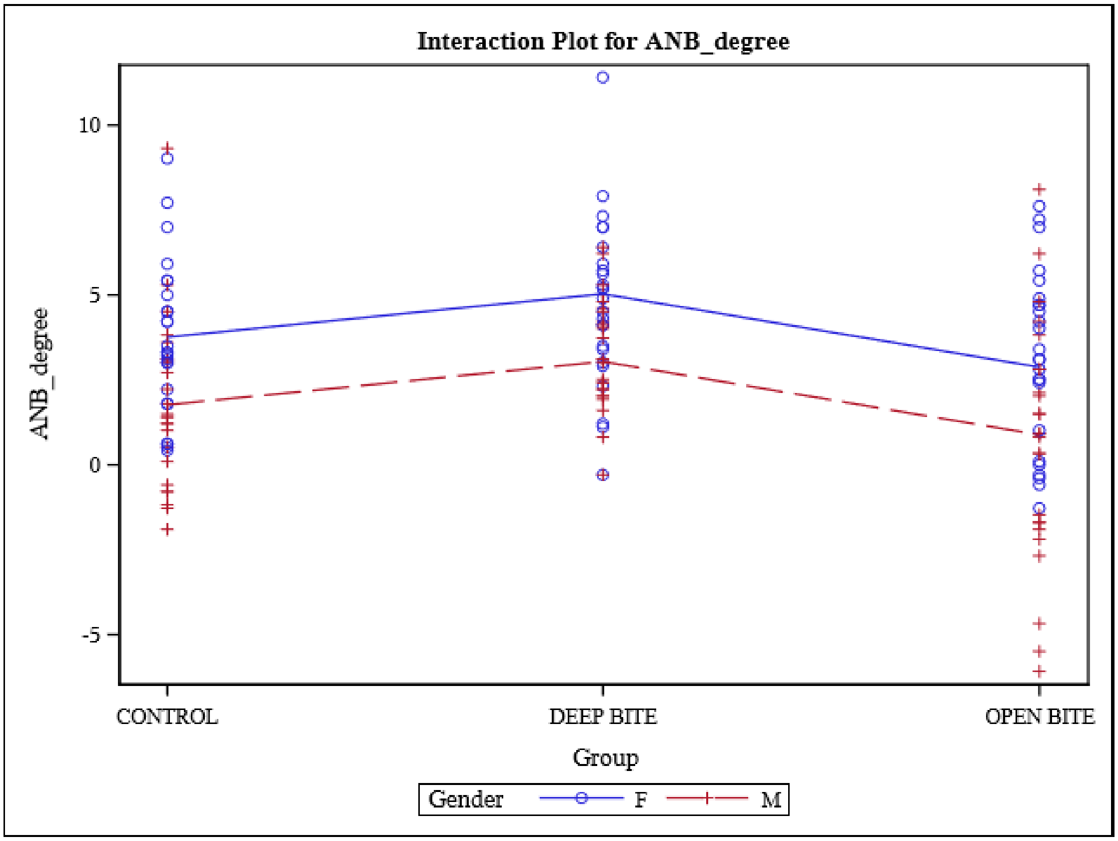



*Figure 4.8. Interaction plot for ANB angle – Group and Gender as predictors*

In summary, the results in Figures 4.1, 4.2, 4.3 and 4.4 show that significant differences were found for all measurements, between the normal, deep bite and open bite groups. The MMB-Wits mean values were significantly lower in all groups compared to the FOP Wits and BOP Wits values. In addition, the average mean values for the females were significantly larger in all group subjects.

### 4.4 Correlation between the different Wits measurements

The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to each other were generally moderate to high ranging from 0.56 to 0.89. The correlation values are depicted in Table 4.9. Overall, the strongest correlations were found between BOP Wits and MMB Wits in the open bite group (r=0.89).

| | **Groups** | | |
|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** |
| FOP Wits-BOP Wits | 0.71 | 0.74 | 0.80 |
| FOP Wits-MMB Wits | 0.60 | 0.56 | 0.69 |
| BOP Wits- MMB Wits | 0.83 | 0.78 | 0.89 |

*Table 4.9: Intraclass Correlation Coefficients for the three groups*

According to the Paired t-test (Figures 4.9 and 4.10) used to calculate the difference between the mean values of the FOP Wits and BOP Wits, the results showed that for a p value of 0.05, there is no statistical difference (p=0.25) between the mean values of these two Wits appraisals in the normal overbite group.

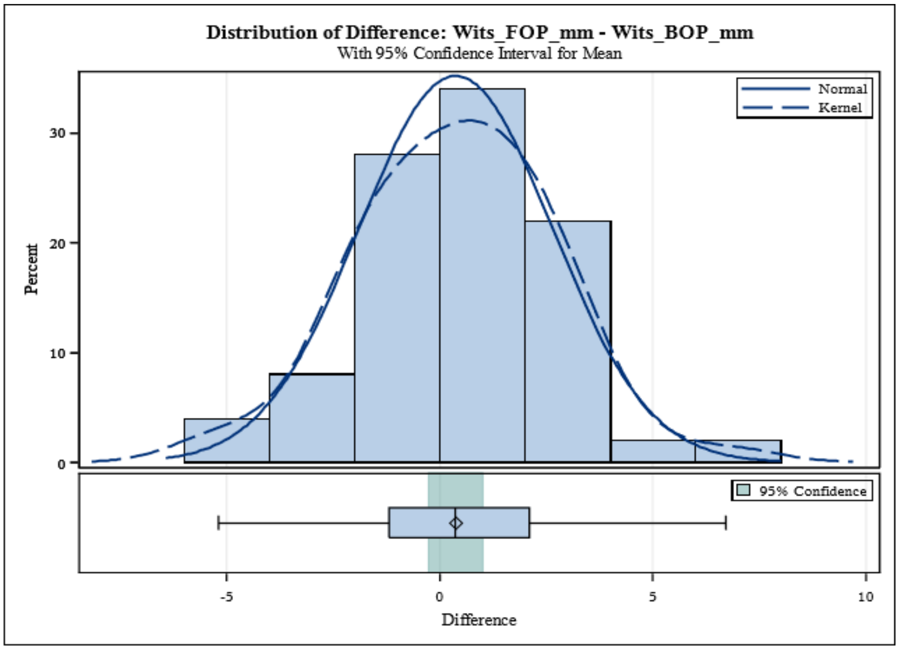



*Figure 4.9 Paired T-test: Difference of the means FOP Wits – BOP Wits in the control group*

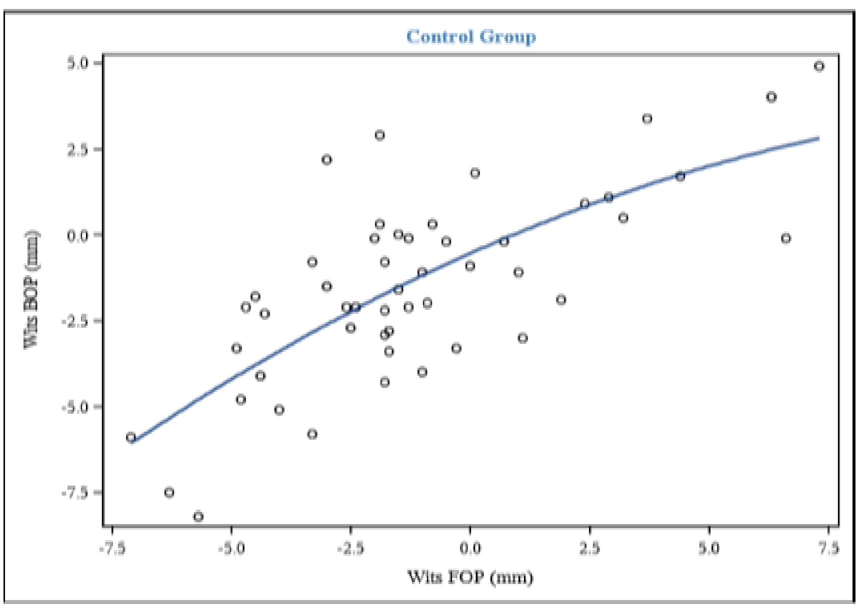



*Figure 4.10 Intraclass Correlation of FOP Wits – BOP Wits in the control group*

According to the Paired t-test (Figures 4.11 and 4.12) used to calculate the difference between the mean values of the FOP Wits and MMB Wits, the findings demonstrated that for a p value of 0.05, there is a statistical difference ($p<0.001$) between the mean values of these two Wits appraisals in the normal overbite group.

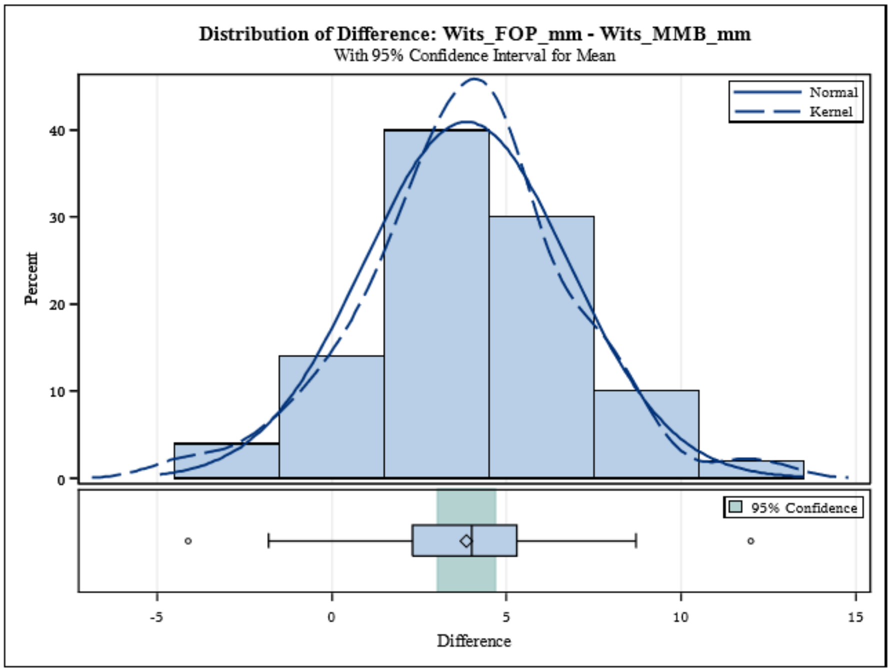



*Figure 4.11 Paired T-test: Difference of the means FOP Wits – MMB Wits in the control group*

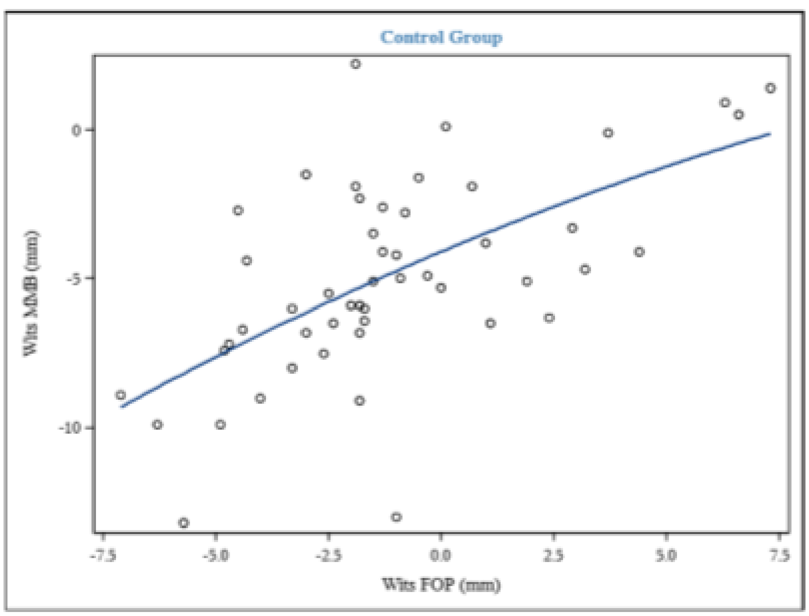



*Figure 4.12 Intraclass Correlation Coefficient of FOP Wits – MMB Wits in the control group*

According to the Paired t-test (Figures 4.13 and 4.14) used to calculate the difference between the mean values of the BOP Wits and MMB Wits, the results showed that for a p value of 0.05, there is a statistical difference ($p<0.0001$) between the mean values of these two Wits appraisals in the normal overbite group.

