ANGULAR CEPHALOMETRIC MEANS FOR AFRICAN AMERICANS

A Thesis
Submitted to
the Temple University Graduate Board

In Partial Fulfillment
of the Requirements for the Degree
MASTER OF SCIENCE

---

by
Daniel Markel
August 2025

Thesis Approvals:

James J. Sciote, Thesis Advisor, Orthodontics
Jeffrey H. Godel, Orthodontics
Carmen Doumit, Orthodontics

ABSTRACT

Introduction: Cephalometric analysis is routinely used in orthodontics for diagnosing and treating patients. Angular cephalometric measurements are particularly important in determining the relationship between anatomical landmarks. Norms for these measurements are important adjuncts that help clinicians determine if a patient's morphology is normal. Previous studies, like the *Bolton Standards of Dentofacial Developmental Growth Study*, established cephalometric norms predominantly focused on the Caucasian population. While there have only been a few studies conducted on the African American population, these studies have omitted important angular measurements. This study aims to establish comprehensive norms for the African American population of North Philadelphia and to compare these norms to previously determined norms in other populations.

Materials and Methods: Twenty-six angular cephalometric measurements were determined on 600 African American subjects at Temple University's Orthodontic Screening Clinic. Subjects ranged from seven--eighteen years of age and were further divided based on sex. Statistical analyses were used to determine significance between previously documented studies, gender, and age.

Results: Of the 600 subjects (333 female, 267 male) the mean age was 13.50. Intrarclass correlation coefficient (ICC) was excellent for 23 measurements, good for 2, and moderate for 1. Compared to the Bolton Standards, the sample showed significant differences for 24 measurements: increased mandibular-protrusion (FH-Na-Pog, SN-Pog, Bo-Na-Pogo, SNB), maxillary-protrusion (SNA), Class II (ANB), hyperdivergence (FH-Go-Gn, SN-Go-Gn, ANS-PNS-Go-Gn, Y-axis), incisor-proclination (PNS-ANS-U1, SN-

U1, Go-Gn-L1, Na-U1, U1-L1, SN-L1). Compared to previous African American means, the sample showed increased mandibular-protrusion (FH-Na-Pog, SNB), Class II (ANB), hyperdivergence (SN-Go-Gn, Y-axis), incisor-proclination (U1-NA, U1-L1). 6 measurements showed no significant differences.

Conclusion: The study population of 600 African American subjects, showed significant differences in angular cephalometric measurements when compared to the Bolton Standards, which was conducted on a sample of Caucasian subjects. The study population displayed increased hyperdivergence, incisor-proclination, bimaxillary protrusion, and Class II compared to the Bolton Standards. Differences with previous African American studies were sporadic but aligned in the same direction relative to Bolton Standards suggesting secular trends, a difference in study design, or other factors. These results highlight the need for population-specific norms in orthodontic diagnosis and treatment planning.

ACKNOWLEDGEMENTS

Committee members, thank you for your inspiration and guidance. You have shown me what it means to be a lifelong learner, always striving to grow and further the profession. This thesis would not have been possible without your support.

Dr. Godel, I have learned an incredible amount from you during my time at Temple. Your dedication to your patients, the field of orthodontics, the residents, and the department has been nothing short of inspiring.

Dr. Sciote, thank you for being a dedicated mentor over the past four years. As a dental student, I was fortunate to have the opportunity to conduct research with you. Your contributions to the field will remain with me throughout my career.

Dr. Doumit, you have been an incredible support system throughout my residency. I have gained so much from your guidance and look forward to applying this knowledge in the future.

Dr. Lim, thank you for your support in analyzing the data. It was instrumental in creating this thesis.

My co-residents, I am privileged to have such a supportive, intelligent, and dedicated group of peers who are also incredible friends. I cannot wait to see you flourish in your careers as we continue to learn alongside one another.

My family and friends, every step of this journey has been possible because of you. Your love has been the cornerstone of my education, lifting me up every time I stumbled. Thank you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Skull relationships are evaluated by orthodontists using linear and angular measurements. Angular measurements provide crucial information in relating two points to one another via a reference point. Orthodontists routinely use compilations of angular measurements to paint a picture that will develop into a formal diagnosis. Each measurement carries little value as a standalone degree, but in conjunction with other measurements, it becomes an essential diagnostic tool (Graber, Vanarsdall, & Vig, 2011)

For orthodontists to establish the severity of deviations in cephalometric analysis, norms are commonly referenced to determine acceptable ranges. Cephalometric norms are essential tools in navigating orthodontic diagnosis and treatment planning. Norms vary by race, age, and sex; therefore, it is integral to have representative and contemporary data within each of these categories.

Over the past century, studies have attempted to create universal norms but have had shortcomings (Profft, Fields, Larson, & Sarver, 2019). *The Bolton Standards of Dentofacial Developmental Growth study* is a commonly referenced study that established norms for twenty-six angular cephalometric measurements. This study analyzed “ideal” Caucasian faces; therefore, the established norms have limited application in non-Caucasian populations (Broadbent & Golden, 1975). Despite these shortcomings, a study has yet to be conducted establishing updated norms for the African American population in each of the 26 angular measurements. Furthermore, studies that have established norms for individual angular measurements, have overlooked the adolescent population in their studies.

The goal of this study is to establish angular cephalometric norms for the African American population.

The present study consists of three aims. 1) To define cephalometric angular averages for North Philadelphia's African American population presenting at Temple University's Orthodontic Clinic. 2) To compare cephalometric angular averages in North Philadelphia's African American population presenting at Temple University's Orthodontic Screening Clinic to Caucasian norms established in the Bolton Standards of Dentofacial Developmental Growth study. 3) To compare cephalometric angular averages in North Philadelphia's African American population presenting at Temple University's Orthodontic Screening Clinic to previously studied African American norms when those norms are available.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Role of Cephalometrics in Orthodontics

Throughout history, experts have attempted to measure and identify relationships between various facial features. In the 1400's Leonardo da Vinci used a grid system to demonstrate facial proportions and centuries later, Petrus Camper (1722-1789) an anthropologist, studied the human face through age and compared human jaws to jaws of other species. Using dry skulls to evaluate craniofacial anatomy, Camper identified the first reference plane from middle of the porus acousticus to the base of the nose (Wahl, 2006). In the late nineteenth century, William Roentgen discovered the x-ray, which allowed for the development of the study of *cephalometrics* that utilized radiographs for the analysis of craniofacial anatomy as opposed to the dry skulls used by anthropologists in centuries prior (Wahl, 2006).

Cephalometrics is defined as the measurement of the bones of the cranium and face from an image produced from a radiographic cephalometer (Profft, Fields, Larson, & Sarver, 2019). In the mid-twentieth century, several influential cephalometric analyses were created such as the Downs, Steiner, Wits, and McNamara analyses. These analyses utilize various anatomic landmarks to identify and categorize skeletal and dental relationships. Each analysis had its unique set of advantages and disadvantageous, so it is important to apply several systems to properly diagnose and treat orthodontic patients (Bishara, Fahl, & Peterson, 1983). Cephalometric analysis allows for quantifying skeletal and dental discrepancies and allows the clinician to identify to what extent orthodontic or surgical intervention can resolve the underlying malocclusions (Profft, Fields, Larson, & Sarver, 2019)

2.2 The Bolton Brush Study – A Craniofacial Growth Study

From 1930-1985, eleven major craniofacial growth studies were conducted. Generally, these studies collected, serial lateral cephalograms as well as other radiographic and non-radiographic data on growing children and their malocclusions. Radiographic and sampling techniques varied between each study, but many took radiographs on a quarterly, semi-annual, or annual basis over the course of development (Al-Jewair, Stellrecht, Lewandowski, & Chakaki, 2018).

