The Influence of Facial Pattern on Skeletal Class I Subjects- A Cephalometric Analysis

By

Caley Hoediono

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Dedication

Once upon a time, there was a little girl, who in the seventh grade, decided she wanted to become an Orthodontist. She believed that one day, like her mother, she would become a strong, independent woman who could achieve anything that she set her mind to. It has been a lifetime of hard work and sacrifice, tears of both joy and sadness, doubts as well as self-affirmations, many failures but also many successes. I dedicate this culmination of my efforts to every little girl in the world who has big dreams. With hard work and determination, you can do anything.

Abstract

Objective

The purpose of this study was to assess the correlations between the Wits appraisal (using maxillomandibular bisector as the occlusal plane), ANB analysis and facial pattern in skeletal Class I subjects

Materials and methods

A retrospective chart review was completed on 100 Class I subjects according to the ANB angle. The maxillomandibular bisector (MMB) was used as the occlusal plane to determine the anteroposterior maxillomandibular relationship according to the Wits appraisal. Four additional measurements (mandibular plane angle, Y-axis, lower facial height and facial axis) associated with facial pattern were measured to determine whether the Wits or ANB analysis is correlated in classifying skeletal and facial patterns

Results

A weak correlation was found between ANB and Wits ($r=0.38$) that was statistically significant ($p<0.05$). Correlations between ANB and all facial pattern measurements were also weak, but they were not statistically significant ($p>0.05$). Moreover, associations were found between Wits and facial pattern measurements ranging from low to high (-0.05 to 0.57) and were all statistically significant ($p<0.05$). The strongest correlations were between facial axis ($r=0.57$), MPA ($r=-0.46$) and Wits. A moderate correlation was found between lower facial height and Wits ($r=-0.331$). There were no substantive differences between males and females.

Conclusions

The Wits appraisal using the maxillomandibular bisector occlusal plane is a valid indicator of the anteroposterior discrepancy and facial pattern. Wits may be a more accurate predictor of facial pattern vs. ANB. However, caution must be exercised in trying to relate Wits appraisal to the gold standard of the ANB angle.

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Chapter 1

Introduction

Classification of skeletal disharmonies is one of the most important aspects of diagnosis and clinical orthodontics. Cephalometric analysis is used to diagnose jaw discrepancies in order to develop accurate and reliable treatment plans. However, no single analysis is considered sufficient to accurately describe the sagittal jaw relationship in every patient. As a result, the use of multiple analyses has been advocated for in the classification of anteroposterior jaw relationships in individual patients (Bishara, Fahl et al. 1983, Jacobson 1988, Sherman, Woods et al. 1988). However, there is also no universal consensus for the selection of the measurements which should be used.

Various analyses have been proposed with multiple linear and angular parameters, with the aim to simplify the diagnosis of the sagittal jaw discrepancies. Traditionally, the ANB angle has been used to compare the relationship of the denture bases to each other and to this day remains the gold standard (Jacobson 1975, Del Santo 2006). ANB is derived from measuring the angle between a line projected from Nasion to A point and Nasion to B point. In normal occlusions it is 2 ± 2 degrees. Angles greater than this indicate a class II jaw discrepancy and angles less than this indicate a class III skeletal base (Jacobson 1975). However, studies have identified deficiencies in the ANB angle due to variability in cranial base landmarks (Jacobson 1975, Palleck et al. 2001).

In 1975, Jacobson proposed an alternative method to diagnosing anteroposterior jaw relationships with the Wits appraisal. This was intended for use as a supplement to cephalometric diagnosis in classifying skeletal relationships. The primary advantage of this appraisal is that it does not rely on the use of cranial base landmarks. Traditionally, the Wits appraisal is measured by drawing the functional occlusal plane (a line through the region of maximum intercuspation) on a lateral cephalogram and projecting two lines from this plane through A and B points, respectively (AO and BO). The distance and direction between points AO and BO determine the sagittal jaw relationship. The average jaw relationship is 1mm in males and 0mm in females (Jacobson 1975).

The Wits appraisal has been demonstrated to provide a reliable and reproducible classification of jaw relationships and is frequently utilized in clinical orthodontics (Jacobson 1975 and 1988, Palleck et al. 2001, Del Santo 2006). However, the Wits appraisal is not without its shortcomings (Del Santo 2006, Zamora et al. 2013). First, since the functional occlusal plane is a dental reference, there is doubt as to whether it may be accurately used to classify skeletal relationships (Foley 1997). Moreover, the functional occlusal plane is difficult to locate and reproduce on the cephalogram due to various factors such as dental overlap, missing and malpositioned teeth and dental restorations (Foley 1997). As such, approaches to decrease the variation and error related to the Wits measurement have been investigated and include the following: mathematical tables to "correct" the Wits value (Hussels & Nanda 1984, Järvinen 1988), geometric equations to account for skeletal variations (Rotberg et al. 1980) and the use of alternative reference planes to which A and B point perpendiculars can be projected (Freeman 1981, Oktay 1991, Hall-Scott 1994, Foley et al. 1997); these planes include the Bisecting occlusal plane and the Maxillomandibular Bisector (Provencal 2016). The Maxillomandibular Bisector (MMB) in particular, has been demonstrated to have lower technique error and is easier to construct on lateral cephalograms, compared to other reference planes. It also has the advantage that it does not rely on the dentition or cranial base landmarks in its construction (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001).

Since its inception, Wits appraisal has received a mixed response from the orthodontic community and has been the subject of debate among experts in cephalometrics. Some studies reported good correlation between ANB angle and Wits appraisal and concluded that it was a good estimate of sagittal jaw relationships (Jarvinen 1988, Thayer 1990). However, many others found weak correlations and poor predictability between the two analyses (Sherman, Woods et al. 1988, Nanda and Merrill 1994, Nanda 2004).

Because the ANB angle and the Wits appraisal evaluate the same skeletal jaw relationships, theoretically they should have a strong correlation. However, the agreement between the two is not as strong as expected, implying weakness in at least one parameter (Del Santo 2006). Reducing the inaccuracies associated with both the ANB angle and Wits measurements can enhance their validity and reinforce their supportive roles in the assessment of anteroposterior jaw relationships. Therefore, a need still remains to determine these inaccuracies in order to overcome their shortcomings.

Chapter 2

Literature Review

2.1 Introduction of Cephalometry

Analysis of craniofacial patterns was first initiated by anthropologists and anatomists who recorded the various dimensions of ancient dry skulls. The measurement of these dry skulls from osteological landmarks, called craniometry, was then applied to living subjects so that a longitudinal growth study could be undertaken. This technique- the measurement of the head of a living subject from the bony landmarks- is called cephalometry (Athanasiou 1995). Cephalometry was later revolutionized by the discovery of x-rays by Roentgen in 1895 and subsequently, the lateral head film was introduced by Pacini in 1922 (Athanasiou 1995). In 1931, Broadbent and Hofrath were the first to introduce radiographic cephalometry to orthodontics (Damstra, Fourie et al. 2010). Their cephalograms were taken from the lateral side of the patient's head (Leonardi, Annunziata et al. 2008). They also used a head holder called a cephalostat to center the patient's head with the superior borders of the external auditory meatus resting on the upper parts of two ear-rods. The lowest point on the inferior bony border of the left orbit, was at the level of the upper parts of the ear-rods and the nose clamp was fixed at the root of the nose to support the upper part of the face. The lateral cephalometric radiograph (cephalogram) itself is the product of a two-dimensional image of the skull in a lateral view, enabling the relationship between teeth, bone, soft tissue and empty space to be scrutinized both horizontally and vertically (Athanasiou 1995).

Lateral cephalometric analysis is a valuable assessment tool to diagnose, treatment plan and assess treatment results in orthodontics. Its major use is for diagnostic purposes to characterize the patient's skeletal and dental relationships, clarify the anatomic basis for a malocclusion and evaluate dentofacial proportions. This includes the quantitative measure of sagittal jaw discrepancy using a tracing of the lateral cephalogram. Traditionally, this was done by hand-tracing, but digital tracing is now more commonly employed. These tracings used cephalometric landmarks, defined as a series of points that define anatomical locations or structures or constructed points (for example, the intersection of two planes) (Proffit 2013).

Another and equally important clinical use of radiographic cephalometrics in orthodontics is in recognizing and evaluating changes brought about by orthodontic treatment. Superimpositions taken from serial cephalometric radiographs before, during and after treatment can be superimposed to study changes in jaw and tooth positions respectively. The observed changes result from a combination of growth and treatment (except in nongrowing adults) (Proffit 2013).

In order to classify a patient's skeletal relationship and determine the underlying basis for malocclusion, various analyses were created to compare patients to established norms. These norms aid the categorization of patients based on their soft tissue profile, skeletal pattern and dental pattern. These classifications can help in deciding on an individualized and appropriate treatment plan for every patient (Singh and Davies 2011). The first cephalometric analysis was popularized after World War II by Downs (Downs 1956). From there, 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, Bergman 1999) were created to attempt to measure the ideal craniofacial characteristics.

In any technique for cephalometric analysis, a horizontal line is used to establish a reference area. At an international congress of anatomists and physical anthropologists held in Frankfort, Germany in 1882, it was determined that the horizontal reference line of choice for orientation of skulls would be the Frankfort plane, which extends from the upper rim of the external auditory meatus (porion) to the inferior border of the orbital rim (orbitale). It was also determined that this was the best representation of the natural orientation of the skull. This reference line was used from the start of cephalometrics and is still commonly employed today. However, it has two disadvantages; the first is that both landmarks, porion and orbitale, are difficult to reliably locate on the radiograph. The second problem is that everyone orients his or her head in a characteristic position that is established physiologically, not anatomically. For the most part, a patient's true horizontal line closely approximates the Frankfort plane, however some individuals can show significant differences, up to 10 degrees (Downs 1956, Lundström and Lundström 1995).

Natural head position (NHP), where the patient holds their head level as determined by their internal physiologic mechanism is now the recommended reference plane in cephalometry. This concept was conceived by Moorrees and Kean (1958) to standardize the head position within the cephalostat using extracranial reference lines. It is obtained when a patient is relaxed and looking at a distant object of into their own eyes in a mirror (Proffit 2013). This reference line is more reproducible, as shown by Lundström et al (1992) who looked at pre-treatment cephalometric films and lateral photographs. They concluded that the natural head position is more appropriate to determine true horizontal and vertical reference lines. Various follow-up studies have been done and the overall conclusion is that natural head position is significantly more consistent than any other internal reference planes and should be the plane of choice when taking lateral cephalograms (Cooke 1990, Peng and Cooke 1999).

2.2 ANB Angle and its Limitations

The ANB angle was first introduced by Riedel in 1952 and since then, it has become the most popular means for evaluating the anteroposterior relationship of the skeletal bases in cephalometrics (Jacobson 1988, Oktay 1991). It is defined as the difference between the SNA and SNB angles and in normal occlusions is usually 2 degrees (+/- 2 degrees). Angles greater than the norm indicate a tendency toward class II jaw disharmonies; smaller angles suggest class III jaw discrepancies (Jacobson 1975). However, the ANB angle can be influenced by rotations and changes of the anteroposterior and vertical jaw dimensions relative to the cranial base (Holdaway 1956, Ferrazzini 1976, Luder 1978). Therefore, this has brought into question the validity of the ANB angle as well as its use as the sole measure of skeletal relationships.

The factors that have been demonstrated to influence the ANB value have been well documented in the literature (Taylor 1969, Jacobson 1975, Hussels and Nanda 1984, Jacobson 1988, Jarvinen 1988, Oktay 1991, Hurmerinta, Rahkamo et al. 1997). The first of which is the anteroposterior position of Nasion point in relation to the jaws. The relative forward or backward positioning of Nasion due to a long or short anterior cranial base or a relative anterior or posterior position of both jaws within the craniofacial complex can influence the ANB angle (Jacobson 1975). If Nasion is positioned more forward due to an increased anterior cranial base, ANB angle will be reduced. In addition, a reduction in ANB angle will also be seen if both jaws are positioned more posteriorly in the craniofacial complex. Conversely, if Nasion is retropositioned from a reduced anterior cranial base length or if the jaws are positioned more forwards in the craniofacial complex, the ANB angle will increase (Fig 2.1, Jacobson 1975).

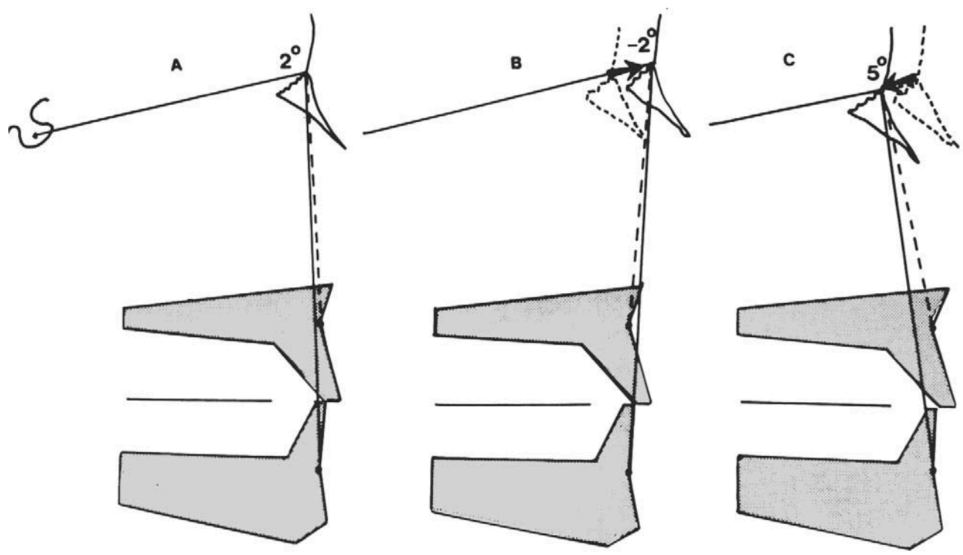

Fig 2.1. *A-P Position of Nasion and its effects on ANB. A- An average skeletal base. B- Nasion is positioned farther forward, reducing the ANB angle. C- Nasion is positioned farther backward, increasing the ANB angle. (Jacobson 1975)*

Jacobson (1976) stated that the ANB is only reliable when the mandibular plane angle to SN is average (32 degrees +/- 2 degrees). A high mandibular plane angle suggests a divergent type of profile where, in most cases, the anterior cranial base is tipped up superiorly in the front. This can reduce the SNA angle. The opposite is also true- a low mandibular plane angle suggests a convergent profile and the SNA angle is larger than the average norm.

A second factor affecting the ANB angle is the rotational effect of the jaws. Clockwise rotation of the jaws relative to the cranium or cranial reference plane (eg. Sella-Nasion plane) results in an increased ANB angle and a class II jaw relationship. Whereas, counter-clockwise rotation produces a smaller ANB angle and a class III jaw relationship (Jacobson 1975). To determine the extent to the rotation of the jaws, mandibular plane angle is again noted. A high mandibular plane angle indicates clockwise rotation of the jaws, and a reduced mandibular plane angle reduces the ANB angle. In addition, clockwise or counter-clockwise rotation of the SN reference plane (due to Nasion or Sella turcica being positioned superiorly or inferiorly to each other) can increase or decrease the SNA reading, affecting ANB (Figure 2.2, Jacobson 1976).

