EXPLORING THE SOURCES OF VARIATION IN THE SN-FH ANGLE AND ITS COMPONENTS: A COMPARISON OF THREE ETHNIC GROUPS

A Thesis

by

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ABSTRACT

Purpose

The purpose of this study was to assess the SN-FH angle in three ethnicities- North American Caucasian, Black and Mexican- while also providing insight on the variability of both the sella-nasion and Frankfort horizontal reference planes between and within these populations. Secondarily, the study aimed to determine if the SN-FH angle correlates to facial divergence and growth tendencies observed radiographically.

Materials and Methods

This retrospective, cross-sectional study included 309 de-identified radiographs gathered from the Texas A&M College of Dentistry Orthodontic Department patient archives. The radiographs consisted of three ethnic groups and included both males and females. A custom cephalometric analysis was created using Dolphin Imaging Software (Version 11.9) and radiographs were subsequently digitized. Linear and angular measurements were derived from the tracings in order to compare the SN-FH angle within and between the three groups. Additional measures of facial divergence, head posture, and growth forecast were also analyzed and compared to the SN-FH angle. SPSS was used for statistical analysis. A two-way analysis of variance was used to evaluated group and sex differences, controlling for age. In order to consolidate all of the variables analyzed for this study and discover particular underlying trends related to the SN-FH angle, a principal component factor analysis with varimax was completed.

Results

Coefficients of variation indicated that SN contributed more to the variability seen in the SN-FH angle than the FH reference plane. The entire sample had an average SN-FH angle of 8.6°. There was no difference in the SN-FH angle between sexes. In regards to the ethnic differences, there was a significant difference in the SN-FH angle between Caucasians and African-Americans ($p<0.001$). African-Americans had larger SN-FH angles than Caucasians. There was no difference in the angle between Mexican-Americans and Caucasians or African-Americans. Seven factors contributed to the overall variation seen in the sample; of those factors, five were significantly correlated to the SN-FH angle: maxillo-mandibular relationship to SN, upper to lower face height ratio, cranial base angulation, and growth pattern. The maxillo-mandibular relationship to SN factor explained over forty percent of variation seen in the SN-FH angle.

Conclusions

The average SN-FH angle is not 7°, though this value has come to be accepted in the orthodontic community. The value is actually larger than 7° in most populations. There is little or no sex difference in the SN-FH angle. The larger SN-FH angle observed in African-Americans are due to both genetic and environmental factors that may lead to a flatter anterior cranial base and more superior position of porion. The SN-FH angle is influenced by growth pattern, the anterior-posterior position of the jaws, and upper to lower face height. The strong correlation between the SN-FH angle and the Mx-Mn relationship to SN indicate that SN is a more prominent component in determining the individual variation seen in the SN-FH angle, rather than the FH reference plane.

DEDICATION

To Thomas “Uncle Doc” Woodard

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All work for the thesis was completed by the student, under the advisement and with assistance from Dr. Buschang of the Texas A&M College of Dentistry Department of Orthodontics.

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NOMENCLATURE

SN	The sella-nasion reference plane
FH	The Frankfort horizontal reference plane
SN-FH	The angle formed by the sella-nasion and Frankfort horizontal reference planes
ANOVA	Analysis of variance

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CHAPTER I

INTRODUCTION AND

LITERATURE REVIEW

Introduction

Both sella-nasion (SN) and Frankfort horizontal (FH) serve as widely used cephalometric reference planes in the fields of orthodontics and oral surgery. The angulation of these reference planes can skew subsequent measurements and lead to misdiagnosis of skeletal discrepancies. Previous literature has shown great variability in both of these reference planes, though many practitioners have accepted that SN carries more variability. The average angle between SN and FH is touted in the orthodontic community as seven degrees; however, some studies have shown that this angle carries statistically significant sexual dimorphism that deviates from the accepted seven degrees. Studies that have included this angle in their data also show that the angle is quite variable when comparing different ethnic groups. Currently, the literature concerning varying SN-FH angles is limited when it comes to accepting an average value for various ethnicities or providing evidence that this angle varies more so within ethnicities than between them. Additionally, there has yet to be any work that compares more than two ethnicities, while also exploring the extent to which the SN and FH reference planes should be used for diagnosis. Determining any trends of variability for the SN or FH planes within certain populations can inform orthodontic diagnoses in a more predictable manner. The proposed study is cross-sectional in nature and aims to explore the SN-FH angle in three ethnicities- North American

Caucasian, Black, and Mexican- while also providing insight on the variability of both the sella-nasion and Frankfort horizontal reference planes between and within these populations. Secondarily, this study will determine if the SN-FH angle correlates to overall growth tendencies and various craniofacial presentations observed radiographically.

Cephalometrics

In the field of orthodontics, reference planes are heavily relied upon for assessing craniofacial morphology, diagnosing jaw disharmonies, and providing subsequent treatment modalities. Before the basic cephalostat was introduced by Holly Broadbent in 1931, orthodontists relied on craniometry and anthropometric measurements to assess craniofacial discrepancies. Sliding and spreading calipers were used to gather a series of measurements, which would then be translated into ratios. Two-dimensional cephalograms provided orthodontists with a detailed view of angular facial components and their relationship to the cranial base. Without the advent of cephalometry, the many reference planes used in orthodontics would be irrelevant, as most are derived from the skeleton. Once Broadbent introduced the cephalostat, cephalograms emerged as a nuanced way to longitudinally assess growth of the craniofacial complex and also to definitively diagnose skeletal discrepancies. Orthodontists immediately had access to much more information than ever before, but without normative data or reference planes, the measurements really carried no significant meaning.

The Frankfort Horizontal Plane

William Downs developed the first comprehensive cephalometric analysis in 1948 using Frankfort Horizontal as the reference plane. Several skeletal measurements are derived from the analysis and describe a subject's retrognathism, orthognathism, or prognathism. Downs chose Frankfort horizontal as the main reference plane in his analysis because it could be identified accurately with both radiographs and photographs. The use of Frankfort Horizontal as a reference plane extends even further back than the emergence of cephalometrics, as it was officially defined in 1884 during an anthropology meeting in Frankfort Germany. This plane is constructed using orbitale and porion, and it is considered the reference plane most reflective of the true horizontal[1, 2]; however, several studies have shown that Frankfort horizontal can deviate quite significantly from the true horizontal. In 1957, Bjehin reported that the average FH plane is about two degrees below the true horizontal, but this angle can range from -11 to +15 degrees[3]. In contrast, Madsen et al. reported a range from -17 to +6 degrees with the average FH plane deviating about five degrees below the true horizontal[1]; this study included males and females from ages 12 to 18, while the aforementioned study included those between age 22 and 36 years of age. Several other authors have shown the large variability of the FH plane as it relates to the true horizontal (see Table 1), yet the explanation for this range of values remains partially unknown[2, 4, 5].

Sources of FH Variation

Ultimately, porion and orbitale determine FH, and their final spatial positions relate to several other anatomical structures. Understanding how these landmarks are influenced by the craniofacial complex aids in determining the underlying variation of the FH reference plane. Porion is to some extent dictated by the position of the posterior cranial base, glenoid fossa, and position of the condyle. All of these structures are related intimately, as the position of basion will influence the position of the glenoid fossa, which houses the condyle. Ohtsuki et al. showed that the length of the entire cranial base steadily increases from birth to age 18. This is partly due to growth of the posterior cranial base; more specifically, growth at the spheno-occipital synchondrosis. This cartilaginous region does not ossify until 15-20 years of age. As such, it plays a role in the final position of basion and indirectly, porion[6] . Furthermore, basion's position is also influenced by the changes in angulation of the cranial base. The most rapid rate of growth for the anterior cranial base is between the ages of 0 and 3 years old. During this time, the cranial base angle decreases as a result of normal cranial base flexure. This flexure is a hallmark characteristic of the human skull that serves as an adaptation to our bipedal posture. It results in a more anteriorly positioned basion. Porion will also be displaced more anteriorly, as the occipital bone, which houses basion, articulates with the temporal bone which houses the external auditory meatus, and thus porion. After about age six, the profundity of this flexure is miniscule.