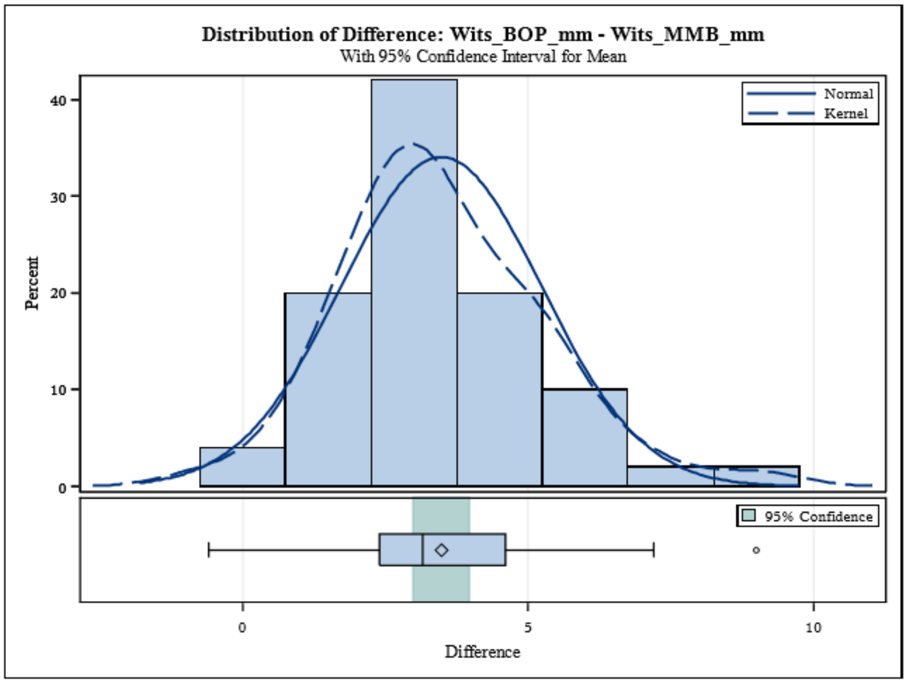



*Figure 4.13. Paired T-test: Difference of the means BOP-Wits – MMB-Wits in the control group*

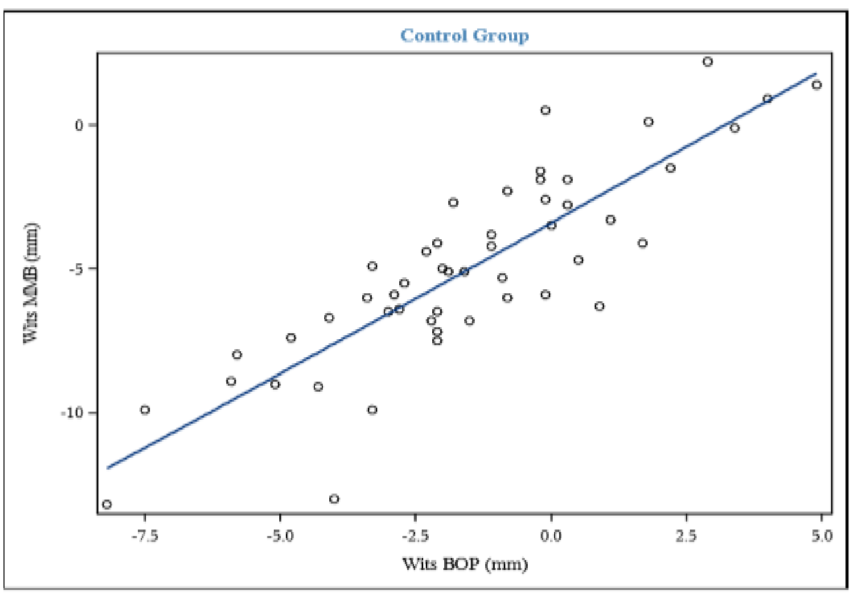



*Figure 4.14 Intraclass Correlation of BOP Wits – MMB Wits in the control group*

According to the Paired t-test (Figures 4.15 and 4.16) used to calculate the difference between the mean values of the FOP Wits and BOP Wits, the results showed that for a p value of 0.05, there is no statistical difference (p=0.76) between the mean values of these two Wits appraisals in the deep bite group.

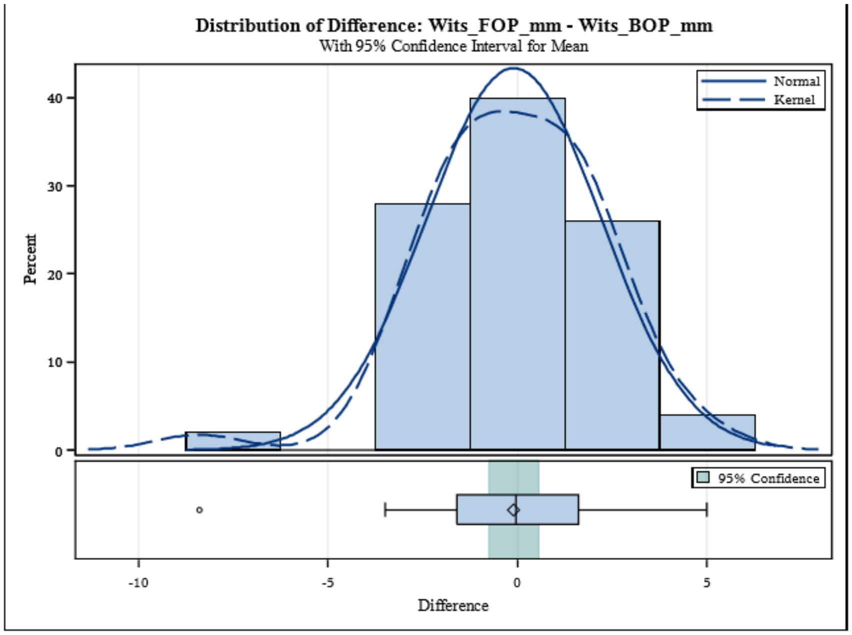



*Figure 4.15 Paired T-test: Difference of the means FOP Wits – BOP Wits in the deep bite group*

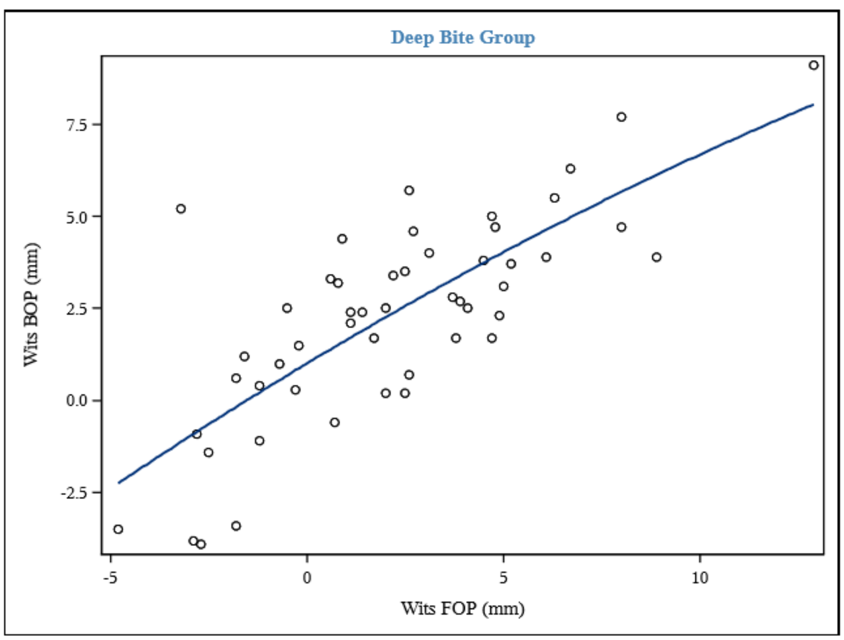



*Figure 4.16 Intraclass Correlation of FOP Wits – BOP Wits in the deep bite group*

According to the Paired t-test (Figures 4.17 and 4.18) used to calculate the difference between the mean values of the FOP Wits and MMB Wits, the findings showed that for a p value of 0.05, there is a statistical difference ($p<0.0001$) between the mean values of these two Wits appraisals in the deep bite group.

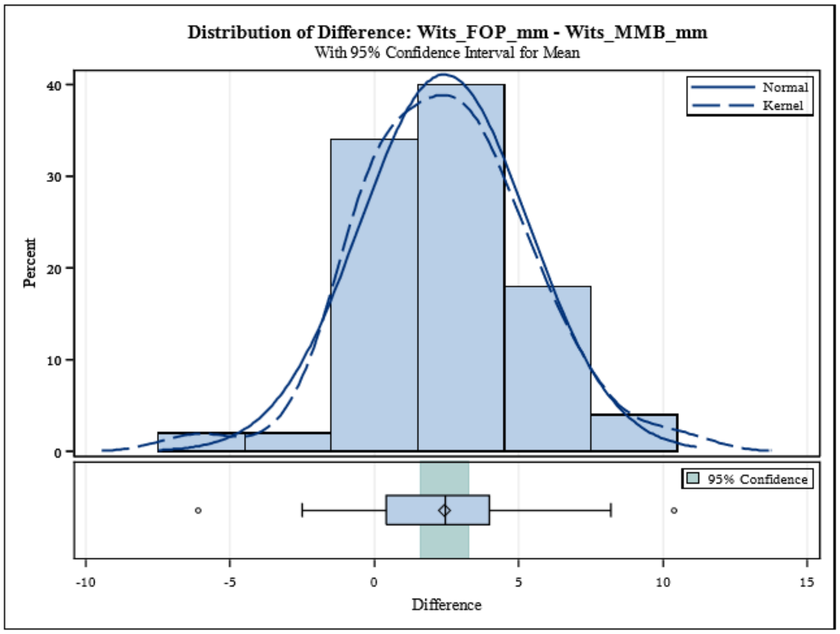



*Figure 4.17 Paired T-test: Difference of the means FOP Wits – MMB Wits in the deep bite group*

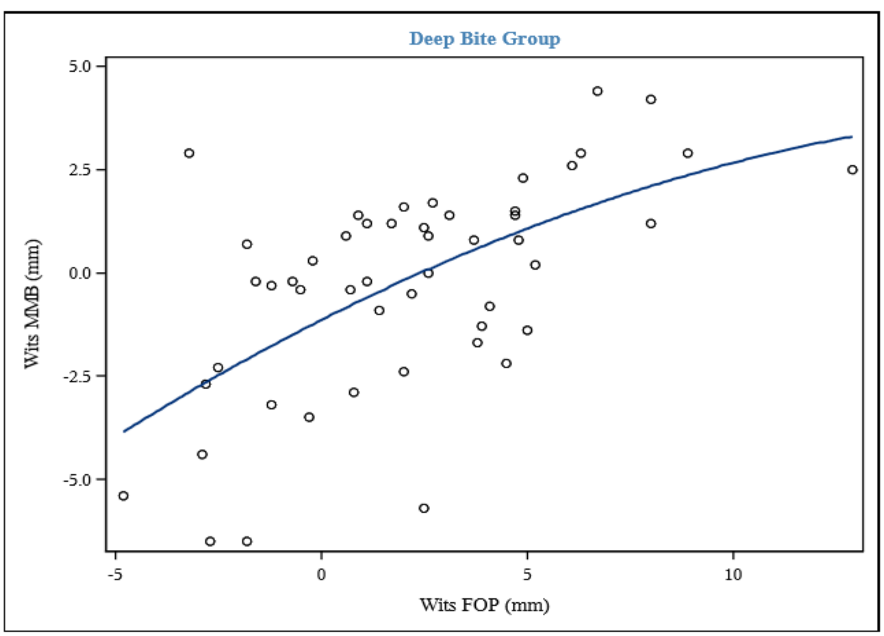



*Figure 4.18 Intraclass Correlation of FOP Wits – MMB Wits in the deep bite group*

According to the Paired t-test (Figures 4.19 and 4.20) used to calculate the difference between the mean values of the BOP Wits and MMB Wits, the results showed that for a p value of 0.05, there is a statistical difference (p<0.0001) between the mean values of these two Wits analyses in the deep bite group.

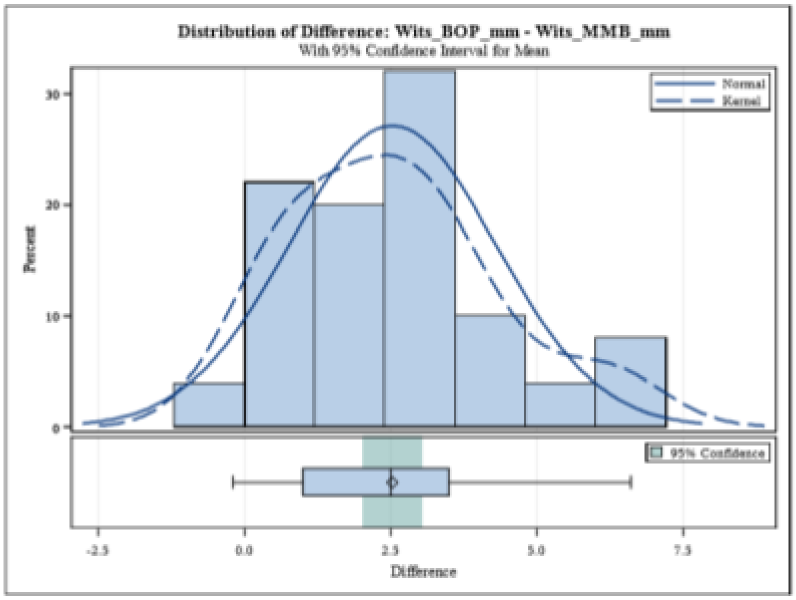



*Figure 4.19 Paired T-test: Difference of the means BOP Wits – MMB Wits in the deep bite group*

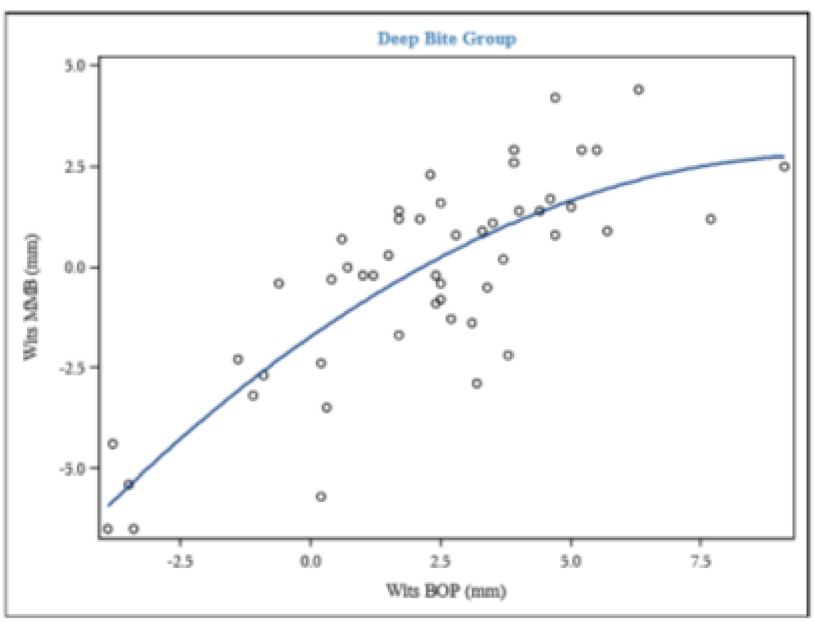



*Figure 4.20 Intraclass Correlation of BOP Wits – MMB Wits in the deep bite group*

According to the Paired t-test (Figures 4.21 and 4.22) used to calculate the difference between the mean values of the FOP Wits and BOP Wits, it showed that for a p value of 0.05, there is a statistical difference (p=0.04) between the mean values of these two Wits appraisals in the open bite group.