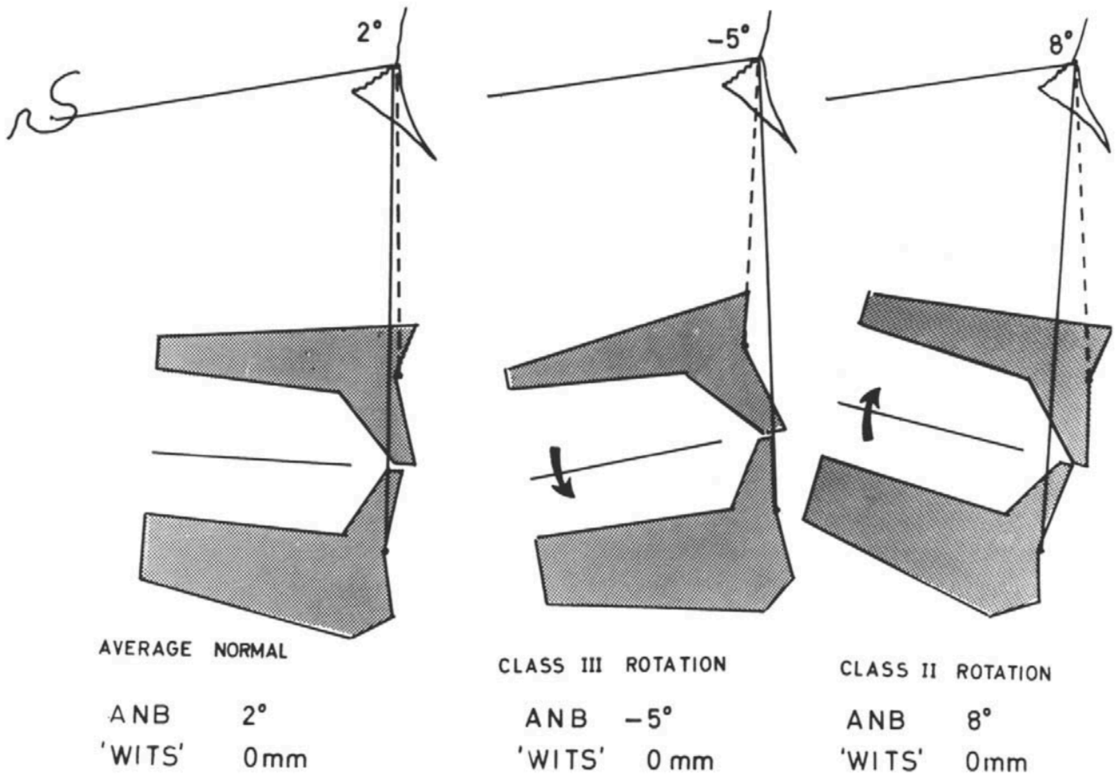

Fig 2.2. *Rotation of the S-N plane and its effects on ANB. A. An average skeletal base. B. Counterclockwise rotation of the jaws, reducing the ANB angle. C. Clockwise rotation of the jaws, increasing the ANB angle. (Jacobson 1975)*

According to Oktay (1991), various other factors have also been reported to influence the ANB angle. These include: the vertical position of Nasion (also reported by Bishara et al 1983 and Chang in 1987), the change in the SN angle to the occlusal plane, the degree of facial prognathism, growth of the patient, orthodontic treatment and the patient's age (ANB decreases with increasing age). Lastly, both Proffit (2013) and Oktay (1991) noted that as SNA and SNB become larger and the jaws more protrusive, even if their sagittal skeletal relationship stays unchanged, the ANB angle will be increased.

2.3 Attempts to Overcome the Drawbacks of ANB

In order to overcome the limitations of the ANB angle, many authors have proposed new analyses that use different cranial base landmarks, reference planes, angles or linear measurements.

In 1950, Freeman demonstrated the variation that could be introduced by the relative position of Nasion and pointed out that the ANB difference might be misleading in the evaluation of the jaw relationships. He introduced the AXB angle, which extended a perpendicular line from point A to Frankfort horizontal, with X marking the point of intersection. A line was also extended from point B to X forming the AXB angle (Fig 2.3). Freeman proposed that this angle provided data similar to the ANB measurement but eliminated the problems associated with Nasion (Beatty 1975).

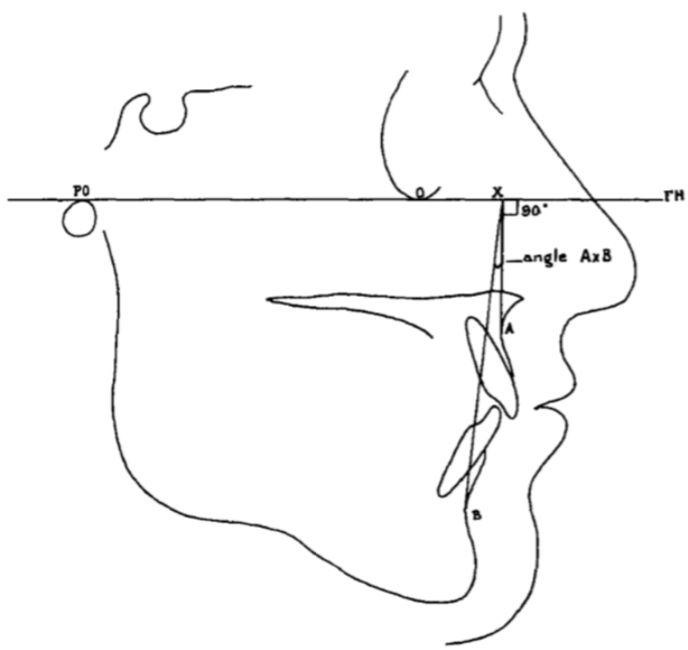

Fig 2.3. *Freeman's AXB angle (1981). The angle formed by the intersection of perpendicular lines drawn from points A and B to Frankfort Horizontal.*

Beatty (1975) furthered Freeman's work with his own analysis, the AXD angle (Fig 2.4). The S-N plane was used instead of Frankfort horizontal and the same perpendicular line from point A was extended to this plane, with X marking the point of intersection. This angle however eliminated point B and instead constructed a perpendicular line from point D (cross-section of the symphysis of the mandible) to the S-N plane. Beatty claimed to find a better correlation with this angle vs. ANB angle and Wits appraisal, while still eliminating the problems with Nasion.

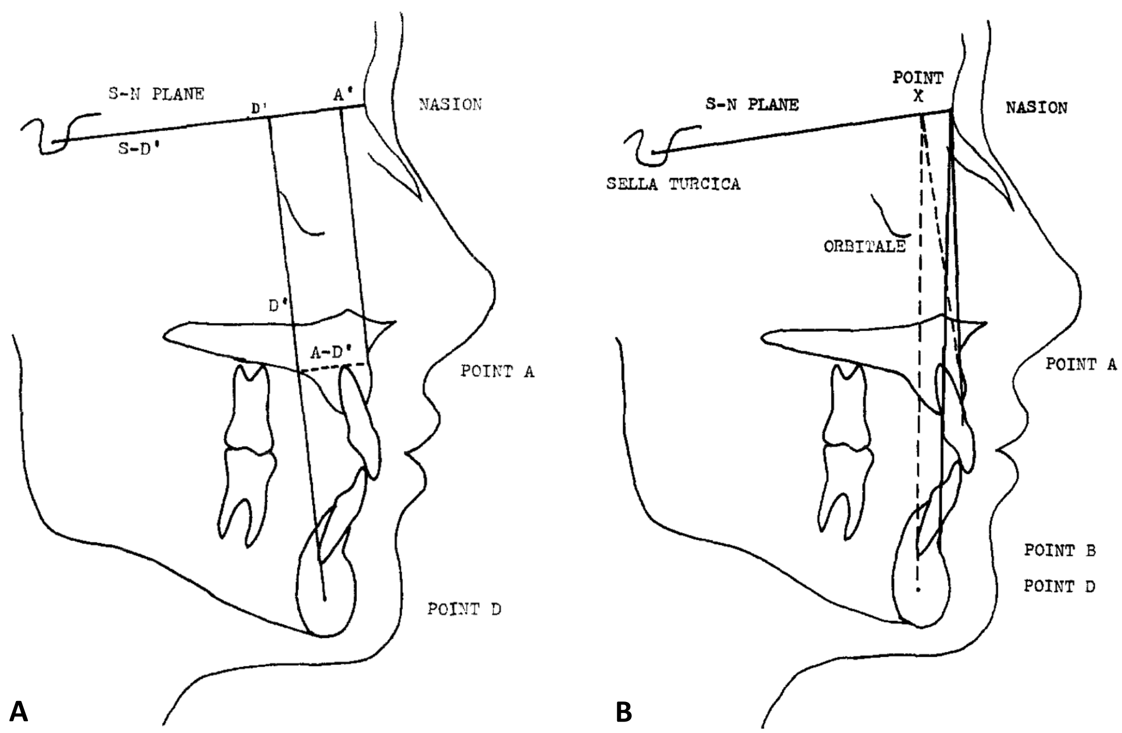

Fig 2.4. *Beatty (1975).* ***A.*** *The points used in the AXD angle. The angles used for the both AXD and AXB angle.*

The drawback of both Freeman and Beatty's analyses was that variation in the length of the face proved to be a dominant factor. As the face length increases with growth, the apical bases become more divergent while the angular measurement (AXB or AXD) remains the same.

The result is that two patients with identical ANB values will have a different horizontal distance between points A and B since the length of their faces may vary (Beatty 1975).

Chang (1987) proposed the "AF-BF" measurement, which measures the distance between perpendicular lines drawn from point A (AV) and point B (BV) to Frankfort Horizontal. The normal values were determined to be 3.87mm $\pm$2.63mm for females and 3.43$\pm$2,93mm for males, respectively. He concluded that this measurement was the true measurement of anteroposterior relationship of the maxilla to the mandible because it did not rely on Nasion and was not affected by the vertical positions of A and B point. (Fig 2.5)

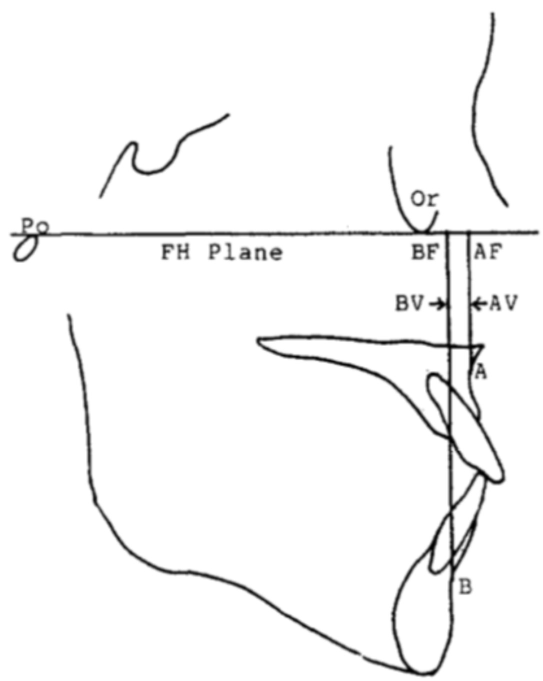

Fig 2.5. *Chang's AF-BF measurement (1987). Two lines are projected through A and B points perpendicular to Frankfort Horizontal. The distance between these lines are measured.*

Stoner, Lindquist et al. (1956) came up with a measurement that was almost identical to Chang's, taking two perpendicular lines from Frankfort Horizontal through A and B points (Fig 2.6). However, he rendered a mean value of 9.03mm from his group of 57 cases with a range from 0-17mm.

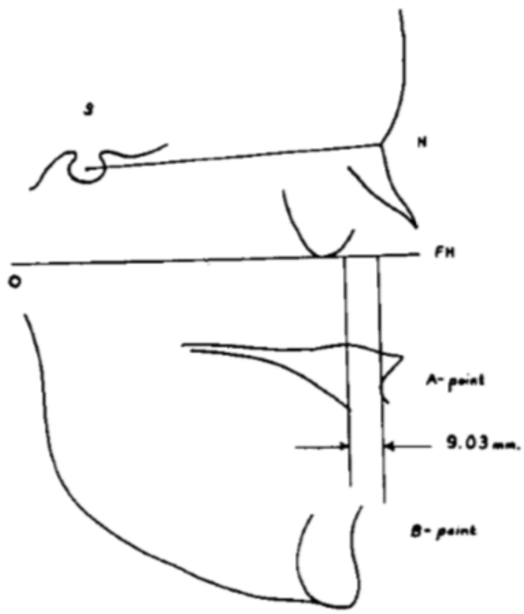

Fig 2.6. *Stoner, Lindquist et al.'s A-B distance (1956). Two lines are projected through A and B points perpendicular to Frankfort Horizontal. The distance between these two lines is measured, with a mean of 9.03mm.*

Bhad, Nayak et al. (2013) proposed the W angle, which measured the anteroposterior skeletal discrepancy between the maxilla and the mandible. It involved three points: S (midpoint of sella turcica), M (midpoint of the premaxilla) and G (centre of the largest circle that is tangent to the internal, inferior, anterior and posterior surfaces of the mandibular symphysis). Three lines connect these points in addition to a line from point M perpendicular to S-G line. Finally, the W angle measures the angle between the between the perpendicular line from point M to S–G line and the M–G line (Fig 2.7). Subjects with a class I skeletal pattern had a W angle between 51 and 56 degrees, Class II's a value below 51 degrees and class III's above 56 degrees. These authors suggested that the W angle was a more consistent evaluation of the sagittal jaw relationship.

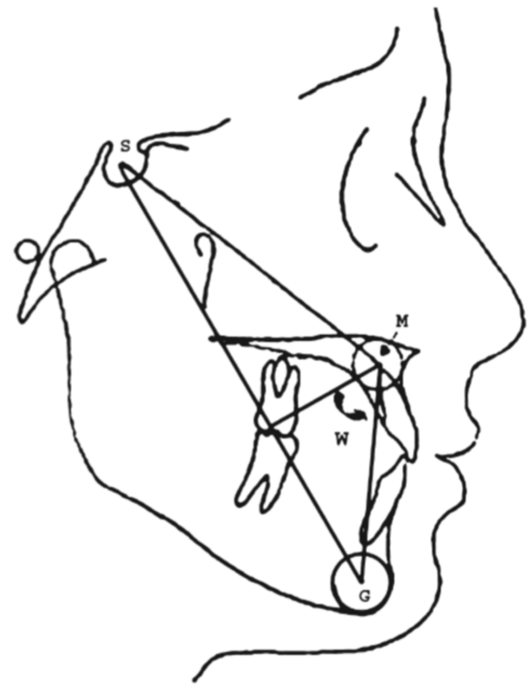

Fig 2.7. *Bhad, Nayak et al. (2013)*

A study by Sachdeva in 2012 compared various analyses that evaluated the anteroposterior jaw relationships, including the ANB angle, Wits analysis, and W angle to determine the most reliable measurement. It was found that the W angle is a valuable assessment of anteroposterior jaw discrepancy between the maxilla and the mandible.

Kannan (2012) also evaluated the reliability of many methods, including: AXD, AXB, Wits appraisal using the MM Bisector, ANB angle, and AF-BF distance. MM Bisector was shown to be superior for assessing anteroposterior jaw relationships over the other methods While this study was valuable, it did not account for rotational effects of growth of the jaws.

Various other analyses have been created to account for the rotational effects of the jaws (Kumar et al. 2012, Neela, Mascarenhas et al. 2009, Bhad, Nayak et al. 2013). The limited studies comparing these lesser used analyses have demonstrated no statistically significant correlations with the ANB angle or Wits appraisal.

2.4 Wits Analysis

In 1975, Jacobson described the shortcomings of the ANB angle and introduced an alternative analysis. It consisted of projecting perpendicular lines from points A and B onto a "functional occlusal plane" (FOP). The points projected onto the FOP are named AO and BO, respectively. The measured distance between these two points on the occlusal plane gives a linear measurement of the skeletal jaw discrepancy (Figure 2.8). In Class I skeletal patients, points AO and BO tend to generally coincide with each other, with an average of 1mm in males and 0mm in females. In class II patients, BO is posterior to AO (positive value in millimetres) and in class III patients, point BO is more forward than AO (Jacobson 1988).

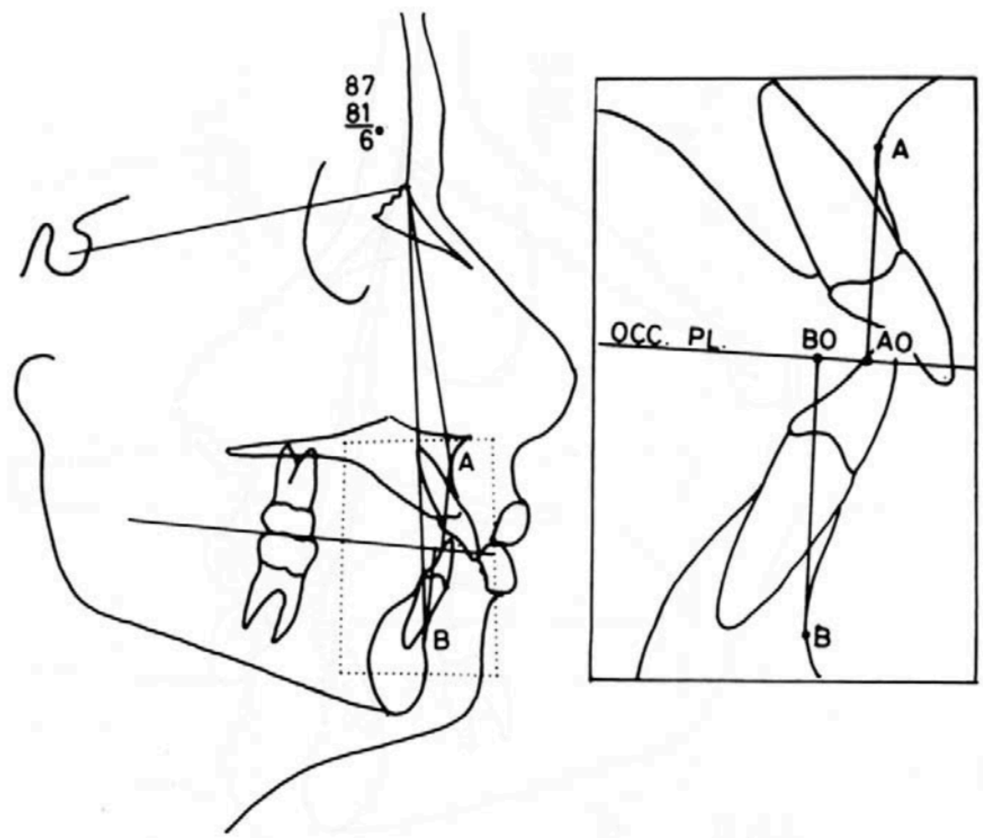

Fig 2.8. *The Wits Appraisal. Perpendicular lines are drawn from points A and B to the occlusal plane. The linear measurement is the distance measured from AO to BO. (Jacobson 1975)*

The Wits analysis was originally conceived to determine the extent to which the jaws are related to each other anteroposteriorly, while overcoming variations in craniofacial physiognomy (Jacobson 1975, Oktay 1991). However, while it eliminates the dependence on cranial landmarks, it relies instead on its occlusal reference plane, the functional occlusal plane (FOP). The FOP is defined as "a line bisecting the overlap of the maxillary and mandibular molars and premolar cusp" (Jacobson 1975). This plane was determined at the time to be the most suitable from which to relate both jaws. Jacobson (1975) also stated that when relating the jaws to this common plane, clockwise or counterclockwise rotation of the jaws relative to cranial or extracranial reference planes would in no way affect the overall assessment of severity of jaw disharmony.