The saddle angle does not only influence porion from a cranial base flexure standpoint, but also in terms of skeletal classification. In obtaining cephalograms on over 500 subjects, Bjork related the saddle angle to the degree of prognathism in the face[7]. A reduction in the saddle angle led to an increase in mandibular prognathism; he credited this to a more anterior position of basion. Several decades later, Hopkin demonstrated a progressive and significant increase in the saddle angle as it relates to jaw discrepancy[8]. In other words, the saddle angle was significantly decreased in Class III subjects, and it increased for the control group (Class I) and even more so for the Class II subjects- with Class II division 1 subjects having the largest cranial base angle. A meta-analysis comparing subjects with Class I, II, and III malocclusions further solidified the conclusion that Class II subjects have a larger cranial base angle and longer total cranial base length, while Class III patients tended to have greater flexure of the saddle angle and a subsequently shorter total cranial base length[9]. For Class II subjects, this all translates into porion also residing in a more inferior and posterior position. Similarly, the glenoid fossa orientation will directly affect the position of porion, as both structures are located on the temporal bone. In 1997, Baccetti et al. showed that the glenoid fossa was positioned more posteriorly and inferiorly in Class IIs than Class IIIs, and in 2008 he published another study comparing Class II to Class I subjects and the glenoid fossa remained more posterior in Class IIs[10]. This finding indicates that basion would therefore also be positioned more posteriorly in these subjects, as the temporal and occipital bones must articulate with one another. Wylie and Johnson suggest that patients with vertical dysplasia, or those who are hyperdivergent, tend to have a glenoid fossa positioned more superiorly, while hypodivergent patients will have a fossa and subsequent condyle positioned more inferiorly[11].

The position of orbitale will primarily depend upon the anterior cranial base and nasomaxillary complex. The nasal septum is a prominent growth center that influences maxillary growth in the horizontal and vertical directions. Damage or removal of the nasal septum will create scar tissue that impedes maxillary growth[12]. The intrinsic growth properties of the cranial base synchondroses displace the facial complex downward and forward, which will inevitably influence the position of orbitale. Additionally, the maxilla undergoes its own differential resorption and remodeling in response to its downward and forward displacement that will also influence the AP and vertical position of orbitale.

Porion and orbitale are not stagnant landmarks; understanding the changes they undergo with normal growth may help to make sense of why Frankfort horizontal can have such great variability. As the maxilla undergoes primary displacement from the cranium and cranial base, it goes through its own compensatory remodeling process that consists of resorption at the nasal floor, apposition at the palatal floor and apposition on the floor of the orbit, which produces a secondary displacement. Simultaneously, the eruption of teeth leads to apposition of alveolar bone. Maxillary rotation, which occurs with normal growth, also influences the final position of orbitale. All of these processes were shown by Bjork and Skieller when they used metallic implants to record how the maxilla grows in three dimensions over a span of 16 years[13]. The time-related changes for porion rely on the displacement and remodeling of the previously discussed structures that determine its position. In 1998, Buschang and Santos-Pinto evaluated the longitudinal growth changes of the condyle in male and female children and adolescents, then subsequently described the changes of the glenoid fossa[14]. For both males and females, the fossa was displaced posteriorly and inferiorly about 3-4mm over the four-year periods. Fewer than 10 percent of the sample showed anterior fossa displacement and 20-30% showed superior displacements. Though the majority of subjects experienced posterior and inferior displacement of the fossa, these findings still suggest that the vertical and AP movements of the glenoid fossa, and therefore porion, are subject to variability.

The Sella-Nasion Plane

In 1953, Cecil Steiner introduced a cephalometric analysis that used the sella-nasion line as its primary reference plane. The SN reference plane serves as a two-dimensional approximation of the anterior cranial base. The anterior cranial fossa houses the projecting frontal lobe and consists of the cribriform plate, the orbital plate of the frontal bone, and the lesser wings of the sphenoid. Technically it does not include sella turcica, as that is a part of the middle cranial fossa; however, from a cephalometric standpoint, the anterior cranial base extends from sella to nasion.

Sources of SN Variation

As FH variability was mostly influenced by the posterior cranial base, SN is more influenced by the anterior cranial base and the multiple factors that determine its final position. The length of the anterior cranial base from sella to nasion steadily increases from birth until at least age 18[6]. However, we can see that this is largely due to an increase in length from the derived spheno-ethmoid point to nasion. After about age 7, the distance from sella to the spheno-ethmoid point remains fairly constant with only slight increases noted over the next twelve years. The results from Stramrud found similar patterns in regard to the anterior cranial base[15]. In his study, cephs were obtained from age three through twenty-five for a total sample size of four hundred and sixty-four. He noted a steady increase in the length from nasion to sella, but also recorded the frontal bone thickness and a measurement he defined as the length of the anterior cranial fossa. This measurement was derived from the difference between the SN length and the frontal bone thickness. The anterior cranial fossa length increased until about age 7, after which it remained relatively unchanged. The spheno-ethmoidal synchondrosis ossifies around age 7 to age 8. As such, the majority of the increased length in the anterior cranial base comes from forward movement of nasion with frontal sinus growth. These changes all translate into varying lengths and angulations of the sella-nasion reference plane.

This variation associated with SN is of particular importance to the orthodontist when attempting to interpret a patient's cephalogram. Its length and angulation can inflate or underestimate cephalometric measurements used to aid in the diagnosis and treatment planning. Unpacking the reported variability of SN is the first step to understanding the underlying genetic, environmental, and epigenetic factors at play. Several studies have explored the variability of the SN reference plane as it relates to the true horizontal (Table 2). Lundstrom et al. reported a mean value of 2.6 degrees in a sample consisting of both males and females ranging from 10-14 years old[16]. Though the sex distribution was not specified, Cooke et al. had a sample size three times that of the aforementioned study in which a mean SN angulation was 6.8 degrees[17]. In contrast, Leitao and Nanda examined all male subjects and reported an average angulation of 8.19 degrees[18]. Though these studies differ when it comes to sample size and age, all suggest being cautious when using SN because it is too variable to reliably assess skeletal disharmony and other dentofacial measurements used in orthodontic cephalometric analysis.

Identifying SN versus FH

Though both the SN and FH reference planes vary in their angulations, it is also important to address the reproducibility of these planes. If one reference plane is more difficult to accurately trace, then it may be advantageous to rely less heavily upon it during diagnosis.

Previous works have argued that both sella and nasion are much easier to identify when compared to porion and orbitale; however, Rickett's refuted this claim after demonstrating that there was no difference in accuracy when locating either the SN or FH plane[19]. He adds that the FH reference plane possesses anatomical significance, as it relates to the 'basic sense' organs of sight and hearing; furthermore, the ability to visualize FH clinically provides an additional advantage over SN. Though Ricketts did provide sound arguments for using FH over SN, his inherent bias cannot be ignored. FH was the plane used for his particular cephalometric analysis, and as such, he aimed to show his orthodontic colleagues that it was a viable, or perhaps better, choice over the SN plane. Another study investigated the reproducibility of several cephalometric landmarks and planes to find that both sella and nasion could be identified more accurately from a horizontal perspective when compared to porion and orbitale[20]. However, when evaluating the prevalence of vertical discrepancies amongst the four points, the order of accuracy-from best to worst- was sella, porion, orbitale, then nasion. A more recent meta-analysis supports Richardson's findings in that sella demonstrated the best repeatability and reproducibility, while nasion is consistently identified horizontally, but becomes more difficult from a vertical perspective[21]. The study assessed a total of fifteen landmarks and both orbitale and porion were ranked between 13th and 15th for both vertical and horizontal values. When comparing the reproducibility of several reference planes, one study concluded that the sella-nasion line was reproduced more accurately than the Frankfort horizontal[22]. Ideally, the most accurate reference for orthodontic diagnosis would be natural head position, which is defined as a "standardized and reproducible position of the head in an upright position with the eyes focused on a point in the distance at eye level, implying that the visual axis is horizontal"[23].

Natural head position (NHP) provides a stable extracranial reference, rather than relying on cephalometric planes, such as SN and FH, that vary amongst patients and undergo their own changes over time. Though NHP has found to be reproducible, positioning patients appropriately is technique sensitive[24]. As such, SN and FH are used more frequently during cephalometric diagnosis as reference planes; therefore, it is important to address the variability of these lines to accurately interpret cephalograms and provide a sound diagnosis.

The SN-FH Angle and Its Variation

The SN-FH angle has been widely studied in an effort to primarily address the angulation of SN; however, very few, if any studies, have considered that this angle's variation comes from a combination of the SN and FH planes. An average value of 7 degrees for this angle has come to be accepted[25, 26]. This 'constructed horizontal' plane consists of rotating the SN line seven degrees clockwise; however, the slope of the anterior cranial base is quite variable[2, 27], so this horizontal plane actually may not be representative of the patient's true horizontal at all. The slopes of the anterior cranial base and Frankfort horizontal are quite variable, and this variability is once again quite evident given that the reported range for the SN-FH angle is from 2 to 15 degrees[28]. Ellis and McNamara recruited thirty adult females who all had well-balanced faces and Class I occlusion. Within this sample, the SN-FH value ranged from about 3 to almost 15 degrees. This study re-emphasizes the interindividual differences that persist within both the SN and FH plane[29].

