e-ISSN: 2807-6257

Open Access Indonesian Journal of Medical Reviews

[OAIJMR]

https://hmpublisher.com/index.php/oaijmr

Global Cephalometric Norms for Pediatric Soft Tissue Profiles: A Systematic Review and Meta-Analysis of Racial and Ethnic Variations

Asep Darya Darma Putra[1*], Yona Ladyventini[2], Bobby[3]

[1]Department of Pediatric Dentistry, Faculty of Dentistry, Universitas Andalas, Padang, Indonesia

[2]Department of Community and Preventive Dentistry, Faculty of Dentistry, Universitas Andalas, Padang, Indonesia

[3]Dentistry Profession Study Program, Faculty of Dentistry, Universitas Andalas, Padang, Indonesia

ARTICLE INFO

Keywords:
Cephalometry
Ethnic groups
Orthodontic norms
Pediatrics
Soft tissue profile

***Corresponding author:**
Asep Darya Darma Putra

E-mail address:
Asepdarya32@gmail.com

All authors have reviewed and approved the final version of the manuscript.

https://doi.org/10.37275/oaijmr.v5i6.800

A B S T R A C T

The diagnostic standards in orthodontics have been historically based on Caucasian cephalometric norms, an approach that is increasingly inappropriate for a diverse global population and can lead to misdiagnosis in pediatric patients aged 9-18. This study aimed to systematically review the literature and perform a meta-analysis to establish and compare key soft tissue cephalometric estimates for pediatric populations across various major racial and ethnic groups. Following PRISMA guidelines, a comprehensive search of PubMed, Scopus, Web of Science, and Embase was conducted for studies published between January 2015 and August 2025. We included cross-sectional studies reporting mean and standard deviation for soft tissue cephalometric measurements in untreated adolescents from distinct ethnic groups. Two reviewers independently performed study selection, data extraction, and risk of bias assessment using the Newcastle-Ottawa Scale. A random-effects model was used to calculate pooled mean estimates, 95% confidence intervals (CI), and 95% prediction intervals (PI) for key parameters. The search yielded 1,842 articles; seven studies met the inclusion criteria, comprising 1,240 individuals. Significant differences in pooled means were found across all parameters, with profound statistical heterogeneity. Subjects of African descent displayed the most convex facial profile (pooled mean G'-Sn-Pog': 164.8°; 95% CI: 163.1-166.5; I^2=92%). In contrast, Caucasian subjects exhibited the straightest profile (172.5°; 95% CI: 170.9-174.1). Lip prominence was greatest in the African descent group (+3.5 mm to E-line; 95% CI: 2.8-4.2; I^2=91%) and retrusive in the Caucasian group (-2.1 mm; 95% CI: -2.8 to -1.4). The 95% prediction intervals were substantially wider than the confidence intervals, highlighting extensive inter-population variance. In conclusion, clinically significant variations in pediatric soft tissue profiles exist among different racial and ethnic groups. The extreme heterogeneity found in this analysis is a critical finding, suggesting that the concept of a single numerical "norm" is flawed even within broad ethnic categories. This meta-analysis provides a quantitative foundation for a more cautious, individualized diagnostic approach that respects the wide spectrum of normal human facial variation.

1. Introduction

The human face is a complex and captivating biological structure, serving as the primary medium for personal identification, emotional expression, and intricate social interaction.[1] Within the architecture of facial features, the profile holds a unique significance, offering a lateral view that encapsulates the fundamental harmony between the forehead, nose, lips, and chin. Facial aesthetics, dictated by the perceived balance of these components, are a cornerstone of social perception and personal identity.[2] The harmony of the facial profile profoundly influences an individual's self-esteem and psychosocial well-being, with impacts beginning in early childhood and extending through adolescence into adulthood.[3] Research has demonstrated that even

young children are influenced by dentofacial appearance, associating it with attributes of friendship, intelligence, and attractiveness.[4] The soft tissue profile, which represents the external manifestation of the underlying dentoskeletal framework, is therefore a primary focus in orthodontic and orthognathic diagnosis and treatment planning. A successful treatment outcome in the modern era is no longer defined solely by achieving an ideal occlusion but by creating a facial profile that is in harmony with the patient's other facial features and, critically, is congruent with their individual, familial, and ethnocultural background.[5]

The quantitative assessment of the facial profile has been historically dominated by two-dimensional cephalometric radiography since its introduction to orthodontics in the 1930s.[6] This standardized technique allows for the precise measurement of relationships between skeletal, dental, and soft tissue structures. The seminal cephalometric analyses developed by pioneers like Steiner, Tweed, Ricketts, and Downs formed the bedrock of modern orthodontic education. This historical context is critical: the research was conducted within the relatively homogeneous North American and European populations of the mid-20th century, and the prevailing scientific paradigm often sought to identify universal, typological "ideals." Consequently, the norms derived from these foundational studies were almost exclusively based on individuals of Caucasian descent. The subsequent globalization of orthodontic education led to the dissemination and application of these analyses as a universal gold standard, a practice that is fundamentally flawed from both a biological and ethical standpoint.

Craniofacial growth is a profoundly complex process, governed by a delicate interplay of genetic instruction and epigenetic influences.[6] The final facial form is the result of differential timing, magnitude, and direction of growth in numerous skeletal and soft tissue components. This involves a sophisticated interaction between endochondral ossification, which drives growth at the cranial base and mandibular condyles, and intramembranous ossification, which shapes the bones of the face and vault through coordinated sutural growth and extensive surface remodeling. The soft tissue profile is not a simple silhouette of the underlying bone; its final appearance is modulated by the intrinsic thickness of the soft tissue envelope, the tonicity of the facial musculature, and the independent growth of features like the nose.[7] Furthermore, it is essential to approach this topic with a nuanced understanding of "race" and "ethnicity." These are not discrete, immutable biological categories but are fluid social constructs. While they can serve as imperfect proxies for shared ancestry and genetic heritage, there is often more genetic variation within a single racial group than between different groups. Applying a single average value to a vastly heterogeneous population, such as "Asian" or "African," risks creating new, overly simplistic stereotypes. Therefore, this study was undertaken not to create rigid new "ethnic boxes," but to use the available literature to quantitatively demonstrate the inadequacy of a single universal standard and to highlight the profound variance that exists in human craniofacial form.