However, the Wits appraisal also has limitations. As previously noted by numerous authors, changes of the occlusal plane by tooth movement caused by dental development or orthodontic treatment can cause variations in the Wits values (Chang 1987, Hussels and Nanda 1984, Sherman, Woods et al. 1988, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). In fact, it has been reported that the FOP can either rotate in a random fashion with growth (Hussels and Nanda 1984, Rushton, Cohen et al. 1991) or rotate in a counterclockwise direction with age (Sherman, Woods et al. 1988, Hall-Scott 1994). There may also be variations in the vertical positions of points A and B. Therefore, this appraisal is easily affected by the vertical dimensions of the jaws and the occlusal plane inclination.

2.5 Alternative Reference Planes Proposed for the Wits Appraisal

As previously discussed, the Wits analysis is a measure of the sagittal jaw discrepancy that eliminates the need for cranial base landmarks. However, this appraisal can still be influenced by the functional occlusal reference plane (FOP) (Figure 2.9). In fact, the FOP rotates more compared to a traditional occlusal plane, resulting in less correlation with ANB (Tanaka, Ono et al. 2006). In order to overcome the disadvantages of the FOP, various other occlusal reference planes have been proposed.

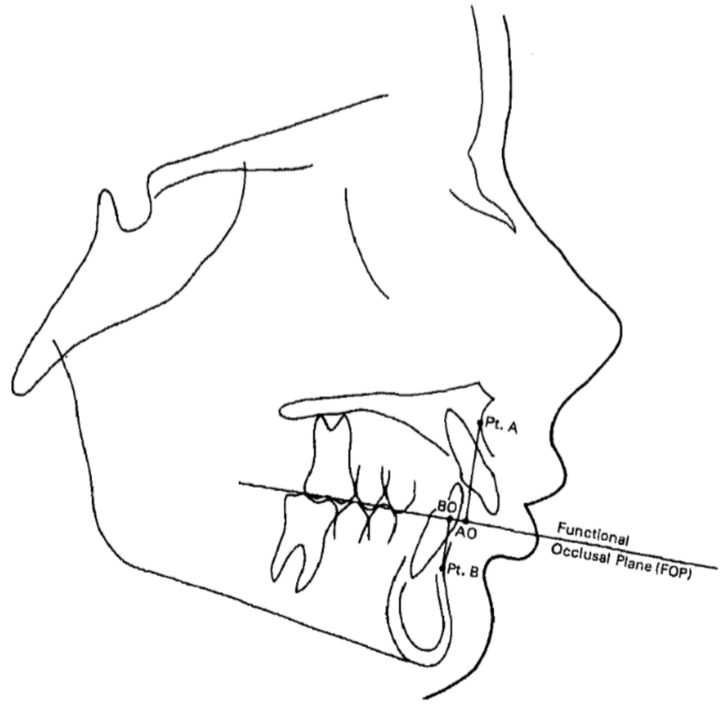

Fig 2.9. *Functional Occlusal Plane. Thayer (1990)*

The Bisecting occlusal plane has been proposed as one such alternative reference plane to the Wits analysis (Hall-Scott 1994, Foley et al. 1997, Provencal 2016) (Figure 2.10). Downs (1948) defines it as the plane that bisects the overlap of the distobuccal cusps of the permanent first molars and the incisor overlap. It is suggested that this plane of reference is easier to locate and some studies show that it rotates in the same direction as the maxillomandibular complex with growth (Palleck et al. 2001). Importantly, however, it still relies on the dentition for identification, calling into question its validity for classifying skeletal relationships.

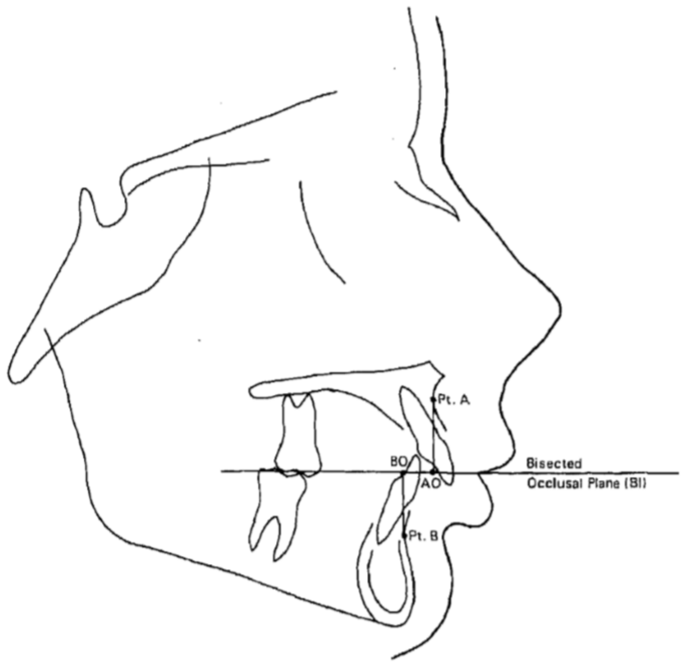

Fig 2.10. *Bisecting Occlusal Plane. Thayer (1990)*

Thayer (1990) compared Wits measurements to the FOP vs. BOP and determined that their occlusal plane could be used as an adjunct in the assessment of the anteroposterior jaw relationships. He also found that the Wits measurements using BOP were related to dental measures whereas FOP Wits values were more corelated to skeletal measures. This was disputed by Palleck et al (2001) who demonstrated that the BOP was more reproducible than the FOP because the FOP inclination could change with growth. Del Santo (2006) examined the influence of occlusal plane cant on the Wits appraisal to the BOP and ANB angle. He found a lack of correlation between BOP Wits and the ANB measurement in high occlusal plane angle patients. Conversely, it was found that in low occlusal plane angle patients that both assessments had high correlations.

Alternatively, the Maxillomandibular bisector is a reference plane that can also be used for the Wits analysis (Hall-Scott 1994, Foley et al. 1997, Palleck et al. 2001, Provencal 2016) (Figure 2.11). This plane is constructed by bisecting the angle created by the intersection of the maxillary plane (ANS-PNS) and mandibular planes (Me-Go) (Hall-Scott 1994). Its main advantage over the other two reference planes is that it doesn't rely on the dentition for identification and eliminates the problems associated with it such as: missing teeth, unerupted or malpositioned teeth, mixed dentitions, deep Curves of Spee, molar overlap, and dental restorations (Palleck et al. 2001). It also doesn't rely upon cranial base landmarks, unlike the ANB angle.

Various authors have shown that the MMB Wits is more reproducible than the FOP or BOP in every skeletal pattern and that treatment changes in the MMB Wits values reflect changes in the ANB angle (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001, Provencal 2016). Hall-Scott (1994) and Foley (1997) both found in their studies that the MMB reference plane showed the least amount of measurement error, whereas the FOP showed the greatest amount of error (three times that of MMB). In addition, MMB was shown to have a higher correlation with ANB than either the FOP or BOP in class I and III subjects. Furthermore, the cant of the MMB reflects the rotation of the maxillomandibular complex with growth (Hall-Scott 1994). Similar findings were confirmed in a study with class II Division 1 subjects that MMB was more reliable and reproducible and had better correlations with ANB angle (Foley, Stirling et al. 1997). Most recently, Provencal (2016) found that the MMB Wits had a higher correlation coefficient to the ANB angle than the FOP, further confirming its validity as an indicator of the anteroposterior skeletal discrepancy. Therefore, these studies have been the basis in the choice of occlusal plane for this particular study.

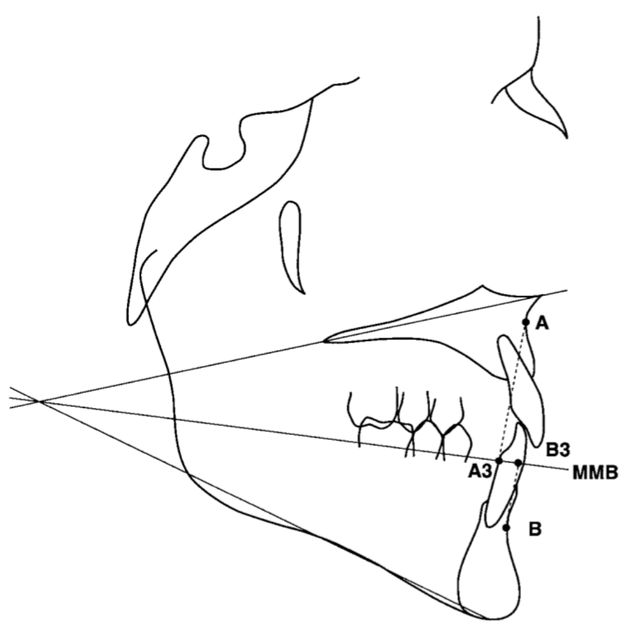

Fig 2.11. *Maxillomandibular bisector occlusal plane. Palleck et al. (2001)*

2.6 Correlation between ANB Angle and Wits Appraisal

ANB angle and the Wits appraisal assess the same skeletal sagittal jaw relationships so they should, theoretically, have good agreement. However, their correlation is not as strong as expected, suggesting weakness in at least one assessment tool (Del Santo 2006). Richardson (1982) found a strong correlation (r= 0.67) in patients with a normal occlusion using FOP Wits, agreeing with Jarvinen's (r= 0.62) and Oktay's later findings (r= 0.76) (Jarvinen 1988, Oktay 1991). Ishikawa et al. (2000) instead used BOP Wits and found a more moderate correlation of r= 0.57 in skeletal class I subjects. However, other studies have shown inconsistencies in their findings, ranging from as low as r= 0.08 to as high at 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 (1980) has even gone as far to suggest that the Wits does not solely describe the anteroposterior skeletal relationship, but rather as the vertical dimension varies, so do the sagittal jaw discrepancies (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). Richardson (1982) interestingly did a study where she showed that by controlling inclination of the BOP, the correlation could improve from r= 0.67 to 0.80.

Del Santo (2006) further examined the angulation of the occlusal plane and its correlations between ANB angle and Wits. This author showed a tendency for lack of consistency between ANB and Wits assessments in high occlusal plane angle patients and a lack of certainty in at least one measurement. In contrast, in the low occlusal plane angle patients, both assessments were consistent and had a high correlation. In addition, Iwasaki et al. (2002) determined that in flat mandibular plane angles or flat occlusal planes, the Wits appraisal may express little to no skeletal discrepancy even if the individual has an evident discrepancy. They concluded that because of this, the ANB angle is a more accurate cephalometric tool to evaluate the sagittal jaw discrepancy in patients vs. Wits. However, this was challenged in another study that compared the correlation between ANB angle and Wits appraisal in all facial types. They found moderate correlations (r= 0.62) in all groups and determined that facial type does not affect the agreement between ANB and Wits values (Tanaka, Ono et al. 2006).

The previously cited studies only used either the FOP or BOP without comparing the correlations between the two. This was done by Thayer in 1990, who showed that the correlation coefficient value between ANB and FOP Wits was r= 0.76 vs. r= 0.68 between ANB and BOP Wits. He determined that the correlations between both these occlusal planes were both strong and significant.

Studies examining the correlations between ANB angle and the MMB Wits, on average, have shown stronger correlations vs. the BOP and FOP planes. Hall-Scott (1994) found a correlation of r= 0.83 in their adult group and r= 0.95 in children between ANB angle and MMB Wits. They stated that these correlations were stronger vs. FOP or BOP. Swoboda (2013) found slightly lower correlations in class I subjects (r= 0.60). Palleck et al. (2001) described a range of moderate to high correlations from r=0.54 to 0.69 in skeletal class I patients. Most recently, Provencal (2017) found moderate to high correlations in a larger sample, ranging from r=0.57 to 0.74. When the results of these studies are combined, the correlation coefficients between ANB and MMB Wits are on average, r= 0.66 in class I subjects, r=0.71 in class II subjects and r=0.77 in class III subjects (Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). This reinforces the validity of MMB as a reference plane when using the Wits appraisal to classify sagittal jaw relationships.

One thing to keep in mind when reviewing this literature is its degree of clinical applicability. Horowitz, Hixon et al. (1966) stated in their book 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". The majority of the studies comparing the correlations between ANB angle and the Wits appraisal, regardless of which occlusal plane was used have rendered correlation coefficient values less than 0.8, indicating that the clinical application of these numbers may be limited. In addition, there is a lack of interchangeability between ANB angle and Wits appraisal in their use as assessing skeletal jaw discrepancies (Horowitz, Hixon et al. 1966, Provencal 2017). Therefore, differences between these two assessment tools often likely occur due to a weakness in at least one of the parameters.

The low agreement between the ANB angle and Wits appraisal suggests a mutual independency of the two assessment tools (Rotberg, Fried et al. 1980, Jarvinen 1981). Both are influenced by displacement and simultaneous remodeling that occur in craniofacial development, which can distort the resulting values. In order to mitigate this, techniques for geometric correction of both analyses have been suggested but these techniques are complicated and time consuming (Freeman 1981, Roth 1982, Hussels and Nanda 1984, Williams, Leighton et al. 1985, Hussels and Nanda 1987, Sherman, Woods et al. 1988). The consensus in the literature recommends the careful interpretation of both analyses (Rotberg, Fried et al. 1980, Bishara, Fahl et al. 1983, Jacobson 1988, Sherman, Woods et al. 1988, Ishikawa, Nakamura et al. 2000). Nevertheless, if there is inconsistency in the classification and degree of severity of the skeletal jaw discrepancies between the two measurements, it can be difficult to determine which analysis is appropriate on which to base clinical decisions. This has motivated researchers to find new or modify existing cephalometric assessment tools to have stronger correlations.

2.7 Facial Pattern

A large component of orthodontic literature has been dedicated to studying dentofacial relationships. Since there is a large variation of these relationships within each evaluated population, many attempts have been made to describe the range of normal variation of the human face and determine a system that identifies the various facial types (Bishara and Jakobsen 1985).

In orthodontics, some terminology used to describe the facial pattern include: dolichocephalic, brachycephalic and mesocephalic; hyperdivergent, neutral or hypodivergent; long, medium or short; skeletal open bite or skeletal deep bite. The terms euryprosopic, mesoprosopic and leptoprosopic also appear in European orthodontic literature (Franco et al. 2013). The terminology used to describe the craniofacial complex originated from classical anthropometry. The most common classification system was the cranial index, which described the skull as mesocephalic (average face), brachycephalic (short/broad face) and dolichocephalic (long face). This terminology was later introduced into the orthodontic literature by Ricketts (1960).

With the introduction of radiographic cephalometry, the interest in variability of facial patterns was advanced and facial types were studied with emphasis on their association with malocclusion and skeletal relationship (Bishara 1985). Bjork's famous implant studies described two types of mandibular growth- forward and backward. These two types of condylar growth were influenced by the location of the center of rotation of the mandible (Bjork 1969, Bishara 1985). Schudy (1964) studied the interaction of anteroposterior and vertical facial dysplasias and emphasized the importance of vertical facial proportions in orthodontic treatment. Schudy used the mandibular plane angle to divide his sample into three groups: average, retrognathic and prognathic. He concluded that the mandibular plane angle was useful in describing the different facial types and should be considered when treatment planning (Schudy 1964, Bishara 1985). Bishara and Augspurger also found that normal variation in the relationship of the mandibular plane angle to the cranial base (via S-N plane) is associated with variation in skeletal and dental relationships (Bishara & Augspurger 1975). Zamora et al. (2013) recently found that almost half of the subjects in their study, for whom the Wits and ANB diagnosis of anteroposterior relationships did not coincide, had a mesofacial pattern and normal mandibular plane angle. Their results indicated a possible correlation between the classification of jaw discrepancies (in cephalometrics) in relation to the patient's facial pattern and mandibular plane angle.

Facial pattern is also determined by other factors, such as the Y-axis, Rickett's lower facial height and Rickett's facial axis (Paranhos et al. 2014, Paranhos, Benedicto et al. 2012). However, the current literature is also unclear about their connection with the ANB or Wits appraisal.