The relationship between the cranial base and the development of various skeletal patterns proves to be a source of controversy in the orthodontic community, as results from studies continue to contradict one another. Cranial base length and angulation are studied extensively to find predictors for favorable or unfavorable sagittal and vertical growth of the jaws. Most of these studies assess the length of the posterior and anterior cranial bases, along with the flexure of the cranial base. This flexure is a hallmark characteristic of the human skull that serves as an adaptation to bipedal posture. As such, the largest increase in cranial base flexion is during the first two years of life[30]. This causes the foramen magnum to be displaced more anteriorly, and a more vertical orientation of the orbits and other facial bones. Enlow and McNamara described man as having a "facial pocket" that forms as a result of a shortened facial complex which rotates to lie underneath the floor of the anterior cranial fossa[31]. Rarely have studies specifically assessed the SN-FH angle as it relates to jaw disharmony; rather, the saddle angle, a measurement representative of cranial base flexure, is explored. In 1992, Bacon et al. compared cranial base structure variations of skeletal Class I and Class II subjects. When evaluating the anterior cranial base (length of SN and SN-Ba angle), the two groups were not statistically different, yet the cranial base flexure (N-S-Ba angle) was more obtuse in the Class II group[32]. In terms of the saddle angle, studies have concluded that the angle is not statistically different amongst subjects with varying malocclusion[33-35]. However, a longitudinal study comparing the saddle angle to jaw discrepancies found that the majority of subjects with a larger than average angle (125°) at five years old would go on to develop a Class II skeletal relationship[36]. In obtaining cephalograms on over 500 subjects, Bjork related the saddle angle to the degree of prognathism in the face. A reduction in the saddle angle led to an increase in mandibular prognathism; he credited this to a more forward displacement of the temporomandibular joint[7]. As previously mentioned, several historic studies have demonstrated how the saddle angle tends to be significantly increased in Class II patients, while it is decreased in Class III patients. One study did show that the posterior cranial base angle, rather than the total cranial base angle (i.e. saddle angle), had a statistically significant negative correlation to the facial angle and B perpendicular, while the anterior cranial base angle did not show a significant relationship to any of the sagittal measurements[34]. D'Alosio et al. concluded that there was no correlation between the SN-FH angle and any of the antero-posterior measurements (ANB, Wits, Mx-Mn differential)[37]. Another study divided subjects based on the value of their SN-FH angle to assess the presence of any differences in antero-posterior jaw measurements amongst those with small, neutral, or larger angles[29]. The SN-FH angles ranged from 2.83° to 14.51°, yet all of the participants had Class I skeletal relationships. This solidifies the notion that local, environmental factors also influence the sagittal components of the craniofacial complex along with the angulations of both the anterior and posterior cranial bases.

Another factor to consider when analyzing the SN-FH angle is head posture. As the SN-FH approximates the angulation of the anterior cranial base, it has been postulated that its flexion relates to postural variables concerning both the craniofacial complex and the curvature of the spine. Many studies have correlated particular growth patterns with certain trends in spinal angulation. Natural head posture is defined as an environmentally-determined neutral head position that can be replicated in a clinical setting by asking a patient to look forward at their eyes in a mirror which is level with their face. In this position, the spine has a configuration unique to each patient; some cervical columns may be curved towards the craniofacial complex and some may be curved away from it. Other patients may exhibit a completely straight spine. Solow evaluated head posture as it related to craniofacial development using a longitudinal sample[38]. Cephalometric radiographs were taken of growing subjects at two time points (mean observation period of 2.7 years). After digitizing the lateral head films, and subsequently superimposing them, strong correlations were found between the change in cervical angulation and the true rotation of the mandible. A decrease in cranio-cervical angulation was related to more forward rotation of the mandible. In other words, hypodivergent subjects tended to present with cervical spinal columns that were straighter or even anteriorly curved towards the craniofacial complex, while hyperdivergent patients had increased cranio-cervical angles and subsequent spinal morphology that resembled a backwards 'c' in relation to the craniofacial complex. In the cross-sectional evaluation of 136 cephalograms, Marcotte determined that those subjects with more retrusive mandibles tended to have higher head postures[39]. In regards to this topic of head posture and its relation to craniofacial morphology, Solow and Sandham reiterated a question that has plagued the orthodontic community for many years: "does facial growth influence the postural relationships or do postural relationships influence facial growth?"[40]. In discussing the etiology of hyperdivergent open-bite malocclusions, Buschang et al. solidify the notion that weaker masticatory musculature is associated with hyperdivergent patients, along with airway obstruction[41]. Enlarged adenoids and tonsils are often seen in patients who present with hyperdivergent, Class II jaw disharmony. The airway obstruction leads to a tendency towards mouth breathing, and the overarching theory is that this pattern of breathing causes patients to position their mandible down and back while also tilting their head upwards. This notion is corroborated by another study that evaluated cephalograms on children aged 7-18 years old who were patients in an immunology and allergy outpatient clinic[42]. All patients were obligatory mouth breathers, and 72 percent of the children had a higher degree of head extension related to the cervical spine. In other words, they had larger cranio-cervical angles. These patients also presented with larger than average anterior facial height, reduced sagittal jaw dimensions and stepper mandibular planes. In regards to the SN-FH angle, its value may be influenced by head posture as well. A more extended postural position could potentially lead to more flexion of the cranial base because the landmarks that make up the SN-FH angle are directly influenced by antero-posterior and vertical positions of the jaws.

Problem Summary

Unpacking the SN-FH angle begins with exploring its potential relationship to the factors that influence our current approach to treatment. The determinants for the spatial orientation of sella, nasion, porion and orbitale all relate to genetically and environmentally driven processes. In orthodontics, we must consider a patient's sex, age, growth pattern, and ethnicity before finalizing a treatment plan. Finding trends amongst certain populations will prove indispensable in discovering how the SN and FH planes assume their positions in individuals. When it comes to the literature addressing this angle and its potential sources of variation, there is no clear cut consensus. Several studies have compared this angle between males and females and have shown gender dimorphism that is statistically significant[43, 44]. For the vast majority of studies, females had larger SN-FH angles than males, indicating that sex may play a role in the angle's value[37, 45, 46]. When evaluating the angle between Frankfort horizontal and the sella-nasion reference planes, Huh et al suggested that the angle did not change significantly over a nine year period[44]. This longitudinal study showed the constancy of the angle from age six to fourteen in both males and females. Though there were large variations among subjects in regards to the value of the angle, it did not vary within an individual significantly during the observation period. This study did not provide the data for individual subjects, but instead came to their conclusions from overall mean values of SN-FH at each age. As such, we cannot confidently say that the angle is stable over time, especially with its multifactorial nature. D'Aloisio et al. aimed to determine what proportion of facial measurements could be explained by variability seen in the cranial base[37]. The SN-FH angle only had a significant correlation to one vertical measurement in females: the mandibular plane angle (SN to Go-Gn). This is to be expected, as the two measurements share a reference plane. Interestingly, the same pattern is not seen with FMA and the SN-FH. This particular sample may have had an average Frankfort Horizontal angulation closer to zero which could help explain this finding, though this is only a speculation, as the author did not specify this.

Studies have also explored the SN-FH angle variation as it relates to ethnicity. Table 3 displays the studies that have compared two different ethnic groups. One study found a statistically significant difference between Mexican Mestizos and Caucasians, with mean SN-FH angles of 7.5° and 9.5°, respectively[47]; all subjects included were also classified as having a Class II Division 1 malocclusion. The difference in SN-FH angles was partly attributed to Mexicans having a FH plane that is higher anteriorly than that of their white counterparts. This translates into a more acute angle for Mexican Mestizos. Another study made cephalometric comparisons between North Mexican and Caucasian adolescents[48]. Their data also revealed that the North Mexican subjects had smaller SN-FH angles; however, this was not deemed a statistically significant finding. Another study compared cranial base measurements of North American blacks to whites of a similar age derived from the *Atlas of Growth in the Aging*

Craniofacial Skeleton [37]. Their findings revealed that black males showed a significantly larger SN-FH angle in comparison to white males. Though the black females had an average SN-FH angle of 9.1 degrees, and the white females average anterior cranial base angulation was 6.1 degrees, the difference was not statistically significant. It is unclear whether the difference in angles can be attributed to the angulation of SN or FH. Ethnicity could be one of the many factors influencing the SN-FH angle, so determining its potential degree of influence on the angle would give further insight into how and when we can reliably use SN and FH as reference planes.