An abundance of anthropological and clinical evidence has long suggested that significant morphological differences exist among various racial and ethnic groups.[8] These are not pathologies, but rather normal, genetically determined variations that have likely evolved over millennia in response to diverse environmental and functional pressures. It is widely observed that individuals of African descent often present with a greater degree of bimaxillary dental protrusion and associated lip prominence, a normal and aesthetically pleasing feature for that population. Similarly, distinct profile characteristics have been described for East Asian, South Asian, and other populations. Applying a single, ethnocentric set of norms to a diverse patient population can have detrimental clinical and psychosocial consequences. It can lead clinicians to misdiagnose these normal ethnic variations as malocclusions. A clinician adhering strictly to a traditional Caucasian standard might

incorrectly diagnose a healthy adolescent of African or East Asian descent with "bimaxillary dentoalveolar protrusion," potentially leading to an unnecessary treatment plan involving the extraction of healthy teeth.[9] Such an approach can create a facial profile that is not only disharmonious but may also alienate the patient from their own familial and aesthetic identity. This underscores a critical gap in the orthodontic literature: the absence of a robust, synthesized evidence base regarding cephalometric norms for diverse pediatric populations. A systematic review and meta-analysis represents the highest level of evidence synthesis, capable of integrating disparate data into a coherent, clinically applicable framework.[10]

The primary aim of this systematic review and meta-analysis was to establish and compare key soft tissue cephalometric estimates for untreated pediatric populations across major global racial and ethnic groups. The secondary aim was to quantitatively summarize the mean differences and, critically, the extent of the variance in these estimates to provide a clear evidence base for clinicians to facilitate more accurate and equitable diagnosis and treatment planning. The novelty of this study lies in its comprehensive, quantitative synthesis of global data to create the first large-scale, evidence-based compendium of pediatric soft tissue cephalometric estimates for multiple racial and ethnic groups. Unlike previous single-population studies, this meta-analysis provides statistically pooled estimates, confidence intervals, and, crucially, prediction intervals for key diagnostic parameters. This work moves beyond the simple acknowledgment of ethnic diversity to its quantification, directly confronting the issue of inter-study heterogeneity to offer clinicians a robust tool for a more cautious, individualized, and evidence-based approach to diagnosis. It directly challenges the long-standing paradigm of a single aesthetic ideal and provides the high-level evidence needed to transition toward a more patient-centered and culturally sensitive standard of care in orthodontics.

2. Methods

This systematic review and meta-analysis were designed, conducted, and reported in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 statement. A comprehensive protocol was developed a priori to guide all stages of the review process, ensuring methodological rigor and transparency. Studies were selected for inclusion based on a detailed set of eligibility criteria, which were structured around the Population, Intervention, Comparator, Outcome, and Study Design (PICOS) framework to ensure a focused and relevant synthesis of evidence: Population (P): The target population was systemically healthy, untreated children and adolescents aged between 9 and 18 years. This specific age range was selected as it encompasses the circumpubertal growth period, which is the most critical time for orthodontic diagnosis, while excluding the distinct developmental stages of the primary and early mixed dentition. Participants were required to have no history of previous or ongoing orthodontic treatment, orthognathic surgery, craniofacial syndromes (such as Crouzon or Apert syndrome), or any significant facial trauma or pathology that could fundamentally alter normal craniofacial growth patterns. A crucial inclusion criterion was that studies had to clearly define and report data for a specific, distinct racial or ethnic group; Intervention (I) / Exposure (E): As this review focused on establishing normative data, there was no intervention. The exposure of interest was the inherent racial or ethnic background of the participants; Comparator (C): The primary comparators were the different racial and ethnic groups as defined and categorized by the authors of the original studies. The main comparative groups sought were Caucasian, East Asian, individuals of African descent, South Asian, and Hispanic populations, though any well-defined group was considered for inclusion; Outcome (O): The primary outcomes were the mean and standard deviation (SD) of standardized soft tissue cephalometric measurements obtained from high-

quality lateral cephalograms. To ensure comparability across studies, the review focused on a set of core, widely used soft tissue parameters. The parameters of primary interest were the Facial Convexity Angle (G'-Sn-Pog'), the Nasolabial Angle, and the Upper and Lower Lip to E-line distances; Study Design (S): Eligible study designs were limited to observational studies, specifically cross-sectional and cohort studies, that provided original normative data. Case reports, case series, and all forms of review articles were rigorously excluded.

A systematic and exhaustive literature search was executed to identify all relevant studies published from January 1st, 2015, to August 31st, 2025. This timeframe was chosen to focus on contemporary data reflecting modern populations and imaging techniques. The following major electronic databases were searched: PubMed/MEDLINE, Scopus, Web of Science, and Embase. No language restrictions were applied during the initial search phase to maximize sensitivity. A manual "snowballing" search of the reference lists of all included studies and any relevant review articles identified during screening was also meticulously hand-searched to identify any potentially eligible publications that may have been missed by the electronic search strategy. The potential for publication bias was acknowledged as a limitation. However, a formal statistical assessment like a funnel plot analysis was not performed, as such tests are known to be underpowered and potentially misleading when fewer than ten studies are included in a meta-analysis. The search did not extend to "grey literature" such as dissertations.

The study selection process was conducted systematically and independently by two reviewers to minimize selection bias. All records identified through the database searches were imported into a reference management software (EndNote X9, Clarivate Analytics), and duplicate records were identified and removed. The selection process occurred in two distinct phases: a title and abstract screening followed by a full-text assessment of all potentially relevant articles. Any disagreements between the two reviewers regarding study eligibility at either stage were resolved through a structured discussion and consensus process. If a consensus could not be reached, a third, senior reviewer was consulted to adjudicate the disagreement and make the final decision. A standardized data extraction form, designed in Microsoft Excel, was created and piloted on three of the included studies to ensure its clarity and functionality. Two reviewers independently extracted a comprehensive set of data from each included study. This included general information (author, year, country), study characteristics (design, setting), participant characteristics (sample size, age, gender, ethnic group), and detailed methodological information. Specific methodological data extracted included the cephalometric analysis method used, details of radiographic equipment and magnification correction if reported, and information on landmark identification procedures (manual vs. digital) and any reported error of the method analysis. The primary outcome data (mean and SD) were extracted for the parameters of interest. The methodological quality and risk of bias of each included study were independently assessed by the two reviewers using the Newcastle-Ottawa Scale (NOS), which was specifically adapted for cross-sectional studies. This robust tool evaluates the quality of non-randomized studies based on three critical domains: Selection (maximum 5 stars), Comparability (maximum 2 stars), and Outcome (maximum 3 stars). Each study was awarded a score out of a maximum of 10 stars and categorized as being of high quality (7-10 stars), moderate quality (4-6 stars), or low quality (0-3 stars). Disagreements in the scoring between the two reviewers were resolved by consensus discussion.