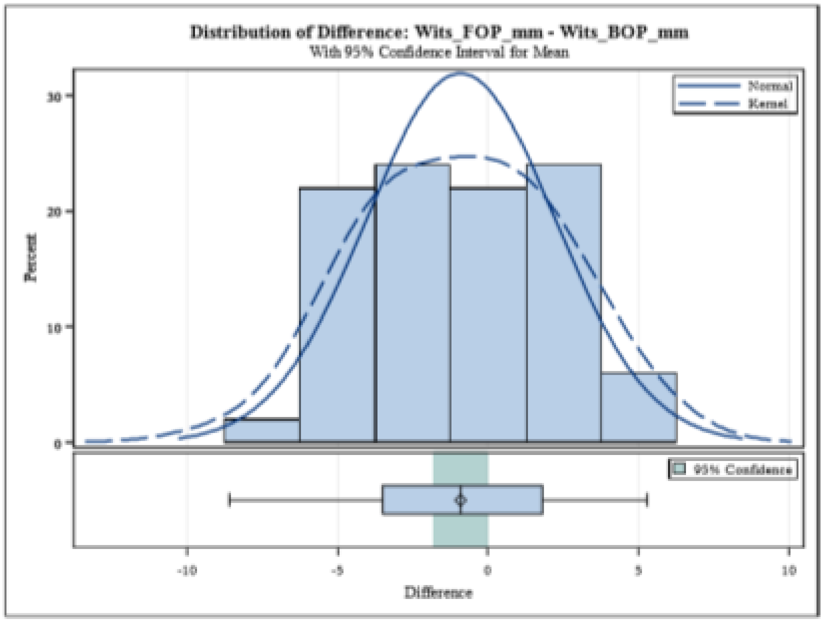



*Figure 4.21 Paired T-test: Difference of the means FOP Wits – BOP Wits in the open bite group*

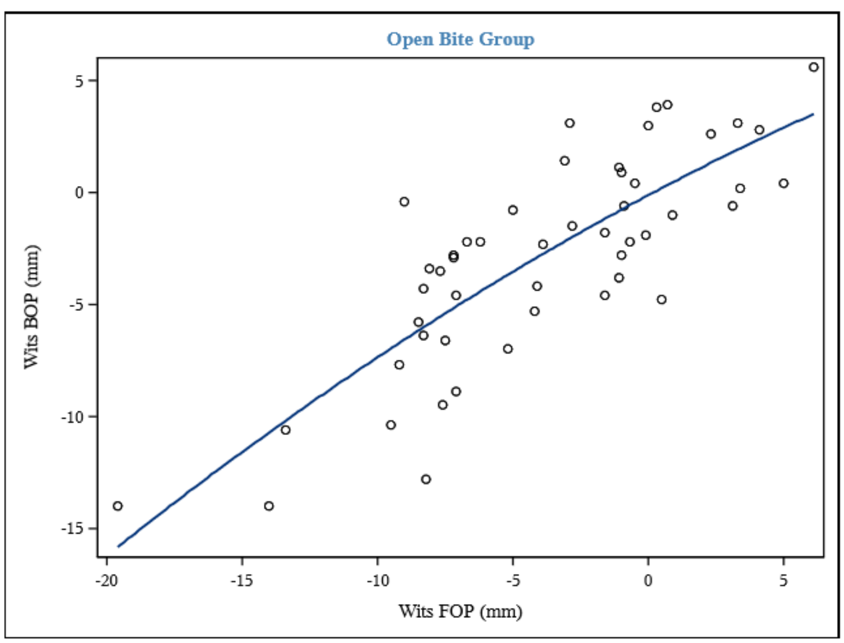



*Figure 4.22 Intraclass Correlation of FOP Wits – BOP Wits in the open bite group*

According to the Paired t-test (Figures 4.23 and 4.24) used to calculate the difference between the mean values of the FOP Wits and MMB Wits, the findings demonstrated that for a p value of 0.05, there is a statistical difference ($p<0.0001$) between the mean values of those two different Wits appraisals in the open bite group.

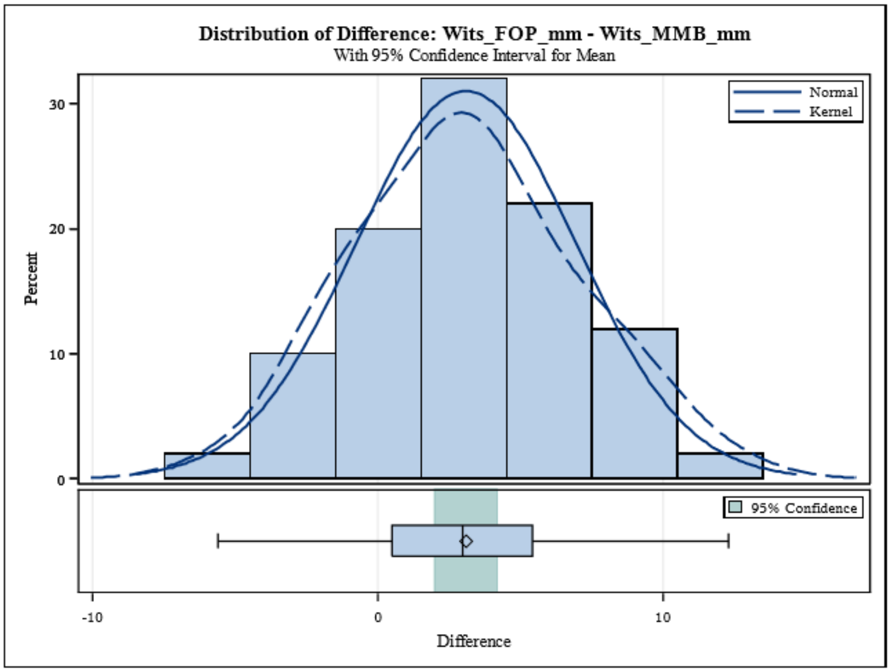



*Figure 4.23 Paired T-test: Difference of the means FOP Wits – BOP Wits in the open bite group*

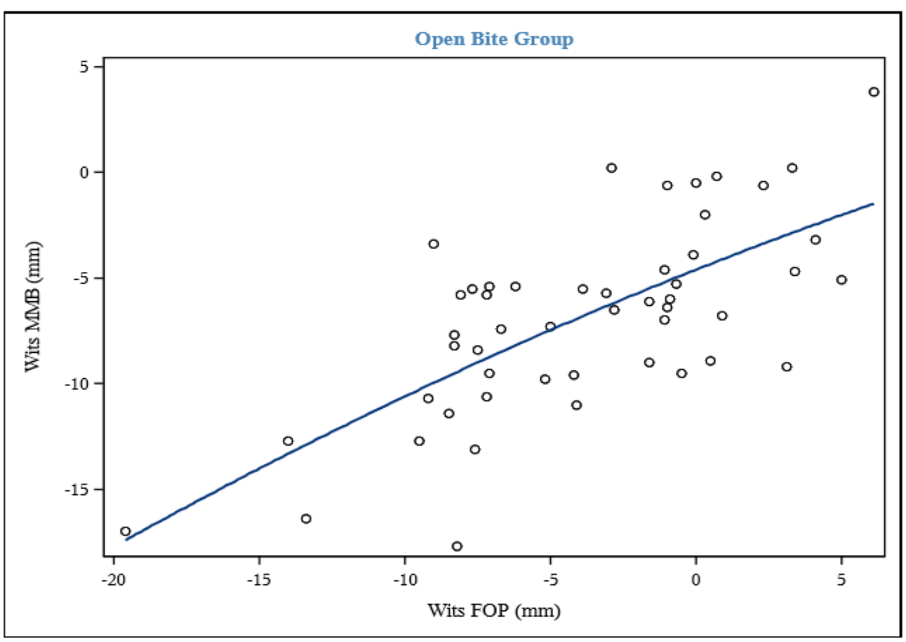



*Figure 4.24 Intraclass Correlation of FOP Wits – MMB Wits in the open bite group*

According to the Paired t-test (Figures 4.25 and 4.26) used to calculate the difference between the mean values of the BOP Wits and MMB Wits, it showed that for a p value of 0.05, there is a statistical difference ($p<0.0001$) between the mean values of these two Wits appraisals in the open bite group.

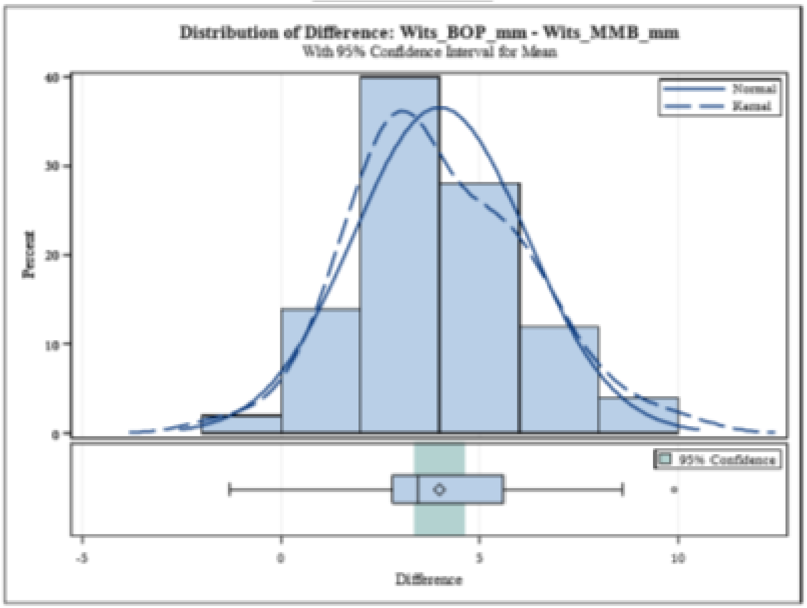



*Figure 4.25 Paired T-test: Difference of the means BOP Wits – MMB Wits in the open bite group*

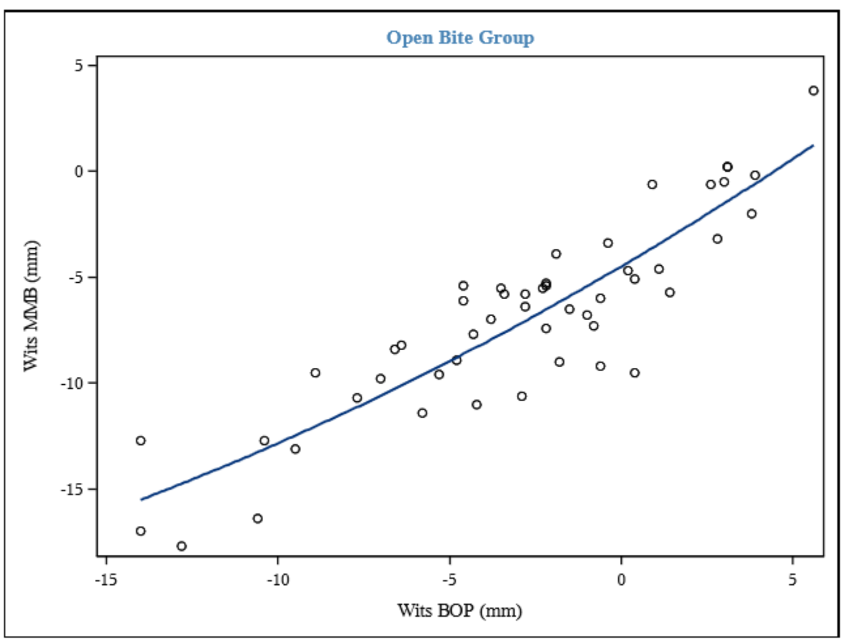



*Figure 4.26 Intraclass Correlation of BOP Wits – MMB Wits in the open bite group*

In summary, there were two situations where the FOP Wits and the BOP Wits appraisals had no statistical difference in their mean values, which were in the control group as well as the deep bite group. All the other combinations demonstrated statistically different means.