As previously mentioned, the Wits appraisal is based on planes of reference that may be affected by the inclination of the horizontal planes and rotation of the jaws. The amount of rotation is related to the facial pattern of the individual. Tanaka, Ono et al. (2006) investigated the influence of facial pattern on the correlation between the Wits appraisal and AF-BF with ANB. They determined that the facial pattern does not have an influence on the correlation of the ANB angle and Wits appraisal. That being said, they observed that in the mesocephalic and dolichocephalic groups, the ANB angle will have a higher value when the Wits values equal zero, whereas a smaller value of ANB will be seen in the brachycephalic group. This is because of the relatively greater horizontal vs. vertical growth. With respect to the Wits appraisal, because the functional occlusal plane was used and is based on the dentition, variability of tooth position was observed independently of the facial type in the individual patient. They also inferred that using the MMB plane should be more reproducible and a higher correlation with ANB angle should be expected as it does not rely on the dentition or cranial base. However, they also concluded that the facial type can be an influencing factor on its measurement, since the palatal plane and mandibular plane clockwise rotation will be greater on dolichocephalic patients and smaller on brachycephalic ones (Tanaka, Ono et al. 2006).

2.8 Digital Radiography vs. Hand-Traced Cephalometric Measurements

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). Digitization of lateral cephalograms permits automatic measurement of landmark relationships.

Computerized radiography and digital tracing have recently become popular and have slowly taken over manual tracing techniques (Albarakati, Kula et al. 2012). It has been suggested that computerized cephalometric analysis eradicates mechanical errors that are produced when tracing lines and landmarks as well as those made when calculating the different linear and angular measurements are made (Chien, Parks et al. 2009).

Studies have shown that digital computerized tracings are easier and have the same reliability when compared to hand tracings (Erkan et al. 2012, Playfair 2013, Prabhakar et al. 2014). Multiple authors have reported a high sensitivity when comparing hand traced cephalometric films to manually chosen landmarks on a digital cephalometric image (Forsyth & Davis 1996, Chen, Chen et al. 2004, McClure, Sadowsky et al. 2005, Erkan, Gurel et al. 2012). Other authors, such as Sayinsu et al (2007), Erkan et al (2012), Prabhakar et al (2014), Uysal (2009) have shown high correlations of validity and reproducibility of digital radiographs in the Dolphin Imaging Software compared to conventional methods.

Playfair (2013) investigated and compared computer based lateral cephalometric analysis to traditional hand-based analysis. He concluded that the semi-automatic mode of Dolphin Imaging software appears as reliable as hand-based analysis and that orthodontists should feel comfortable substituting hand-based analysis for Dolphin cephalometric analysis programs with a high degree of accuracy. Sayinsu et al (2007) also reported high correlations of validity and reproducibility between Dolphin Imaging Software and hand-tracing. Digital imaging also has other advantages, such as archiving, transmission and enhancement. They concluded that the digitized technique is preferred in daily use and for research purposes without loss of quality.

2.9 Rationale for the Study

As previously discussed, the ANB angle is currently the most widely used cephalometric tool to diagnose sagittal jaw relationships. However, there are numerous shortcomings of this measurement due to its reliance on cranial base landmarks. The Wits appraisal was created by Jacobson (1975) to overcome these shortcomings, however, despite measuring the same anteroposterior jaw discrepancy, the current literature demonstrates a low correlation between the two.

In addition, there is evidence that the functional occlusal plane may not be the most accurate occlusal plane to measure the Wits appraisal because it relies on dental landmarks. The studies exploring the different occlusal planes by Hall-Scott (1994), Foley, Stirling et al. 1997, Palleck, Foley et al. 2001 and Provencal 2017 have been the basis in the choice of occlusal plane for this particular study.

Lastly, it is unclear whether there is a relationship between the ANB angle, Wits appraisal and the facial pattern of the patient. If there was a relationship between facial pattern and either or both of these measurements, it would reinforce their use as a diagnostic tool as they would not only be able to classify the sagittal jaw relationship but also the facial pattern of the patient.

2.10 Purpose

The purpose of this investigation was to assess the correlation between the Wits appraisal (when using maxillomandibular bisector as the occlusal plane) and ANB analysis with the mandibular plane angle, Y- axis, lower facial height and facial axis in skeletal class I subjects and verify the facial pattern in these analyses.

2.11 Null Hypotheses

The null hypotheses for this study state that:

1. There is no correlation between mandibular plane angle, Y-axis, lower facial height, facial axis and ANB angle or Wits appraisal when using the maxillomandibular bisector as the occlusal plane in skeletal class I patients.
2. Facial pattern does not correlate with differences found between ANB angle and Wits appraisal classification in skeletal class I patients.

Chapter 3

Materials and Methods

3.1 Ethics

Ethics approval was granted on May 8th, 2017 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 August 29th ,2003 and July 26th, 2017. The chosen sample size comprised 100 subjects and consisted of 50 females and 50 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	21.55	14	59	7.60

Table 3.1. *Summary statistics for the sample.*

Inclusion criteria

- Fully erupted and occluded permanent dentition, with the exception of third molars
- No missing teeth in either the upper or lower arch
- No impacted teeth
- No craniofacial abnormalities
- Skeletal class I anteroposterior jaw relationship as determined by an ANB value between 0^o and 4^o taken from digital cephalograms from the University of Manitoba Orthodontic Clinic
- Dental malocclusions had no bearing on case selection
- Treatment performed clinically on these subjects had no bearing on case selection
- Both males and females included equitably

Exclusion criteria

- Unerupted permanent dentition with the exception of third molars
- One or more missing teeth in either the upper or lower arch
- Impacted teeth (except for third molars)
- Craniofacial abnormalities or syndromes
- Skeletal class II or class III patients as determined by ANB

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 (Caley Hoediono) using the Dolphin™ 11.7 imaging software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). Film magnification was standardized for each film, which matched a 30 mm ruler included in each film view.

Intra-rater and inter-rater reliability of the lateral cephalometric radiograph measurements were calculated utilizing the Intraclass Correlation Coefficient test (ICC). Ten percent of the sample was randomly selected to be re-measured by a second independent examiner (Catherine Fontaine-Sylvestre). Each of the 10 lateral cephalometric radiographs 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.

3.4 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, 100 subjects total were included to ensure sufficient sample size.

3.4.2 General statistics

For *correlation analyses:* Pairwise Spearman correlations were assessed to relate the ANB angle to the Wits values, ANB to facial pattern measurements and the Wits to facial pattern. The p-value was considered significant at $\alpha<0.05$.

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

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

3.5.2 Digitized cephalometric radiography

In our study, the lateral cephalogram's data was transferred into JPEG format into Dolphin Imaging™ 11.5 software and manual landmark identification was carried out by the primary examiner (Caley Hoediono). The images were then digitally traced and all measurements were completed on the Dolphin Tracing Software.

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). Based on these anatomical landmarks, linear and angular measurements are performed as part of a cephalometric analysis of the lateral cephalometric radiograph.

This study used predefined anatomical landmarks, measurements and analyses that are widely recognized in the literature. (Riedel 1952, Jacobson 1976, Foley, Stirling et al. 1997, Palleck, Foley et al. 2001). These landmarks, as well as the linear and angular measurements, are illustrated in Figures 3-1 and 3-2. The definitions of the landmarks and measurements used in this study are provided in Tables 3.2, 3.3, and 3.4.

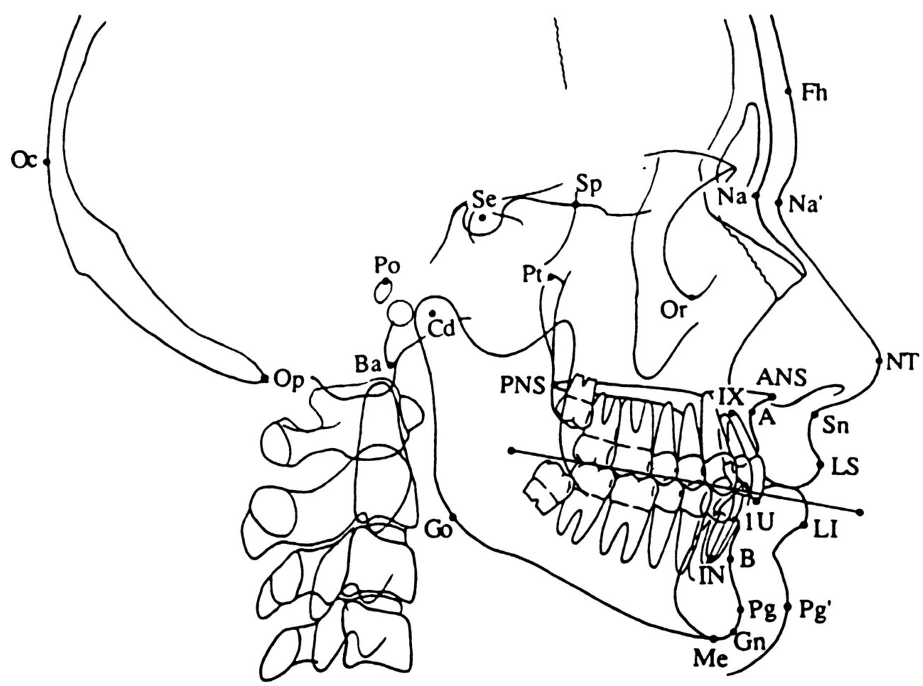

Figure 3.1 *Cephalometric landmarks*

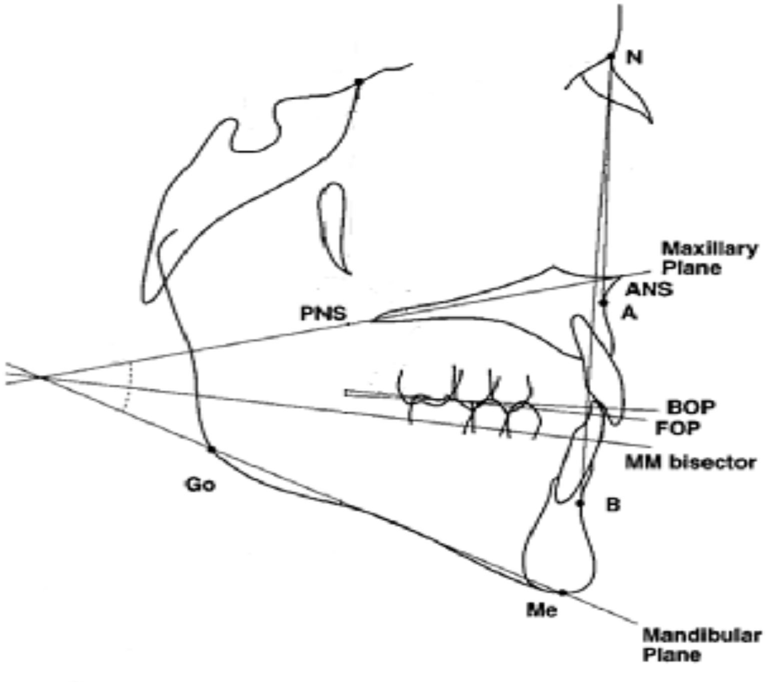

Figure 3.2 *Cephalometric Planes*

Landmarks	*Definitions*	*References*
Sella (S)	Midpoint of the pituitary fossa (sella turcica).	(Athanasiou 1995)
Nasion (Na)	Junction of the nasal and frontal bones.	(Broadbent. 1975)
Anterior nasal spine (ANS)	Tip of bony anterior nasal spine in the midline or median plane. The most anterior point on the maxilla at the level of the palate.	(Moyers and Moyers 1988, Athanasiou 1995)

Posterior nasal spine (PNS)	Intersection of a continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose. Most posterior point at the sagittal plane on the bony hard palate.	(Broadbent. 1975, Riolo 1974, Athanasiou 1995)
A-point (Subspinale)	Deepest, most posterior midline point on the curvature between the ANS and prosthion.	(Broadbent. 1975, Athanasiou 1995)
B-point (supramentale)	Deepest, most posterior midline point on the bony curvature of the anterior mandible, between infradentale and pogonion.	(Broadbent. 1975, Athanasiou 1995)
Anatomical Gonion (Go)	Most convex point where the posterior and inferior curve of the ramus meet.	(Broadbent. 1975, Athanasiou 1995)
Gnathion (Gn)	Most anteroinferior point on the symphysis of the chin. It is constructed by intersecting a line drawn perpendicular to the line connecting Menton and Pogonion.	(Broadbent. 1975, Athanasiou 1995)
Menton (Me)	Point most inferior on mandibular symphysis.	(Broadbent. 1975, Athanasiou 1995)
Am	Point A projected in a perpendicular fashion onto the maxillomandibular bisector plane	(Hall-Scott 1994)

Bm	Point B projected in a perpendicular fashion onto the maxillomandibular bisector plane	(Hall-Scott 1994)
PT point	Junction of the pterygomaxillary fissure and the foramen rotundum	(Jacobson and Jacobson 2006)
Basion	The lowest point on the anterior rim of the foramen magnum	(Jacobson and Jacobson 2006)

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

Plane	*Description*	*Reference*
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 anatomical 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 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)
Mandibular plane angle	Angle formed by Mandibular plane and Sella-Nasion plane	(Athanasiou 1995))
Y-Axis	Angle formed from Sella-Gnathion plane and Sella-Nasion plane. It describes the growth pattern of the mandible as it emerges from the craniofacial complex.	(Jacobson and Jacobson 2006)
Lower Facial Height	Linear measurement extending from ANS to Menton in mm.	(Jacobson and Jacobson 2006)
Facial Axis Angle	Angle formed between the Basion-Nasion plane and the plane from foramen rotundum (PT point) to Gnathion.	(Ricketts 1960)

Table 3.4 *Definitions of angular and linear measurements*

CHAPTER 4

Results

4.1 Sample Group Statistics

A summary of the cephalometric measurements is described in Table 4-1. The mean, minimum and maximum values for ANB were within the normal range. The mean for the Wits appraisal was class III (-3.8mm) and there was a wide range of values that included patients that had all three classifications (I, II and III). The mandibular plane angle mean value was within the normal range, however the minimum and maximum values varied from brachycephalic to dolichocephalic facial patterns. The Y-axis mean value was on the high end of the normal range and the range also varied from brachycephalic to dolichocephalic patterns. Lastly, both the lower facial height and facial axis angle mean values were both within their normal ranges and also contained a large range of values and both facial patterns.

Groups	*Normal Values*	*Mean*	*Min.*	*Max.*	*SD*
1. ANB (°)	2°±2°	2.1	0	3.9	1.1
2. Wits (mm)	Males: 1mm Females: 0mm	-3.8	-11.4	3.9	3.3
3. Mandibular Plane Angle (°)	32°±2°	31.6	19.6	47.3	5.9
4. Y-axis (°)	66°±2°	68.2	59.1	76.8	3.7
5. Lower Facial Height (mm)	65±4.5mm	64.6	51.7	81.7	6.0
6. Facial Axis Angle (°)	90°±3.5°	89.9	80.1	100.4	4.3

Table 4.1. *ANB, Wits and Facial Pattern Measurement Statistics*

4.2 Reliability

The reliability and reproducibility of the results were validated by re-measuring 10% of the selected sample. This sample was randomly selected and re-measured by the primary investigator (Caley Hoediono) as well as a second independent examiner (Catherine Fontaine-Sylvestre) at two different time points that were 1 month apart. The reliability was assessed using Intraclass Correlation Coefficient (ICC) values ranging from 0 (no agreement) to 1 (perfect agreement).

4.2.1 Intra-rater reliability

An Intraclass Correlation Coefficient (ICC) was calculated to quantify the intra-rater reliability of the results (Table 4.2). The intra-examiner findings showed a high consistency in the repeated measurements. The facial axis showed a disproportionately lower ICC value due to one outlier measurement. Once this outlier was omitted and the Intraclass Correlation Coefficient was re-measured, its value went up to 0.99 and the subsequent mean increased to 0.96. The outlier was most likely due to data entry error, regardless in both instances the ICC values indicate extremely high reliability. Based on these results we can be confident that the reliability and reproducibility of the cephalometric radiographic measurements are reliable.

INTRA-RATER RELIABILITY	
Variables examined	**Intraclass Correlation**
ANB	0.96
Wits	0.99
Mandibular Plane Angle	0.99
Y-Axis	0.98
Lower Facial Height	0.86
Facial Axis	0.82
Average	**0.93**

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

4.2.2 Inter-rater reliability

The inter-examiner Intraclass Correlation Coefficient values were all determined to be high, with an average value of 0.91. Based on these results we can be confident that the reliability and reproducibility of the cephalometric radiographic measurements are reliable.