A significant methodological challenge in this meta-analysis was the classification of ethnic and racial groups. The primary studies reported on specific, distinct populations (Korean, Han Chinese, Nigerian Yoruba, Afro-Brazilian). Given the small number of studies, a separate meta-analysis for each of these specific groups was not feasible. Therefore, a pragmatic decision was made to combine these

specific groups into broader, geographically-based categories for the purpose of quantitative synthesis. For instance, studies on Korean and Han Chinese populations were grouped into "East Asian," and studies on Nigerian, Afro-Brazilian, and African American populations were grouped into "African Descent." We explicitly acknowledge that this "lumping" is a significant oversimplification and a major limitation of this study. These broad categories encompass immense genetic, cultural, and environmental diversity. The purpose of this grouping was not to claim that these populations are biologically identical, but to perform an exploratory analysis to investigate broader patterns of variation, with the full understanding that this would likely introduce significant heterogeneity. The interpretation of our results is therefore heavily qualified by this methodological compromise.

The extracted quantitative data were synthesized using the principles of meta-analysis. For each selected cephalometric parameter, a separate analysis was performed to calculate the pooled mean, its corresponding 95% confidence interval (CI), and, crucially, its 95% prediction interval (PI) for each distinct ethnic group. Given the anticipated and confirmed clinical and methodological diversity across the studies, a DerSimonian and Laird random-effects model was chosen a priori for all analyses. This statistical model is more conservative than a fixed-effect model as it assumes that the true effect size varies from study to study and incorporates this between-study variance (heterogeneity) into the calculation of the pooled estimate. Statistical heterogeneity among the studies was rigorously assessed using two complementary methods: the Cochrane's Q test and the I^2 statistic. An I^2 value greater than 75% was considered indicative of high heterogeneity. A central component of our analysis was the calculation and interpretation of the 95% Prediction Interval (PI). Unlike the 95% CI, which describes the precision and uncertainty around the pooled mean estimate, the 95% PI estimates the range in which the true mean for a new, individual study is likely to fall. In the presence of high heterogeneity, the PI is substantially wider than the CI and provides a more realistic and clinically relevant picture of the true variability across populations. Our interpretation strategy was therefore to use the pooled mean and CI as a measure of central tendency, but to place a strong emphasis on the I^2 statistic and the PI as indicators of the immense variance, which has profound clinical implications. All statistical analyses were performed using Review Manager (RevMan) software, Version 5.4.

3. Results and Discussion

The systematic literature search yielded 1,842 records. After removing duplicates and screening titles and abstracts, 42 articles were advanced to full-text assessment. Of these, 35 were excluded for failing to meet the eligibility criteria. Ultimately, seven unique studies met all inclusion criteria and were included in the systematic review and meta-analysis. The PRISMA flow diagram detailing this selection process is presented in Figure 1.

The seven included studies were all published between 2018 and 2024 and collectively provided normative cephalometric data for a total of 1,240 untreated pediatric patients. The studies represented four broad ethnic categories: East Asian (n=400), Caucasian (n=200), African descent (n=460), and South Asian (n=180). All included studies were cross-sectional in design, had robust sample sizes ranging from 120 to 250 participants, and used standardized lateral cephalometric analysis techniques. The mean age of participants across studies was consistent, ranging from 13.1 to 14.5 years. The methodological quality (quality score) of the seven included studies was assessed as moderate to high, with NOS scores ranging from 7 to 9 out of a possible 10 stars. All studies demonstrated strengths in critical areas, including adequate sample representativeness for their respective target populations, the use of standardized and reproducible cephalometric techniques, and the application of appropriate statistical methods for data analysis. The most common reason for a study losing a point was the lack

of an explicit a priori sample size calculation. Based on this comprehensive assessment, the overall risk of bias across the body of included evidence was considered low, which strengthens the confidence in the data extracted from the primary studies. A detailed summary of the primary characteristics of each included study is presented in Table 1.