Currently, the literature concerning varying SN-FH angles is limited when it comes to accepting an average value for various ethnicities or providing evidence that this angle varies more so within ethnicities than between them. Additionally, there has yet to be any work that compares more than two ethnicities, while also exploring the extent to which the SN and FH reference planes should be used for diagnosis. Determining any trends of variability for SN or FH within certain populations can inform orthodontic diagnoses in a more predictable manner. The proposed study is cross-sectional in nature and aims to explore the SN-FH angle in three ethnicities- North American Caucasian, Black, and Mexican- while also providing insight on the variability of both the sella-nasion and Frankfort horizontal reference planes between and within these populations. Secondarily, this study will use various cephalometric measurements to assess whether or not the SN-FH angle may play a role in the presentation of various malocclusions and craniofacial growth patterns.

Study Aims

1. Assess the SN-FH angle between and within three distinct ethnicities
2. Evaluate the variability of SN and FH as separate reference planes
3. Determine if and how SN-FH relates to dento-skeletal measurements of growth direction as well as skeletal divergence

CHAPTER II

MATERIALS AND METHODS

This cross-sectional study aimed to assess the variability of the SN-FH angle and its components within and between three distinct ethnic groups- North American Caucasian, Black, and Mexican- and subsequently determine what other facets of the craniofacial complex may contribute to this angle. Additionally, it explored the sources of variation within the SN-FH angle. De-identified lateral cephalometric radiographs were used for all measurements. Subjects of European and African descent were gathered from initial records of patients who were treated at Texas A&M College of Dentistry in the Orthodontic Department; the radiographs were de-identified prior to the co-investigator obtaining them. The radiographs for Mexican Americans consisted of de-identified cephalograms that have been used in previous Texas A&M research completed in the Orthodontic Department. The department has had these radiographs for greater than ten years after they were provided by a private practitioner in Houston, Texas. The selection criteria were as follows: 1) Class I molar relationship (as determined by cephalometric analysis), 2) falls within the ages of 10 and 16 years old, 3) no history of prior orthodontic treatment, and 4) absence of gross skeletal or soft tissue asymmetries. Moreover, all subjects in the primary or mixed dentition were excluded. Subject demographics for this study can be found in Table 4. The patient population for this study included 309 radiographs, consisting of 147 males and 162 females. A relatively equal amount of males and females for each ethnicity were sampled for the study. To control for maturational differences between males and females, males were between ages 11 and 16, while females were between ages 10 and 15 years old. In terms of ethnicity, there were 93 radiographs used for the Mexican-American group, 102 used for the African-American group, and 114 used for the Caucasian group.

Because this study was retrospective and required no patient interaction or access to protected health information, it was deemed exempt by the Institutional Review Board at Texas A&M College of Dentistry. One resident digitized all radiographs using Dolphin Imaging System Version 11.9 (Patterson Dental Company; Chatsworth, CA) and re-traced 15 radiographs more than two weeks apart to measure reliability. Several cephalometric landmarks were be included in the tracing process; Table 5 defines each of these points, and Table 6 provides a description of the various reference planes that used. After the landmarks were assigned to each cephalogram, the SN-FH angle was established, along with several linear and angular measurements (Tables 7-9). Values for the SN-FH angle will be assigned to each subject and subsequently compared between and within groups. Secondarily, cephalometric measurements related to cranial morphology were obtained in order to assess any interactions or relationships between the SN-FH angle and facial divergence as well as growth forecast.

Statistical Analysis

For statistical analysis, SPSS Version 36.0 (Chicago, IL) was used. Measures of skewness and kurtosis indicated a normal distribution of data. There were a total of twenty-nine measurements obtained for this study. In order to consolidate the variables and discover powerful underlying trends related to the SN-FH angle, a principal rotated factor analysis was completed. Factor analyses are used to group strong relationships amongst observed variables. These systematic interdependencies reflect a single, latent variable or factor. Seven independent factors were identified (Table 10). Based on the variables that contributed to the factors, they reflected (in order of importance based on the amount of variation explained) size, head posture, mandibular divergence, maxilla-mandibular relationship relative to SN, growth forecast, cranial base angulation, and upper to lower face height proportions. In total, these factors explained 86.9 percent of the variation of the 29 variables included in the analysis. Due to the normal data distribution, a two-way analysis of variance was used to evaluated group and sex differences, controlling for age. For ethnic differences, Bonferroni post-hoc comparisons were computed to determine exactly where the significant differences occurred. (Tables 12 and 14). Moreover, bivariate Pearson correlations were computed between the SN-FH angle and the seven factors (Table 15).

CHAPTER III

RESULTS

SN vs FH Variation

When evaluating the SN-FH, it is important to determine which reference plan contributes the most variance to the angle. Based on two angles that share a common reference plane, (i.e. MPA and FMA) it as possible to determine if SN or FH was more variable. MPA displayed a larger coefficient of variation than FMA (26.7 vs 22.5), indicating that the SN reference plan tends to vary more than the FH plane.

The SN-FH Angle: Sex and Group Differences

There was no statistically significant differences between males and females the SN-FH angle (Figure 3 and Table 11). Males and females had average values of 8.51° and 8.80°, respectively. There was, however, a significant difference between ethnic groups. African-Americans had significantly larger SN-FH angles (9.29°) than Mexican-Americans (8.50°) and Caucasians (8.18°), who did not differ significantly (Figure 4 and Table 12). For the entire sample, the average SN-FH angle was 8.66°.

Factor Analysis: Sex and Group Differences

Sex Differences

The primary difference between males and females was size, followed by head posture (Figure 5 and Table 13). Males were larger in size than females, but had smaller cranio-cervical angles. Females appeared to have more angulated cervical vertebrae, while males had either straight or even forward curving cervical vertebrae in relation to the craniofacial complex. Males exhibited a more horizontal growth pattern with greater chin projection, while females exhibited a more vertical, less favorable, growth pattern. The remaining factors did not show any significant differences between males and females.

Ethnic Differences

Three of the factors displayed statistical significant differences between Mexican-Americans, Caucasians, and African-Americans: size, growth forecast, and upper to lower face height proportions (Figure 6 and Table 14). For size, Mexican-Americans were the smallest, followed by African-Americans, and then Caucasians ($p<0.001$). In other words, Caucasians had longer face heights and potentially greater eruption of teeth than the other two groups. In terms of growth direction, Mexican-Americans had the largest factor score (0.52), followed by African-Americans (-0.02), and Caucasians (-0.41). Caucasians presented with the smallest Y-axis value, while Mexican-Americans had the largest, along with increased values for ANB. For the seventh factor, upper to lower facial height proportions, African-Americans had the smallest values, followed by Mexican-Americans and then Caucasians ($p<0.001$). Caucasians had the longest upper face heights, while African-Americans had the longest lower face heights.

Bivariate Correlations between Factors and the SN-FH Angle

The SN-FH angle was not significantly related to the size or head posture factors. The strongest correlation was between the SN-FH angle and the maxillo-mandibular relationship to SN factor. The positive and high correlation indicates that the subjects who exhibit more maxillary and mandibular retrusion have larger SN-FH angles. In that same regard, the larger the Y-axis relative to SN, the smaller the SN-FH angle.

The second strongest relationship was between the SN-FH angle and the upper to lower face height proportion factor. Though this correlation was low ($R=-0.329$), it showed that as the upper-to-lower face height proportions increased, the SN-FH angle decreased.

The growth forecast and cranial base angulation factors displayed low, but statistically significant, correlations to the SN-FH angle. The growth forecast factor was negatively related to the SN-FH angle, indicating that as the chin is displaced further backwards and ANB increases, SN-FH decreases. The cranial base angulation factor was positively related to the SN-FH angle; as the anterior cranial base angle increased, overall cranial base angulations also increased.

Lastly, the mandibular divergence factor showed a very low relationship with SN-FH. As a subject becomes more hyperdivergent subjects had smaller SN-FH angles. This aligns with the previously mentioned relationship between the upper to lower face height ratio factor and the SN-FH angle. An increase in lower face height was typically seen in subjects with hyperdivergent tendencies, and both of these factors related negatively to the SN-FH angle.

CHAPTER IV

DISCUSSION AND CONCLUSIONS

Our first conclusion is that the average SN-FH angle is not 7°. The findings indicate that it is actually larger than seven degrees, with a combined mean of 8.6° across the three ethnic groups. When evaluating this angle in each ethnic group separately, all of the mean values were above 8°. The majority of studies that have quantified the SN-FH angle, have also shown that its mean angulation is above 7°[29, 37, 43, 46, 49-51]. Only two studies have reported average values below 7°[52, 53].