**4.5 Correlation of the different Wits measurements by gender**

The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to each other in the female and male groups were generally moderate to high ranging from 0.52 to 0.90 for the females and from 0.56 to 0.85 for the male. The correlation values are depicted in Table 4.10 and 4.11. Overall, the strongest correlations were found between BOP Wits and MMB Wits in all groups and gender (0.82 to 0.90). Therefore, these data follow the same trend as the data when genders are combined. No difference could be demonstrated. In all groups, the correlation is higher between BOP Wits and MMB Wits and lower between FOP Wits and MMB Wits. Same conclusions were drawn by including both genders in the sample.

| | **Female** | | |
|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** |
| FOP Wits-BOP Wits | 0.63 | 0.72 | 0.76 |
| FOP Wits-MMB Wits | 0.61 | 0.52 | 0.63 |
| BOP Wits- MMB Wits | 0.86 | 0.82 | 0.90 |

*Table 4.10. Intraclass correlation for the female group*

| | **Male** | | |
|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** |
| FOP Wits-BOP Wits | 0.75 | 0.74 | 0.80 |
| FOP Wits-MMB Wits | 0.56 | 0.61 | 0.68 |
| BOP Wits- MMB Wits | 0.82 | 0.76 | 0.85 |

*Table 4.11. Intraclass correlation for the male group*

### 4.6 Spearman Correlation Coefficients between the Wits measurements and the ANB angle

The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to the ANB angle were generally low to moderate ranging from 0.39 to 0.76. The correlation values are depicted in Table 4.12. Overall, the strongest correlation was found between MMB Wits and ANB angle in the open bite group (r=0.74).

| | **Groups** | | | |
|---|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** | **Average** |
| FOP Wits – ANB | 0.39 | 0.50 | 0.45 | 0.45 |
| BOP Wits – ANB | 0.72 | 0.60 | 0.65 | 0.66 |
| MMB Wits – ANB | 0.68 | 0.57 | 0.74 | 0.66 |

*Table 4.12. Spearman Correlation Coefficients between ANB angle and the different Wits measurements in the three groups*

### 4.7 Spearman Correlation Coefficients by gender between the Wits measurements and the ANB angle

The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to the ANB angle were generally low to moderate for both the female and male groups ranging from 0.24 to 0.76 for the females and from 0.28 to 0.68 for the males. The correlation values are depicted in Table 4.13 and 4.14. Overall, the BOP Wits and the MMB Wits have similar correlation values to the ANB angle.

| | **Females** | | | |
|---|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** | **Average** |
| FOP Wits – ANB | 0.24 | 0.57 | 0.49 | 0.43 |
| BOP Wits – ANB | 0.69 | 0.74 | 0.66 | 0.69 |
| MMB Wits – ANB | 0.56 | 0.76 | 0.70 | 0.67 |

*Table 4.13. Spearman Correlation Coefficients for females between ANB angle and the different Wits measurements in the three groups*

| | Males | | | |
|---|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** | **Average** |
| FOP Wits – ANB | 0.28 | 0.28 | 0.35 | 0.30 |
| BOP Wits – ANB | 0.64 | 0.45 | 0.55 | 0.54 |
| MMB Wits – ANB | 0.56 | 0.53 | 0.68 | 0.59 |

*Table 4.14. Spearman Correlation Coefficients for males between ANB angle and the different Wits measurements in the three groups*

# CHAPTER 5

# DISCUSSION

## 5.1 Review of the limitations of the Wits appraisal and the ANB angle

The Wits appraisal and the ANB angle are cephalometric measurements widely used to evaluate the sagittal discrepancy between the maxilla and the mandible (Bishara, Fahl et al. 1983, Oktay 1991, Baik and Ververidou 2004, Del Santo 2006). Various parameters to assess the sagittal jaw relationship have been suggested, but the ANB angle described by Riedel (1952) is still the most utilized (Tanaka, Ono et al. 2006). However, there are significant shortcomings in both measurements. The identification of the landmarks, particularly A and B points, introduces the potential for tracing errors of greater than 1.50 mm in more than 20% of lateral cephalograms (Baumrind and Frantz 1971, Baumrind and Frantz 1971). In addition, the upward and forward movement of Nasion with growth (Enlow and Hans 2008) as well as rotation of the jaws with growth and, most importantly, with orthodontic treatment may also influence the accuracy of the ANB angle (Hussels and Nanda 1984, Nanda and Merrill 1994).

The Wits appraisal was introduced by Jacobson in 1975 (Jacobson 1975) to overcome the drawbacks of ANB angle (Jacobson 1975, Hussels and Nanda 1984). Jacobson suggested that an increased ANB angle in an individual with a perfect occlusion could be due to an anterior position of the maxilla in relation to Nasion and/or to a clockwise rotation of the upper jaw in relation to the anterior cranial base. In these situations, Jacobson concluded that an important difference may occur in the Wits analysis and the ANB angle. According to Hussels (1984), the parameter that influences the ANB angle the most is the anterior facial height, characterized by an increase of Sella-Nasion to the occlusal plane angle, the distance between Nasion and B-point, as well as the distance between A and B-points (Hussels and Nanda 1984, Hussels and Nanda 1987). However, the Wits analysis also has its drawbacks. Del Santo (2006) mentionned that: ″because the Wits measurement is calculated by drawing the projections of Point A and B on the functional occlusal plane, and because the occlusal plane cant is influenced by the facial growth direction, dental eruption, and alveolar bone development, its shortcomings also demand attention″ (Del Santo 2006). Therefore, geometric effects of the occlusal plane inclination modulates the ANB and Wits measurements. The critical limitation of the Wits analysis is that it uses an occlusal plane that relies on the teeth to assess skeletal parameters (Hussels and Nanda 1984, Sherman, Woods et al. 1988, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001).

Hence, there is an ongoing search for more accurate cephalometric measurements to assess the skeletal relationships. Numerous criteria have to be evaluated in order to determine the proper diagnosis and treatment plan for an orthodontic patient. The anteroposterior jaw relationship is of great importance to accurately address whether a skeletal discrepancy exists, and if so, to what degree (Del Santo 2006)? Many authors have provided new measurement tools to assess the skeletal discrepancy, but more research on the current analyses, such as the ANB angle and the Wits appraisal, is still necessary. These cephalometric measurements are widely used and further research would only provide a better understanding of their limitations and thus, a more accurate application. Therefore, understanding the limitations results in better answers.

The present study attempted to identify agreement or disagreement between ANB and Wits assessments in increased and decreased overbite groups, in comparison to a control group with a normal overbite. To evaluate the accuracy of the Wits analysis measurements in diagnosing sagittal jaw discrepancies, the ANB angle was utilized as a standard with which to compare the Wits measurements. Despite its drawbacks, the ANB angle is a useful reference tool, and has been shown not to be any less reliable than any other cephalometric parameters as an anteroposterior jaw measurement.

**5.2 Reliability of the measurements**

The maxillo-mandibular bisector Wits analysis (MMB Wits), first described by Hall-Scott (1994), used a geometrically derived plane that eliminated the problems found in correctly identifying the occlusal plane and was purported to not change significantly with growth and rotation of the jaws (Hall-Scott 1994). Studies have shown that this bisector is highly reproducible (Richardson 1966, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001, Ganiger, Nayak et al. 2012). In addition, studies have shown that the MMB Wits measurement is more reproducible than Wits measurements to either the FOP or BOP in every skeletal pattern, and that growth and treatment changes in the MMB Wits values reflect the ANB angle’s changes (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). In addition, there is an agreement in the literature that the reproducibility of the functional occlusal plane is very low compared to the BOP (Thayer 1990), Jacobson 1975, Robertson and Pearson 1980, Rotberg, Fried et al. 1980, Brown 1981, Jarvinen 1981, Richardson 1982, Roth 1982, Hussels and Nanda 1984, Chang 1987, Rushton, Cohen et al. 1991, Haynes and Chau 1995).

In our study, the intra-rater reliability as well as the inter-rater reliability correlations were slightly higher for the MMB Wits measurements (r=1.0 and r=0.97) compared to the FOP Wits (r=0.99 and r=0.92) and BOP Wits (r=0.99 and r=0.96). This finding once again demonstrates the ease of identifying the landmarks and the reproducibility of the MMB Wits appraisal. Palleck & al. (2001) also found that both the MMB and the BOP were more reproducible than the FOP (Palleck, Foley et al. 2001). The reliability helps to determine how well an anteroposterior parameter will be able to diagnose a sagittal skeletal discrepancy. In our study, repeat tracings of 15 radiographs designed to test the reliability of the MMB, FOP and BOP Wits measurements, showed that while the MMB Wits was more reliable, the difference between the BOP and the MMB is not clinically significant. On the other hand, the reliability of the FOP Wits was shown to be significantly lower, especially when two different orthodontists have to accurately trace it.

The reproducibility of the measurements was also determined via the hand-tracing of 15 cephalograms, which demonstrated correlation of $r>0.97$ for all measurements. 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.

To summarize, the reproducibility of the measurements (r) for the cephalometric measurements for the sample investigated in this study is very high. All tracing errors fell within acceptable limits with a correlation of $r>0.88$ for all measurements, indicating good reproducibility.

### 5.3 Differences between the groups

#### *5.3.1 Age*

The subjects included in the sample were randomly chosen from the archives of the graduate orthodontic clinic of the University of Manitoba. All ages were included. However, patients had to be in the permanent dentition stage. The mean age for the male and female groups were calculated in the normal, increased and decreased overbite samples. No significant difference ($p>0.05$) in the age of the subjects was found between the three groups ($p=0.17$). Similarly, when considering males and females separately, no significant difference ($p>0.05$) was found between their age ($p=0.32$). Due to the nature of the graduate orthodontic clinic where the cases were selected from, patients may start their treatment at different ages which would explain the standard deviations being large, considering that the radiographs were taken for orthodontic diagnosis prior to start treatment which can be highly variable, in an orthodontic residency program. Thus, given the broad standard deviations, it is not possible to make a precise conclusion.

#### *5.3.2 Mean values of FOP Wits appraisal*

The present study showed that there were statistically significant differences in the readings of Wits values between the three groups. We found mean values for the FOP Wits of -1.11 mm ± 3.21 in the normal overbite group, 2.17 mm ± 3.57 in the deep bite group and -3.83 mm ± 5.24 in the open bite group. Numerous studies have calculated the mean value of FOP Wits in different situations (Table 5.1). Foley et al. (1997) found 1.70 mm ± 1.69 in a sample of 36 Class II div 1 subjects (Foley, Stirling et al. 1997). Palleck et al. (2001) showed FOP Wits mean values of -2.02 mm ± 3.58 in a sample of 35 Class I subjects and -9.02 mm ± 3.04 in 10 skeletal Class III patients (Palleck, Foley et al. 2001). Moreover, Thayer et al. (1990) found a mean value of 0 mm ± 2.8 in a sample of 35 skeletal Class II division 1 males (Thayer 1990). Jacobson (1975) reported a mean value of -1.17 mm ± 1.9 in 21 skeletal Class I male individuals (Jacobson 1975). In 25 adult females selected on the same basis, points AO and BO generally coincided. The calculated mean reading was -0.10 mm ± 1.77. Therefore, Jacobson established mean values of -1 mm ± 1 in males and 0 mm ± 1 in females (Jacobson 1975). He also mentioned that in skeletal Class II jaw discrepancies, one would obtain a positive reading whereas in skeletal Class III jaw disharmonies, the Wits reading would be negative. Finally, Tanaka et al. (2006) showed that the functional occlusal plane tends to present more negative Wits appraisal values, compared to measurements to the bisected occlusal plane since the FOP rotates more clockwise with respect to the bisecting occlusal plane, resulting in less correlation with skeletal parameters (Tanaka, Ono et al. 2006).

| DIFFERENT MEAN VALUES OF THE FOP WITS MEASUREMENTS | |
|---|---|
| Provencal, 2016 | -1.11 mm ± 3.21 (normal overbite)<br>2.17 mm ± 3.57 (deep bite)<br>-3.83 mm ± 5.24 (open bite) |
| Foley, 1997 | 1.70 mm ± 1.69 (skeletal class II div 1) |
| Palleck, 2001 | -2.02 mm ± 3.58 ( skeletal Class I)<br>-9.02 mm ± 3.04 (skeletal Class III) |
| Thayer, 1990 | 0 mm ± 2.8 (skeletal Class II division 1 males) |
| Jacobson, 1975 | -1 mm ± 1 (males)<br>0 mm ± 1 (females) |

*Table 5.1 Summary of the FOP Wits mean values cited in the literature*

Considering that the control group has a majority of skeletal Class I subjects according to the ANB angle, we would expect a mean value similar to the one Jacobson (1975) reported for Class I subjects. Indeed, -1.11 ± 3.21 mm falls within the norm of Class I skeletal as per Jacobson. Additionally, there were more skeletal Class II subjects in the deep bite group compared to the control group which would imply higher Wits values and it was exactly what the results confirmed. The same idea could be applied to the open bite group. More skeletal Class III patients were included in that group. Therefore, lower Wits values were obtained.