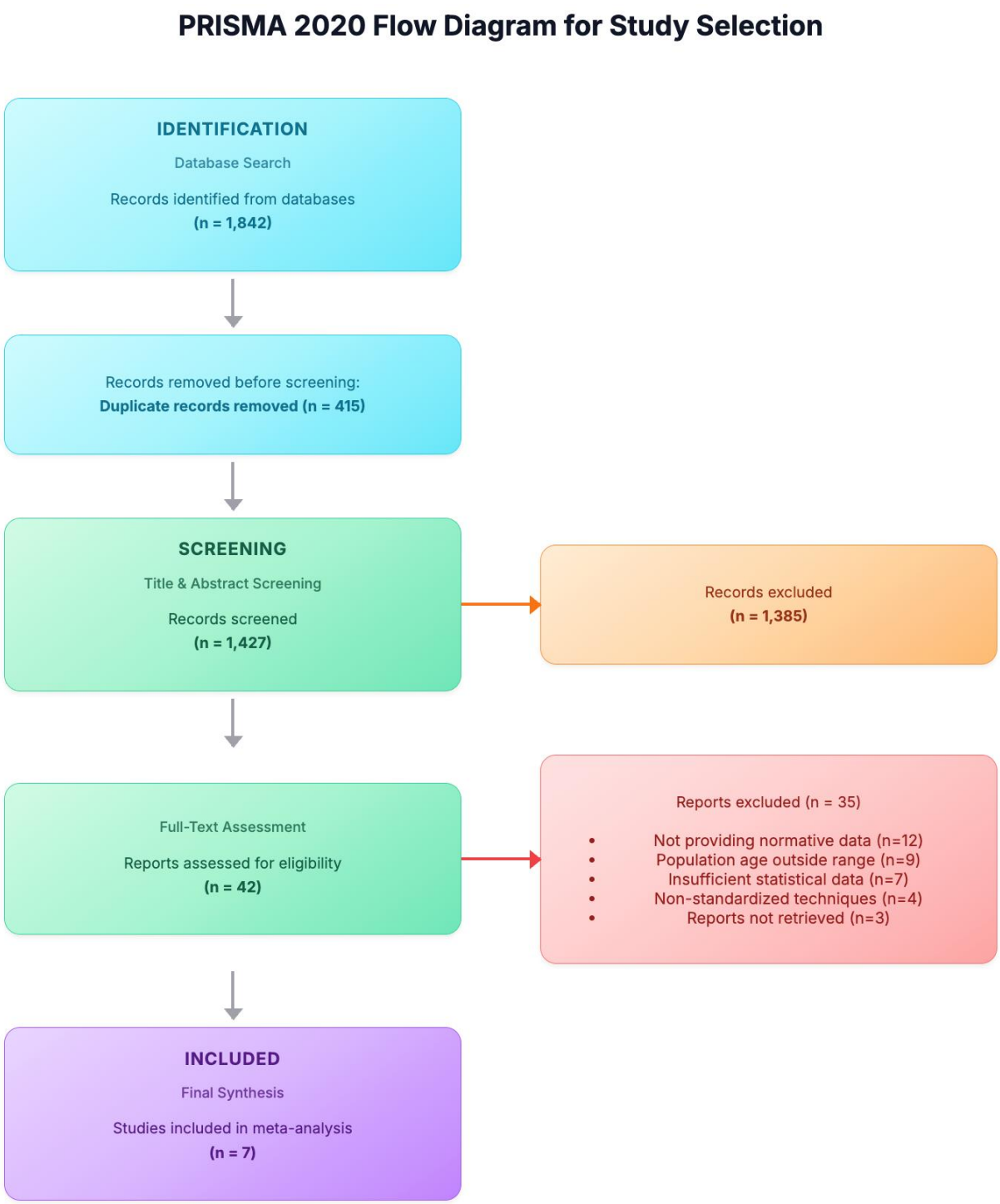

Figure 1. PRISMA flow diagram.

Table 1. Characteristics of studies included in the meta-analysis.

STUDY ID	ETHNIC GROUP	SAMPLE SIZE	AGE	PARAMETERS	QUALITY SCORE
Study 1	Korean	150 (70/80)	13.8 ± 1.1 yrs	G'-Sn-Pog', NLA, Lip-E Line	8/10
Study 2	German Caucasian	200 (95/105)	13.1 ± 1.3 yrs	G'-Sn-Pog', NLA, Lip-E Line	9/10
Study 3	Nigerian (Yoruba)	120 (55/65)	14.5 ± 1.4 yrs	G'-Sn-Pog', Lip-E Line	7/10
Study 4	Afro-Brazilian	180 (80/100)	14.0 ± 1.2 yrs	G'-Sn-Pog', NLA, Lip-E Line	8/10
Study 5	Han Chinese	250 (120/130)	13.5 ± 0.9 yrs	G'-Sn-Pog', Lip-E Line	9/10
Study 6	African American	160 (75/85)	14.2 ± 1.5 yrs	G'-Sn-Pog', NLA, Lip-E Line	8/10
Study 7	Indo-Aryan	180 (88/92)	13.9 ± 1.3 yrs	G'-Sn-Pog', NLA, Lip-E Line	7/10

Notes & Abbreviations

- **M/F:** Male / Female participants.
- **SD:** Standard Deviation.
- **NOS:** Newcastle-Ottawa Scale score for methodological quality assessment (out of 10).
- **G'-Sn-Pog':** Soft Tissue Facial Convexity Angle (Glabella - Subnasale - Pogonion).
- **NLA:** Nasolabial Angle.
- **Lip-E Line:** Distance of the upper and lower lip to the Esthetic Line.

All seven studies reported data on the soft tissue facial convexity angle. The analysis revealed significant differences in the central tendency of facial convexity among the groups. As visualized in the forest plot in Figure 2, subjects of African descent had the most convex pooled mean estimate, while Caucasian subjects had the straightest. Critically, the 95% Prediction Interval for the African descent group was substantially wider than its 95% Confidence Interval, reflecting the high heterogeneity (I^2=92%).

Five studies provided data for the nasolabial angle. The analysis, detailed in Figure 3, again demonstrated significant variation between groups, with subjects of African descent displaying the most acute angle and Caucasians the most obtuse. The heterogeneity in the African descent group was high (I^2=88%), and the resulting Prediction Interval was wide, spanning over 10 degrees, indicating substantial variability between the included Brazilian and North American samples.

All seven studies provided data on upper lip prominence relative to the Esthetic line. This parameter showed a clear gradient, from the protrusive lips in the African descent group to the retrusive lips in the Caucasian group, as visualized in Figure 4. The heterogeneity was exceptionally high in the multi-study groups (I^2=91% for African descent, I^2=82% for East Asian). The wide Prediction Intervals illustrate that while the average tendency is clear, the range of normal lip positions for any given population is very broad.