In regards the sexual dimorphism as it related to the SN-FH angle, the findings of the present study indicate that there is little or no difference between males and females. Females had an average value of 8.8° and males had an average value of 8.5°; this small difference was not statistically significant. Previous literature has shown that females tend to have larger values for this angle, but the difference is usually not large enough to be significant[45-47]. A possible explanation for this finding is the difference in head posture seen between males and females. Our findings agree with previous studies that have found sexual dimorphism present in head posture[54, 55]. Females tended to have more extended head posture than males. With this orientation, it is possible that orbitale must be displaced downward more in females to compensate to re-establish the horizontal visual axis that we have adapted over evolution. However, the displacement differences at orbitale may not be profound enough to create sexual dimorphism in the SN-FH angle. Establishing the presence or absence of sexual dimorphism for the SN-FH angle allows for further understanding of what contributes to its variance.

When comparing the SN-FH angle between the three ethnic groups, African-Americans displayed significantly larger SN-FH angles in comparison to Caucasians, while Mexican-Americans showed no difference from Caucasians or African-Americans. D'Aloisio et al. compared the cranial base in African-Americans and Caucasians and concluded that black males had larger SN-FH angles than their white male counterparts[37]. There were no ethnic differences in SN-FH for females. On the contrary, Connor and Moshiri compared cephalograms of 50 white and 50 black patients and found no significant difference for the SN-FH angle between the two ethnicities[46]. Moreover, Fonseca compared African-American and Caucasians females and did not find a difference between the two for the angle[52]. When analyzing the vertical position of nasion in relation to the FH reference plane, one study found that Caucasians had significantly larger values than African-Americans, suggesting that African-Americans had a flatter anterior cranial base[56]. If that is indeed the case in the current study, the larger SN-FH angle in African-Americans could be explained by a heightened position of porion. Many studies have concluded that African-Americans have more obtuse saddle angles than Caucasians[37, 57], so perhaps a more posterior-superior position of basion also places porion more superior as well, thus opening up the SN-FH angle. The difference observed between African-Americans and Caucasians suggest that underlying genetic factors play a role in cranial base morphology. From a growth and development standpoint, the anterior cranial base, approximated by the SN reference plane, finishes the majority of its growth by age seven[6]. At this point, the spheno-ethmoidal synchondrosis ossifies. The only major change that happens to the anterior cranial base after that is a slight increase in length with the growth of the frontal sinus and subsequent anterior movement of nasion. Additionally, the majority of cranial base flexure takes place pre-natally and during the first two years of life. As such, one's cranial base orientation is established quite early in life, and the SN-FH orientation is directly influenced by these early events that are influenced by both genetics and one's environment.

When comparing the SN-FH angle between Mexican-Americans and Caucasians, Phelan found that Caucasians had significantly larger values- about 2 degrees[47]. One reason he gave for this difference was that the anterior leg of the FH plane in Mexican-Americans was more tipped upwards. Several other studies noted the lessened SN-FH divergence in Mexican-Americans compared to Caucasians[48, 58]; however, our study did not detect any significant differences between these groups. This could be a result of our larger sample size and subsequent increased power.

After evaluating the seven factors identified in our sample as they relate to the SN-FH angle, it was clear that the angle's orientation is influenced by growth pattern and AP position of the maxilla and mandible. The most important factor contributing to the SN-FH variation was the Mx-Mn relationship to SN (factor 4). The single factor explained 42.5% of the variation seen in the SN-FH angle. It's important to note that the variables contributing to this factor all had a common reference plane of SN, which will directly influence both the SN-FH angle, as well as the Y-axis, SNA, and SNB. As the SN reference plane steepens, SNA and SNB appear more retrusive while the Y-axis appears larger. Though this relationship exists, it does not negate the fact that specific variables containing the SN reference plane correlated more closely to the SN-FH angle in comparison to those variables containing the FH reference plane. This tells us that SN plays a more prominent role in determining the individual variation seen in the SN-FH angle. The grouping of variables completed in a factor analysis not only consolidates the variables, but it also creates more powerful conglomerate variables that provide more information about the sample as a whole.

Lastly, the upper to lower face height (U:LFH) factor significantly influenced the SN-FH angle. More specifically, U:LFH explained 10.8 percent of the variation seen in the SN-FH angle and larger angles were associated with smaller U:LFH ratios. The findings showed that African-Americans has the smallest U:LFH ratio and largest SN-FH value. These radiographs were both a part of our sample population and illustrate the relationship between U:LFH ratio and SN-FH angulation well. A possible explanation for this finding deal with the vertical position of orbitale. Our findings indicated that smaller upper to lower face height ratios correlated to larger SN-FH angles. As such, subjects with larger SN-FH angles may have longer lower face heights in comparison to their upper face height. Those who take on this phenotype tend to exhibit a more vertical growth pattern. As such, we would expect both the maxilla and mandible to be displaced downward more than what is typically observed, and orbitale would also take on a more inferior position. We would expect this to translate into a longer upper face height as well; however, the vertical position of ANS may be masking this. The study found a negative correlation between the SN-FH angle and the palatal plane to FH angle, indicating that a more negative palatal plane is correlated with a higher SN-FH angle. A negative palatal plane would cause the UFH measurement to actually appear smaller and the lower face height measurement to appear even larger.

When comparing the individual variance of the sella-nasion plane versus the Frankfort horizontal plane, it is clear that SN plays a larger role in explaining the variance observed in the SN-FH angle. In other words, though both angles may vary in relation to a true horizontal, the

SN reference plane varies more so and thus makes a larger contribution to the different SN-FH angles observed in a population. Previous studies support this claim in suggesting that the SN angulation as it relates to a subject's true horizontal is more variable than that of the Frankfort horizontal[2-4]. Awareness of the greater variability seen in the SN reference plane allows practitioners to be more mindful about its angulation may over or underestimate typical values used in diagnosis, such as SNA, SNB, angulation of the upper incisor, and the mandibular plane angle to SN. Angular values that include SN should be evaluated closely before declaring a definitive skeletal or dental diagnosis. Cases in which the practitioner is weary of the SN angulation may lead to using measurements that use Frankfort horizontal instead.