The unnecessary radiographic exposure of the subjects has provided an ethical dilemma, and it is unlikely that such growth studies will be repeated in the future. Despite this, these studies have proven immensely important in understanding craniofacial growth and development. Follow-up studies have used data from craniofacial growth studies to determine norms for various parameters. One of the original longitudinal craniofacial growth studies, the Bolton Brush Study, used the cephalometric radiographs of subjects to establish "norms" for various linear and angular measurements (Broadbent & Golden, 1975).

The Bolton-Brush Growth Study was conducted between 1929 and 1959, during which more than 200,000 radiographs were taken. The study took place in Cleveland, Ohio and is currently housed at the Case Western Reserve University School of Dental Medicine. To establish norms, the study determined "*Bolton Faces*" which were used to quantify the norms. The following criteria were used to determine which subjects would be selected for the Bolton Standards: excellent occlusion according to dental casts, no syndromes, faces that fell within statistically derived means of craniofacial measurements, subjectively determined “aesthetic” faces, availability of long-term records (Broadbent & Golden, 1975).

Approximately 500 subjects qualified as “*Bolton Faces*”; their records were extracted from the longitudinal study and used to determine norms. The subjects have semi-annual radiographs taken from the ages of one to four and have annual radiographs taken from the age of four to eighteen. All subjects were of Caucasian (mostly Central European) descent. For each of the twenty-six angular measurements, the mean, standard deviation, standard error, minimum, and maximum were determined and categorized based on the age and gender of the subject (Broadbent & Golden, 1975). The breadth of this study has made it incredibly valuable in determining a metric for craniofacial growth and development.

2.3 Clinical Application of the Bolton-Brush Study

Of the twenty-six angular measurements identified in the Bolton-Brush study, many have been integrated into subsequent analyses that are commonplace in cephalometric analyses.

One of the first cephalometric analyses was brought forth by William B. Downs in 1948. Downs utilized the Frankfort Horizontal as a reference plane for his measurements. He used nine of the angular measurements mentioned in the Bolton-Brush study such as: OrPo-NaPogo (1), OrPo-GoGn (4), SGn-OrPo (5), OrPo-Occl. Pl (6), U1-L1 (7), GoGN-L1 (18), Occl. Pl-L1 (19), N-A-Pogo (23), and AB-NPogo (24) (Downs, 1952).

In the following decade, Cecil C. Steiner popularized the use of cephalometrics in clinical orthodontics. He extracted the following measurements that were used in the Bolton-Brush study: Occl pl.-SN (10), GoGn-SN (11), SNA (20), SNB (21), ANB (22) , U1-NA (25) , L1-NB (26) (Steiner, 1953). The angular measurements described in the Bolton-Brush study have both academic and clinical significance and are widely used in an array of cephalometric analyses.

2.4 Craniofacial Growth Studies for the African American Population

Caucasian and African American populations have considerable variability between one another in terms of facial features and cephalometric measurements. Previous studies have determined that African American children ages twelve to sixteen, have increased convexities and mandibular plane angles when compared to their Caucasian counterparts (Altemus L. A., 1960). This study included subjects with "normal occlusion", but only those with complete permanent dentition (except for third molars). This limitation does not give a comprehensive comparison on the norms for African Americans based off age and gender and is insufficient in comparing to the Bolton Brush Study. Furthermore, most of the angular measurements were not included in the Altemus study.

A further study was conducted to attempt to replicate the Alabama Analysis, a set of norms for Southern Caucasian children, but on the Southern, African American population (Alexander, 1978). This study included fifty subject ages eight to thirteen with the "best" occlusions (Class I molar and acceptable anterior occlusion and profile). Fourteen angular measurements were evaluated and the authors report that the African Americans children in their study on average have a more anteriorly positioned maxilla than the mandible, more proclined and protruded incisors, and have decreased occurrence of Class II and III dental malocclusions when compared to Caucasian children (Alexander, 1978). The limitation of this study includes its sample size, age restrictions, and incomplete cephalometric analysis when compared to the measurements used in the Bolton Brush Study.

Another study, attempted to create cephalometric norms for African American children and compare them to the norms determined by the University of Alabama for Southern Caucasian children (Drummond, 1968). This study compared forty African subjects from the age of eight to twenty-three that had Class I molar relationship and lacked any facial deformities. This study determined that the African American group had on average a steeper mandibular plane, more anteriorly positioned maxilla and more proclined and protruded lower incisors, and more protruded, but not proclined, upper incisor (Drummond, 1968). This study, similarly to the Alexander et al. study, was limited by the sample size and incomplete cephalometric analysis. Furthermore, the decision for Angle Class I molar classification as inclusion criteria is not sufficiently supported as there are no additional skeletal inclusion or exclusion criteria. A follow-up study confirmed the findings of this study but expanded its sample size to seventy-two with an age range from eight to twenty years old. The study also excluded subjects that did not have Class I skeletal and dental relationships. Despite this, the measurements included in this study were incomplete when compared to the Bolton-Brush set of angular measurements.

Previous studies that have evaluated cephalometric norms for the African American population have been incomplete due to their sample size, inclusion and exclusion criteria for age, location, craniofacial and dental morphology. No current longitudinal or cross-sectional study has comprehensively analyzed the angular measurements used in the Bolton Brush Study for the African American population.

2.5 Clinical Application of Cephalometric Norms for the African American Population

Cephalometric norms may influence treatment planning decisions. Having accurate norms is important in both treatment planning and predicting outcomes. For example, Cecil C. Steiner explained in what became known as the "Steiner Chevrons" that for every degree that ANB increases, certain dental compromises in incisor position and angulation must occur in order to maintain a proper overjet (Servoss, 1973). These principles are particularly useful in determining treatment goals, deciding whether a case is extraction or non-extraction, and planning anchorage.

The recommendations for the studies may be different base off morphologic differences in races. To date, no study has established averages for the African American population. Once this data is determined, Steiner Chevrons may be able to be more relevant in treating African American patients.

2.6 Morphologic Differences Between African American and Caucasian Populations

African American and Caucasian profiles have significant morphologic differences. One of the more commonly discussed difference is the increased bimaxillary dentoalveolar protrusion in the African American population; both soft and hard tissue measurements show a protrusive relationship in African Americans (Altemus L. , 1963). African Americans have also been shown to have steeper mandibular plane angles and more proclined incisors (Cotton, Tanako, & Wong, 1951). As previously described, African Americans have increased ANB angle and greater prevalence of Class II relationships (Alexander, 1978). In terms of mandibular morphology, studies have shown African Americans to have longer mandibular bodies (Altemus L. A., 1960). Despite, this, African Americans have shorter ramal heights (Drummond, 1968).

Given these anthropometric differences, it is expected that the angular norms derived from the Bolton-Brush study would vary for African American subjects. Measurements that pertain to steeper mandibular angles such as angular measurements 4, 5, 9, 11, 13, 16 are expected to be increased. Measurements that pertain to increased lower incisor proclination such as 7, 17, 19 are expected to be decreased and 26 to be increased. Measurements that pertain to increased maxillary protrusion such as angular measurements 20 and 23 are expected to be increased.