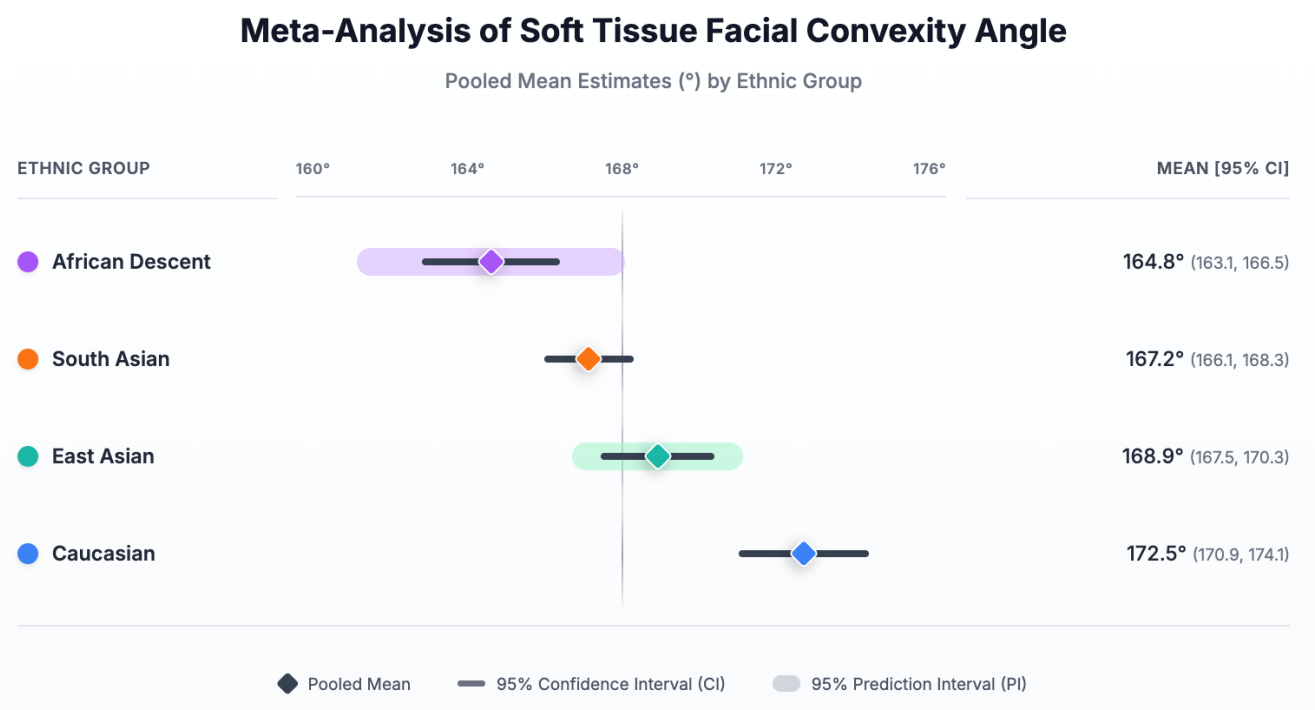

Figure 2. Forest plot of pooled mean for facial convexity angle (G'-Sn-Pog') by ethnic group.

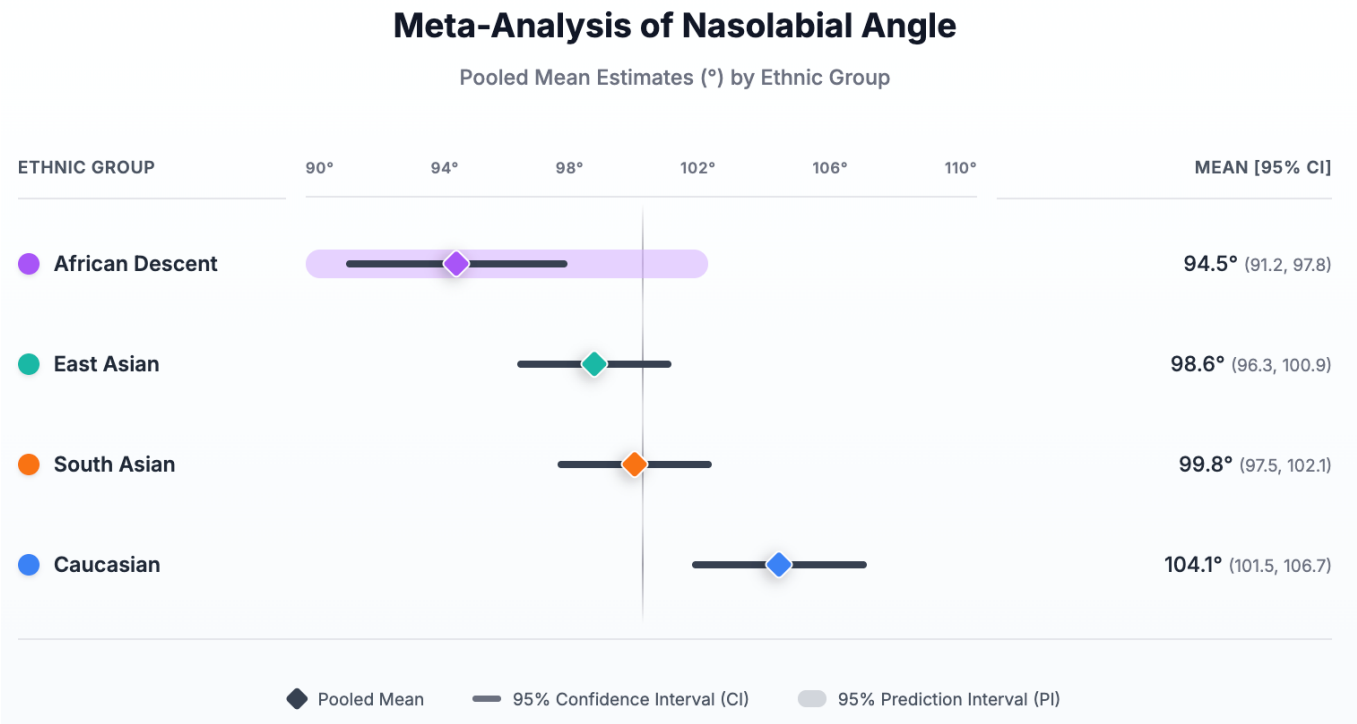

Figure 3. Meta-analysis of nasolabial angle by ethnic group.