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APPENDIX A

FIGURES

Figure 1. Age – Sex Differences

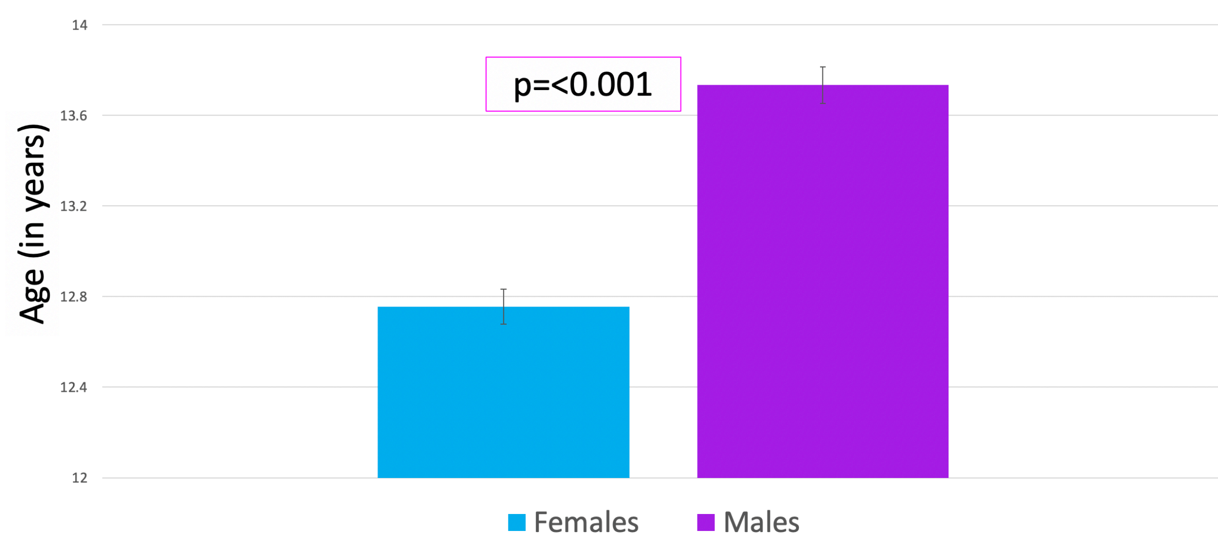


Figure 2. Age – Group Differences

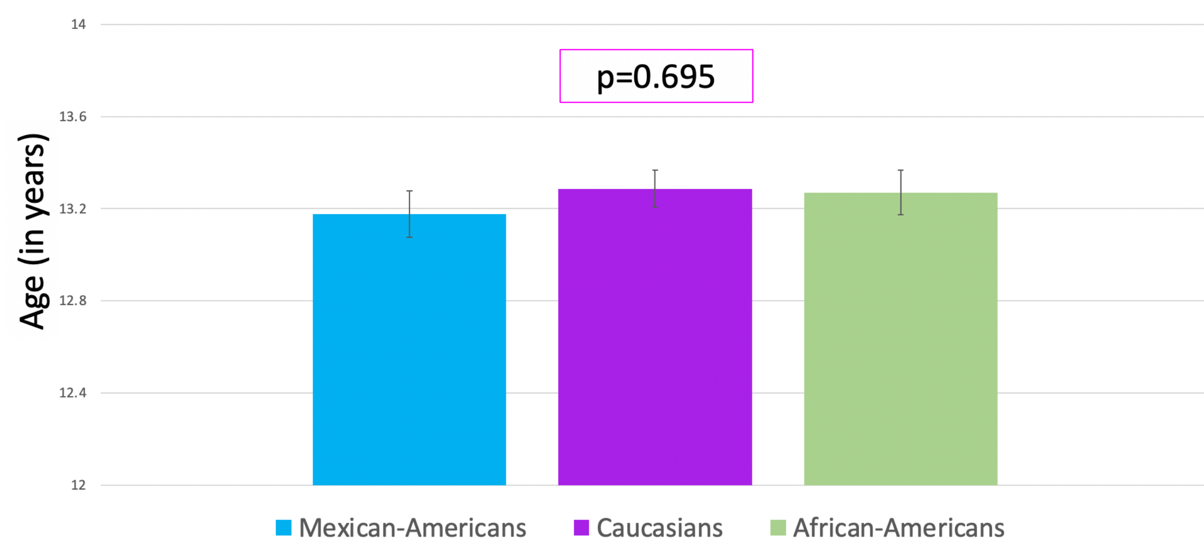


Figure 3. SN-FH Angle – Sex Differences

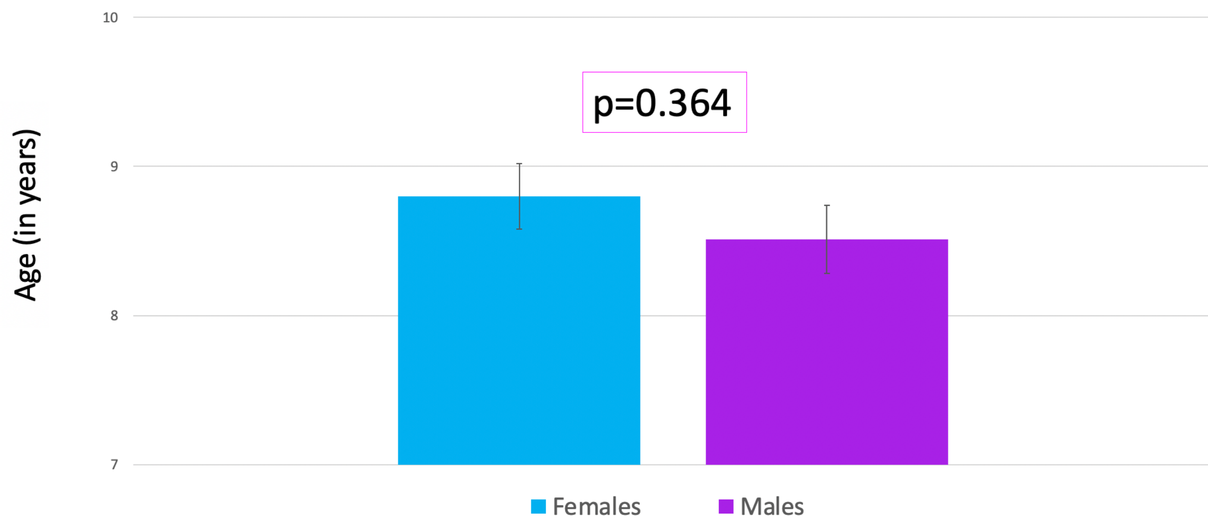


Figure 4. SN-FH Angle – Group Differences

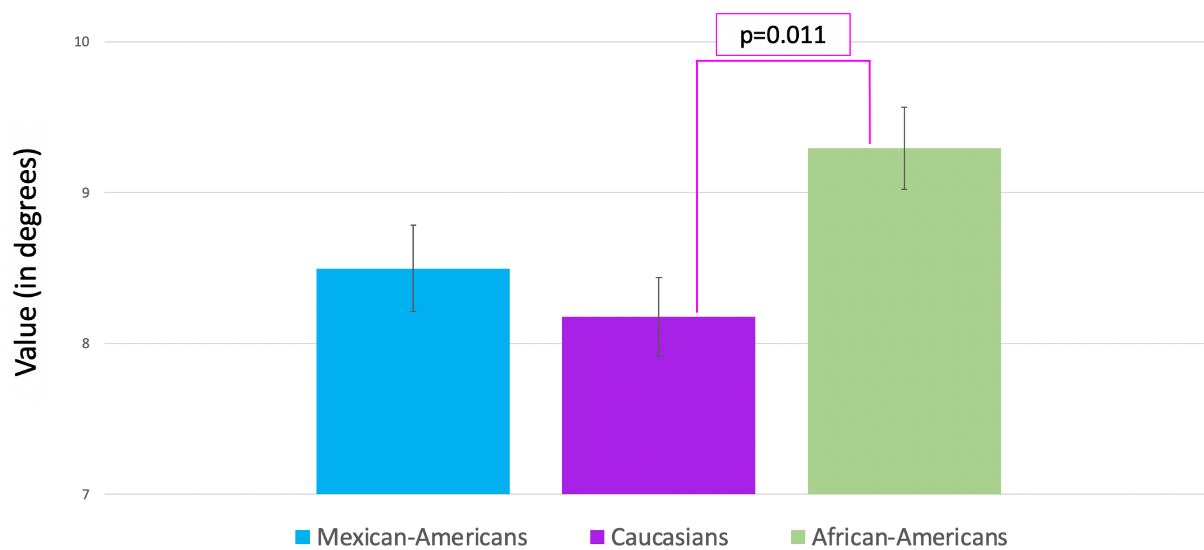


Figure 5. Factor Analysis – Sex Differences

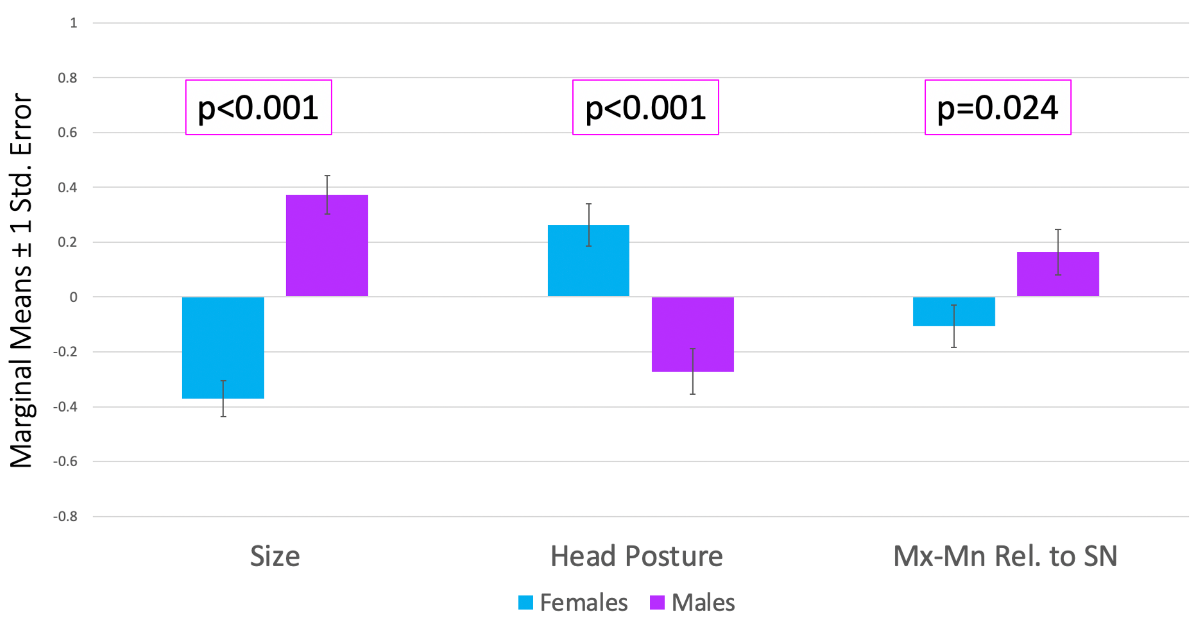
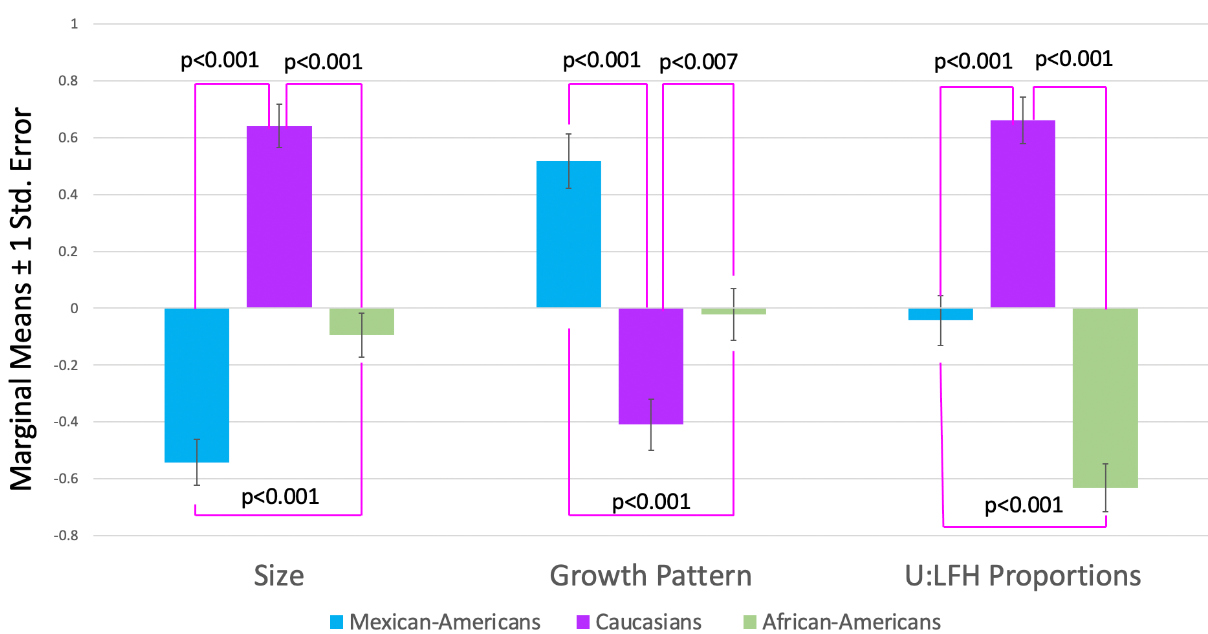


Figure 6. Factor Analysis – Group Differences



APPENDIX B

TABLES

Table 1. Mean FH angulation to true horizontal across several studies

Reference	Sample Size	Age	Mean HOR-FH Angle	Range
Barbera et al. (2009)	40 (20 females; 20 males)	≥17 yrs	-2.5 °± 4.9	-12.0° to 8.0°
Bjehin et al. (1957)	35 (11 females; 24 males)	22-36 yrs	-1.8°± 4.6	-11.7° to 15.3°
Madsen et al. (2008)	57 (38 females; 19 males)	12-18 yrs	-4.82°± 4.6°	-17.1° to 5.9°
Quadir (2017)	90 (60 females; 30 males)	15-35 yrs	-2.0°± 3.0	-7.**0**° to 5.0°
Zebeib (2014)	36 (23 females; 13 males)	16-35 yrs	-1.6°± 3.4	-8.0° to 8.0°

Table 2. Mean SN angulation to true horizontal across several studies

Reference	Sample Size	Age	Mean HOR-SN Value
Bjehin (1957)	35 (11 females; 24 males)	22-36 yrs	4.3°± 4.0
Moorrees and Kean (1958)	61 (all females)	18-20 yrs	4.7°± 3.9
Solow and Tallgren (1971)	120 (all males)	22-33 yrs	9.6°±3.6
Cooke and Wei (1988)	120 (sex distribution not specified)	12 yrs	6.8°± 5.6
Lundstrom et al. (1995)	27 (13 females; 14 males)	10-14 yrs	2.6°± 5.4
Leitao and Nanda (2000)	284 (all males)	18-25 yrs	8.19°± 4.45
Barbera et al. (2009)	40 (20 females and 20 males)	17 yrs	6.7°± 5.5
Zebeib and Naini (2014)	46 (23 females; 13 males)	16-35 yrs	9.1°± 5.1

Table 3. Mean SN-FH angulation across several studies

Reference	N	Population	Mean SN-FH
Alvez et al. (2008)	200 (males and females; does not specify distribution)	Brazilian	7.91°±0.23 (total)
Connor and Moshiri (1985)	100 (50 males; 50 females)	Caucasian (N=50) African-American (N=50) *25 males and females in each subgroup	9.33° ± 2.29 (Caucasian females) 9.28° ± 3.75 (Caucasian males) 9.53° ± 3.53 (A-A females) 8.98° ± 3.12 (A-A males)
D'Aloisio and Pangrazio-Kulbresh (1992)	100 (42 males; 58 females)	African-American	9.1°±3.4 (males) 9.6°± 4.2 (females)
Ellis et al. (1988)	81 (all female)	European descent/Caucasian	7.97°
Fonseca and Klein (1978)	60 (all females)	African-American (n=40) Caucasian (n=20)	5.2° (African-American) 5.5° (Caucasian)
Giri et al. (2017)	238 (111 males; 127 females)	Nepalese	6.71°± 3.13 (total) 6.36°± 2.76 (males) 7.01°± 3.4 (females)
Huh et al. (2014)	223 (107 males; 116 females)	South Korean	Range: 8.45-8.95° (males) 9.26-9.74° (females)