### *5.3.3 Mean values of BOP Wits appraisal*

This present study found mean values for the BOP Wits of -1.48 ± 2.75 mm in the normal overbite group, 2.27 ± 2.79 mm in the deep bite group and -2.91 ± 4.70 mm in the open bite group. In comparison, Foley et al. (1997) found 2.97 mm ± 1.74 in Class II div 1 subjects (Foley, Stirling et al. 1997) and Palleck et al. (2001) showed mean values of -1.61 ± 2.61 mm in skeletal Class I patients and -6.69 ± 2.64 mm in Class III subjects (Palleck, Foley et al. 2001). Moreover, Thayer et al. (1990) found a mean value of 4.1 ± 3.0 mm in a sample of 35 skeletal Class II division 1 males (Thayer 1990) (Table 5.2).

| DIFFERENT MEAN VALUES OF THE BOP WITS MEASUREMENTS | |
|---|---|
| Provencal, 2016 | -1.48 mm ± 2.75 (normal overbite)<br>2.27 mm ± 2.79 (deep bite)<br>-2.91 mm ± 4.70 (open bite) |
| Foley, 1997 | 2.97 mm ± 1.74 (skeletal class II div 1) |
| Palleck, 2001 | -1.61 mm ± 2.61 ( skeletal Class I)<br>-6.69 mm ± 2.64 (skeletal Class III) |
| Thayer, 1990 | 4.1 mm ± 3 (skeletal Class II division 1 males) |

*Table 5.2 Summary of the BOP Wits mean values cited in the literature*

Among all these studies, it is possible to notice a certain trend. The BOP Wits mean values were generally more positive than the FOP Wits values. However, in this study, we demonstrated that in one situation, this seemed not to be true. In the control group, the FOP Wits mean value was slightly higher than the BOP Wits value but according to the Paired t-test used to calculate the difference between the mean values of the FOP Wits and BOP Wits, the results showed no statistical difference (p=0.25) between these mean values in the normal overbite group. This could be explained by two factors. The functional occlusal plane is highly influenced by the depth of the curve of Spee. Also, the bisecting occlusal plane is mostly influenced by the amount of overbite. With our sample, we could extrapolate that subjects with normal overbite generally had a flat curve of Spee. Thus, the two planes were traced closely to each other.

In addition, the same distribution of the mean values found between the groups with the FOP Wits appraisal, was demonstrated with the BOP Wits. We found more negative mean values in the open bite group and positive values in the deep bite group. Our results are similar to the norms established by Jacobson in 1975. Jacobson (1975) suggested that in skeletal class II jaw discrepancies, one would obtain a more positive reading whereas in skeletal Class III jaw disharmonies, the Wits reading would be negative and lower than -1 mm ± 1 (Jacobson 1975).

### *5.3.4 Mean values of MMB Wits appraisal*

We found mean values for the MMB Wits of -4.96 ± 3.37 mm in the normal overbite group, -0.26 ± 2.59 mm in the deep bite group and -6.91 ± 4.51 mm in the open bite group. In comparison, Hall-Scott's cross-sectional study reported a mean MMB Wits value of approximately -4 mm for children and -4.5 mm for adults with normal occlusions (Hall-Scott 1994). Comparatively, Palleck et al. (2001) found a mean MMB Wits value of approximately -4.5 mm for children (aged 12 years) and -5.5 mm for older adolescents (aged 16 years) with class I malocclusion. They also established a mean MMB Wits value in a Class III sample of approximately –8.5 mm for children and –9.8 mm for adolescents (Palleck, Foley et al. 2001). Finally, Foley et al. (1997) showed MMB Wits mean value of 1.13 ± 1.27 for Class II div 1 patients (Table 5.3).

| DIFFERENT MEAN VALUES OF THE MMB WITS MEASUREMENTS | |
|---|---|
| Provencal, 2016 | -4.96 mm ± 3.37 (normal overbite)<br>-0.26 mm ± 2.59 (deep bite)<br>-6.91 mm ± 4.51 (open bite) |
| Hall-Scott, 1994 | -4 mm (Children, Class I)<br>-4.5 mm (Adults, Class I) |
| Foley, 1997 | 1.13 mm ± 1.27 (skeletal class II div 1) |
| Palleck, 2001 | -4.5 mm (Children, Class I)<br>-5.5 mm (Adolescents, Class I)<br>-8.5 mm (Children, Class III)<br>-9.8 mm (Adolescents, Class III) |

*Table 5.3 Summary of the MMB Wits mean values cited in the literature*

According to Palleck et al. (2001), the mean MMB Wits values for Class I, Class II, and Class III populations were distinct and displayed a triphasic distribution for easy classification (Palleck, Foley et al. 2001). In our study, we also found a triphasic distribution between the normal overbite, increased and decreased overbites. In addition, mean MMB Wits values are consistently more negative than the mean FOP Wits and BOP Wits values which follow the trend that was demonstrated previously by many authors (Hall-Scott 1994, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001).

### *5.3.5 Comparison of the mean values between the three Wits appraisals*

There were two situations where the FOP Wits and the BOP Wits appraisals had no statistical differences in their mean values; in the control group ($p=0.25$) as well as the deep bite group ($p=0.76$). All of the other combinations demonstrated statistically different means ($p<0.05$). In the sample of deep bites, the Curve of Spee was probably accentuated which might have created a similar inclination of the bisecting occlusal plane and the functional occlusal plane. Considering that we did not take into consideration the depth of the Curve of Spee while selecting the sample, it is only extrapolation. In the control group, the FOP Wits mean value is not statistically different than the BOP Wits value. As mentioned before, this could be explained by the absence of a Curve of Spee, as well as of a favorable overbite that makes the two planes almost coincident.

Additionally, the functional occlusal plane tends to present negative Wits appraisal values, compared to measurements to the bisected occlusal plane, since the FOP rotates more clockwise (Tanaka, Ono et al. 2006).

### *5.3.6 Mean values by gender*

The potential effect of gender was examined in Tables 4.7 and 4.8 and Figures 4.5, 4.6 and 4.7. No discernible differences were noted in the general trends of any of the cephalometric measurements. However, there were statistically significant differences found in the mean values of the Wits measurements. In the three different groups of overbite, females had significantly ($p=0.0001$) larger mean MMB Wits (2.2 mm) values than the males. Similarly, the FOP Wits mean values were larger for the females with an average mean of 1.4 mm more positive than the males. This finding concurred with the gender difference established by Jacobson (1975) (Jacobson 1975). Finally, the same result has been illustrated with the BOP Wits appraisal. The mean values in the three groups showed statistically significant differences ($p<0.05$) for gender (p=0.002). Females had on average mean values of 1.7 mm more positive than the males which was statistically significant (p=0.002).

These difference were deemed to be clinically significant and it does suggest that the females, on average, have more a convex profile type than males which has been extensively reported in the literature (Bishara, Fahl et al. 1983, Burstone 1998, Proffit 2013). This finding is also important to take into consideration as past research has shown that changes in the ANB angle as low as 3° can impact linear extrapolations such as Wits type analyses (Rushton, Cohen et al. 1991). Moreover, Thayer et al. demonstrated that an error of 5° in the inclination of the occlusal plane may change the Wits appraisal by 3-6 mm, depending on the vertical dimensions of the face (Thayer 1990).

## 5.4 Correlation between the three Wits measurements (FOP, BOP, MMB)

### *5.4.1 Correlation between BOP Wits and FOP Wits*

Moderate correlations were found between the BOP Wits and FOP Wits appraisals ranging from 0.71 to 0.80. This finding is similar to what Thayer et al. found in 1990 (Table 5.4). They looked at lateral cephalometric radiographs of 35 males and showed a correlation of r=0.84 between the functional occlusal plane and the bisected occlusal plane (Thayer 1990). The slight difference between these correlations might be explained by the chosen sample size's criteria. Thayer, despite finding good correlations with both occlusal planes (FOP and BOP) warned that in patients with deep bite in a mixed dentition stage, the BOP may vary significantly from the FOP of the permanent and primary molars (Thayer 1990). Deep overbite alone does not seem to introduce major differences in the Wits appraisal with functional and bisecting occlusal planes. However in deep Curve of Spee patients, this difference can be clinically significant (Nizam 2014).

### *5.4.2 Correlation between FOP Wits and MMB Wits*

In this study, the poorest correlations were found between the FOP Wits values and the MMB Wits values ranging from r=0.56 in the deep bite group to r=0.69 in the open bite group (Table 5.4). This result suggests that the functional occlusal plane is mainly influenced by the dentoalveolar bases. On the opposite, the maxillo-mandibular bisector is independent of the dental bases and only related to the skeletal components which would explain the poor correlations between these two Wits appraisals. This finding supports the conclusions from Tanaka et al. (2006) who reported that the FOP Wits was mainly representing the relationship between the dentoalveolar components of the jaws. As the FOP Wits appraisal relies on dento-alveolar structures to describe a skeletal relationship, it has been shown to be profoundly influenced by a change in the inclination of the FOP caused by growth or orthodontic treatment (Hussels and Nanda 1984, Sherman, Woods et al. 1988, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). The MMB does not depend on the teeth and thus eradicated various associated issues with identification such as: mixed dentition, unerupted or crowded teeth, missing teeth, severe curves of Spee, dental restorations or molar overlap.

### *5.4.3 Correlation between BOP Wits and MMB Wits*

The best agreements were found between the BOP Wits and the MMB Wits ranging from r=0.78 to r=0.89 (Table 5.4). Horowitz and Hixon 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″ (Horowitz, Hixon et al. 1966). Correlation between the BOP Wits and MMB Wits demonstrated correlation coefficients of r>0.78, indicating the possibility of interchanging their use as assessing skeletal jaw discrepancy in all types of overbite. This finding concurs with the study of Tanaka et al. (2006) which showed that the bisected occlusal plane rotates in the same fashion as the skeletal bases resulting in more correlation with the skeletal parameters compared to the FOP Wits (Tanaka, Ono et al. 2006)

| **SUMMARY OF THE CORRELATIONS BETWEEN THE WITS APPRAISALS** | |
|---|---|
| FOP and BOP Wits | Provencal, 2016: 0.71 to 0.80<br>Thayer, 1990: 0.84 |
| FOP and MMB Wits | Provencal, 2016: 0.56 to 0.69<br>Hall-Scott, 1994: 0.08 to 0.38 |
| BOP and MMB Wits | Provencal, 2016: 0.78 to 0.89<br>Hall-Scott, 1994: 0.45 to 0.47 |

*Table 5.4: Summary of the Wits correlations cited in the literature*

### *5.4.4 Correlation of the Wits appraisals by gender*

The data were assessed by separating the cephalometric measurements based on gender, as seen in Tables 4.10 and 4.11. No statistical difference was seen in the Intraclass Correlation Coefficients between the different Wits measurements in both males and females. The correlations were generally moderate to high ranging from r=0.52 to r=0.90 for the females and from r=0.56 to r=0.85 for the males. Overall, the strongest correlations were found between BOP Wits and MMB Wits with agreements of r>0.82 for the females and r>0.76 for the males. Therefore, these data had the same tendency as the data when genders were combined. No differences can be demonstrated. In addition, the agreement values are lower between FOP Wits and MMB Wits appraisals. The same conclusions were drawn with the complete sample.

In summary, the correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to each other were generally moderate to high ranging from r=0.56 to r=0.89. Overall, the strongest correlation was found between BOP Wits and MMB Wits appraisals in the open bite group (r=0.89) and the lowest agreement was found between FOP Wits and MMB Wits in the deep bite group (r=0.56). These findings demonstrate that the bisecting occlusal plane is closely related to the skeletal parameters and on the contrary, the functional occlusal plane is more related to the dental parameters. Secondly, the open bite group had higher correlations for every paired Wits measurements. This could be explained by the absence of an increased Curve of Spee that greatly influences the functional occlusal plane. Moreover, we could extrapolate that in our sample of open bite patients, the position of the teeth was more consistent with the true position of the jaws than in normal and deep bite subjects, meaning that the main cause of the open bite was skeletal rather than dental. The teeth were more leveled than in the two other groups.

## 5.5 Correlation between the ANB angle and the different Wits appraisals

### *5.5.1 Correlation between ANB angle and FOP Wits measurement*

In the present study, the correlations found between the ANB angle and the functional occlusal plane Wits measurements (FOP Wits) were low (r= 0.39 to 0.50*).* The FOP Wits was also the assessment tool that was the least correlating to the ANB angle. Thayer et al. (1990) compared the correlation of the FOP Wits to the ANB angle and concluded that the highest correlation to the ANB was found by the functional occlusal plane Wits as illustrated by the following correlation values (FOP ANB: r= 0.76), which was not demonstrated in our study. Foley et al. (2001) found correlation of r=0.22 for FOP ANB in Class I patients. They also showed a correlation of r=0.35 for FOP ANB for skeletal class III patients which represents correlations similar to our findings. Tanaka et al. (2006) found that the correlation between the functional occlusal plane and the ANB angle (r=0.45) was lower than the one between the bisecting occlusal plane and the ANB angle (r=0.62) (Tanaka, Ono et al. 2006) which concurs with our result. What is interesting to note is the very low correlation between the ANB angle and FOP Wits appraisal especially in the control group (r=0.39). These findings suggest that FOP Wits may not be a viable measurement method if the goal is to compare the finding to the ANB angle in any types of overbite.