INTER-RATER RELIABILITY	
Variables examined	**Intraclass Correlation**
ANB	0.94
Wits	0.98
Mandibular Plane Angle	0.97
Y-Axis	0.97
Lower Facial Height	0.98
Facial Axis	0.99
Average	0.97

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

4.3 Correlations between Measurements

4.3.1 ANB and Wits

Spearman's Rank Correlation Coefficient was calculated to determine the correlation between ANB and Wits. The results are shown in Table 4.4 and a scatter plot was constructed to demonstrate their relationship (Fig 4.1). A weak correlation was found between the ANB and Wits and the p value determined that this value was highly statistically significant ($p<0.00008$).

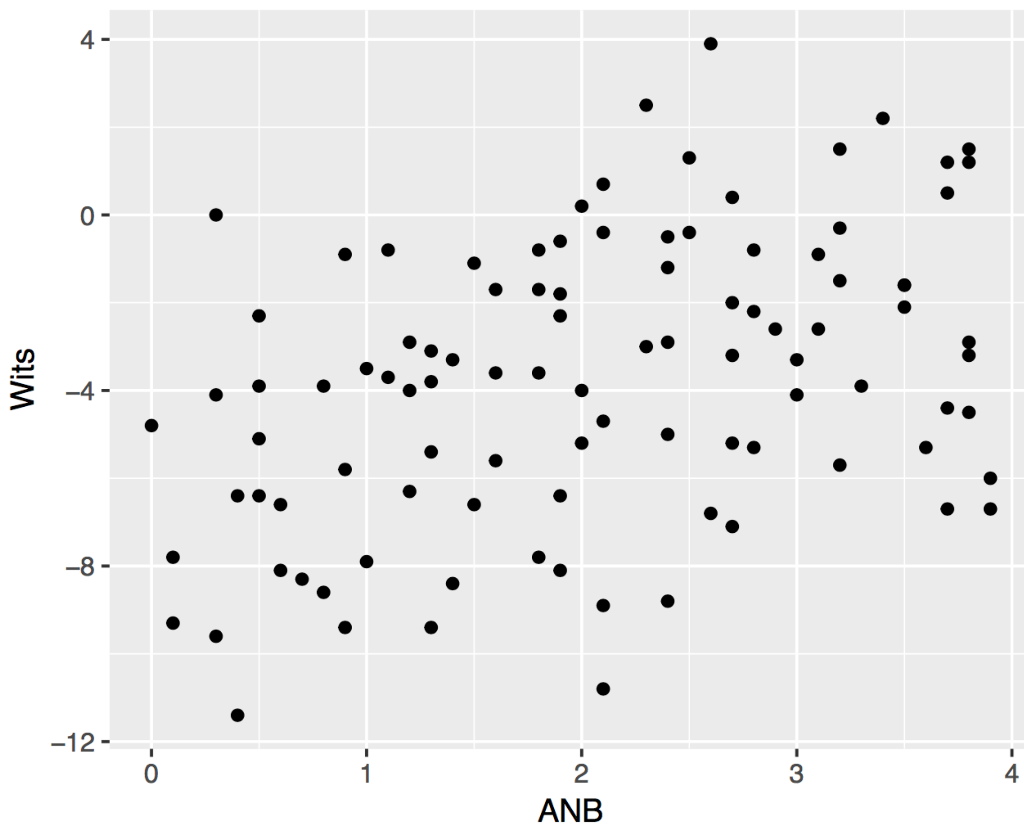

Figure 4.1. *Scatter plot depicting a weak positive correlation between ANB and Wits*

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Variables examined	**Spearman's Rank Value**	**P Value**
ANB vs. Wits	0.38	0.00008

Table 4.4. *Spearman's Rank Correlation Coefficient values comparing ANB and Wits*

4.3.2 ANB and Facial Pattern Measurements

Spearman's Rank Correlation Coefficient was calculated to determine the correlations between ANB and each respective facial pattern measurement (Table 4.5). On average, weak associations were found with respect to all the facial pattern measurements (r= 0.105). This is demonstrated in figure 4.2, where none of the scatter plots comparing ANB and the facial measurements demonstrate a visual pattern. The strongest correlation was determined to be between ANB and Y-axis (r= 0.209) and it was the only correlation that was considered statistically significant ($p<0.05$).

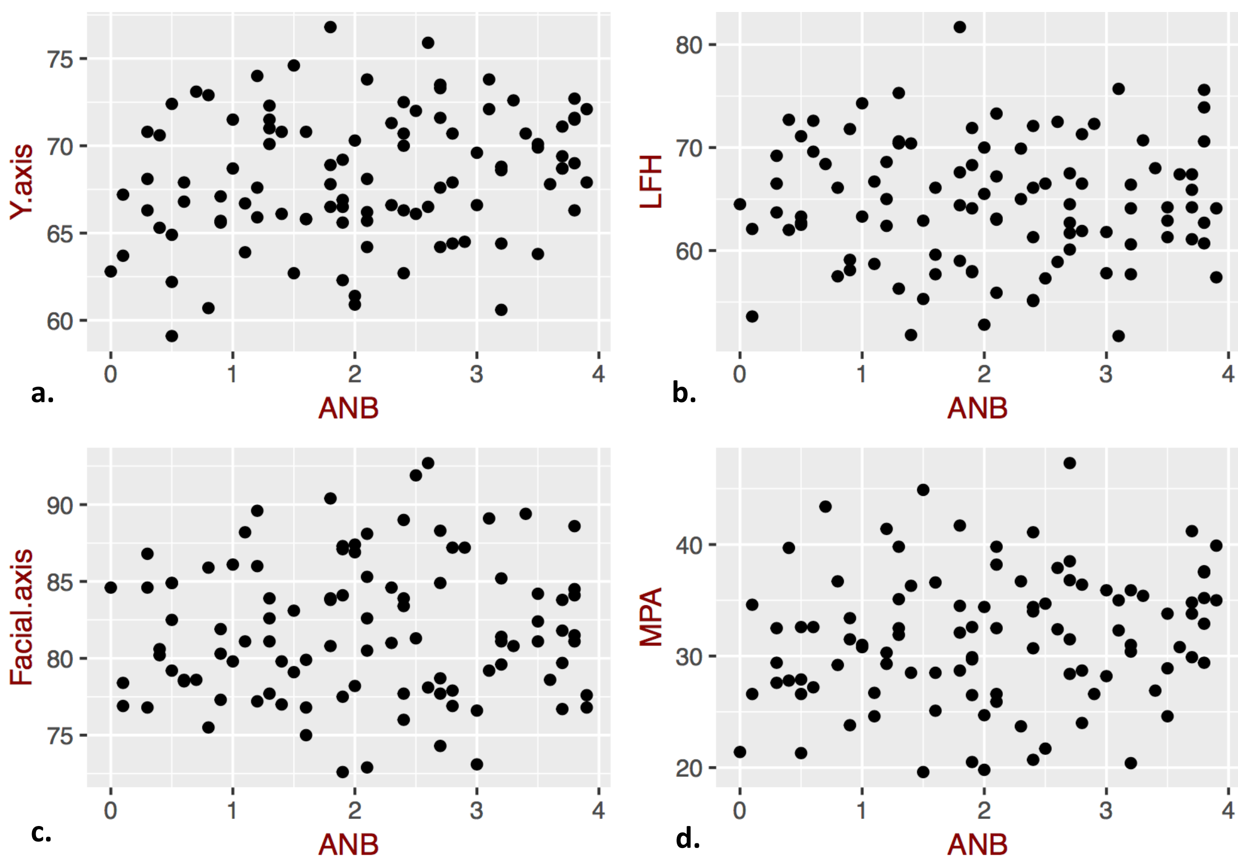

Figure 4.2. *Scatter plots comparing ANB and the Facial Pattern Measurements.* ***a.****- ANB vs. Y-Axis.* ***b.****- ANB vs. Lower Facial Height.* ***c.****- ANB vs. Facial Axis.* ***d.****- ANB vs. MPA*

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Facial Pattern Measurements	**Spearman's Rank Value (ANB)**	**P Value**
Mandibular Plane Angle	0.193	0.055
Y-Axis	0.209	0.037
Lower Facial Height	-0.020	0.842
Facial Axis	0.038	0.705
Average	**0.105**	**0.410**

Table 4.5. *Spearman's Rank Correlation Coefficient values comparing ANB and Facial Pattern Measurements*

4.3.3 Wits and Facial Pattern Measurements

Spearman's Rank Correlation Coefficient was calculated to determine the correlations between Wits and each respective facial pattern measurement (Table 4.6). Associations were found, ranging from low to high (-0.05 to 0.57). This is demonstrated in figure 4.3, where scatter plots comparing Wits and the facial measurements show the respective relationships between the measurements. The strongest correlations were between facial axis ($r=0.57$), MPA ($r=-0.46$) and Wits, all of which were statistically significant ($p<0.05$). A moderate correlation was found between lower facial height and Wits ($r=-0.331$), which was also statistically significant ($P<0.05$). Conversely, Y-axis and Wits showed the weakest association of the four measurements and it was a negative correlation ($r= -0.046$). This was also the only finding of the four that was not statistically significant ($p<0.05$).

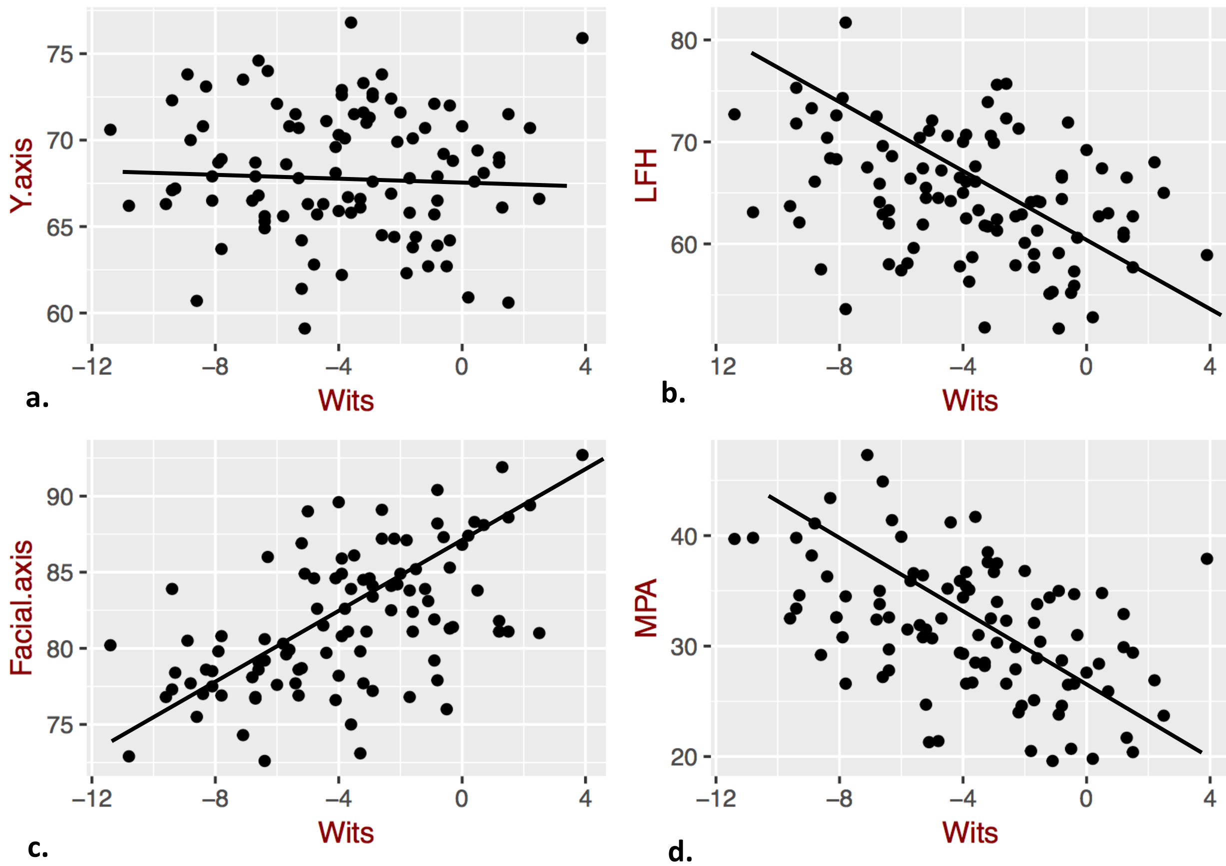

Figure 4.3. *Scatter plots comparing Wits and the Facial Pattern Measurements.* ***a.****- Wits vs. Y-Axis.* ***b.****- Wits vs. Lower Facial Height.* ***c.****- Wits vs. Facial Axis.* ***d.****- Wits vs. MPA*

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Facial Pattern Measurements	**Spearman's Rank Value (Wits)**	**P Value**
Mandibular Plane Angle	-0.463	0.000001
Y-Axis	-0.046	0.65
Lower Facial Height	-0.331	0.00077
Facial Axis	0.566	8.3E-10
Average	**-0.0685**	**0.162693**

Table 4.6. *Spearman's Rank Correlation Coefficient values comparing Wits and Facial Pattern Measurements*

4.4 Differences between Genders

All variables examined in this study were also stratified according to gender to determine possible gender differences. There were no substantive differences between males and females.

4.4.1 ANB vs. Wits

The Spearman's rank correlation coefficient for males was lower vs. females (r=0.26 vs. 0.48, Table 4.8). However, the male value was not statistically significant, whereas the female value was significant ($p<0.05$, Table 4.9).

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Variables examined	**Males**	**Females**
ANB vs. Wits	0.26	0.48

Table 4.8. *Spearman's Rank Correlation Coefficient values comparing ANB and Wits, stratified by gender.*

P-VALUES FOR SPEARMAN'S RANK CORRELATION COEFFICIENT		
Variables examined	**Males**	**Females**
ANB vs. Wits	0.07	0.0004

Table 4.9. *P-values for Spearman correlations, stratified by gender.*

4.4.2 ANB vs. Facial Pattern Measurements

Comparisons between ANB and facial pattern measurements separated by gender can be seen in Table 4.10. On average, the Spearman rank correlation coefficients for males was lower vs. females (r= 0.15 vs. 0.66). However on closer inspection, mandibular plane angle and Y-axis were the only two variables that significantly differed between genders. The remaining variables were similar between males and females.

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Facial Pattern Measurements	**Males (ANB)**	**Females (ANB)**
Mandibular Plane Angle	0.160	0.274
Y-Axis	0.044	0.363
Lower Facial Height	-0.064	-0.022
Facial Axis	0.011	0.047
Average	**0.151**	**0.662**

Table 4.10. *Spearman's Rank Correlation Coefficient values comparing ANB and Facial Pattern Measurements, stratified by gender.*

4.4.3 Wits vs. Facial Pattern Measurements

Comparisons between Wits and facial pattern measurements separated by gender can be seen in Table 4.11. There were no substantive differences between Spearman rank correlation coefficients between males and females.

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Facial Pattern Measurements	**Males (Wits)**	**Females (Wits)**
Mandibular Plane Angle	-0.43	-0.40
Y-Axis	-0.11	0.08
Lower Facial Height	-0.47	-0.38
Facial Axis	0.44	0.58
Average	**-0.14**	**-0.03**

Table 4.11. *Spearman's Rank Correlation Coefficient values comparing Wits and Facial Pattern Measurements, stratified by gender.*

CHAPTER 5

DISCUSSION

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

The ANB angle, as described by Riedel (1952) is currently the most widely utilized parameter to assess the sagittal jaw relationship and is considered the gold standard (Tanaka, Ono et al. 2006). However, there are significant shortcomings with this measurement. Landmark identification introduces the potential for tracing errors of greater than 1.5mm in more than 20% of lateral cephalograms (Baumrind and Frantz 1971, Baumrind and Frantz 1976). Furthermore, Nasion moves upwards and forwards in addition to rotation of the jaws during growth (Enlow and Hans 2008). Lastly and perhaps most importantly, orthodontic treatment may influence the accuracy of the ANB angle (Hussels and Nanda 1984, Nanda and Merrill 1994).

Additional factors have been suggested by other authors which may influence the ANB angle. These include: anterior facial height, characterized by an increase of Sella-Nasion to the occlusal plane angle, the distance between Nasion and B-point, and the distance between A and B-points (Hussels and Nanda 1984, Hussels and Nanda 1987).

The Wits appraisal was proposed by Jacobson in 1975 as an alternative method to overcome the drawbacks of the 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 a clockwise rotation of the upper jaw in relation to the anterior cranial base. According to him, this differentiated the Wits appraisal and the ANB angle.

However, the Wits appraisal is not without its shortcomings (Del Santo 2006, Zamora et al. 2013). This appraisal is calculated by drawing projections of Point A and B on the functional occlusal plane, but the occlusal plane cant can be influenced by the facial growth direction, dental eruption and alveolar bone development. More importantly, since the functional occlusal plane is a dental reference, there is doubt as to whether it may be accurately used to classify skeletal relationships (Foley 1997). Lastly, the functional occlusal plane is difficult to locate and reproduce on the cephalogram due to various factors such as dental overlap, missing and malpositioned teeth and dental restorations (Foley 1997). Our study attempted to mitigate some of these factors by using the Maxillomandibular bisector occlusal plane, which does not rely on a dental reference and has been previously shown to have a stronger correlation with the ANB angle (Del Santo 2006).