Hung, C. (1991)	216 (104 males; 112 females)	Chinese	7.26°±1.92 (total)
Moore, J. W. (1976)	130 (males and females; does not specify distribution)	European descent/Caucasian	9.80°± 2.81 (total)
Quiroz et al. (1999)	233 (does not specify sex distribution)	Venezuelan	7.23°± 0.43 (males) 6.96°± 0.27 (females)
Reddy et al. (2019)	180 (90 males; 90 females)	South Indian	8.06°± 3.34 (total) 7.42°± 3.62 (males) 8.7°±3.48 (females)
Riolo et al. (1974)	83 (47 males; 36 females)	European descent/Caucasian (MI Growth Study)	4.85° (males) 5.43° (females)
Shimizu et al. (2018)	66 (all females)	Japanese (n=33) Spanish (n=33)	8.0°±3.1 (Japanese) 11.2°±2.3 (Spanish)

Table 4. Subject Demographics

	Males			Females				Difference
	Mean	SD	N	Mean	SD	N	Total N	Probability
Mexican American	13.80	0.88	44	12.54	0.49	49	93	<0.001
African American	13.45	1.46	50	13.09	1.40	52	102	0.209
Caucasian	13.94	0.67	53	12.63	0.55	61	114	<0.001
Total N			147			162	309	
Mean	13.73	1.07		12.75	0.93			0.715

Table 5. Cephalometric Landmark Definitions

Landmark	Definition
Sella (S)	The midpoint of the sella turcica
Nasion (N)	Most anterior point of the naso-frontal suture
Orbitale (Or)	Most inferior point of the orbit; if the outline of two orbital floors can be seen, the average distance between the two should be used
Porion (Po)	Most superior point of the external auditory meatus
Subspinale (A point)	Most posterior point on the curve between the anterior nasal spine and the crest of the alveolar process
Supramentale (B point)	Most posterior point on the outer contour of the mandibular alveolar process
Anterior Nasal Spine (ANS)	Most anterior point on the maxilla at the level of the palate
Posterior Nasal Spine (PNS)	Most posterior point on the maxilla at the level of the palate
Condylion (Co)	Most posterior-superior point on the condyle
Gonion (Go)	Most posterior-inferior point at the angle of the mandible. It can be located by bisecting the angle formed by the junction of the ramal and mandibular planes.
Menton (Me)	Most inferior point on the outline of the symphysis
Pogonion (Pog)	Most anterior point of the bony chin
Gnathion (Gn)	Midpoint between Me and Pog
Articulare (Ar)	Point of intersection between posterior border of ramus and basilar part of the occipital bone
Basion (Ba)	Anterior point of the foramen magnum
Pterygomaxillary point	Intersection of inferior border of the foramen rotundum with posterior wall of the pterygomaxillary point
Cv2tg	The most superior posterior limit of the odontoid process
Cv2ip	The inferior posterior limit of the odontoid process
Cv4tg	The superior posterior point of the 4^{th} cervical vertebra
Cv4ip	Inferior posterior point of the 4^{th} cervical vertebra