CHAPTER 3

AIMS OF THE INVESTIGATION

3.1 Specific Aims

The objective of this present study is to determine angular cephalometric norms in North Philadelphia's African American population and to compare these norms to previously established Caucasian norms in the *Bolton Standards of Dentofacial Developmental Growth study*. Specific aims are:

1. To define cephalometric angular averages for North Philadelphia's African American population presenting at Temple University's Orthodontic Clinic.
2. To compare cephalometric angular averages in North Philadelphia's African American population presenting at Temple University's Orthodontic Screening Clinic to Caucasian norms established in the Bolton Standards of Dentofacial Developmental Growth study.
3. To compare cephalometric angular averages in North Philadelphia's African American population presenting at Temple University's Orthodontic Screening Clinic to previously studied African American norms when those norms are available.

3.2 Significance

Updated and relevant norms are important tools in diagnosing, treating, and evaluating growth in orthodontic patients. If a set of norms for the angular Bolton measurements are identified in a population of African American adolescents, these values will have greater clinical relevance during treatment of the aforementioned population.

CHAPTER 4

MATERIALS AND METHODS

4.1 Study Design

A lateral cephalometric radiograph is part of orthodontic screening at the Temple University Kornberg School of Dentistry (TUKSoD) Orthodontics Clinic. Six hundred study subjects were selected from individuals who had undergone orthodontic screening at TUKSoD Orthodontic Clinic between January 1, 2010, and December 1, 2023, based on specific inclusion and exclusion criteria. All radiographs were taken on the Planmeca ProMax 3D 2S at Temple University's Orthodontic Clinic, which has a magnification of 1.13. Official IRB determination for this study was "Approval for a Project Involving Human Subjects Research that is Approved as Exempt" (Appendix A).

4.2 Inclusion and Exclusion Criteria

Six hundred study subjects were selected based on the inclusion and exclusion criteria as outlined in Table 1 and Table 2. The study subjects ranged in age from 7 to 18 years old at the time of their screening visit, during which their photos and radiographs were taken. Patients' racial identity was obtained from an optional, self-reported Temple Health Questionnaire. Patients' age, gender, and pre-treatment screening records, including facial photos and cephalometric radiographs, from self-identified African-American patients were collected and were reviewed. Patients were excluded from the study due if craniofacial anomalies, significant parafunctional habits, or poor quality cephalogram were taken.

Table 1: *Inclusion Criteria*

Inclusion Criteria	1. Patients between the ages of 7 and 18 2. Patients with pre-treatment lateral cephalometric radiographs. 3. Patients who self-identified as "African American/Black" in the Temple Health Questionnaire. 4. Patients who had lateral cephalograms taken in maximal intercuspation.

Table 2: *Exclusion Criteria*

Exclusion Criteria	1. Patients younger than 7 or older than 18 at the time of the radiograph. 2. Patients who did not self-identify as "African American/Black" or did not report their race on their health questionnaire. 3. Patients who underwent orthodontic treatment before having the cephalometric radiograph taken. 4. Patients who did not have lateral cephalograms taken in maximal intercuspation. 5. Patients with lateral cephalometric radiographs that do not allow for accurate analysis, including those with head positioning errors, image blurriness, and indistinguishable points. 6. Patients who reported any parafunctional habit at the screening, such as non-nutritive sucking and/or mouth breathing. 7. Patients with noticeable facial asymmetries that can be detected from their pre-treatment records. 8. Patients with craniofacial anomalies or syndromes.

4.3 Cephalometric Landmarks, Measurements, and Analysis

All cephalometric radiographs were taken using the Planmeca ProMax 3D 2S at Temple University's Orthodontic Clinic, which has a magnification increase of 13%. In this study, the Planmeca ProMax 3D 2S has a 45mm calibration ruler that is captured in the radiograph, providing two fiducial points to minimize magnification error.

After the sample selection, fifteen anatomical landmarks (Table 3) were identified using Dolphin Imaging Software (version 11.95.08.67 SP3 Premium). With minor head positioning errors, averages between non-coincident contralateral points were used to plot the landmark. Based on these fifteen landmarks, twenty-six angular measurements were calculated as shown in Table 4 and Figure 1, which are identical to those studied in the Bolton Growth Study.

Table 3. *Anatomical Landmarks For Cephalometric Analysis (Broadbent, Et Al., 1975)*

Anterior Nasal Spine (ANS)	Sharp median process formed by the forward prolongation of the two maxillae at the lower margin of the anterior aperture of the nose.
A-Point (A)	Also known as subspinale. Point in the median sagittal plane where the lower front edge of the anterior nasal spine meets the front wall of the maxillary alveolar process.
Articulare (Ar)	Intersection of the lateral radiographic image of the posterior border of the ramus with the base of the occipital bone.
B-Point (B)	Also known as supramentale. Deepest midline point on the anterior curvature of the mandible.
Gnathion (Gn)	Lowest, most anterior midline point on the symphysis of the mandible.
Gonion (Go)	External angle of the mandible located on the lateral radiograph by bisecting the angle formed by tangents to the posterior border of the ramus and the inferior border of the mandible (a line from the menton to the posteroinferior border of the mandible).
Lower Incisor (L1)	Line passing through the apical and incisal tips of the lower central incisors.
Nasion (Na)	Point where midsagittal plane intersects the most anterior point of the nasofrontal suture.
Occlusal Plane (Occl pl)	Line passing through one half the cusp height of the first permanent molars and one half the overbite of the incisors.
Orbitale (Or)	Lowest point on the inferior margin of the orbit.
Pogonion (Pogo)	Most anterior point on the symphysis of the mandible in the median plane when the head is viewed in Frankfort relation.
Porion (Po)	Pont on the upper margin of the porus acusticus externus.

Table 3. *(continued)*

Posterior Nasal Spine (PNS)	Process formed by the united projecting medial ends of the posterior borders of the two palatine bones.
Sella Turcica (S)	Hypophyseal or pituitary fossa of the sphenoid bone, lodging the pituitary body. S is the center of the Sella as seen in lateral radiograph.
Upper Incisor (U1)	Line passing through the apical and incisal tips of the upper central incisors.

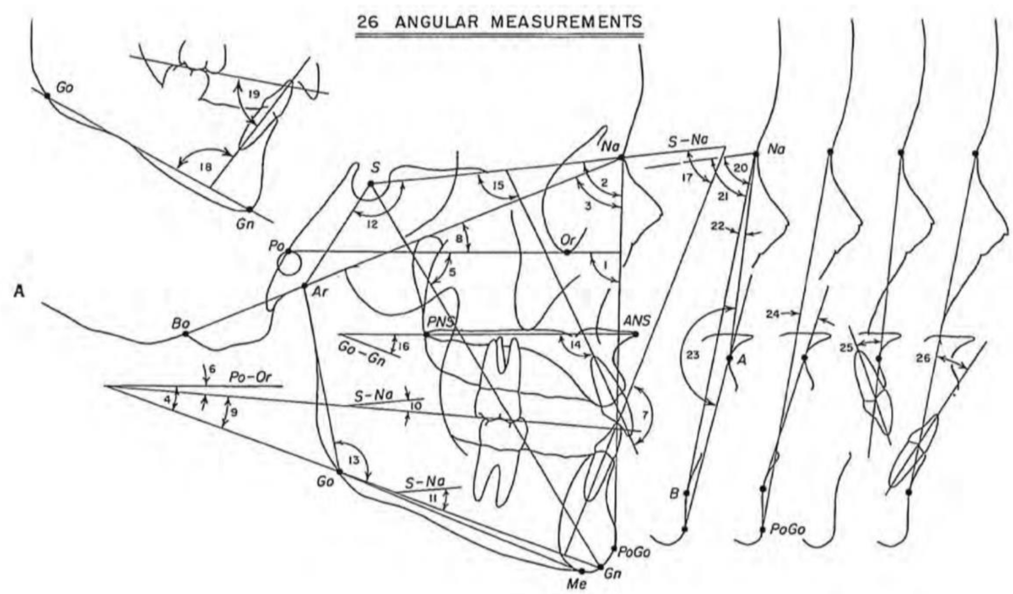

Figure 1. Diagram Representing 26 Angular Measurements Studied in the Bolton Study by Broadbent, et al. (1975).