### *5.5.2 Correlation between ANB angle and BOP Wits measurement*

In our research, we found correlations ranging from 0.60 to 0.72 which is comparable to numerous former studies. Foley et al. (1997) also found a correlation of r=0.53 for the BOP-ANB in Class I patients. Moreover, they found a lower correlation for skeletal Class III patients which was r=0.32 (Foley, Stirling et al. 1997). In addition, Tanaka (1999) found a correlation between the bisecting occlusal plane and the ANB angle of r=0.62 (Tanaka, Ono et al. 2006). Thayer et al. (1990) demonstrated a correlation value of r=0.68 (Thayer 1990). Del Santo et al. (2006) looked at 122 patients with high and low angle. They concluded an overall correlation of BOP-ANB of r=0.76 (Del Santo 2006). Ishikawa et al. found a correlation coefficient of r=0.57 values in skeletal Class I patients (Ishikawa, Nakamura et al. 2000) which was comparable to the agreement noted by Richardson (r = 0.67) and Jarvinen (r = 0.62) (Richardson 1982, Jarvinen 1988). In contrast, Oktay et al. (1991) studied 145 cephalograms from 63 male subjects and 82 female subjects and reported strong correlation (r= 0.76) among the BOP Wits analysis and the ANB angle (Oktay 1991). No description of the patients' malocclusion was mentioned.

Zamora et al. (2013) evaluated the correlation between the Wits appraisal (to the bisected occlusal plane) and the ANB angle using CBCT imaging (Zamora, Cibrian et al. 2013). They showed a very low correlation of r=0.26. Additionally, they found that in the 45 patients in whom the ANB angle and BOP Wits appraisal did not correlate, 49% of these subjects had a mandibular plane angle that was considered to be within the range of normal (i.e. a mesognathic facial type). These authors did not find any relationship between the mandibular plane angle and the ANB angle (r=.04), similar to the conclusions drawn from Hussels (1984) and Nanda (1971), nor did they determine a significant correlation between the mandibular plane angle and Wits appraisal (r=0.24) (Nanda 1971, Hussels and Nanda 1984).

### *5.5.3 Correlation between ANB angle and MMB Wits measurement*

Correlations of the maxillo-mandibular bisector Wits appraisal to the ANB angle were somewhat larger (r=0.57 to 0.74) than with the FOP Wits, this finding being similar to what Palleck et al. (2001) and Foley et al. (1997) concluded (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). However, the correlations of the MMB Wits and the BOP Wits to the ANB angle were similar, which differed from former studies comparing them (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001).

In the present study, the highest correlation to the ANB angle was with the MMB Wits appraisal in the open bite group (r=0.74). According to the ANB angle, in that specific group, there were 23 patients with a class I skeletal pattern, 14 patients with a class II skeletal pattern and 13 with a skeletal Class III relationship. Our finding seems different to the ones presented by Swoboda (2013), Hall-Scott (1994) and Palleck (2001). Swoboda found that the highest correlations with the ANB angle were between the ANB angle and MMB Wits appraisal in a sample of Class I subjects (r=0.60) (Swoboda 2013). This conclusion was also drawn from the findings of Palleck et al. (2001) 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 (Palleck, Foley et al. 2001). Therefore, in this study, to obtain the same results as those previous studies, the highest correlation should have been between the MMB Wits and the control group considering that this group was highly comprised of patients with a skeletal class I relationship (60% of the group) compared to the open bite group which included only 46% of class I skeletal individuals. However, our current research, the sample size was larger; a sample size calculation to establish 80% power was taken into consideration to create the ideal sample, which has not been done with many previous similar studies.

As mentioned before, Horowitz and Hixon 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″ (Horowitz, Hixon et al. 1966). In this research, the results demonstrated correlation coefficients to the ANB angle of less than r=0.8, indicating a lack of interchangeability in their use as assessing skeletal jaw discrepancy. In theory, as the ANB angle and Wits appraisal evaluate the same anteroposterior relationship of the maxilla and mandible, they should have a high correlation. A weak correlation between the ANB angle and Wits appraisal has been demonstrated in numerous studies (Rotberg, Fried et al. 1980, Bishara, Fahl et al. 1983, Chang 1987, Jarvinen 1988, Thayer 1990, Gul e and Fida 2008) suggesting that differences between these two assessment tools of jaw discrepancies often occur, likely due to a weakness in at least one of the parameters. Because of the general higher correlation between the different Wits appraisal measurements (FOP Wits, BOP Wits, MMB Wits) ranging from r=0.56 to r=0.89 , which are independent of Nasion, it is suggested that the poor correlations shown with the ANB angle may at least be attributed to the position of Nasion, which tends to change throughout growth moving forward and upward (Zamora, Cibrian et al. 2013).

Several studies have looked at the anteroposterior jaw relationships and have tried to evaluate the level of correlation in comparison to the gold standard, the ANB angle (Tanaka, Ono et al. 2006). The measurements that correlate well with the ANB angle, in a positive (same direction) or negative (opposite direction) fashion, could permit orthodontists to utilize that measurement as an adjunct to the ANB angle or as an alternative if the ANB measurement cannot be accurately traced. The aim of this study was to assess which of the Wits type measurements – MMB Wits, FOP Wits, or BOP Wits - best correlates with the ANB angle in a sample population of normal, increased or decreased overbites. Hall-Scott et al. (1994) assessed 36 adults with skeletal Class I and 43 children with malocclusions (no distinction of Angle or skeletal classification given) and concluded that the MMB Wits measurement showed great correlation with the ANB angle in adults (r = 0.83) and in children (r = 0.95) (Hall-Scott 1994). Palleck et al. (2001) studied 35 Class I and 10 Class III subjects and found the correlation between the ANB angle and the MMB Wits measurement to be lower in orthodontically treated cases (r = 0.69) as well as in controls (r = 0.67) (Palleck, Foley et al. 2001). Similar results were established by Foley et al. when assessing Class II Division 1 patients who had receive orthodontic treatments (r=0.63), although they found stronger correlations to the ANB angle amongst the control group (r = 0.85) (Foley, Stirling et al. 1997). Foley et al. (1997) also found a correlation of r= 0.69 for MMB-ANB in Class I patients and correlation of r=0.40 for skeletal class III patients.

The trends found by Foley (1997) and Palleck (2001) in their studies were also found in ours.  Generally, the correlation between ANB and the MMB Wits were moderate. However, the present study has also demonstrated that a similar correlation was obtained between the BOP Wits and the ANB angle, a finding that differs from what Palleck et al. (2001) and Foley et al. (1997) concluded (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001)

| SUMMARY OF THE CORRELATIONS BETWEEN THE WITS APPRAISALS AND ANB ANGLE | | |
|---|---|---|
| **ANB and FOP Wits** | Provencal, 2016 | 0.39 to 0.50 |
| | Thayer, 1990 | 0.76 |
| | Tanaka, 2006 | 0.45 |
| | Foley, 1997 | 0.22 (skeletal Class I)<br>0.35 (skeletal Class III) |
| | Gul, 2008 | 0.42 |
| | Roetberg, 1980 | 0.08 to 0.62 |
| **ANB and BOP Wits** | Provencal, 2016 | 0.60 to 0.72 |
| | Zamora, 2013 | 0.26 |
| | Del Santo, 2006 | 0.76 |
| | Ishikawa, 2000 | 0.57 (skeletal Class I) |
| | Richardson, 1982 | 0.67 |
| | Jarvinen, 1988 | 0.62 |
| | Oktay, 1991 | 0.76 |
| | Thayer, 1990 | 0.68 |
| | Tanaka, 2006 | 0.62 |
| | Foley, 1997 | 0.53 (skeletal Class I)<br>0.32 (skeletal Class III) |
| | Bishara, 1983 | 0.60-0.63 (males vs females) |

| SUMMARY OF THE CORRELATIONS BETWEEN THE WITS APPRAISALS AND ANB ANGLE | | |
|---|---|---|
| **ANB and MMB Wits** | Provencal, 2016 | 0.57 to 0.74 |
| | Swoboda, 2013 | 0.60 (skeletal Class I) |
| | Palleck, 2001 | 0.54 to 0.69 (skeletal Class I) |
| | Hall-Scott, 1994 | 0.83 (adults)<br>0.95 (children) |
| | Foley, 1997 | 0.63 to 0.85 (skeletal Class II div 1)<br>0.69 (skeletal Class I)<br>0.40 (skeletal Class III) |

*Table 5.5 Summary of the correlations between the ANB angle and the different Wits appraisals*

### *5.5.4 Correlation between ANB angle and Wits measurements by gender*

The data were then assessed by separating the cephalometric measurements based on gender, as depicted in Tables 4.13 and 4.14. No statistical difference was seen in the Spearman Correlation Coefficients for both males and females. The correlations were generally low to moderate ranging from 0.24 to 0.76 for the females and from 0.28 to 0.68 for the males. Overall, BOP Wits and MMB Wits appraisals had similar correlation to the ANB angle. Therefore, these data follow the same trend as the data when genders were combined.

Based on the findings of this study, the general guidelines should suggest that caution must be exercised in trying to relate any of MMB Wits, FOP Wits, or BOP Wits to the gold standard of the ANB angle. No measurement showed a high level of correlation with the ANB angle and all were at a low to moderate level. The results do suggest that FOP Wits is not a viable alternative to the ANB angle for all types of overbite subjects. However, this research supports the ability to interchange MMB Wits and BOP Wits as a mean of evaluating sagittal jaw discrepancies in all types of overbites. The high level of correlation between the BOP Wits and the MMB Wits has demonstrated that their difference in measurement will likely not create a significant difference in a clinical context.

### 5.6 Error in the study

The capability of this study to accurately measure the correlation between these cephalometric assessment tools is greatly influenced by precise landmark identification and cephalometric images of high quality. The difficulty in identifying proper landmark location caused by poor lateral cephalogram quality and individual anatomic variation was a potential source of error in this research. Some landmarks can be more difficult to identify than others (Baumrind and Frantz 1971) and, as a result, some discrepancies in particular measurements may have occurred. In addition, the use of a constructed plane (MMB) requires that it be drawn at a specified inclination, as opposed to connecting two distinct points, it does allow for a reduction in accuracy (Proffit 2013). The error study done suggested that there was a very high level of reliability for all of the measurements used, meaning the potential impact of these errors was likely low.

A positive of this study is that sufficient power was chosen for the groups. Earlier power studies suggested the need for 47 individuals in each group (Swoboda 2013). The ability to obtain sufficient power of 80% a priori means that the risk of type II error is decreased.

The very nature of the graduate orthodontic program from which the cases were selected introduces selection bias that impacts the ability to extrapolate the findings of this study to a global scale. Severity of malocclusion, growth patterns and overbite have been shown to vary, depending on the ethnic background of the individual (Proffit, Fields et al. 1998). The results found in this population sample suggest that there may not be a good correlation with similar studies done in non-Caucasian regions of the world.

### 5.7 Futures studies

A further potential area for a research should be on establishing a measurement that integrates the rotational effects that happen with growth of the maxillo-mandibular complex (Neela, Mascarenhas et al. 2009, Kumar, Valiathan et al. 2012, Bhad, Nayak et al. 2013). The MMB Wits measurement does account for changes in the position of Nasion, but can be influenced by the rotation of the mandible. A downward and backward clockwise rotation is commonly seen in vertical patients and this would modify the B point extrapolation as well as the bisector itself. Therefore, an alternative study could take into consideration the impact of the vertical nature of growth and treatment effects on the MMB Wits appraisal. Some angles have been proposed in the literature such as the W-angle (Figure 5.1) and the YEN angle (Figure 5.2). The W-angle uses three skeletal landmarks – point S, point M, and point G – to measure an angle that indicates the severity and the type of skeletal dysplasia in the sagittal dimension. Point S is defined by the midpoint of the sella turcica. Point M is defined by the midpoint of the premaxilla and Point G is defined by the centre of the largest circle that is tangent to the internal inferior, anterior, and posterior surfaces of the mandibular symphysis (Bhad, Nayak et al. 2013). This angle showed that a patient with a W-angle between 51° and 56° can be considered to have a Class I skeletal pattern (Bhad, Nayak et al. 2013). The Yen analysis uses the same landmarks as the W-angle but measures a wider angle as shown in Figure 5.2 (Neela, Mascarenhas et al. 2009). They both seem to address the rotational issue of the jaws, however, to date there have not been any published research which accounts for the influence of growth on these assessment tools and questions have been raised regarding the accuracy and validity of the landmarks utilized (Neela, Mascarenhas et al. 2009, Bhad, Nayak et al. 2013). Research utilizing this data set evaluating the YEN and W angles could facilitate the identification of the best method of correlating the maxillo-mandibular sagittal relationship to the present gold standard of the ANB angle. In addition, these assessment tools may demonstrate to be more reliable amongst all types of malocclusions and more tolerant of growth, possibly leading to them being accepted by the orthodontic community as the potential new gold standard.