Because each analysis has its disadvantages, there is ongoing research into additional cephalometric measurements that may assess skeletal relationships more accurately. The anteroposterior jaw relationship is a cornerstone of orthodontic diagnosis and treatment planning and it is critical to determine the proper skeletal diagnosis in order to accurately determine whether a skeletal discrepancy exists and the degree to which it needs to be addressed (Del Santo 2006). The literature has suggested new formulas to assess skeletal discrepancies, but a closer examination of the traditional measurements, such as ANB and Wits, is still necessary. These cephalometric measurements are easy and popular but there is still a significant intrinsic lack of certainty. Further research would provide a better understanding of their limitations, and if the limitations are mastered, better application of their useful information can be expected (Hussels & Nanda 1984, Del Santo 2006, Provencal 2017).

5.2 Reliability of the measurements

The reliability and reproducibility of the measurements were tested in this study. The results showed a high consistency in the repeated measurements for intra-rater as well as inter-rater reliability, with both values showing over ninety percent agreement. That being said, differences were observed between the respective measurements.

Maxillo-mandibular bisector Wits (MMB Wits) ranked the highest in both intra and inter-rater reliability (r= 0.99 and r=0.98), confirming Hall-Scott's findings that it is a highly reproducible measurement (Hall-Scott 1997). In addition, these values were higher compared to ANB (r= 0.96 and r=0.94). This finding confirms the ease of identifying the landmarks and reproducibility of the MMB Wits appraisal compared to ANB (Foley, Stirling et al 1997, Palleck, Foley et al 2001). As the reliability helps to determine how well an anteroposterior parameter will be able to diagnose a sagittal skeletal discrepancy, it can be inferred from this study that the MMB Wits may provide a more reliable measure of this discrepancy in comparison to ANB. However, whether this finding is clinically relevant remains unknown and despite its shortcomings, the ANB angle provides a reference point from which to work that is familiar to most clinicians (Foley et al 1997, Palleck et al 2001).

The mandibular plane angle ranked second highest, with values of r= 0.99 and r=0.97 for intra and inter-rater reliability, respectively. These findings were expected to be similar to the MMB Wits reliability measures, as MMB Wits contains mandibular plane angle as part of its measurement.

The facial axis exhibited the lowest intra-rater reliability (r= 0.86), however the inter-rater value was among the highest (r=0.99). The preliminary data was re-examined to determine justification for this finding. It was apparent that there was one outlier measurement in the data that can account for this. The statistical analysis was repeated after omitting this outlier, and the intra-rater reliability for lower facial height increased to r=0.99. This outlier was most likely due to data entry error, however in both instances the ICC values indicate high reliability.

In our study, we were able to determine the reproducibility by re-tracing 10% of our sample. Sources of potential error in the measurement of these values possible include: 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 (Provencal 2017). Hand traced cephalograms were not required in this instance because numerous studies have demonstrated that digital computerized tracings are easier and have the same reliability when compared to hand tracings (Erkan et al. 2012, Playfair 2013, Prabhakar et al. 2014). Therefore, we determined that re-tracing 10% of our sample was sufficient and this was confirmed by consistently high ICC scores for all measurements.

5.3 Correlations between Measurements

5.3.1. ANB and Wits

The Wits analysis has been recommended to be used as an adjunct to the ANB angle and is not meant to be considered on its own as a defining variable in cephalometric analysis (Palleck et al 2001). Oktay (1991) concluded that the ANB angle was not less reliable than any other cephalometric measurement as a sagittal A-P parameter. That being said, as Rotberg et al (1980) has stated, “there are no strong or predicable correlations between the Wits appraisal and the ANB angle.” In addition, as previously stated by several authors, the ANB angle is influenced by the anterior cranial base position and the possible rotation of the craniofacial complex, whereas the Wits is influenced only by the occlusal plane, without influence of the cranial base. It is for these reasons that the Wits analysis provides useful insight into classification of the skeletal base that may not otherwise be possible with the ANB angle.

A weak correlation was found between ANB and MMB Wits (r=0.38), with only 41% of subjects being classified as Class I according to Wits. A summary of the correlations from the literature can be seen in Table 5.1. Zamora et al (2013)’s study using CBCT confirms these findings as they also demonstrated a low correlation (r=0.268) between ANB and Wits. They also suggested that the accuracy of their measurements was much greater since their records were in 3D vs. 2D.

However, these findings disagree with Palleck et al (2001) and Foley et al (1997)’s results, where moderate correlations were observed in Class I subjects. However, both studies reported a wide range of values (0.261-0.738) in their sample and their sample sizes were significantly smaller. Tanaka et al (2006) found a moderate correlation (r=0.62) and concluded that, “facial type does not influence the correlation between ANB and Wits. Thus, a reference plane utilizing the mandibular plane, an indicator of facial type, is not expected to adversely alter the relationship between the ANB angle and Wits appraisal.”

In Horowitz and Hixon’s 1966 book, *The Nature of Orthodontic Diagnosis*, they 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″. Our results demonstrated a low correlation coefficient of less than r=0.8, indicating a lack of interchangeability in their clinical ability to assess skeletal jaw discrepancies. This has also been confirmed from numerous studies (Rotberg, Fried et al. 1980, Bishara, Fahl et al. 1983, Chang 1987, Jarvinen 1988, Thayer 1990, Gul e and Fida 2008). Because ANB and Wits assess the same skeletal discrepancy, they should, theoretically, have a high correlation. In reality, the correlation is clearly not as strong as expected, suggesting weakness in at least one, if not both assessment tools (Del Santo 2006). One such weakness could potentially be due to the position of Nasion, which tends to change throughout growth moving forward and upward (Zamora et al 2013).

SUMMARY OF THE CORRELATIONS BETWEEN ANB ANGLE AND WITS APPRAISAL	
Hoediono, 2018	0.38
Palleck, 2001	0.537-0.691
Foley, 1997	0.261-0.738
Zamora, 2013	0.268
Hall-Scott, 1994	0.83
Bishara et al 1983	0.598-0.627
Tanaka et al	0.62

Table 5.1. *Summary of the ANB and Wits correlations cited in the literature*

5.3.2. ANB and Facial Pattern Measurements

ANB and facial pattern measurements such as mandibular plane angle, lower facial height, Y-axis and facial axis have traditionally been treated as mutually exclusive. ANB is considered the most widely used measure of anteroposterior jaw discrepancy, whereas the previously mentioned facial pattern measurements tend to give an idea about a patient's vertical discrepancy. But if a patient had a class I skeletal base, wouldn't there be a reasonable expectation to find a certain proportion of patients with a mesocephalic pattern? And if so, how strong is the correlation between the two? Furthermore, the ANB angle itself contains vertical components, such as the upward or downward rotation of the maxilla and mandible, inclination of the anterior cranial base and vertical position of Nasion. Del Santo (2006) investigated the influence of various inclinations on the ANB angle and found that the anteroposterior maxillomandibular relationships changed significantly for all variables, including Y-axis and Lower Facial Height, two variables also used in our study. In fact, they also mentioned that the most important factor affecting the ANB assessment is the Lower Facial Height. These factors have an important geometric influence in the assessment of sagittal jaw relationships and how much these factors affect the ANB angle to reflect the patient's facial pattern is worth closer examination (Del Santo 2006).

Jacobson (1976) was among the first to criticize the diagnostic value of Riedel's ANB angle and pointed out its various influencing factors. Not only did he mention the factors played by the cranial base and rotation of the jaws, but he also suggested that ANB was only reliable if the mandibular plane angle was normal. A high mandibular plane angle indicates a divergent pattern and in most of these cases, the anterior cranial base is tipped up anteriorly or there is clockwise rotation of both the jaws, which reduces the SNA angle and increases ANB. Conversely, a low mandibular plane angle indicates a convergent pattern with a larger SNA and smaller ANB. Based on this, Jacobson concluded that a mandibular plane angle in excess of 1 standard deviation of the norm causes the SNA angle to become suspect, which in turn affects the ANB (Jacobson 1976).

In our study, the mean mandibular plane angle was within the norms (Table 4.1). However, there was a wide range of values (19.6-47.3) with only 29% of the subjects exhibiting a normal mandibular plane angle. This indicates that in the skeletal class I sample (according to ANB), there was large variability in the facial pattern.

In Zamora et al (2013)'s study, they found that 49% of their sample had a mesofacial pattern according to mandibular plane angle. Of these 49%, there was a high percentage of individuals with differences between ANB and Wits despite this pattern. Our study agreed with these findings, with almost a third (29%) of our sample having a mesofacial pattern but 18 of those (62%) presenting with differences between ANB and Wits. This contrasts Jacobson (1976)'s conclusions that the ANB was only reliable if the mandibular plane was normal as a high percentage of individuals with a normal growth pattern still had differences between ANB and Wits.

A weak correlation was found between mandibular plane angle and ANB (r= 0.19, Table 4.5). These results reflect the findings of various other authors that did not find any correlation with ANB (Nanda 1971, Hussels & Nanda 1984, Zamora et al 2013). From these results, it can then be inferred that changes in the ANB angle are neither predictable nor closely related to changes in the mandibular plane angle (Nanda 1971, Hussels & Nanda 1984).

The Y-axis exhibited the strongest correlation of all the facial pattern measurements, however it was still weak (r=0.21). This was the only facial pattern measurement with respect to ANB that had a statistically significant correlation. Y-axis is an angle-based measurement that incorporates the cranial base by using the S-N plane and Gnathion point.

According to Jacobson (1976), clockwise or counter-clockwise rotation of the S-N line (due to nasion or sella turcica being positioned relatively superiorly or inferiorly to each other) either increases or decreases the SNA reading and in turn, ANB. Therefore, since Y-axis relies on cranial base landmarks, there will not always be agreement between Y-axis and ANB angle due to changes in the inclination of the cranial base.

The Spearman's Rank Correlation between ANB and Lower Facial Height was determined to be the weakest of all the facial pattern measurements and was not statistically significant. These results concur with Del Santo (2006)'s findings that as a patient grows, if their lower facial height increases then the anteroposterior proportion also increases, thus an increased ANB angle. More than likely, there is a backward rotational component to the mandible as vertical growth occurs, contributing to A and B points getting further apart, thus increasing ANB.

Similar results were also found with the facial axis (a weak correlation that was not statistically significant, Table 4.5). This may also be due to a backward rotation of the mandible as a result of vertical growth. Poor correlations can also be explained by variability in the horizontal and/or vertical position of Nasion, as facial axis uses the Basion-Nasion plane. As explained by Jacobson (1975), the position of Nasion is influenced by an excessively long or short anterior cranial base or a relative posterior or anterior positioning of both jaws within the skeletal craniofacial complex. Lastly, errors in landmark identification can occur as the foramen rotundum can sometimes be difficult to locate on a lateral cephalogram.

5.3.3. Wits and Facial Pattern Measurements

With respect to mandibular plane angle, the results of our study showed a statistically significant moderate correlation with Wits (r= -0.46. Table 4.6). This is in agreement with Zamora et al (2013), who also found a correlation, but it was slightly weaker (r= 0.24). The sample size for our study was larger, but their study used CBCTs vs. lateral cephalograms, which may be more accurate because their study examined 3D images vs 2D (Zamora 2012). It is well known that small changes in the occlusal plane angle can affect the Wits measurement (Jacobson 1975, 1976, 1988, Robertson 1980, Rotberg et al 1980, Jarvinen 1981, Richardson 1982, Hussels & Nanda 1984, Chang 1987, Haynes & Chau 1995) and occlusal plane inclination depends directly on facial growth direction (Del Santo 2006). The occlusal plane of choice in this study was the maxillomandibular bisector, which uses the bisecting line between the maxillary and mandibular plane. As such, the results of our study with respect to Wits and mandibular plane angle were to be expected and demonstrated that the mandibular plane and MMB line are not mutually exclusive. This is an indication that changes in the inclination of the mandibular plane can affect the MMB reference plane, and this may be an influencing factor on the resulting Wits measurement and potentially the facial pattern. In addition, since mandibular plane angle is a measure of facial pattern, it can be inferred that differences in the facial pattern may be reflected in the Wits values. That being said, the clinical significance of these findings is still questionable, as correlation values of less than r=0.8 mean little clinical predictive value when applied to an individual (Horowitz & Hixon 1966).

Facial axis, like the mandibular plane angle, also demonstrated a moderate correlation with Wits (r= 0.57), which was statistically significant. This was especially of interest because facial axis can be influenced by the position of Nasion, whereas Wits is independent of Nasion and other cranial base landmarks. However, it exhibited the strongest correlation of all the facial pattern measurements, indicating that there may be a relationship between Wits and the facial pattern with respect to facial axis. Currently, no other studies have investigated the correlation between these two variables and further follow-up is recommended to confirm these findings.

The weakest correlations were found between Wits, Y-axis (r= -0.05) and lower facial height (r= -0.33) and the former was not statistically significant. Millet & Gravely (1991) concluded in their study that the SN-Y-axis angle correlated very poorly with the Wits analysis and our study echoes those findings. With respect to the lower facial height, many authors have suggested that variation in the anterior facial height, make the use of the ANB angle as a measure of skeletal pattern misleading (Taylor 1969, Beatty 1975, Jacobson 1975). Our findings suggest that the same may also be true in relation to Wits. Del Santo (2006) also found that significant changes did not occur in the lower facial height with changes in the Wits measurement, which also confirms our observation. That being said, our finding with respect to this variable was not statistically significant, therefore caution of the interpretation of this finding should be exercised.

5.4 Use of Maxillomandibular Bisector (MMB) and Wits

As previously mentioned, Jacobson (1976) advocated for using the functional occlusal plane (FOP) as the reference plane of choice but warned that if the mandibular plane angle was greater than one standard deviation from the mean, the resulting ANB angle may be arguable. Many authors, however, have found great variations in the Wits calculated to the FOP (Rotberg et al 1980, Jarvinen 1981, Rushton et al 1991). Among these authors, Nanda et al (1994) concluded that mild changes in the occlusal plane's cant can cause major variations in the Wits. In addition, Rushton et al (1991) explained that the FOP was a challenging line to trace and resulted in large variations of 1mm/more in the Wits measurement. Therefore, its relationship to the FOP continues to shed doubt.

The MMB reference plane uses a line that bisects the maxillary and mandibular plane. Other authors that have investigated the use of different reference planes have found that MMB may be a more reliable reference plane as it eliminates the need for relying on the cranial and denture bases and the cephalometric landmarks are easier to identify (Foley 1991, Hall-Scott 1994, Provencal 2017). This study further confirms that the use of the MMB occlusal plane is a reliable indicator of the sagittal discrepancy and may be a better reference landmark to A and B point than Nasale.

In addition, the inclination of this plane has been determined to change the least of all of the occlusal planes (Foley 1991, Hall-Scott 1994). Furthermore, the occlusal plane inclination depends on the facial growth direction, as determined by the mandibular plane angle. Our findings confirm that there is a relationship between Wits and mandibular plane angle, and furthermore, facial pattern. Therefore, the Wits appraisal may be a more accurate predictor of the facial pattern than ANB when using this plane.

5.5 Correlations by Gender

Correlations based on gender were examined, as seen in Tables 4.8-4.10. The correlations were generally low to moderate, ranging from 0.07-0.47 for males and -0.022-0.58 for females. With respect to ANB and Wits, the correlation coefficients were slightly lower for males vs. females, but this was not statistically significant. This also applied to ANB vs. Facial pattern measurements, where the most significant differences were less than 1 correlation coefficient value. Therefore, it can be said that overall, there were no substantive differences between males and females.

Based on the findings of our study, the Wits appraisal using the maxillomandibular bisector occlusal plane is a valid indicator of the sagittal discrepancy and facial pattern. Wits may be a more accurate predictor of facial pattern vs. ANB. The occlusal plane (MMB) may be a better reference landmark to A point and B point than Nasale. It is recommended that the "gold standard" ANB angle be used in combination with the Wits Appraisal in order to glean the best correlations with the facial pattern measurements.

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. Difficulty in identifying accurate landmark location caused by poor lateral cephalogram quality as well as individual anatomic variation is a potential source of error in this research. Some landmarks can be more difficult to identify than others and, as a result, some discrepancies in particular measurements may have occurred (Baumrind and Frantz 1971, Baumrind and Frantz 1976).

Another limitation of this study was that it was done with the use of lateral cephalograms, which are two dimensional in nature. This introduces a source of error because measurements are being taken from a two-dimensional image of a three-dimensional subject. A cone beam CT may be a better choice in order to derive the most accurate information available in future studies.

The use of a constructed occlusal plane (MMB) requires that it be drawn at a specified inclination, instead of connecting two distinct points. This can be a source of reduction in accuracy (Proffit 2013). However, the magnitude of error may be small compared to relying on an occlusal plane that is derived from using the dentition. In addition, the error study done suggested that there was a very high level of reliability for all of the measurements used, therefore the potential impact of any error is likely to be very low.