Cephalometric measurements present a range of inaccuracies with some points being less predictable than others. The magnitude of errors on cephalometric radiographs varies in both size and distribution based on the point. According to Baumrind & Frantz (1971), the following points need to be considered when analyzing a cephalometric radiograph: Firstly, even when duplicating assessments of the same head film, errors in identifying landmarks cannot be overlooked. Secondly, the extent of error significantly differs from one landmark to another. Lastly, the errors for most landmarks do not occur randomly, but rather demonstrate a systematic pattern, with each landmark having its own distinct and typically non-circular margin of error. It was also noted that a horizontal variability may affect linear measurements more severely than angular measurements (Baumrind & Frantz, 1971).

Table 4. *List of Angular Cephalometric Measurements (Broadbent, et al., 1975)*

Angular Measurement No. 1	(Po-Or)-(Na-Pogo)
Angular Measurement No. 2	S-Na-Pogo
Angular Measurement No. 3	Bo-Na-Pogo
Angular Measurement No. 4	(Or-Po)-(Go-Gn)
Angular Measurement No. 5	(Or-Po)-(S-Gn)
Angular Measurement No. 6	(Or-Po)-(Occl pl)
Angular Measurement No. 7	U1-L1
Angular Measurement No. 8	(Na-Bo)-(Po-Or)
Angular Measurement No. 9	(Occl pl)-(Go-Gn)
Angular Measurement No. 10	(Na-S)-(Occl pl)
Angular Measurement No. 11	(Na-S)-(Go-Gn)
Angular Measurement No. 12	Na-S-Ar
Angular Measurement No. 13	Ar-Go-Gn
Angular Measurement No. 14	(PNS-ANS)-U1
Angular Measurement No. 15	(S-Na)-U1
Angular Measurement No. 16	(ANS-PNS)-(Go-Gn)
Angular Measurement No. 17	(S-Na)-L1
Angular Measurement No. 18	(Go-Gn)-L1
Angular Measurement No. 19	(Occl. pl)-L1
Angular Measurement No. 20	S-Na-A
Angular Measurement No. 21	S-Na-B

Table 4. (*continued)*

Angular Measurement No. 22	A-Na-B
Angular Measurement No. 23	Na-A-Pogo
Angular Measurement No. 24	(Na-Pogo)-(B-A)
Angular Measurement No. 25	(Na-A)-U1
Angular Measurement No. 26	(Na-B)-L1

4.4 Data Collection, Management, and Statistical Analysis

The study subjects in this study were anonymized and given unique subject IDs. Their cephalograms were uploaded to Dolphin and traced using the software. Any documents linking the patient's medical record number to their subject ID were destroyed immediately after data collection.

An Excel spreadsheet was created to categorize each subject based on their de-identified subject ID, gender, and age. Each of the twenty-six angular measurements were added to the spreadsheet, as evident in Appendix B.

To address Aim 1, the mean, standard deviation, standard error, maximum, and minimum will be calculated for each angular measurement.

To address Aim 2, an independent t-test was used to compare the study's angular cephalometric norms of African Americans in Philadelphia with those published in Bolton Standards of Dentofacial Developmental Growth in Table 5.

To address Aim 3, an independent t-test was used to compare the study's angular cephalometric norms of African Americans in Philadelphia to previously established African American means in Table 5. The demographics varied in each of the studies that established African American means. The Alexander 1978 study used measurement from a patients aged 8-13 with the "best occlusions" from Jefferson County, Alabama (Alexander, 1978). For the Anderson et al. study, the sample was taken from a 1959 sample of 40 boys and 40 girls, 12-16 years old with "normal occlusion" (Anderson, Anderson, Hornbuckle, & Hornbuckle, 2000). For the Oliveira et al study, subjects were from Southeastern Brazil and reported at least partial African ancestry. Mean age was 22.4 years and subjects had Class I occlusion with minor crowding and minor misalignment (Oliveira, Copello, Silva, Nojima, & Nojima, 2021). The subjects from the Cotton et al. study, used 10 males and 10 females ages 11-34 from the San Francisco Bay area and subjects with "no real malocclusion were included" (Cotton, Tanako, & Wong, 1951). Table 5 use the following studies were used to identify the African American angular cephalometric means: Alexander, 1978; Anderson, Anderson, Hornbuckle, & Hornbuckle, 2000; Oliveira, Copello Silva, Nojima, & Nojima 2021; Cotton, Tanako, & Wong, 1951.

In this study, there were two examiners conducting the cephalometric measurements. In addition to the above statistical analyses, interrater reliability was assessed based on the intraclass correlation coefficient . Probability values less than 0.05 will be accepted as statistically significant.

Table 5. *Summary of Angular Cephalometric Measurements in the Bolton Standards of Dentofacial Growth Study and in Studies Sampling African American Subjects*

Angular Measurement	Anatomic Points	Bolton Standard Means	African American Means
No. 1	(Po-Or)-(Na-Pogo)	86.39	87.25
No. 2	S-Na-Pogo	80.1	N/A
No. 3	Bo-Na-Pogo	63.25	N/A
No. 4	(Or-Po)-(Go-Gn)	24.58	27.25
No. 5	(Or-Po)-(S-Gn)	59.63	63.3
No. 6	(Or-Po)-(Occl pl)	9.15	N/A
No. 7	U1-L1	136.18	123

Table 5. *(continued)*

Angular Measurement	Anatomic Points	Bolton Standard Means	African American Means
No. 8	(Na-Bo)-(Po-Or)	23.14	N/A
No. 9	(Occl pl)-(Go-Gn)	15.44	N/A
No. 10	(Na-S)-(Occl pl)	15.48	17.8
No. 11	(Na-S)-(Go-Gn)	30.91	26.47
No. 12	Na-S-Ar	121.99	N/A
No. 13	Ar-Go-Gn	127.17	N/A
No. 14	(PNS-ANS)-U1	109.15	N/A
No. 15	(S-Na)-U1	101.09	108.4
No. 16	(ANS-PNS)-(Go-Gn)	22.82	N/A
No. 17	(S-Na)-L1	57.26	46.2
No. 18	(Go-Gn)-L1	91.86	6.6
No. 19	(Occl. pl)-L1	72.7	63.9
No. 20	S-Na-A	82.41	84.7
No. 21	S-Na-B	79.05	79.7
No. 22	A-Na-B	3.37	5
No. 23	Na-A-Pogo	174.42	9.6
No. 24	(Na-Pogo)-(B-A)	6.44	-7.7
No. 25	(Na-A)-U1	18.67	23.7
No. 26	(Na-B)-L1	21.8	33.9

CHAPTER 5

RESULTS

5.1 Angular Measurements for African Americans in North Philadelphia

600 lateral cephalometric radiographs were traced by two graduate residents in Temple University's orthodontic program based on the inclusion and exclusion criteria. Fifteen landmarks were plotted on each. Intraclass Correlation Coefficient (ICC) was evaluated and is listed in Appendix C. An ICC score < 0.50 was considered poor; between 0.50 and 0.75 moderate; between 0.75 and 0.90 good; above 0.90 excellent. Twenty-three angular measurements had excellent scores, two had good scores, and one had a moderate score.