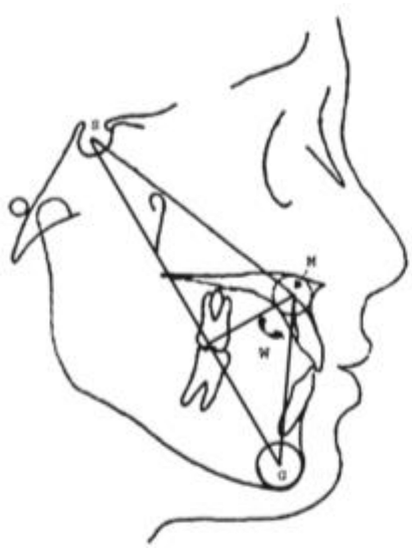



*Figure 5.1* W- angle

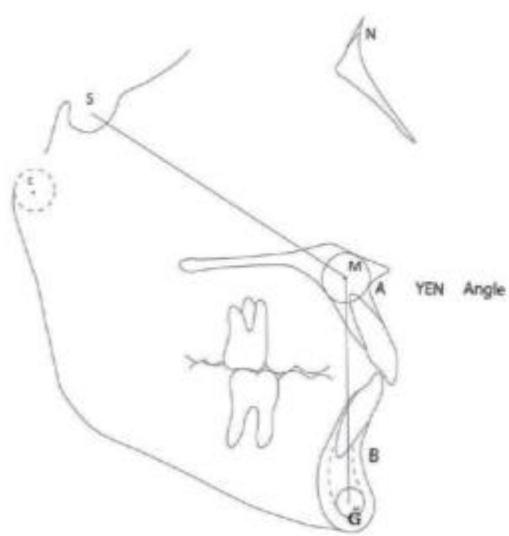



*Figure 5.2* Yen angle

Moreover, it would be interesting to assess whether a different bisector plane would better correlate with the ANB angle and therefore be utilized as an alternative technique for assessing the anteroposterior relationship of the jaws, while not being influenced by the changes due to orthodontic treatment and growth. Thus, a plane that would utilize more reliable landmarks and incorporate the potential changes in the position of Nasion which is also reflected in the gold standard of ANB angle.

This research was needed because orthodontists make decisions depending on correct diagnosis. Treatment objectives and treatment plans are greatly driven by cephalometric assessment. If diagnosis is inadequate, treatment plans can be incorrect, and treatment times might be increased. More consequences, such as parental and patients disappointment, are also common.

**5.8 Revisiting the null hypotheses**

The null hypotheses for this study stated that:

1. There is no statistically significant difference between the 3 sagittal reference planes (FOP, BOP, MMB) in the Wits mean values. This first hypothesis is rejected. Statistical differences are found between the mean values of all of them except between the FOP Wits and BOP Wits mean values in patients with normal or deep bites.

2. There is no statistically significant difference between the Wits correlation values when comparing 3 different sagittal occlusal planes (FOP, BOP, MMB). This second hypothesis is rejected. Differences are found between the Wits measurements and their correlation.

3. There is no statistically significant difference between the Wits and ANB's correlation values when comparing 3 different sagittal occlusal planes (FOP, BOP, MMB). This second hypothesis is only partially supported. Differences in the correlations are found between the FOP Wits-ANB correlation compared to the BOP Wits and the MMB Wits correlations to the ANB angle. However, no difference was found between the BOP Wits and the MMB Wits correlations to the ANB angle. As a whole, this second hypothesis is rejected.

# CHAPTER 6

# CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions

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

1. The Wits appraisal using the MM bisector is a valid indicator of the anteroposterior skeletal discrepancy. The MMB Wits had a higher correlation coefficient to the ANB angle than the FOP Wits, further reinforcing its validity.

2. As a general guideline, caution must be exercised in trying to relate any of MMB Wits, FOP Wits, or BOP Wits to the gold standard of the ANB angle. No measurement has a high level of correlation with the ANB angle.

3. The results show that FOP Wits is not a viable alternative to the ANB angle for all types of overbite subjects, as the correlations were $r<0.50$.

4. Gender does not influence the correlation between the ANB angle and the different Wits measurements.

5. Gender does not influence the correlation between the three Wits measurements (FOP, BOP, MMB).

6. Gender is a significant determinant of the mean values of the ANB angle, the MMB Wits, the BOP Wits, or the FOP Wits measurements with females having constantly more positive values.

7. The functional occlusal plane is the least reliable occlusal plane to trace while the maxillo-mandibular is the most reliable.

## 6.2 Recommendations

It is recommended that:

1. The Wits measurements be used in addition to the ANB angle because they are not considered interchangeable as demonstrated by the correlation coefficients being relatively low. These findings explain the discrepancies that are present in some cases between the measured values of the ANB angle and the clinical judgment of the orthodontist.

2. The MMB Wits or the BOP Wits be used in preference to the FOP Wits if the goal is to correlate the measurement with the ANB angle.

3. The MMB Wits and the BOP Wits be used interchangeably in all patients to calculate the sagittal jaw discrepancy of a patient.

4. In open bite patients, if the BOP Wits is traced, the mean value established by Jacobson should not be used because a statistically significant difference is present between the FOP Wits' mean value and the BOP Wits' mean value.

## 6.3 Future studies

1. Knowing that the BOP has different mean values in certain situations, it would be important to establish its own mean value in skeletal Class I, II and III as it has been calculated with the ANB angle and the original Wits analysis.

2. An interesting research could also be to establish the mean value by gender for the ANB angle. This study showed that there is a difference of 2° between males and females. Jacobson did establish that difference with the Wits analysis and the ANB seems to have that same tendency. Therefore, it should be taken into consideration while assessing our patients.

3. Another potential area for research could be on establishing a measurement that integrates the rotational effects that happen with growth of the maxillo-mandibular complex.

4. In this study, the Curve of Spee was not taken into account. Perhaps a future study would consider samples with similar Curve of Spees and how different curves might influence the different Wits analyses.

5. Moreover, it would be interesting to assess whether a different bisector plane would better correlate with the ANB angle and therefore be utilized as an alternative technique for assessing the anteroposterior relationship of the jaws, while being not influenced by the changes due to orthodontic treatment and growth. Then, it could be possible to assess the changes in class I, class II and class III samples with this new Wits appraisal.

# CHAPTER 7

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# CHAPTER 8

# APPENDICES

## 8.1 ETHICS APPROVAL

HEALTH RESEARCH ETHICS BOARD (HREB)
CERTIFICATE OF FINAL APPROVAL FOR NEW STUDIES
Delegated Review

| PRINCIPAL INVESTIGATOR:<br>Dr. V. Provencal | INSTITUTION/DEPARTMENT:<br>U of M/Preventive Dental Science/Orthodontics | ETHICS #:<br>H2015:266 (HS18695) |
|---|---|---|
| APPROVAL DATE:<br>September 3, 2015 | EXPIRY DATE:<br>**Sepember 3, 2016** | |
| STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable):<br>Dr. W. Wiltshire | | |

| PROTOCOL NUMBER:<br>NA | PROJECT OR PROTOCOL TITLE;<br>Reliability of 3 Sagittal Reference Planes using the WITS Analysis in the Assessment of Openbite and Deepbite Subjects |
|---|---|
| SPONSORING AGENCIES AND/OR COORDINATING GROUPS:<br>NA | |

| Submission Date of Investigator Documents:<br>June 8 and August 27, 2015 | HREB Receipt Date of Documents:<br>June 15 and August 28, 2015 |
|---|---|

THE FOLLOWING ARE APPROVED FOR USE:

| Document Name | Version(if applicable) | Date |
|---|---|---|
| **Protocol:** | | |
| Revised REB Submission Form dated August 27, 2015 | | |
| **Consent and Assent Form(s):** | | |
| **Other:** | | |
| Master List | | submitted August 27, 2015 |
| Data Collection/Capture Sheet | | submitted August 27, 2015 |

**CERTIFICATION**

The above named research study/project has been reviewed in a ***delegated manner*** by the University of Manitoba (UM) Health Research Board (HREB) and was found to be acceptable on ethical grounds for research involving human participants. The study/project and documents listed above was granted final approval by the Chair or Acting Chair, UM HREB.

**HREB ATTESTATION**

The University of Manitoba (UM) Research Board (HREB) is organized and operates according to Health Canada/ICH Good Clinical Practices, Tri-Council Policy Statement 2, and the applicable laws and regulations of Manitoba. In respect to clinical trials, the HREB complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations of Canada and carries out its functions in a manner consistent with Good Clinical Practices.

**QUALITY ASSURANCE**

The University of Manitoba Research Quality Management Office may request to review research documentation from this research study/project to demonstrate compliance with this approved protocol and the University of Manitoba Policy on the Ethics of Research Involving Humans.

**CONDITIONS OF APPROVAL:**

1. The study is acceptable on scientific and ethical grounds for the ethics of human use only. ***For logistics of performing the study, approval must be sought from the relevant institution(s).***
2. This research study/project is to be conducted by the local principal investigator listed on this certificate of approval.
3. The principal investigator has the responsibility for any other administrative or regulatory approvals that may pertain to the research study/project, and for ensuring that the authorized research is carried out according to governing law.
4. **This approval is valid until the expiry date noted on this certificate of approval.** **A Bannatyne Campus Annual Study Status Report** must be submitted to the HREB within 15-30 days of this expiry date.
5. Any changes of the protocol (including recruitment procedures, etc.), informed consent form(s) or documents must be reported to the HREB for consideration in advance of implementation of such changes on the **Bannatyne Campus Research Amendment Form.**
6. Adverse events and unanticipated problems must be reported to the HREB as per Bannatyne Campus Research Boards Standard Operating procedures.
7. The UM HREB must be notified regarding discontinuation or study/project closure on the **Bannatyne Campus Final Study Status Report**.

## 8.2 JOURNAL ARTICLE

# Reliability of three reference planes in the assessment of open bite and deep bite subjects.

**Objectives:** To evaluate the reliability and accuracy of three anteroposterior reference planes applied in the Wits analysis and to correlate them to the ANB angle measurement.

**Materials and methods:** A retrospective chart review was undertaken on 150 subjects. Subjects were categorized into 3 groups based on the value of pre-treatment overbite; 50 normal (1-3 mm), 50 deep (more than 3mm) and 50 open bite (less than 1 mm) subjects. The maxillomandibular bisector (MMB) was used to evaluate the anteroposterior jaw discrepancy and compared to the Wits analysis and the ANB measurement using the bisecting occlusal plane (BOP) and the functional occlusal plane (FOP).

**Results:** The correlations of the Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to each other were moderate to high ranging from 0.56 to 0.89. The strongest correlations were found between BOP Wits and MMB Wits in the open bite group (r=0.89). Moreover, the correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to the ANB angle were low to moderate ranging from 0.39 to 0.76. The strongest correlation was found between MMB Wits and ANB angle in the open bite group (r=0.74).

**Conclusion**: The Wits appraisal using the maxillo-mandibular bisector is a valid indicator of the sagittal discrepancy. The MMB Wits had a higher correlation coefficient to the ANB angle than the FOP Wits, further reinforcing its validity. Caution must be exercised in trying to relate any of the Wits appraisal measurements to the gold standard of the ANB angle.

## INTRODUCTION

Over the last 50 years, numerous cephalometric measurements have been described to assess sagittal jaw discrepancy, and researchers have shown that intrinsic geometric factors influence the validity of the measurements [1-13]. Assessment of the anteroposterior jaw relationship is a primary component of the evaluation of an orthodontic patient and the establishment of a treatment plan. Hence, various linear and angular parameters have been added into cephalometric analyses, with the purpose of simplifying the diagnosis of sagittal discrepancies. The most commonly used of these analyses have been the Wits appraisal and the ANB angle [14-17].

Wits appraisal has received a mixed response from the orthodontic fraternity ever since it's popularization by Jacobson in 1975 and has been a continuing subject of debate. Several studies reported good correlation between Wits and ANB angle and therefore considered the Wits analysis as a good estimate of sagittal jaw relationship [12, 18]. In contrast, others reported a weak correlation and found errors predicting one from the other [13, 19, 20].

Jacobsen [(5, 21)] advocated the utilization of the FOP as a reference line and warned that the ANB angle measure may be arguable if the mandibular plane angle is greater than one standard deviation from the mean. Many authors [22-24] however, have found great variations in the Wits measurement calculated to the FOP. Rushton et al [23] suggested that the FOP was a challenging line to trace and led to large variations of 1 mm or more in the Wits measure. Nanda et al reported that mild changes in the occlusal plane's cant can cause major variations in Wits analysis [20]. The Wits analysis was created to provide clinicians with a parameter that relates both dental bases, bypassing the problem with cranial base inaccuracy, but its relationship to the FOP continues to shed doubt.

Reducing the inaccuracies associated with measuring the Wits parameter can enhance its validity and reinforce its supportive role in the assessment of true sagittal jaw relationship. Numerous analyses have been created trying to "correct" the Wits measure with mathematical tables [8, 12], geometric equations to account for skeletal changes [24] or new reference lines to which A and B point perpendiculars can be drawn [17, 25-27]. A new reference line, the maxillomandibular bisector (MMB), has demonstrated that its technique error implied in its construction is far lower compared to the bisecting occlusal plane (BOP) and the functional occlusal plane (FOP) [27, 28].

Because ANB angle and the Wits appraisal evaluate the same sagittal jaw discrepancy, they should have a good correlation. In fact, the agreement between them is not as accurate as expected; which implies weakness in at least one parameter [16].

The purpose of this investigation was to compare the reliability and validity of the Wits analysis using three different occlusal planes, the FOP, BOP and MMB, and to differentiate between patients exhibiting an increased, normal or reduced overbite. In addition, the correlation between the Wits and ANB values was analysed in the three situations.