One advantage of this study is that sufficient power was chosen for the groups. Earlier power studies suggested a sample size of 47 individuals (Swoboda 2013). Our study of 100 subjects more than doubled this recommendation. The ability to obtain sufficient power of 80% a priori means that the risk of type II error is decreased.

The inherent nature of the graduate orthodontic program at the University of Manitoba from which the sample was selected introduces selection bias that can impact the ability to extrapolate the findings of this study to a global scale. Severity of malocclusion, skeletal pattern and growth patterns have been shown to vary depending on the ethnic background of the individual (Proffit, Fields et al. 1998). Despite the multicultural nature of the patient base at the University of Manitoba, there may not be a good correlation between the findings of this study and similar studies done in non-Caucasian regions of the world.

5.7 Future Studies

Future studies on this topic may include the repetition of this study using three-dimensional cephalometric analysis using 3D imaging such as cone beam CT. Being the planes are formed by three points, instead of two (as in 2D records), the accuracy of the measurements is much greater and opens the door to reassess all the measurements previously established (Zamora et al 2012). However, the risks vs. benefits must be weighed as 3D imaging requires more radiation to the patient. In addition, the use of this type of imaging is relatively new compared to lateral cephalograms and sufficient databases to obtain a sufficient sample size may be limited at this stage.

This study examined the correlations between ANB, Wits and facial pattern measurements based on class I subjects only (according to ANB). Further studies could be done on this subject with samples using class II and class III subjects. It would be of value to determine if there were any significant correlations between ANB and Wits in these types of patients and what proportion of them have a normal, dolichocephalic or brachycephalic pattern.

Finally, future studies may include using samples of different ethnic backgrounds and examining whether there are differences in the correlations of ANB, Wits and facial pattern. It is already well known in the literature that skeletal class II patients are more prevalent in patients of European descent and there is also evidence of class III relationships existing more frequently in Asian populations (Proffit 2013). It would be of interest to see whether the Wits values also agree with these assumptions and whether certain facial patterns are more prevalent in some ethnic backgrounds vs. others.

5.8 Revisiting the null hypotheses

The null hypotheses for this study stated that:

1. There is no correlation between mandibular plane angle, Y-axis, lower facial height, facial axis and ANB or Wits when using the maxillomandibular bisector as the occlusal plane in skeletal class I patients. **This hypothesis is rejected.** Correlations were found between all of the variables measured.

2. Facial pattern does not correlate with differences found between ANB and Wits classification in skeletal class I patients. **This hypothesis is rejected.** Correlations were found with all of the facial pattern measurements with ANB and Wits, ranging from low to moderate.

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 Maxillomandibular bisector as an occlusal plane is a valid indicator of the sagittal discrepancy and facial pattern.
2. The Maxillomandibular bisector (MMB) occlusal plane may be a better reference landmark to A point and B point than Nasale.
3. The orthodontist should not rely on interpretations of ANB and Wits as there is a low correlation between them so they must be considered separately.
4. ANB is a weak predictor of facial pattern of the patient.
5. Wits is a more accurate predictor of facial pattern than ANB.

6.2 Recommendations

It is recommended that:

1. The "gold standard" ANB angle be used in combination with the Wits Appraisal in order to glean the best correlations with the facial pattern measurements. ANB and Wits are not considered interchangeable as demonstrated by the low correlation coefficient. This may explain the discrepancies between measured values of the ANB angle and the clinical judgment of the orthodontist.
2. The Maxillomandibular bisector should be used as the occlusal plane of choice when using the Wits analysis.

CHAPTER 7

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Chapter 8

Appendices

8.1 Ethics Approval

UNIVERSITY OF MANITOBA | Research Ethics - Bannatyne
Office of the Vice-President (Research and International)

P126-770 Bannatyne Avenue
Winnipeg, Manitoba
Canada, R3E 0W3
Telephone : 204-789-3255
Fax: 204-789-3414

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

PRINCIPAL INVESTIGATOR:	INSTITUTION/DEPARTMENT:	ETHICS #:
Dr. Caley Hoediono	U of M/Dentistry/Preventive Dental Science/Resident	HS20845 (H2017:186)

APPROVAL DATE:	EXPIRY DATE:
May 8, 2017	**May 8, 2018**

STUDENT PRINCIPAL INVESTIGATOR SUPERVISOR (If applicable):
Dr. William Wiltshire

PROTOCOL NUMBER:	PROJECT OR PROTOCOL TITLE:
N/A	The Influence of Facial Pattern on Skeletal Class I Subjects - A Cephalometric Analysis

SPONSORING AGENCIES AND/OR COORDINATING GROUPS:
N/A

Submission Date of Investigator Documents:	HREB Receipt Date of Documents:
May 8, 2017	May 8, 2017

THE FOLLOWING ARE APPROVED FOR USE:

Document Name	Version(if applicable)	Date
Protocol:		
Protocol		April 2017
Consent and Assent Form(s):		
Other:		
Master List		May 8, 2017
Data Collection/Capture Sheet		May 8, 2017

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.

- 1 -

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8.2 Journal Article

The Influence of Facial Pattern on Skeletal Class I Subjects- A Cephalometric Analysis

Objective

The purpose of this study was to assess the correlations between the Wits appraisal (using maxillomandibular bisector as the occlusal plane), ANB analysis and facial pattern in skeletal Class I subjects

Materials and methods

A retrospective chart review was completed on 100 Class I subjects according to the ANB angle. The maxillomandibular bisector (MMB) was used as the occlusal plane to determine the sagittal maxillomandibular relationship according to the Wits appraisal. Four additional measurements (mandibular plane angle, Y-axis, lower facial height and facial axis) associated with facial pattern were measured to determine whether the Wits or ANB analysis is correlated in classifying skeletal and facial patterns

Results

A weak correlation was found between ANB and Wits ($r=0.38$) that was statistically significant ($p<0.05$). Correlations between ANB and all facial pattern measurements were also weak, but they were not statistically significant ($p>0.05$). Moreover, associations were found between Wits and facial pattern measurements ranging from low to high (-0.05 to 0.57) and were all statistically significant ($p<0.05$). The strongest correlations were between facial axis ($r=0.57$), MPA ($r=-0.46$) and Wits. A moderate correlation was found between lower facial height and Wits ($r=-0.331$). There were no substantive differences between males and females.

Conclusions

The Wits appraisal using the maxillomandibular bisector occlusal plane is a valid indicator of the anteroposterior discrepancy and facial pattern. Wits may be a more accurate predictor of facial pattern vs. ANB. However, caution must be exercised in trying to relate Wits appraisal to the gold standard of the ANB angle.

Introduction

Classification of skeletal disharmonies is one of the most important aspects of diagnosis and clinical orthodontics. Cephalometric analysis is used to diagnose jaw discrepancies in order to develop accurate and reliable treatment plans. However, no single analysis is considered sufficient to accurately describe the sagittal jaw relationship in every patient. As a result, the use of multiple analyses have been advocated for in the classification of anteroposterior jaw relationships in individual patients [(1-3)]. However, there is also no universal consensus for the selection of the measurements which should be used.

Various analyses have been proposed with multiple linear and angular parameters, with the aim of simplifying the diagnosis of the sagittal jaw discrepancies. Traditionally, the ANB angle has been used to compare the relationship of the maxilla and mandible to each other and to this day remains the "gold standard" [(4-5).] However, studies have identified deficiencies in the ANB angle due to variability in cranial base landmarks [(4,6)].

The Wits appraisal has been demonstrated to provide a reliable and reproducible classification of jaw relationships without the need for cranial base landmarks and is frequently utilized in clinical orthodontics [(4-7)]. However, the Wits appraisal is not without its shortcomings [(5,8)]. First, since the functional occlusal plane is a dental reference, there is doubt as to whether it may be accurately used to classify skeletal relationships [(9)]. Moreover, the functional occlusal plane is difficult to locate and reproduce on the cephalogram due to various factors such as dental overlap, missing and malpositioned teeth and dental restorations [(9)]. As such, approaches to decrease the variation and error related to the Wits measurement have been investigated and include the following: mathematical tables to "correct" the Wits value [(10,11)], geometric equations to account for skeletal variations [(12)] and the use of alternative reference planes to which A and B point perpendiculars can be projected [(9,13,14,15)]; these planes include the Bisecting occlusal plane and the Maxillomandibular Bisector [(16)]. The Maxillomandibular Bisector (MMB) in particular, has been demonstrated to have lower technique error and is easier to construct on lateral cephalograms, compared to other reference planes. It also has the advantage that it does not rely on the dentition or cranial base landmarks in its construction [(6,9)].

Because the ANB angle and the Wits appraisal evaluate the same skeletal jaw relationships, theoretically they should have a strong correlation. However, the agreement between the two is not as strong as expected, implying weakness in at least one parameter [(5,16)].

Reducing the inaccuracies associated with both the ANB angle and Wits measurements can enhance their validity and reinforce their supportive roles in the assessment of anteroposterior jaw relationships. Therefore, a need still remains to determine these inaccuracies in order to overcome their shortcomings.

The purpose of this investigation was to assess the correlation between the Wits appraisal (when using maxillomandibular bisector as the occlusal plane) and ANB analysis with the mandibular plane angle, Y- axis, lower facial height and facial axis in skeletal class I subjects and verify the facial pattern in these analyses.

Materials and Methods

Pre-treatment lateral cephalograms were taken between August 29th, 2003 and July 26th, 2017 and acquired from the archives of the University of [redacted] Graduate Orthodontic Clinic. Digital cephalograms were taken with a Kodak Panoramic/Cephalometric model CS 8000C. The chosen sample size consisted of 100 subjects with 50 females and 50 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). All lateral cephalograms were digitally traced using the Dolphin™ 11.7 imaging software (Dolphin Imaging and Management Systems, Chatsworth, CA, USA). Film magnification was standardized for each film, which matched a 30 mm ruler included in each film view.

Inclusion criteria

- Fully erupted and occluded permanent dentition, with the exception of third molars
- No missing teeth in either the upper or lower arch
- No impacted teeth
- No craniofacial abnormalities
- Skeletal class I anteroposterior jaw relationship as determined by an ANB value between 0^{o} and 4^{o} taken from digital cephalograms from the University of [redacted] Orthodontic Clinic
- Dental malocclusions had no bearing on case selection
- Treatment performed clinically on these subjects had no bearing on case selection
- Both males and females were included equitably

Statistical Analysis

For *correlation analyses:* Pairwise Spearman correlations were assessed to relate the ANB angle to the Wits values, ANB to facial pattern measurements and the Wits values to the facial pattern. The p-value was considered significant at $\alpha<0.05$.

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

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

Results

Sample Group Statistics

A summary of the cephalometric measurements is described in Table 1. The mean, minimum and maximum values for ANB were within the normal range. The mean for the Wits appraisal value was a class III skeletal pattern, (-3.8mm) however there were a wide range of values that included patients who presented with all three classifications (I, II and III). The mandibular plane angle mean value was within the normal range, however the minimum and maximum values varied from brachycephalic to dolichocephalic facial patterns. The Y-axis mean value was on the high end of the normal range and the range also varied from brachycephalic to dolichocephalic patterns. Both the lower facial height and facial axis angle mean values were within their normal ranges and also contained a large range of values inclusive of all three facial patterns.

Groups	*Normal Values*	*Mean*	*Min.*	*Max.*	*SD*
1. ANB (º)	2º±2º	2.1	0	3.9	1.1
2. Wits (mm)	Males: 1mm Females: 0mm	-3.8	-11.4	3.9	3.3
3. Mandibular Plane Angle (º)	32 º±2 º	31.6	19.6	47.3	5.9
4. Y-axis (º)	66 º±2 º	68.2	59.1	76.8	3.7
5. Lower Facial Height (mm)	65±4.5mm	64.6	51.7	81.7	6.0
6. Facial Axis Angle (º)	90º±3.5 º	89.9	80.1	100.4	4.3

Table 1. ANB, Wits and Facial Pattern Measurement Statistics

Reliability

The reliability and reproducibility of the results were validated by re-measuring 10% of the selected sample. This sample was randomly selected and re-measured by the primary investigator as well as a second independent examiner at two different time points that were 1 month apart. The reliability was assessed using Intraclass Correlation Coefficient (ICC) values ranging from 0 (no agreement) to 1 (perfect agreement). The intra-examiner findings showed a high consistency in the repeated measurements with an average of 0.93 (Table 2). The inter-examiner Intraclass Correlation Coefficient values were also determined to be high, with an average value of 0.91 (Table 3). Based on these results we can be confident that the reliability and reproducibility of the cephalometric radiographic measurements are reliable.

INTRA-RATER RELIABILITY	
Variables examined	**Intraclass Correlation**
ANB	0.96
Wits	0.99
Mandibular Plane Angle	0.99
Y-Axis	0.98
Lower Facial Height	0.86
Facial Axis	0.82
Average	**0.93**

Table 2. ICC values for the intra-examiner reliability

INTER-RATER RELIABILITY	
Variables examined	**Intraclass Correlation**
ANB	0.94
Wits	0.98
Mandibular Plane Angle	0.97
Y-Axis	0.97
Lower Facial Height	0.98
Facial Axis	0.99
Average	0.97

Table 3. ICC values for the inter-examiner reliability.

Correlations between Measurements

<u>ANB and Wits</u>

Spearman's Rank Correlation Coefficient was calculated to determine the correlation between ANB and Wits ($r=0.38$). A scatter plot was constructed to demonstrate their relationship (Fig 1). A weak correlation was found between the ANB and Wits and the p value determined that this value was highly statistically significant ($p<0.00008$).

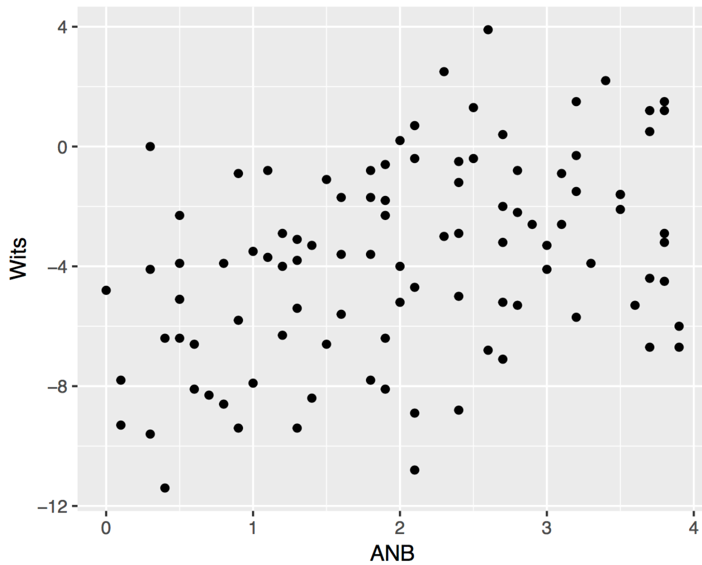

Figure 1. Scatter plot depicting a weak positive correlation between ANB and Wits

ANB and Facial Pattern Measurements

Spearman's Rank Correlation Coefficient was calculated to determine the correlations between ANB and each respective facial pattern measurement (Table 5). On average, weak associations were found with respect to all the facial pattern measurements (r= 0.105). This is demonstrated in figure 2, where none of the scatter plots comparing ANB and the facial measurements demonstrate a visual pattern. The strongest correlation was determined to be between ANB and Y-axis (r= 0.209) and it was the only correlation that was considered statistically significant ($p<0.05$).