600 individuals were included in the study, with a mean age of 13.5 years. The participants' ages ranged from 7 to 18 years. The majority of the participants were between the ages of 11 and 14, with a peak at age 13 and a meant of 13.50. The early adolescent age group was strongly represented in the study.

Table 6. *Study Demographics*

n	**Mean Age**	**Range**	**Female**	**Male**
600	13.50	7-18	333	267

Gender distribution in this study was fairly balanced, with slightly more females than males. Out of the 600 participants, 333 were female, accounting for 55.5% of the total sample size. In contrast, 267 participants were male, representing 44.5% of the total sample.

For each angular measurement, the mean and standard deviation were calculated and a sample size of 600 was used. The data is presented in Table 7.

Table 7. *Angular Cephalometric Norms for African American in North Philadelphia*

#	Mean	SD	*n*
1	90.50	4.03	600
2	80.66	4.59	600
3	65.95	4.15	600
4	25.73	5.29	600
5	57.85	4.00	600
6	6.24	4.03	600
7	116.30	13.13	600
8	24.55	2.82	600
9	17.11	4.01	600
10	15.58	5.22	600
11	35.57	5.87	600
12	127.30	6.05	600
13	127.10	5.95	600
14	116.60	12.06	600
15	110.10	12.57	600
16	29.00	5.33	600
17	46.94	7.99	600
18	82.51	7.40	600
19	27.48	7.05	600
20	85.04	4.34	600
21	80.95	4.55	600
22	4.09	2.98	600
23	171.05	6.56	600
24	5.18	4.07	600
25	25.63	9.74	600
26	34.01	6.74	600

5.2 Comparison to the Bolton Standards of Dentofacial Development

All twenty-six angular measurements were compared to the twenty-six angular measurements in the Bolton Standard of Dentofacial Development. Both studies used the same anatomical landmarks. Sample size for the Bolton Standards was 384 subjects per measurement. An independent T-test was conducted to evaluate if any significant differences existed between the two populations. A p-value of <0.05 was considered significant.

All means calculated for the study population significantly differed from the Bolton Standards except for angular measurements #10 [(Na-S)-(Occl pl)] and #13 [Ar-Go-Gn]. The means from the two studies for each of the angular measurements and the associated p-values are described in Table 8. Independent T-tests were conducted to evaluate if any significant differences existed between the other studies and the current study. A p-value of <0.05 was considered significant. Twenty-four of the twenty-six measurements were statistically significant. Seven of those measurements differed by more than one standard deviation. These are illustrated in Figure 2.

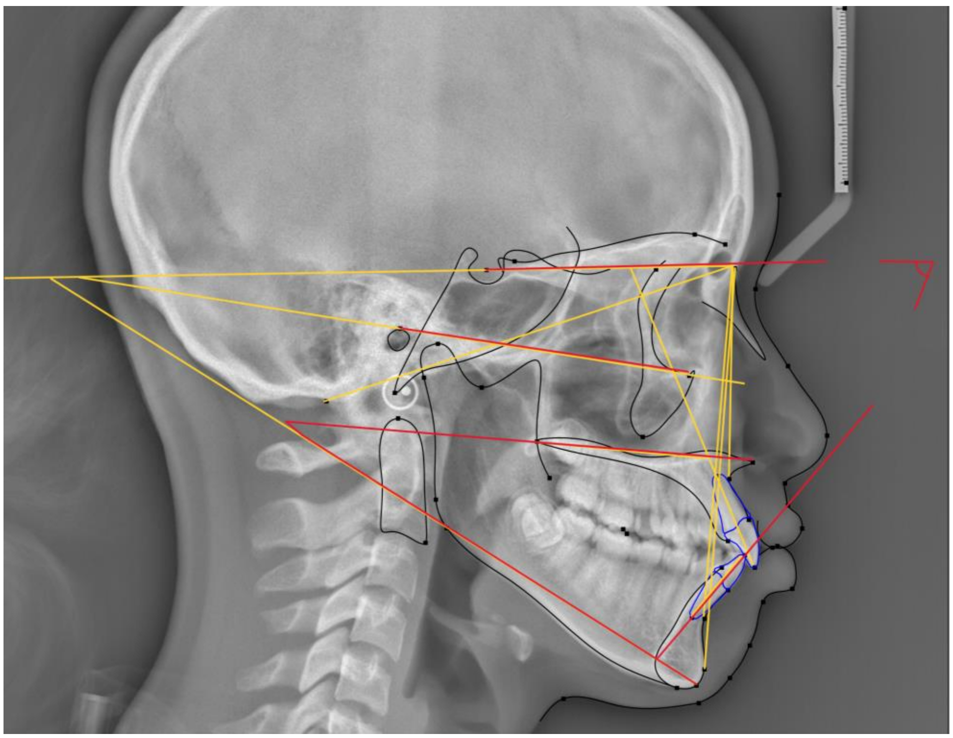

Figure 2. North Philadelphia vs Bolton Standards Angular Measurements with Significant Differences. Yellow lines indicate statistically significant measurements by less than 1 standard deviation. Red lines indicated differences > 1 standard deviation.

Table 8. *Means From the Bolton Standards and North Philadelphia African American Studies*

#	Points	Bolton Standard Means	North Philadelphia African American Means	p-value
1	(Po-Or)-(Na-Pogo)	86.39	90.50	<0.01
2	S-Na-Pogo	80.1	80.66	0.01
3	Bo-Na-Pogo	63.25	65.95	<0.01
4	(Or-Po)-(Go-Gn)	24.58	25.73	<0.01
5	(Or-Po)-(S-Gn)	59.63	57.85	<0.01
6	(Or-Po)-(Occl pl)	9.15	6.24	<0.01
7	U1-L1	136.18	116.30	<0.01
8	(Na-Bo)-(Po-Or)	23.14	24.55	<0.01
9	(Occl pl)-(Go-Gn)	15.44	17.11	<0.01
10	(Na-S)-(Occl pl)	15.48	15.58	0.72
11	(Na-S)-(Go-Gn)	30.91	35.57	<0.01
12	Na-S-Ar	121.99	127.30	<0.01
13	Ar-Go-Gn	127.17	127.10	0.83
14	(PNS-ANS)-U1	109.15	116.60	<0.01
15	(S-Na)-U1	101.09	110.10	<0.01
16	(ANS-PNS)-(Go-Gn)	22.82	29.00	<0.01
17	(S-Na)-L1	57.26	46.94	<0.01
18	(Go-Gn)-L1	91.86	97.49	<0.01
19	(Occl. pl)-L1	72.7	27.48	<0.01
20	S-Na-A	82.41	85.04	<0.01
21	S-Na-B	79.05	80.95	<0.01
22	A-Na-B	3.37	4.09	<0.01
23	Na-A-Pogo	174.42	171.05	<0.01
24	(Na-Pogo)-(B-A)	6.44	5.18	<0.01
25	(Na-A)-U1	18.67	25.63	<0.01
26	(Na-B)-L1	21.8	34.01	<0.01

5.3 Comparison to Previously Established African American Norms

The angular measurements from this study were compared to previously established norms in other African American populations when available. Of the twenty-six angular measurements, sixteen were found to have been previously researched. Nine of the measurements had no norms for the African American population. Norms were collected from four different studies with varying sample sizes, inclusions/exclusion criteria, and age ranges. One of the studies, had no standard deviation described (Cotton, Tanako, & Wong, 1951). An assumption of a standard deviation of 4.0 was made. Independent T-tests were conducted to evaluate if any significant differences existed between the other studies and the current study. A p-value of <0.05 was considered significant. The results are exhibited in Table 9.