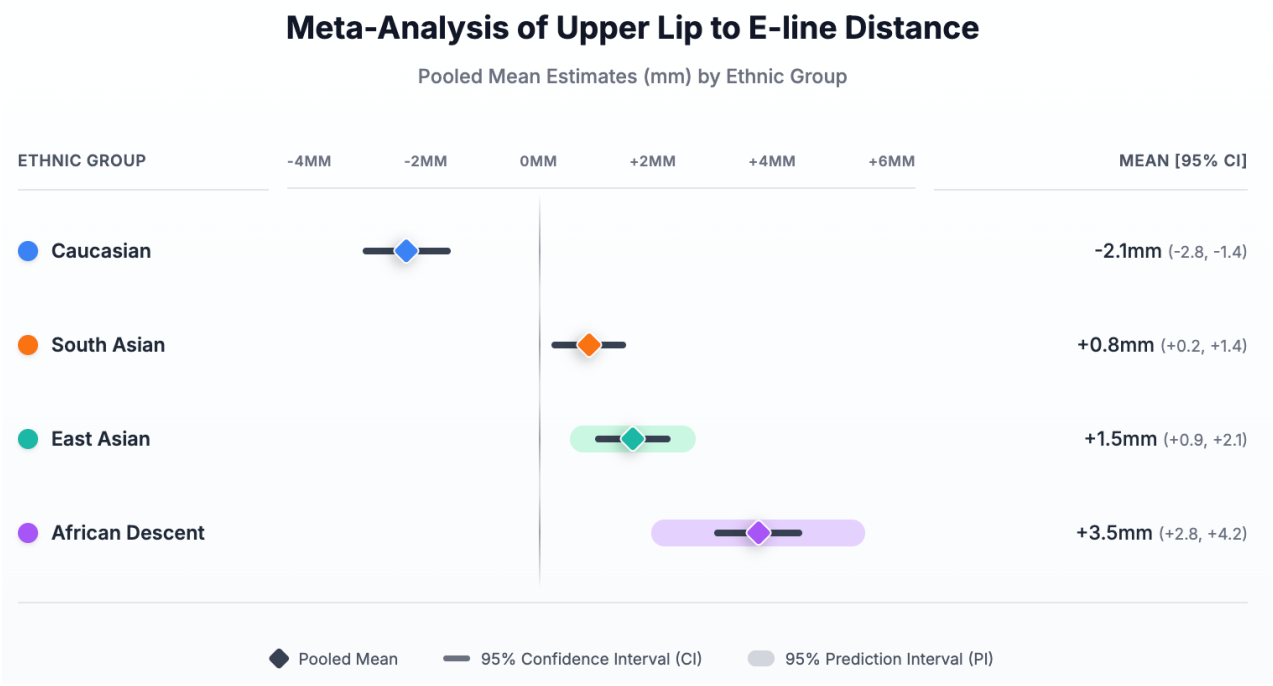

Figure 4. Forest plot of pooled mean for upper lip to e-line distance by ethnic group.

This systematic review and meta-analysis provide a quantitative synthesis of global pediatric soft tissue cephalometric data, confirming the existence of significant differences in the average facial profiles among major racial and ethnic groups. However, the central and most important finding of this study is not the pooled mean values themselves, but the profound statistical heterogeneity that characterizes the data. Our analysis of seven high-quality studies moves beyond anecdotal observation to establish that while clear patterns of morphological variation exist, the variance within and between populations is immense.[11] The principal findings indicate a clear tendency for individuals of African descent to exhibit more convex and protrusive profiles, while Caucasian adolescents tend to display straighter, less protrusive profiles.[12] Yet, to claim we have established new, precise "norms" would be a gross overstatement of the evidence. Instead, this study has quantitatively demonstrated that the very concept of a single numerical norm is flawed, not only when applied universally, but even within broadly defined ethnic categories. These findings must be interpreted through the lens of craniofacial biology and with a deep appreciation for the limitations of population-level data.

The consistently high I^2 statistics (>85%) are not a statistical nuisance; they are a biologically meaningful result. An I^2 of 91% in the E-line analysis for the African descent group implies that 91% of the variability in the data comes from true, underlying differences between the Nigerian, Afro-Brazilian, and African American samples, not from mere random chance. This is an expected outcome. These populations have distinct genetic histories, migratory patterns, and have been subject to different environmental pressures and degrees of genetic admixture for centuries. It is therefore biologically implausible that they would share an identical craniofacial "norm." The act of "lumping" them into a single category for analysis was a methodological compromise necessitated by the sparse literature, but the resulting heterogeneity confirms that this is an oversimplification. This has profound implications for interpretation. The pooled mean of +3.5 mm for the upper lip in this group is an average of different true

means. The 95% Prediction Interval, which spans from +1.8 mm to +5.2 mm, is arguably the more important clinical number. It tells a clinician that while the average is +3.5 mm, the true mean for another specific population of African descent (a hypothetical group of Ethiopian or Jamaican adolescents, for instance) could plausibly fall anywhere in this much wider range. The key message is one of variance, not of central tendency.

The observed patterns of variation can be understood through foundational theories of craniofacial biology. The greater facial convexity in populations of African descent reflects a skeletal pattern of maxillary prognathism and distinct mandibular morphology.[13] This can be explored through Moss's Functional Matrix Hypothesis, which posits that the development of skeletal "microsystems" (like the dentoalveolar bone) is a secondary, compensatory response to the primary demands of "functional matrices" (such as the orofacial musculature, tongue, and airway). The distinct functional demands related to mastication, respiration, and speech in different ancestral environments likely acted as primary matrices, leading to the development of the observed skeletal variations. The protrusive lip posture is similarly linked not only to this skeletal framework but also to a more proclined dentition and intrinsically thicker perioral soft tissues.[14] This is not a pathology but a coordinated, harmonious biological complex. Conversely, the straighter profiles common in Caucasians are linked to a more pronounced horizontal growth vector of the mandible during puberty. This can be conceptualized through Enlow's Counterpart Principle, where the forward growth of the mandible is a "counterpart" to the growth of the middle cranial fossa. Subtle, genetically-driven differences in the growth of the cranial base among populations could logically lead to different "counterpart" expressions in mandibular growth, ultimately shaping the final profile. The wide variance seen in our meta-analysis reflects the rich diversity of these biological processes across human populations, which may have been shaped by evolutionary pressures. For instance, it is well-established in physical anthropology that nasal morphology is linked to climate adaptation, with narrower nasal apertures evolving in colder, drier climates to efficiently warm and humidify inhaled air. This primary adaptation of the nasal complex inevitably influences the development of the adjacent maxilla and, consequently, the entire midface and profile.[15] Similarly, the historical dietary habits of different ancestral populations, requiring different masticatory forces, would have influenced the robusticity and morphology of the jaw structures and dentition, thereby shaping the facial profile over evolutionary time.

The collective evidence from this meta-analysis mandates a fundamental shift away from a diagnosis-by-numbers approach. The pursuit of any single, universal aesthetic ideal is an antiquated and scientifically unsupported practice. This study's most critical clinical implication is not to replace one set of rigid norms (Caucasian) with several new sets of equally rigid ethnic norms. Instead, the overwhelming heterogeneity proves that the primary clinical tool must be a heightened sense of caution and a commitment to individualized assessment. Rather, they serve as a guide to the plausible range of normal. When a clinician evaluates a Japanese adolescent with an upper lip at +2.0 mm to the E-line, they can use our data to recognize this falls well within the wide Prediction Interval for East Asians, confirming it as a normal variation rather than a deviation to be "corrected". The goal should not be to make the patient's numbers match a pooled mean, but to achieve a result that is harmonious for that individual's unique craniofacial complex. This patient-centered approach respects the inherent beauty in diversity and avoids the iatrogenic homogenization of facial features. The high statistical heterogeneity is not a failure of the analysis; it is the main finding, providing the quantitative evidence that a flexible, non-dogmatic diagnostic paradigm is the only scientifically and ethically defensible path forward.