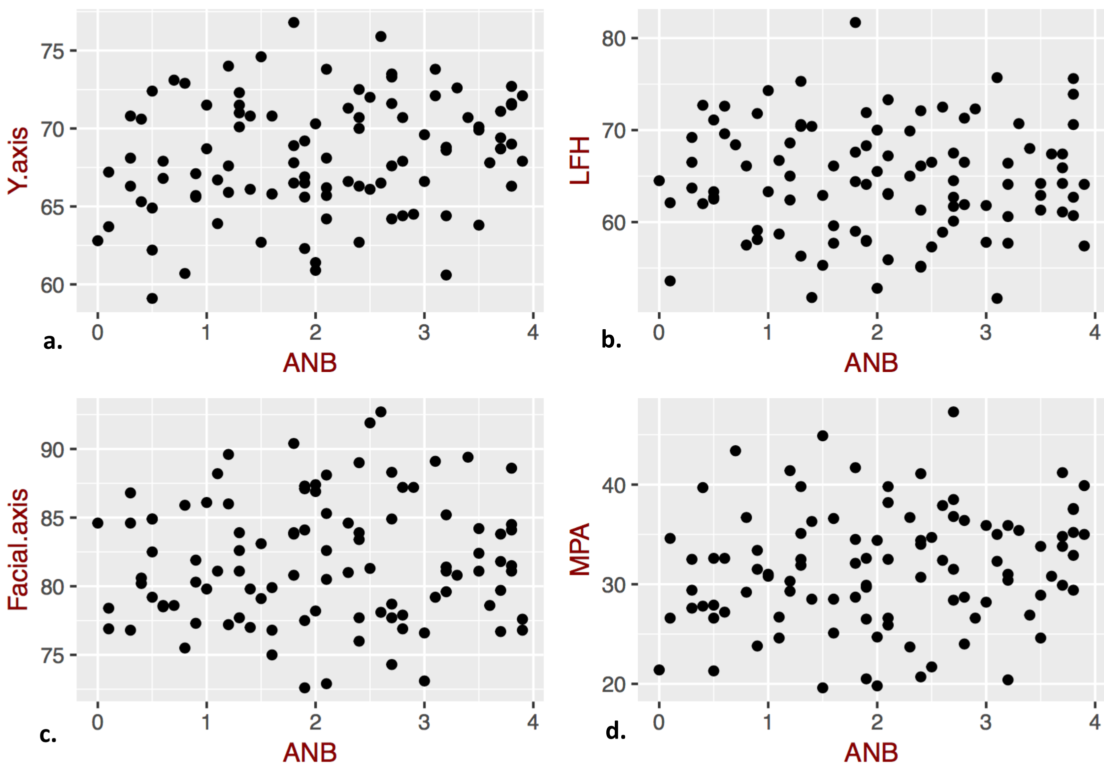

Figure 2. Scatter plots comparing ANB and the Facial Pattern Measurements. ***a.****- ANB vs. Y-Axis.* ***b.****- ANB vs. Lower Facial Height.* ***c.****- ANB vs. Facial Axis.* ***d.****- ANB vs. MPA*

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Facial Pattern Measurements	**Spearman's Rank Value (ANB)**	**P Value**
Mandibular Plane Angle	0.193	0.055
Y-Axis	0.209	0.037
Lower Facial Height	-0.020	0.842
Facial Axis	0.038	0.705
Average	**0.105**	**0.410**

Table 5. Spearman's Rank Correlation Coefficient values comparing ANB and Facial Pattern Measurements

Wits and Facial Pattern Measurements

Spearman's Rank Correlation Coefficient was calculated to determine the correlations between Wits and each respective facial pattern measurement (Table 6). Associations were found, ranging from low to high (-0.05 to 0.57). This is demonstrated in figure 3, where scatter plots comparing Wits and the facial measurements show the respective relationships between the measurements. The strongest correlations were between facial axis ($r=0.57$), MPA ($r=-0.46$) and Wits, all of which were statistically significant ($p<0.05$). A moderate correlation was found between lower facial height and Wits ($r=-0.331$), which was also statistically significant ($P<0.05$). Conversely, Y-axis and Wits showed the weakest association of the four measurements and it was a negative correlation ($r= -0.046$). This was also the only finding of the four that was not statistically significant ($p<0.05$).

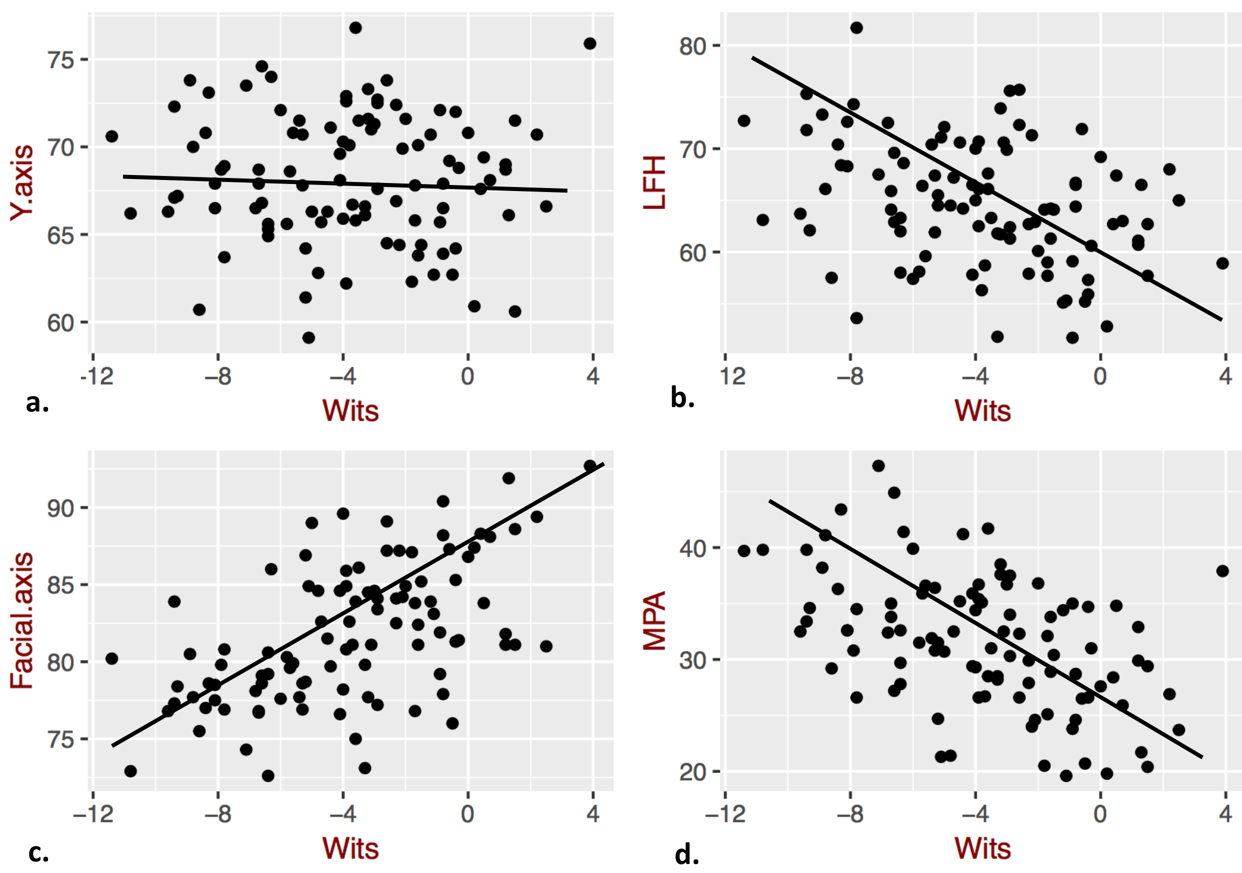

Figure 3. Scatter plots comparing Wits and the Facial Pattern Measurements. ***a.****- Wits vs. Y-Axis.* ***b.****- Wits vs. Lower Facial Height.* ***c.****- Wits vs. Facial Axis.* ***d.****- Wits vs. MPA*

SPEARMAN'S RANK CORRELATION COEFFICIENT		
Facial Pattern Measurements	**Spearman's Rank Value (Wits)**	**P Value**
Mandibular Plane Angle	-0.463	0.000001
Y-Axis	-0.046	0.65
Lower Facial Height	-0.331	0.00077
Facial Axis	0.566	8.3E-10
Average	**-0.0685**	**0.162693**

Table 6. Spearman's Rank Correlation Coefficient values comparing Wits and Facial Pattern Measurements

Differences between Genders

All variables examined in this study were also stratified according to gender to determine possible gender differences. There were no substantive differences between males and females ($r < 1$, $p < 0.05$).

Discussion

ANB and Wits

A weak correlation was found between ANB and MMB Wits (r=0.38), with only 41% of subjects being classified as Class I according to Wits. Zamora et al (2013)'s study using CBCT confirms these findings as they also demonstrated a low correlation (r=0.268) between ANB and Wits [(8)]. They also suggested that the accuracy of their measurements was much greater since their records were in 3D vs. 2D.

However, these findings disagree with Palleck et al (2001) and Foley et al's (1997) results, where moderate correlations were observed in Class I subjects [(6,9)]. However, both studies reported a wide range of values (0.261-0.738) in their sample. In addition, their sample sizes were significantly smaller. Tanaka et al (2006) found a moderate correlation (r=0.62) and concluded that, “facial type does not influence the correlation between ANB and Wits [20]. Thus, a reference plane utilizing the mandibular plane, an indicator of facial type, is not expected to adversely alter the relationship between the ANB angle and Wits appraisal.”

ANB and Wits describe the same skeletal relationships, therefore they should have a very high correlation. In reality, the correlation is clearly much weaker than expected, suggesting weakness in at least one, if not both parameters [5]. One such weakness could potentially be due to the position of Nasion, which tends to change throughout growth moving forward and upward [8].

ANB and Facial Pattern Measurements

In our study, the mean mandibular plane angle was within the norms (Table 1). However, there was a wide range of values (19.6-47.3) with only 29% of the subjects exhibiting a normal mandibular plane angle. This indicates that in our skeletal class I sample (according to ANB), there was large variability in the facial pattern.

In Zamora et al’s (2013) study, they found that 49% of their sample had a mesofacial pattern according to mandibular plane angle. Of these 49%, there was a high percentage of individuals with differences between ANB and Wits despite this pattern [8]. Our study agreed with these findings, with almost a third (29%) of our sample having a mesofacial pattern but 18 of those (62%) presenting with differences between ANB and Wits. This contrasts Jacobson (1976)’s conclusion that the ANB was only reliable if the mandibular plane was normal, as a high percentage of individuals with a normal growth pattern still had differences between ANB and Wits [21].

A weak correlation was found between mandibular plane angle and ANB (r= 0.19, Table 5). These results reflect the findings of various other authors that did not find any correlation with ANB [8,10,22]. From these results, it can then be inferred that changes in the ANB angle are neither predictable nor closely related to changes in the mandibular plane angle [10,22].

The Y-axis exhibited the strongest correlation of all the facial pattern measurements, however it was still weak (r=0.21). This was the only facial pattern measurement with respect to ANB that had a statistically significant correlation. Y-axis is an angle-based measurement that incorporates the cranial base by using the S-N plane and Gnathion point. Since Y-axis relies on cranial base landmarks, there will not always be agreement between Y-axis and ANB angle. This is due to changes in the inclination of the cranial base because clockwise or counter-clockwise rotation of the S-N line (due to nasion or sella turcica being positioned relatively superiorly or inferiorly to each other) either increases or decreases the SNA reading and in turn, ANB [21].

The Spearman's Rank Correlation between ANB and Lower Facial Height was determined to be the weakest of all the facial pattern measurements and was not statistically significant. These results concur with Del Santo (2006)'s findings that as a patient grows, if their lower facial height increases then the anteroposterior proportion also increases, thus an increased ANB angle [5]. More than likely, there is a backward rotational component to the mandible as vertical growth occurs, contributing to A and B points getting further apart, thus increasing ANB.

Similar results were also found with the facial axis (a weak correlation that was not statistically significant, Table 5). This may also be due to a backward rotation of the mandible as a result of vertical growth. Poor correlations can also be explained by variability in the horizontal and/or vertical position of Nasion, as facial axis uses the Basion-Nasion plane. Moreover, errors in landmark identification can occur as the foramen rotundum can sometimes be difficult to locate on a lateral cephalogram.

Wits and Facial Pattern Measurements

With respect to mandibular plane angle, the results of our study showed a statistically significant moderate correlation with Wits (r= -0.46. Table 6). This is in agreement with Zamora et al (2013), who also found a correlation, but it was slightly weaker (r= 0.24) [8]. The sample size for our study was larger, but their study used CBCTs vs. lateral cephalograms, which may be more accurate because their study examined 3D images vs 2D [23]. It is well known that small changes in the occlusal plane angle can affect the Wits measurement and occlusal plane inclination depends directly on facial growth direction [2,4,5,10,12,21,24,26,27,28]. The occlusal plane of choice in this study was the maxillomandibular bisector, which uses the bisecting line between the maxillary and mandibular plane. As such, the results of our study with respect to Wits and mandibular plane angle were to be expected and demonstrated that the mandibular plane and MMB line are not mutually exclusive. This is an indication that changes in the inclination of the mandibular plane can affect the MMB reference plane, and this may be an influencing factor on the resulting Wits measurement and potentially the facial pattern. In addition, since mandibular plane angle is a measure of facial pattern, it can be inferred that differences in the facial pattern may be reflected in the Wits values. That being said, the clinical significance of these findings is still questionable, as correlation values of less than r=0.8 mean little clinical predictive value when applied to an individual [(29)].

Facial axis, like the mandibular plane angle, also demonstrated a moderate correlation with Wits (r= 0.57), which was statistically significant. This was especially of interest because facial axis can be influenced by the position of Nasion, whereas Wits is independent of Nasion and other cranial base landmarks. However, it exhibited the strongest correlation of all the facial pattern measurements, indicating that there may be a relationship between Wits and the facial pattern with respect to facial axis. Currently, no other studies have investigated the correlation between these two variables and further follow-up is recommended to confirm these findings.

The weakest correlations were found between Wits, Y-axis (r= -0.05) and lower facial height (r= -0.33) and the former was not statistically significant. Millet & Gravely (1991) concluded in their study that the SN-Y-axis angle correlated very poorly with the Wits analysis and our study echoes those findings [(30)]. With respect to the lower facial height, many authors have suggested that variation in the anterior facial height, make the use of the ANB angle as a measure of skeletal pattern misleading [(4,31,33)]. Our findings suggest that the same may also be true in relation to Wits. Del Santo (2006) also found that significant changes did not occur in the lower facial height with changes in the Wits measurement, which also confirms our observation [(5)]. That being said, our finding with respect to this variable was not statistically significant, therefore caution of the interpretation of this finding should be exercised.

Use of Maxillomandibular Bisector (MMB) and Wits

The MMB reference plane uses a line that bisects the maxillary and mandibular plane. Other authors that have investigated the use of different reference planes have found that MMB may be a more reliable reference plane as it eliminates the need for relying on the cranial and denture bases and the cephalometric landmarks are easier to identify [(9,1516)]. This study further confirms that the use of the MMB occlusal plane is a reliable indicator of the sagittal discrepancy and may be a better reference landmark to A and B point than Nasale.

In addition, the inclination of this plane has been determined to change the least of all of the occlusal planes [9,15]. Furthermore, the occlusal plane inclination depends on the facial growth direction, as determined by the mandibular plane angle. Our findings confirm that there is a relationship between Wits and mandibular plane angle, and furthermore, facial pattern. Therefore, the Wits appraisal may be a more accurate predictor of the facial pattern than ANB when using this plane.

Based on the findings of our study, the Wits appraisal using the maxillomandibular bisector occlusal plane is a valid indicator of the sagittal discrepancy and facial pattern. Wits may be a more accurate predictor of facial pattern vs. ANB. The occlusal plane (MMB) may be a better reference landmark to A point and B point than Nasale. It is recommended that the "gold standard" ANB angle be used in combination with the Wits Appraisal in order to glean the best correlations with the facial pattern measurements.

Conclusions

1. The Wits appraisal using the Maxillomandibular bisector as an occlusal plane is a valid indicator of the sagittal discrepancy and facial pattern.
2. The Maxillomandibular bisector (MMB) occlusal plane may be a better reference landmark to A point and B point than Nasale.
3. The orthodontist should not rely on interpretations of ANB and Wits as there is a low correlation between them so they must be considered separately.
4. ANB is a weak predictor of facial pattern of the patient.
5. Wits is a more accurate predictor of facial pattern than ANB.

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8.3 Journal article submission received

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Detailed Status Information

Manuscript #	052819-365
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Current Stage	Initial QC Started
Title	The Influence of Facial Pattern on Skeletal Class I Subjects- A Cephalometric Analysis
Running Title	Influence of Facial Pattern on Class I Subjects
Manuscript Type	Original Article
Special Section	N/A
Corresponding Author	Caley Hoediono (University of Manitoba)
Contributing Authors	William Wiltshire , Kris Row , Charlene Solomon
Financial Disclosure	I have no relevant financial interests in this manuscript.
Abstract	Objective The purpose of this study was to assess the correlations between the Wits appraisal (using maxillomandibular bisector as the occlusal plane), ANB analysis and facial pattern in skeletal Class I subjects Materials and methods A retrospective chart review was completed on 100 Class I subjects according to the ANB angle. The maxillomandibular bisector (MMB) was used as the occlusal plane to determine the sagittal maxillomandibular relationship according to the Wits appraisal. Four additional measurements (mandibular plane angle, Y-axis, lower facial height and facial axis) associated with facial pattern were measured to determine whether the Wits or ANB analysis is correlated in classifying skeletal and facial patterns Results A weak correlation was found between ANB and Wits (r=0.38) that was statistically significant (p<0.05). Correlations between ANB and all facial pattern measurements were also weak, but they were not statistically significant (p>0.05). Moreover, associations were found between Wits and facial pattern measurements ranging from low to high (-0.05 to 0.57) and were all statistically significant (p<0.05). The strongest correlations were between facial axis (r=0.57), MPA (r=-0.46) and Wits. A moderate correlation was found between lower facial height and Wits (r=-0.331). There were no substantive differences between males and females. Conclusions The Wits appraisal using the maxillomandibular bisector occlusal plane is a valid indicator of the anteroposterior discrepancy and facial pattern. Wits may be a more accurate predictor of facial pattern vs. ANB. However, caution must be exercised in trying to relate Wits appraisal to the gold standard of the ANB angle.
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