Of the sixteen measurements with previously established norms, ten had significant differences from the values that were established and are illustrated in Figure 3 (angular measurements 1, 5, 7, 10, 11, 19, 21, 22, 24, and 25). Six were not statistically significant from the means found in this study (angular measurements 4, 15, 17, 20, 23, and 26).

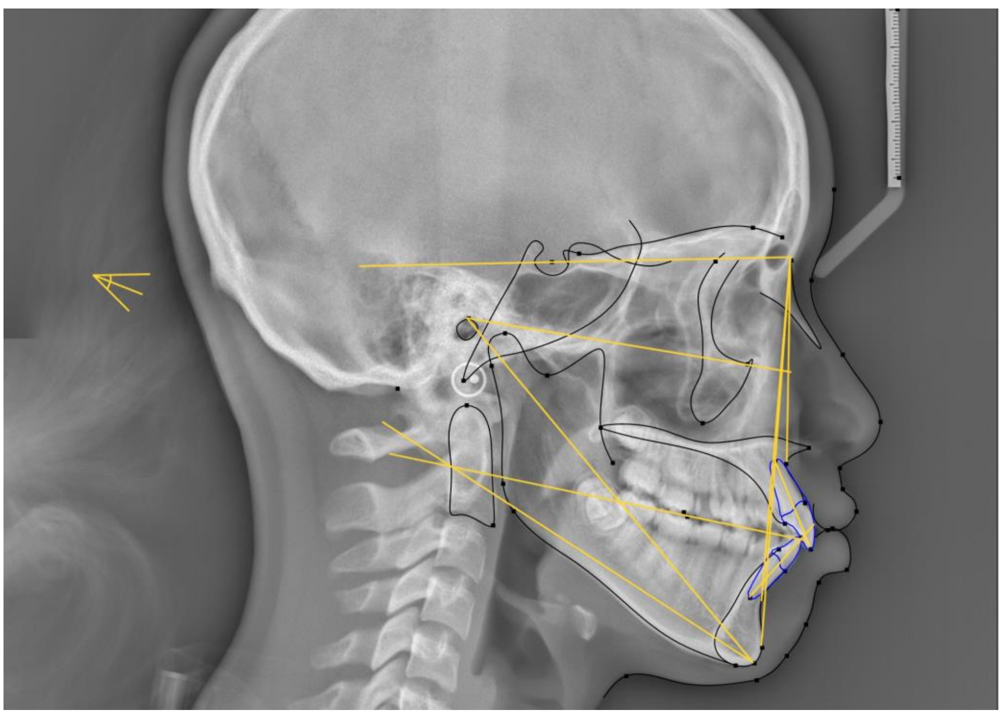

Figure 3. North Philadelphia vs Previously Established African American Angular Measurements with Significant Differences. Yellow lines indicate statistically significant measurements.

Table 9. *Previously Established Means for African American (A.A) Population and North Philadelphia African American Studies*

#	Points	Previously Established A.A. Means	North Philadelphia A.A. Means	p-value	Referencing Study
1	(Po-Or)-(Na-Pogo)	87.25	90.50	<0.01	(Cotton, Tanako, & Wong, 1951)
2	S-Na-Pogo	N/A	80.66	N/A	N/A
3	Bo-Na-Pogo	N/A	65.95	N/A	N/A
4	(Or-Po)-(Go-Gn)	27.25	25.73	0.11	(Cotton, Tanako, & Wong, 1951)
5	(Or-Po)-(S-Gn)	63.3	57.85	<0.01	(Cotton, Tanako, & Wong, 1951)
6	(Or-Po)-(Occl pl)	N/A	6.24	N/A	N/A
7	U1-L1	123	116.30	<0.01	(Cotton, Tanako, & Wong, 1951)
8	(Na-Bo)-(Po-Or)	N/A	24.55	N/A	N/A
9	(Occl pl)-(Go-Gn)	N/A	17.11	N/A	N/A
10	(Na-S)-(Occl pl)	17.8	15.58	<0.01	(Alexander, 1978)
11	(Na-S)-(Go-Gn)	26.47	35.57	<0.01	(Oliveira, Copello, Silva, Nojima, & Nojima, 2021)
12	Na-S-Ar	N/A	127.30	N/A	N/A
13	Ar-Go-Gn	N/A	127.10	N/A	N/A
14	(PNS-ANS)-U1	N/A	116.60	N/A	N/A
15	(S-Na)-U1	108.4	110.10	0.09	(Alexander, 1978)
16	(ANS-PNS)-(Go-Gn)	N/A	29.00	N/A	N/A
17	(S-Na)-L1	46.2	46.94	0.45	(Alexander, 1978)
18	(Go-Gn)-L1	N/A	97.49	N/A	N/A
19	(Occl. pl)-L1	63.9	27.48	<0.01	(Alexander, 1978)
20	S-Na-A	84.7	85.04	0.58	(Alexander, 1978)
21	S-Na-B	79.7	80.95	0.04	(Alexander, 1978)
22	A-Na-B	5	4.09	<0.01	(Alexander, 1978)
23	Na-A-Pogo	170.4	171.05	0.49	(Cotton, Tanako, & Wong, 1951)
24	(Na-Pogo)-(B-A)	-7.7	5.18	<0.01	(Cotton, Tanako, & Wong, 1951)
25	(Na-A)-U1	23.7	25.63	0.02	(Alexander, 1978)
26	(Na-B)-L1	33.9	34.01	0.89	(Anderson, Anderson, Hornbuckle, & Hornbuckle, 2000)

CHAPTER 6

DISCUSSION

6.1 Angular Cephalometric Data Comparison

This study determined significant differences in all but two of the twenty-six angular cephalometric measurements evaluated. It is possible to group the measurements with the associated morphologic presentation. When compared to the Bolton Standards, the sample showed increased mandibular-protrusion (FH-Na-Pog, SN-Pog, Bo-Na-Pogo, SNB), maxillary-protrusion (SNA), Class II (ANB), hyperdivergence (FH-Go-Gn, SN-Go-Gn, ANS-PNS-Go-Gn, Y-axis), and incisor-proclination (PNS-ANS-U1, SN-U1, Go-Gn-L1, Na-U1, U1-L1, SN-L1). There were no significant differences in occlusal plane inclination (Na-Sn-Occl. Plane) and gonial angle (Ar-Go-Gn). When compared to the previous studies involving African Americans, ten of the sixteen measurements available showed significant differences, with the study sample showing increased mandibular-protrusion (FH-Na-Pog, SNB), Class II (ANB), hyperdivergence (SN-Go-Gn, Y-axis), and incisor proclination (U1-NA, U1-L1). The 6 measurements that did not have significant differences include the mandibular plane angle (Or-Po-Go-Gn), incisor proclination (U1-S-Na, L1-S-Na, Na-B-L1), and maxillary protrusion (SNA, Na-A-Pogo). The variations in means will be compared in the following chapters based on study design, sample population, and anatomic variability.