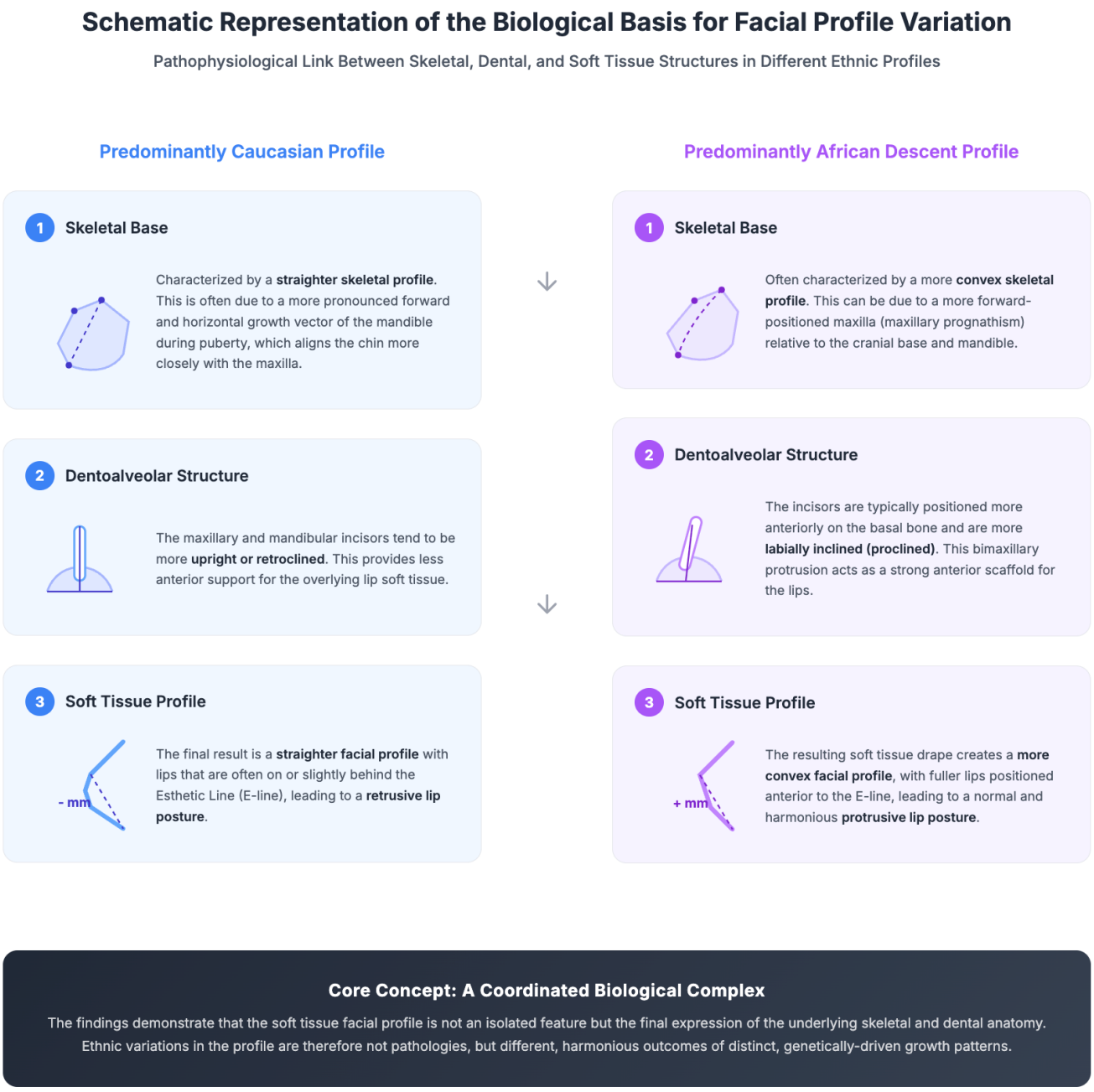

Figure 5. Schematic representation of the biological basis for facial profile variation.

The schematic presented in Figure 5, titled "Schematic Representation of the Biological Basis for Facial Profile Variation," serves as a powerful visual synthesis of the core findings and central thesis of our manuscript. It moves beyond the presentation of statistical data to offer a clear, mechanistic explanation for why the observed differences in soft tissue facial profiles exist among diverse ethnic populations. By deconstructing the facial profile into its constituent biological layers—the foundational skeletal base, the supportive dentoalveolar structure, and the resultant external soft tissue drape—the figure provides an elegant and scientifically robust framework for understanding facial form. It

compellingly argues that the variations revealed by our meta-analysis are not isolated phenomena but are the predictable and harmonious outcomes of distinct, genetically-driven developmental pathways.[16] This interpretation will explore the intricate details presented in the figure, linking them to established theories of craniofacial growth and pathophysiology to underscore their profound significance for modern clinical practice. The figure's primary strength lies in its comparative two-column layout, which contrasts the developmental cascade of a "Predominantly Caucasian Profile" with that of a "Predominantly African Descent Profile." This is not an attempt to create a rigid dichotomy, but rather to use two well-documented and distinct morphological patterns as archetypes to illustrate the fundamental principles of variation. Each column follows a logical, sequential progression from the underlying cause to the ultimate effect, a narrative structure that is both scientifically informative and didactically effective.