Table 6. Reference Plane Definitions

Reference Plane	Definition
Sella-Nasion (SN)	Line formed when connecting S to N point
Frankfort Horizontal (FH)	Line formed when connecting Po to Or
Palatal Plane (PP)	Line formed when connecting ANS to PNS
Mandibular plane (MP)	Line formed when connecting Go to Gn

Table 7. Craniofacial Linear Measurements

Craniofacial Measurement	Definition
Anterior Face Height (AFH)	Length from Nasion to Menton
Upper Anterior Face Height (UAFH)	Length from Nasion to ANS
Lower Anterior Face Height (LAFH)	Length from ANS to Menton
Posterior Face Height (PFH)	Length from Sella to Gonion
U6 to Palatal Plane	Distance from occlusal surface of U6 to palatal plane
U1to Palatal Plane	Distance from incisal surface of U1 to palatal plane
L6 to Mandibular Plane	Distance from occlusal surface of L6 to mandibular plane
L1 to Mandibular Plane	Distance from incisal surface of L1 to mandibular plane

Table 8. Craniofacial Angulation Measurements

Craniofacial Angle	Name/Definition
SNA	A-P classification of the Maxilla
SNB	A-P classification of Mandible
ANS	AP classification of M-Mn relationship
N-S-Ba	Cranial Base Angle
SN-FH	Anterior Cranial Base Angle
BaS-FH	Posterior Cranial Base Angle
SN-MP	Mandibular Plane Angle
FH-MP	Frankfort to Mandibular Plane Angle
PP-FH	Palatal plane angle
FH to S-Gn	Y-axis
Ba-Pt-Gn	Facial Axis
Ar-Go-Me	Gonial Angle
Y-Axis	Angle formed between SN and S-Gn
Downs Y-axis	Angle formed between FH and S-Gn
Facial Axis	NaBa-PtGn

Table 9. Cranio-cervical Angles

Cranio-cervical Angle	Definition
Greater Cervical Angle	The supplementary acute angle of Cv2tg, Cv2ip, and Cv4ip
OPT-NSL	Angle formed from a line tangent to Cv2tg and Cv2ip and the sella-nasion reference plane
OPT-HOR	Angle formed from a line tangent to Cv2tg and Cv2ip and the Frankfort horizontal reference plane
CVT-NSL	Angle formed from a line tangent through Cv2tg and Cv4ip and the sella-nasion reference plane
CVT-PP	Angle formed from a line tangent through Cv2tg and Cv4ip and the palatal plane

Table 10. Principal Component Factor Analysis

Factor 1: Size
Factor 2: Head Posture
Factor 3: Mandibular Divergence
Factor 4: Maxillo-mandibular Relationship to SN
Factor 5: Growth Pattern
Factor 6: Cranial Base Angulations
Factor 7: Upper to Lower Face Height Proportions

	Component						
	1	2	3	4	5	6	7
BaSN	-0.199	0.039	0.041	0.375	0.042	**0.827**	-0.251
SBaFH	0.194	-0.072	0.044	-0.060	0.140	**0.860**	0.179
NBaFH	**0.662**	-0.174	-0.045	-0.044	-0.219	0.419	**0.428**
SNA	-0.123	-0.199	-0.097	**-0.826**	0.331	0.058	-0.053
SNB	-0.067	-0.234	-0.092	**-0.859**	-0.172	-0.091	-0.026
ANB	-0.091	0.033	0.011	-0.001	**0.843**	0.253	-0.040
FMA	0.055	0.179	**0.884**	0.146	0.286	-0.110	-0.118
MPA	0.058	0.228	**0.747**	0.486	0.153	0.014	-0.288
NaMe	**0.936**	0.011	0.112	0.152	-0.092	-0.048	0.168
SNPP	-0.036	-0.047	0.093	**0.680**	0.154	0.146	0.398
ArGoMe	-0.014	-0.017	**0.834**	-0.093	-0.034	0.054	0.116
ANSMe	**0.935**	0.081	0.215	0.050	0.023	-0.030	-0.229
U:LFH	-0.278	-0.162	-0.255	0.194	-0.102	0.007	**0.820**
S-Go	**0.786**	-0.095	-0.412	-0.181	-0.048	-0.115	0.335
Co-Go	**0.716**	-0.074	-0.458	-0.102	-0.099	-0.026	0.293
P:AFH	0.022	-0.152	**-0.738**	-0.435	0.055	-0.139	0.293
U6-PP	**0.818**	-0.037	0.033	0.070	-0.150	-0.043	-0.178
U1-PP	**0.827**	0.131	0.125	0.113	0.002	-0.026	-0.257
L1-MP	**0.894**	-0.009	0.073	0.037	0.138	0.106	-0.121
L6-MP	**0.828**	-0.024	-0.121	0.005	0.279	0.054	-0.030
SN-Gn	0.108	0.327	0.312	**0.693**	0.418	0.001	-0.272
Y-axis	0.101	0.262	0.447	0.198	**0.634**	-0.181	-0.014
Facial Axis	-0.188	-0.346	-0.300	-0.430	**-0.510**	0.447	0.125
OPT-NS	-0.005	**0.929**	0.117	0.240	0.078	-0.008	-0.077
OPT-OH	-0.011	**0.943**	0.161	0.047	0.146	-0.075	0.023
CVT-PP	-0.010	**0.961**	0.031	0.009	-0.012	-0.038	-0.162
CVT-SN	-0.023	**0.935**	0.065	0.256	0.044	0.015	-0.015
Eigenvalue	7.495	6.377	2.772	2.428	1.740	1.561	1.107
% Variance	27.758	23.619	10.267	8.991	6.444	5.783	4.101

Table 11. SN-FH Angle Sex Differences

	Females		**Males**		**Group Comparisons**
	Mean	SE	Mean	SE	Probability
SN-FH Angle Value (°)	8.80	0.22	8.51	0.23	0.36

Table 12. SN-FH Angle Group Differences

	Mexican American (1)		**African American (2)**		**Caucasian (3)**		**Three Group Comparisons**	**Bonferroni: Post-Hoc Comparisons**		
								1vs2	**1vs3**	**2vs3**
	Mean	SD	Mean	SD	Mean	SD	Probability			
SN-FH°	8.50	0.29	9.29	0.27	8.18	0.26	0.011	0.13	1.00	0.007

Table 13. Means and Standard Errors for Factors Between Sexes

	Females		**Males**		**Group Comparisons**
Factor	Mean	SE	Mean	SE	Probability
Size	-0.371	0.065	0.373	0.070	<0.001
Head Posture	0.264	0.077	-0.272	0.083	<0.001
Mandibular Divergence	-0.010	0.083	0.010	0.089	0.876
Mx-Mn Relationship to SN	0.022	0.083	-0.020	0.089	0.746
Growth Pattern	-0.106	0.077	0.164	0.083	0.024
Cranial Base	0.040	0.084	-0.048	0.084	0.496
U:LFH Proportions	-0.110	0.071	0.101	0.076	0.054

Table 14. Means and Standard Errors for Factors Between Groups

	Mexican-American		**Caucasian**		**African-Americans**		**Three Group Comparisons**
Factor	Mean	SE	Mean	SE	Mean	SE	Probability
Size	-0.542	0.081	0.641	0.076	-0.095	0.077	<0.001
Head Posture	0.170	0.096	-0.085	0.090	-0.097	0.091	0.078
Mandibular Divergence	-0.085	0.102	-0.083	0.097	0.168	0.098	0.114
Mx-Mn Relationship to SN	-0.090	0.103	0.042	0.097	0.051	0.099	0.551
Growth Pattern	0.518	0.096	-0.409	0.090	-0.022	0.091	<0.001
Cranial Base	-0.037	0.104	-0.061	0.098	0.085	0.099	0.538
U:LFH Proportions	-0.043	0.088	0.661	0.082	-0.632	0.084	<0.001

Table 15. Bivariate Pearson Correlations between SN-FH and Factors

	Factor 1	**Factor 2**	**Factor 3**	**Factor 4**	**Factor 5**	**Factor 6**	**Factor 7**
SN-FH	0.021	0.111	-0.121	0.652	-0.204	0.211	-0.329
Probability	0.713	0.054	0.036	<0.001	<0.001	<0.001	<0.001