6.2 Comparison of Study Design and Demographics

This study evaluated twenty-six angular measurements on a sample of 600 subjects leading to a total of 15,600 measurements. Since the study was a retrospective study, only one set of measurements was taken from each subject at one timepoint. On the other hand, the Bolton Standards, a longitudinal study, collected data of the same thirty-two subjects on an annual basis. The data ranged from ages 7-18, leading to a total of 9,984 measurements. Furthermore, sample selection varied significantly between this study and the Bolton Standards. Presumably, one of the great differences was that the Bolton Standards subjects had “esthetically favorable faces as viewed arbitrarily by [the researchers]” (Broadbent & Golden, 1975). This study did not consider esthetics or occlusion in the selection criteria, with the exception of craniofacial syndromes and parafunctional habits. Furthermore, this study was conducted in an orthodontic clinic. It can be assumed that the population presenting in an orthodontic clinic has a higher rate of malocclusion than the general population. The variability in selection criteria and selection bias may have led to a study sample with a wider range of measurements that may be stray from the ideal. Despite this, the study had a significantly higher number of participants and total measurements than the Bolton Standards, which may also explain the significant variability in angular cephalometric means for twenty-four of the twenty-six measurements.

When comparing the study design to the four studies used to evaluate other African American means, the sample selection was significantly different. All of the studies had different ages ranges than this population. For example, the Alexander study included subjects ages 8-12, which is significantly younger the study population. The Alexander study had an ANB that was statistically significantly higher than that of the study population. This difference may be due changes in growth, as ANB values tend to decrease with age. Furthermore, one of the referenced studies only (Oliveira, Copello, Silva, Nojima, & Nojima, 2021) included adult subjects, which this study included only children.

The selection criteria between this study and the referenced studies, were also different. As previously discussed, this study did not consider occlusion or esthetics as part of the selection criteria, but all four of the reference studies excluded subjects that had certain malocclusions. As previously discussed, selection bias may be present in this study because all subjects presented in an orthodontic screening clinic. The combination of differences in selection criteria, potential for selection bias, and age differences between this study and the reference study may explain some of the significant differences in the results.

This study, the Bolton Standards, and the reference studies, had variable magnification, but it may be assumed that magnification had only minor effects on angular measurements. Variability in head position and systematic tracing errors may have also led to variability in results.

Apart from differences in acquisition and interpretation of the lateral cephalograms, an important variable to take into consideration is the potential for secular trends. The data for this study was acquired between 2010 and 2023, while the Bolton Standards were collected between 1929 and 1970. The changes between these two groups may be attributed to changes in morphology over the years. Studies have compared the Bolton Standards to other longitudinal studies to determine whether there is a relationship between year of birth and various cephalometric parameters. The Antoun et al. article found an increase of SNA and ANB with an increase in year of birth, while determining an inverse relationship between year of birth and SNB. (Antoun, Cameron, Sew Hoy, Herbison, & Farella, 2015). Similarly, this study (with a higher year of birth) showed an increase of SNA and ANB when compared to the Bolton Standards. This trend is not evident when comparing this study with the 1978 reference study for African American means.

6.3 Comparison of Morphology Between Caucasians and African Americans

African American and Caucasian profiles have significant morphologic differences. African Americans tend to have increased bimaxillary protrusion when compared to Caucasians (Altemus L. A., 1960). Furthermore, a more Class II skeletal relationship is evident in the African American population, but with longer mandibular body, shorter ramal height and increased hyperdivergence (Alexander, 1978). African Americans also tend to have more proclined incisors (Cotton, Tanako, & Wong, 1951).

The morphologic variation between the two populations manifests in a difference in cephalometric measurements which was evident between the Caucasian Bolton Standards population the study population. This study found statistically significant increase in mandibular protrusion (#1, 2, 3, 21) and maxillary protrusion (#20) which is consistent with the trends evident in previous studies. Furthermore, an increased Class II relationship as quantified by the ANB angle was found in the study group, which fell in line with the pattern documented in the referenced studies (#22). This study also found the African American study population to be more hyperdivergent with increased angular measurements (#4, 11, 16). Unlike the expectations, there was a slight decrease in Y-axis, which indicates a more hypodivergent relationship in the African American population. This may be attributed to tracing error. The study population also had significantly more proclined incisors (#7), with increased upper incisor (#14, #15, #25) and lower incisor

(#17, 18, 26) proclination. Previous studies have also determined that African American populations have increased incisor proclination when compared to Caucasians.

Angle #10, evaluating the occlusal plan angulation, showed no significant difference. This coincides with the findings of another study showing no difference in occlusal plane angulation between the two racial groups (Freitas, Freitas, Pinzan, & Janson, 2010). Angle #13, a measurement of the gonial angle, also showed no significant difference between the study population the Bolton Standards. Although an increased gonial angle is associated with a hyperdivergent vertical pattern, this was not evident in the study.

6.4 Need for African American Cephalometric Norms

There are significant differences in most angular cephalometric measurements between the Caucasian population examined in the Bolton Standards and the African American population in this study. Furthermore, several of the African American angular means have a difference of more than one standard deviation when compared to the Bolton Standards (#1, 6, 16, 17, 18, 19, 26). Using Caucasian norms for African American patients may lead to misdiagnosis and incorrect treatment planning, especially in those measurements. This study demonstrates an evident need for African American angular cephalometric norms. Future studies should avoid the limitations of this study.

One of the main limitations of this study is the potential for selection bias. Future studies should evaluate subjects without a malocclusion to create a set of norms. A relatively subjective metric should be used to select patients without significant skeletal or dental irregularities. A study could follow the Bolton Standards guidelines for developing stricter inclusion criteria based on occlusion. Furthermore, it would be prudent for the study to expand on African American in different regions of the country and make sure there is an even distribution by age and gender. Future studies could also explore cephalometric norms on non-growing subjects since those values would be of importance in evaluating adult orthodontic patients.

CHAPTER 7

CONCLUSION

The study population of 600 African American subjects, showed significant differences in angular cephalometric measurements when compared to the Bolton Standards, which was conducted on a sample of Caucasian subjects. The following results highlight the need for population-specific norms in orthodontic diagnosis and treatment planning:

1. The study population displayed increased hyperdivergence, incisor-proclination, bimaxillary protrusion, and Class II compared to the Bolton Standards
2. Differences with previous African American studies were sporadic but aligned in the same direction relative to Bolton Standards suggesting secular trends, a difference in study design, or other factors.

REFERENCES

Alexander, T. L. (1978). Cephalometric Standards for African American Children. *American Journal of Orthodontics*, 298-304.

Al-Jewair, T., Stellrecht, E., Lewandowski, L., & Chakaki, R. (2018). American Association of Orthodontists Foundation Craniofacial Growth Legacy Collection in the orthodontic literature-use and trends: A systematic review. *American Journal of Orthodontics and Dentofacial Orthopedics*, 15-25.

Altemus, L. (1963). Comparative Integumental Relationships. *Angle Orthodontist*, 217-221.

Altemus, L. A. (1960). A Comparison Of Cephalofacial Relationships. *The Angle Orthodontist*, 223-240.

Anderson, A., Anderson, A., Hornbuckle, A., & Hornbuckle, K. (2000). Biological derivation of a range of cephalometric norms for children of African American descent (after Steiner). *American Journal of Orthodontics and Dentofacial Orthopedics*, 90-100.

Antoun, J., Cameron, C., Sew Hoy, W., Herbison, P., & Farella, M. (2015). Evidence of secular trends in a collection of historical craniofacial growth studies. *European Journal of Orthodontics*, 60-66.

Baumrind, S., & Frantz, R. (1971). The reliability of head film measurements. *American Journal of Orthodontics*, 111-127.

Bishara, S., Fahl, J., & Peterson, L. (1983). Longitudinal changes in the ANB angle and Wits appraisal: Clinical implications. *American Journal of Orthodontics*, 133-139.