**MATERIALS AND METHODS**

The retrospective patient sample was acquired from the archives of the University of Manitoba Graduate Orthodontic Clinic. Digital cephalograms were taken by residents and assistants as part of the patients' initial orthodontic records with a Kodak Panoramic/Cephalometric model CS 8000C. The chosen sample comprised 150 subjects (75 males, 75 females), which consisted of 75 patients presenting with a pretreatment Class I skeletal relationship (ANB = 0-4°), 54 patients with a Class II jaw relationship (ANB > 4°), and 21 patient with a Class III skeletal pattern (ANB < 0°) as shown in Table I. The mean age of the subjects was 13.1 (SD 1.48).

| Group | Gender | Angle classification | ANB angle | Overjet |
|---|---|---|---|---|
| Control | 25 F, 25 M | I: 34<br>II: 11<br>III: 5 | I: 30<br>II: 14<br>III: 6 | 1-2 mm : 16<br>>2 mm : 33<br><1 mm : 1 |
| Deep bite | 25 F, 25 M | I: 14<br>II: 36<br>III: 0 | I: 22<br>II: 26<br>III: 2 | 1-2 mm : 8<br>>2 mm : 42<br><1 mm : 0 |
| Open bite | 25 F, 25 M | I: 23<br>II: 6<br>III: 21 | I: 23<br>II: 14<br>III: 13 | 1-2 mm : 13<br>>2 mm : 20<br><1 mm : 17 |

*Table I. Summary for the three groups*

***Inclusion criteria***

- All skeletal patterns;
- All Angle molar classifications;
- All growth patterns;
- Fully erupted permanent dentition excluding third molars;
- No missing teeth in either arches;
- No impacted teeth;
- Accurate plaster dental models in maximum intercuspation.

The patients included in this research were categorized as having either an open bite, a deep bite or a normal overbite. Therefore, patients were classified as follow:

– Control group: overbite between 1-3 mm;
– Deep bite group: overbite more than 3 mm;
– Open bite group: overbite less than 1 mm.

The lateral cephalograms were labeled with a unique participant code for blinding purposes. All of the lateral cephalometric radiographs were digitally traced by the primary examiner (Virginie Provencal) using the Dolphin™ 11.7 imaging software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). Film magnification was standardized for each film, which matched an actual 30 mm ruler included in each film view. The radiographic technique established in the Graduate Orthodontic clinic assumed the following requirements; natural head position with the Frankfort horizontal parallel to the floor, correct orientation in cephalostat and correct exposure dosage and time. The images were then digitally traced. The linear and angular measurements used in this study are illustrated in Figure 1.

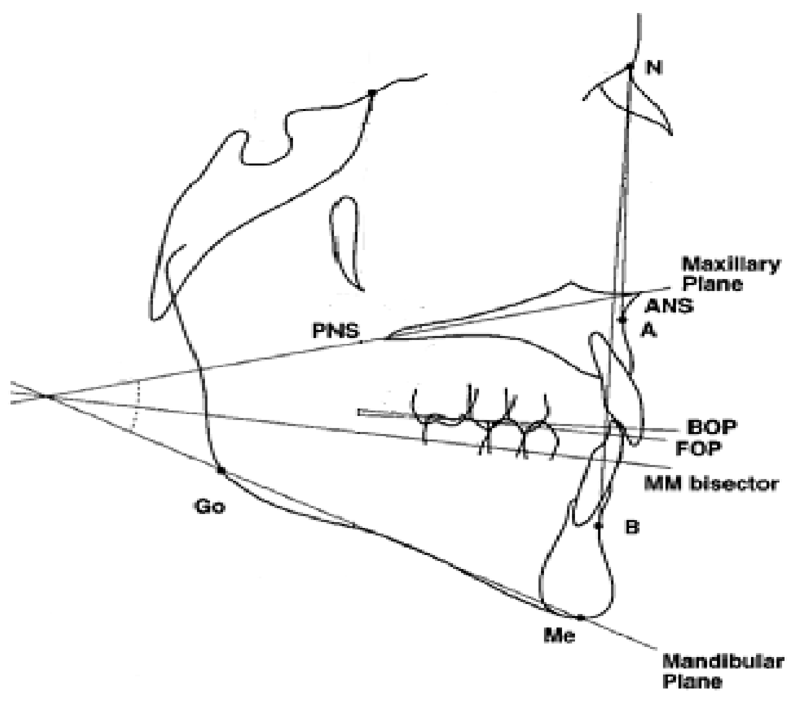


***Figure 1***

Plaster models from pre-treatment records were verified to ensure that the dates they were taken matched the dates of the corresponding cephalometric radiographs. The overbite measurement (mm) was performed on the plaster models. The amount of vertical incisor overlap was measured as a linear distance from the maxillary central incisors to the mandibular incisors. If there was a discrepancy in overbite between the two measurements of up to 2 mm, the greater of the two measurements was recorded. If this discrepancy was greater than 2 mm, the tooth that was deemed to be more malpositioned in relation to the other maxillary anterior teeth was excluded.

For intra-rater and inter-rater reliability, 10% of the sample were randomly selected to be re-measured by the primary examiner as well as a second independent examiner. Therefore, 15 lateral cephalometric radiographs and dental casts were re-measured at intervals 4 weeks apart from the initial measurement to identify landmark identification error.

***Statistical analysis***

For intra and inter-examiner reliability, the measurements were assessed using an interclass correlation coefficient (ICC) test on 10% of the sample included in the study at intervals 4 weeks apart from the initial measurement to identify landmark identification error. Statistical analysis also included a paired t-test for gender differences within groups. An ANOVA F-test was utilized to calculate the difference in age between the control group, the deep bite and the open bite groups. An unpaired t-test ($p<05$) was calculated to evaluate if there is a significant difference between the three groups. Pearson correlation coefficients were assessed to relate the ANB angle to the Wits values in every group. The p-value was considered significant at $\alpha<0.05$. For all statistical tests, *the* statistical software SAS 9.4 was utilized to evaluate the data.

## RESULTS

The ANOVA F-test was used to calculate the difference in age between the control group, the deep bite and the open bite groups. No significant difference ($p>0.05$) in the age of the subjects was found between the three groups, as shown in Table II ($p=0.17$). In addition, the mean values and standard deviations for the investigated pretreatment cephalometric measurements in the three groups are shown in Table III.

| ***Groups*** | ***Mean*** | ***Min.*** | ***Max.*** | ***SD*** |
|---|---|---|---|---|
| Control | 18.33 | 12 | 42 | 7.13 |
| Deep bite | 16.84 | 12 | 44 | 5.85 |
| Open bite | 19.49 | 12 | 59 | 7.99 |
| **Average** | 18.22 | 12 | 48.33 | 6.99 |
| **P value = 0.17** P<0.05 is statistically significant | | | | |

*Table II. Means and Standard Deviations in the three groups for age.*

| | **Control** | **Deep bite** | **Open bite** |
|---|---|---|---|
| Overbite (mm) | 2.00±0.57 | 5.64±1.38 | -1.29±1.49 |
| FOP Wits (mm) | -1.11±3.21 | 2.17±3.57 | -3.83±5.24 |
| BOP Wits (mm) | -1.48±2.75 | 2.27±2.79 | -2.92±4.70 |
| MMB Wits (mm) | -4.96±3.37 | -0.26±2.59 | -6.91±4.51 |
| ANB angle (deg) | 2.74±2.54 | 4.01±2.20 | 1.86±3.30 |

*Table III. Means and Standard Deviations in the three groups.*

The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to each other were generally moderate to high ranging from 0.56 to 0.89. The correlation values are depicted in Table IV. Overall, the strongest correlations were found between BOP Wits and MMB Wits in the open bite group (r=0.89).

| | **Groups** | | | |
|---|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** | **Average** |
| FOP Wits-BOP Wits | 0.71 | 0.74 | 0.80 | 0.75 |
| FOP Wits-MMB Wits | 0.60 | 0.56 | 0.69 | 0.62 |
| BOP Wits- MMB Wits | 0.83 | 0.78 | 0.89 | 0.83 |

*Table IV: Intraclass Correlation Coefficients for the three groups*

The correlations of the three Wits appraisals (FOP Wits, BOP Wits, MMB Wits) to the ANB angle were generally low to moderate ranging from 0.39 to 0.76. The correlation values are depicted in Table V. Overall, the strongest correlation was found between MMB Wits and ANB angle in the open bite group (r=0.74).

| | **Groups** | | | |
|---|---|---|---|---|
| | **Control** | **Deep bite** | **Open bite** | **Average** |
| FOP Wits – ANB | 0.39 | 0.50 | 0.45 | 0.45 |
| BOP Wits – ANB | 0.72 | 0.60 | 0.65 | 0.66 |
| MMB Wits – ANB | 0.68 | 0.57 | 0.74 | 0.66 |

*Table V. Spearman Correlation Coefficients between ANB angle and the different Wits measurements in the three groups*

## DISCUSSION

The Wits appraisal and the ANB angle are cephalometric measurements widely used to evaluate the sagittal discrepancy between the maxilla and the mandible [14-17]. However, there are significant shortcomings in both measurements. In our study, we first calculated the correlation between the different Wits appraisals. A weak correlation between them would demonstrate a great influence of the occlusal plane used in the measurement and the opposite would imply that the reference plane utilized has no importance. Moderate correlations were found between the BOP Wits and FOP Wits appraisals ranging from 0.71 to 0.80, the greatest correlation being in the open bite group. Our result is slightly different than what Thayer et al. found in 1990 (r=0.84). These authors looked at lateral cephalometric radiographs of 35 males without differentiating between the overbite types. Therefore, the difference between these correlations might be explained by the chosen sample size's criteria. However, Thayer et al. warned that in patients with deep bite, the BOP may vary significantly from the FOP which is a trend that we also found in our study. According to Nizam et al., deep overbite alone does not seem to introduce major differences in the Wits appraisal when measured to the functional and bisecting occlusal planes. However in deep Curve of Spee patients, this difference can be clinically significant [29].

In our study, the weakest correlations were found between the FOP Wits values and the MMB Wits values ranging from r=0.56 in the deep bite group to r=0.69 in the open bite group. This result suggests that the functional occlusal plane is mainly influenced by the dentoalveolar bases. In contrast, the maxillo-mandibular bisector measurement is independent of the dental bases and only related to the skeletal components which would explain the poor correlations between these two different Wits appraisals. This finding supports the conclusions from Tanaka et al. (2006) who reported that the FOP Wits was mainly representing the relationship between the dentoalveolar components of the jaws. As the FOP Wits appraisal relies on dento-alveolar structures to describe a skeletal relationship, it has been shown to be profoundly influenced by a change in the inclination of the FOP caused by growth or orthodontic treatment [8, 13, 27, 28]. The MMB does not depend on the teeth and the alveolus and thus eradicates various associated issues with identification such as: mixed dentition, unerupted or crowded teeth, missing teeth, severe Curves of Spee, dental restorations or molar overlap.

The best agreements were found between the BOP Wits and the MMB Wits ranging from r=0.78 to r=0.89. These favorable correlations indicate the possibility of interchanging their use as assessing skeletal jaw discrepancy in all types of overbite. This finding concurs with the study of Tanaka et al. (2006) which showed that the bisected occlusal plane rotates in the same fashion as the skeletal bases resulting in a higher correlation with the skeletal parameters compared to the FOP Wits [(30)].

Moreover, as the ANB angle and Wits appraisal evaluate both the same anteroposterior relationship of the maxilla and mandible, they should be expected to have a high correlation. In the present study, the correlations found between the ANB angle and the functional occlusal plane Wits measurements (FOP Wits) were low (r= 0.39 to 0.50) and the weakest correlation to the ANB angle. Our result is very similar to many other authors' findings [18, 27, 28, 30]. These findings suggest that FOP Wits is not a viable measurement method if the goal is to compare the finding to the ANB angle in any types of overbite.

In our research, we also found correlations between the ANB angle and the bisecting occlusal plane ranging from 0.60 to 0.72 which is comparable to numerous former studies [12, 16, 18, 30-33]. Foley et al. (1997) found a correlation of 0.32 to 0.53 depending on the skeletal pattern [27]. In contrast, Oktay et al. (1991) studied 145 cephalograms and reported strong correlation (r= 0.76) among the BOP Wits analysis and the ANB angle [17] but no description of the patients' malocclusion was mentioned.

Finally, the correlations of the maxillo-mandibular bisector Wits appraisal to the ANB angle were somewhat larger (r=0.57 to 0.74) than with the FOP Wits, this finding being similar to what Palleck et al. (2001) and Foley et al. (1997) concluded [27, 28]. However, the correlations of the MMB Wits and the BOP Wits to the ANB angle were very similar, which differed from previous studies comparing them [27, 28].

In our research, the results demonstrated correlation coefficients to the ANB angle of less than r=0.8, indicating a lack of interchangeability in their use for assessing skeletal jaw discrepancy[34]. Because of the higher general correlation between the different Wits appraisal measurements (FOP Wits, BOP Wits, MMB Wits) ranging from r=0.56 to r=0.89, which are independent of Nasion, it is suggested that the poor correlations shown with the ANB angle may be attributed to the varying position of Nasion, which tends to change throughout growth moving forward and upward [33, 35].

## CONCLUSIONS

- The Wits appraisal using the maxilla-mandibular bisector is a valid indicator of the anteroposterior skeletal discrepancy. The MMB Wits has a higher correlation coefficient to the ANB angle than the FOP Wits, reinforcing the validity of MMB.

- As a general guideline, caution must be exercised in trying to relate any of MMB Wits, FOP Wits, or BOP Wits to the gold standard of the ANB angle. None of the measurements have a high enough level of correlation with the ANB angle for complete diagnostic comfort.

- The results show that FOP Wits is not a viable alternative to the ANB angle for all types of overbite subjects, as the correlations were $r<0.50$.

- Good correlations ($r>0.78$) were found between the MMB and BOP Wits appraisals indicating that the use of either of these measures may be interchangeable in patients and should be used in preference to FOP Wits in all patients.

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