Broadbent, B. H., & Golden, W. (1975). *Bolton Standards of Dentofacial Developmental Growth.* Mosby.

Cotton, W., Tanako, W., & Wong, W. (1951). The Downs Analysis Applied to Three Other Ethnic Groups. *Angle Orthodontist*, 213-220.

Downs, W. B. (1952). The Role of Cephalometrics in Orthodontic Case Analysis and Diagnosis. *American Journal of Orthodontics and Dentofacial Orthopedics*, 162-182.

Drummond, R. (1968). A determination of cephalometric norms for the African American. *American Journal of Orthodontics*, 670-682.

Freitas, L. M., Freitas, K. M., Pinzan, A., & Janson, G. (2010). A comparison of skeletal, dentoalveolar and soft tissue characteristics in white and black Brazilian subjects. *Journal of Applied Oral Sciences*, 135-142.

Graber, L., Vanarsdall, R., & Vig, K. (2011). *Orthodontics: Current Principles and Techniques.* Mosby.

Oliveira, T., Copello, F., Silva, I., Nojima, L., & Nojima, M. (2021). Dentofacial and skeletal pattern in African descendants from southeastern Brazil: clinical prospective study. *Dental Press Journal of Orthodontics*.

Profft, W., Fields, H., Larson, B., & Sarver, D. (2019). *Orthodontics; Current Principles and Techniques.* Philadelphia: Elsevier.

Servoss, J. M. (1973). The acceptability of Steiner's acceptable compromises. *American Journal of Orthodontics*, 161-165.

Steiner, C. C. (1953). Cephalometrics for you and me. *American Journal of Orthodontics*, 729-755.

Wahl, N. (2006). Orthodontics in 3 millennia. Chapter 7: Facial analysis before the advent of the cephalometer. *American Journal of Dentofacial Orthopedics*, 293-298.

APPENDIX A

IRB DETERMINATION: APPROVAL FOR A PROJECT INVOLVING HUMAN SUBJECTS RESEARCH THAT IS APPROVED AS EXEMPT

Temple University
Office of the Vice President for Research

Research Integrity & Compliance
Student Faculty Center
3340 N. Broad Street, Suite 304
Philadelphia PA 19140

Institutional Review Board
Phone: (215) 707-3390
Fax: (215) 204-4609
e-mail: irb@temple.edu

Approval for a Project Involving Human Subjects Research that is Approved as Exempt

Date: 18-Dec-2023

Protocol Number:	31214
PI:	JAMES J. SCIOTE
Review Type:	EXEMPT
Approved On:	18-Dec-2023
Risk:	Minimal risk
Committee:	A1
Sponsor:	NO EXTERNAL SPONSOR
Project Title:	Cephalometric Analysis Norms for African Americans

---

The IRB approved the protocol 31214.

The study was approved under Exempt review. The IRB determined that the research **does not require a continuing review**, consequently there is not an IRB approval period.

As this research was approved as Exempt, the IRB will not stamp the consent or assent form(s).

Note that all applicable Institutional approvals must also be secured before study implementation. These approvals include, but are not limited to, Medical Radiation Committee ("MRC"); Radiation Safety Committee ("RSC"); Institutional Biosafety Committee ("IBC"); and Temple University Survey Coordinating Committee ("TUSCC"). Please visit these Committees' websites for further information.

Finally, in conducting this research, you are obligated to submit the following:

- **Amendments - Any changes to the research that may change the Exempt status of this study must be reviewed and approved by the IRB prior to implementation.** Examples of such changes are: including new, sensitive questions to a survey or interview, changing data collection such that de-identified data will now be identifiable, including an intervention in the methods, changing variables to be collected from medical charts, decreasing confidentiality measures, including minors or adults lacking capacity to consent as subjects when previously only adults with capacity to consent were to be enrolled, no longer collecting signed HIPAA Authorization, etc. Please reach out to the IRB Staff with any questions about if a change to the study warrants an Amendment.
- **Reportable New Information** - Using the Reportable New Information e-form, report new information items such as those described in HRP-071 Policy - Prompt Reporting Requirements to the IRB **within 5 days**.
- **Closure report** - Using a closure e-form, submit when the study is permanently closed to enrollment; all subjects have completed all protocol related interventions and interactions; collection of private identifiable information is complete; and analysis of private identifiable information is complete.

For the complete list of investigator responsibilities, please see the HRP–070 Policy – Investigator Obligations, the Investigator Manual (HRP-910), and other Policies and Procedures found on the Temple University IRB website: https://research.temple.edu/irb-forms-standard-operating-procedures.

Please contact the IRB at (215) 707-3390 if you have any questions.

APPENDIX B

ANGULAR CEPHALOMETRIC MEASUREMENTS RAW DATA

	Subject ID	1	2	3	~	599	600
1	**(Po-Or)-(Na-Pogo)**	89.2	87.8	84.6		87.7	89.3
2	**S-Na-Pogo**	86.7	72	77.3		83	82.7
3	**Bo-Na-Pogo**	65.1	63	61.5		66.5	62
4	**(Or-Po)-(Go-Gn)**	24.9	28.6	30.4		24	31.1
5	**(Or-Po)-(S-Gn)**	60.1	61.6	60.2		58.5	60.5
6	**(Or-Po)-(Occl pl)**	4.2	15.2	14.3		4.2	8.8
7	**U1-L1**	105.9	122.9	142.8		111.5	109.1
8	**(Na-Bo)-(Po-Or)**	24.1	24.8	23.1		21.2	27.3
9	**(Occl Pl)-(Go-Gn)**	17	10.4	13.3		16.5	20.2
10	**(Na-S)-(Occl pl)**	6.7	31	21.5		8.9	15.4
11	**(Na-S)-(Go-Gn)**	27.4	44.4	37.6		28.7	37.8
12	**Na-S-Ar**	117.2	138.2	123.3		122.4	119
13	**Ar-Go-Gn**	127.2	131.2	136.9		121.6	133.8
14	**(PNS-ANS)-U1**	126.1	100.7	103.6		114.5	111.9
15	**(S-NA)-U1**	125.8	90.3	92.4		112.5	112
16	**(ANS-PNS)-(Go-Gn)**	27.2	34	26.5		26.7	37.8
17	**(S-Na)-L1**	51.7	33.2	55.3		43.9	41.1
18	**(Go-Gn)-L1**	79.2	77.6	92.9		72.7	78.8
19	**(Occl pl)-L1**	31.6	25.8	13.2		37.1	33.5
20	**S-Na-A**	89.6	78	82.9		85.5	92.5
21	**S-Na-B**	86.4	74	77.9		82.2	84
22	**A-Na-B**	3.2	4	4.9		3.2	8.5
23	**Na-A-Pogo**	174.2	167.5	168.4		175.3	161.4
24	**(Na-Pogo)-(B-A)**	4.8	3.7	7.1		4.4	7.9
25	**(Na-A)-U1**	36.2	12.3	9.6		27	19.4
26	**(Na-B)-L1**	34.7	40.8	22.7		38.3	43

APPENDIX C

INTRACLASS CORRELATION COEFFICIENT (ICC)

#	ICC
1	0.981
2	0.982
3	0.959
4	0.984
5	0.964
6	0.990
7	0.950
8	0.917
9	0.893
10	0.988
11	0.988
12	0.966
13	0.956
14	0.902
15	0.931
16	0.966
17	0.945
18	0.902
19	0.902
20	0.942
21	0.977
22	0.854
23	0.965
24	0.660
25	0.920
26	0.921