The left column of Figure 5 methodically illustrates the biological processes that culminate in the straighter, more orthognathic profile commonly observed in many individuals of Caucasian ancestry. This profile, which has historically formed the basis of classical orthodontic norms, is presented not as an ideal, but as one of many possible harmonious outcomes of a specific growth pattern. Stage 1: The Foundational Skeletal Base The infographic begins, appropriately, with the skeletal foundation. The schematic depicts a simplified craniofacial skeleton with a dashed line connecting three key points analogous to the soft tissue glabella, subnasale, and pogonion. This line is notably straight, visually representing the core characteristic of this profile: a straighter skeletal profile. The accompanying text provides the crucial pathophysiological explanation for this morphology, citing a "more pronounced forward and horizontal growth vector of the mandible during puberty." This statement is a concise summary of decades of seminal craniofacial research. The growth of the human face is a complex, four-dimensional process, with the maxilla and mandible following different growth trajectories and timelines.[17] While both jaws grow downward and forward relative to the cranial base, the mandible typically undergoes a more significant and prolonged period of growth, often peaking during the adolescent growth spurt. In many Caucasian populations, as documented in the landmark implant studies by Arne Björk, this late-stage mandibular growth has a strong horizontal component. This means the chin point (pogonion) travels forward more than it travels downward. This robust anterior projection of the mandible effectively "catches up" to the maxilla, which generally completes its forward growth earlier. The clinical result of this differential growth is a progressive reduction in skeletal convexity from childhood to early adulthood, leading to the alignment of the chin more directly beneath the maxilla, as depicted in the schematic.[18] This concept is also beautifully explained by Enlow's Counterpart Principle, which posits that the growth of different craniofacial components is interrelated. The forward growth of the mandible can be seen as a dynamic "counterpart" to the growth and spatial positioning of the middle cranial fossa and the maxilla. The specific pattern of these counterpart relationships, genetically determined, is what ultimately defines the skeletal profile. Stage 2: The Supportive Dentoalveolar Structure The second stage in the figure logically progresses to the dentoalveolar complex, the anatomical bridge between the skeleton and the soft tissue. The illustration shows a maxillary incisor in its alveolar housing, characterized by a vertical orientation. The text explains that the incisors in this profile type tend to be more upright or retroclined. This is a critical link in the causal chain. The inclination of the incisors is not an independent variable; it is profoundly influenced by the size and shape of the underlying skeletal base, the available arch length, and the functional environment created by the surrounding soft tissues. This is where Melvin Moss's Functional Matrix Hypothesis provides a powerful explanatory framework. Moss theorized that the growth of bone (the skeletal unit) is a secondary, compensatory response to the primary demands of its

associated functional soft tissue matrix. In the context of the dentoalveolar structure, the lips (orbicularis oris muscle) and tongue constitute a critical functional matrix. In individuals with the growth pattern described in Stage 1, a particular pattern of lip tonicity and activity often creates a containing force that guides the erupting incisors into a more upright position. This "myofunctional equilibrium" ensures that the teeth are positioned in a stable zone between the outward pressure of the tongue and the inward pressure of the lips. The mechanical consequence of this upright dentition, as the figure correctly states, is that it "provides less anterior support for the overlying lip soft tissue." The teeth act as a scaffold for the lips; a vertically oriented or posteriorly inclined scaffold will inevitably result in a less prominent soft tissue drape. Stage 3: The Resultant Soft Tissue Profile. The final stage reveals the external manifestation of the preceding skeletal and dental development. The illustration depicts a soft tissue profile with lips that are relatively flat and positioned posteriorly. A dashed Esthetic Line (E-line) running from the nose to the chin is shown, with the lips falling on or behind this line, visually represented by the "- mm" notation. The text synthesizes the entire process: the final result is a straighter facial profile leading to a retrusive lip posture. This outcome is the logical and harmonious culmination of the previous stages. The straighter skeletal base (Stage 1) creates the foundational framework. The upright dentoalveolar structure (Stage 2) provides minimal anterior projection. Consequently, the overlying soft tissues (Stage 3) drape in a relatively retrusive manner. This entire cascade illustrates the core concept of a "coordinated biological complex," where each component develops in concert with the others to produce a stable and functional outcome. The clinical significance is immense: this specific profile, born of a particular growth pattern, was historically reified as the single standard of beauty and health in orthodontics.[19] Understanding its biological basis allows us to appreciate it as one normal variation among many, and to recognize the fallacy of attempting to force other, different but equally valid, biological systems to conform to this specific endpoint.

The right column of Figure 5 provides a compelling counterpoint, illustrating the developmental pathway that leads to the more convex and protrusive profile commonly and normally observed in many individuals of African ancestry. Stage 1: The Foundational Skeletal Base. The infographic once again begins with the skeleton, but here the schematic is visibly different. The dashed line connecting the key facial points is distinctly curved or convex, visually representing a more convex skeletal profile. The text explains that this is often due to a "more forward-positioned maxilla (maxillary prognathism) relative to the cranial base and mandible." This is a key distinction in craniofacial growth. In many populations of African descent, the entire midface complex, including the maxilla and zygomas, is genetically programmed to be positioned more anteriorly relative to the cranial base. This is a primary skeletal trait, not a dental one. While the mandible in these individuals also grows downward and forward, its final position often does not fully compensate for the prominence of the maxilla. The result is a persistent skeletal convexity that is a normal and stable feature throughout development. The illustration correctly depicts this relationship, showing the chin point positioned more posteriorly relative to the prominent maxillary base. Stage 2: The Supportive Dentoalveolar Structure. The second stage in this column highlights a dramatically different dentoalveolar adaptation. The illustration shows an incisor that is clearly angled forward, or proclined. The text describes this as a state where the incisors are positioned more anteriorly on the basal bone and are more labially inclined (proclined). This is the anatomical basis for what is often termed "bimaxillary protrusion." Crucially, this is presented as a normal variation. Applying the Functional Matrix Hypothesis here, we can infer that a different functional environment supports and, in fact, requires this dental arrangement. The generally fuller and often stronger lip musculature, combined with different patterns of tongue posture and function, creates a myofunctional

equilibrium where the stable position for the teeth is more anterior and proclined.[20] This dentoalveolar structure, as the figure notes, "acts as a strong anterior scaffold for the lips." The forward angulation provides robust support, physically pushing the lips forward and contributing to their characteristic fullness. Stage 3: The Resultant Soft Tissue Profile. The final stage in this column illustrates the soft tissue outcome. The profile is visibly more convex than its Caucasian counterpart, with full, prominent lips. The E-line is shown with the lips positioned well ahead of it, indicated by the "+ mm" notation. The text perfectly summarizes this outcome: a more convex facial profile with a normal and harmonious protrusive lip posture. This profile is, once again, the logical result of a coordinated biological cascade. The convex skeletal base (Stage 1) establishes the underlying framework. The protrusive and proclined dentition (Stage 2) provides powerful anterior support. The final soft tissue drape (Stage 3) reflects this internal architecture, resulting in a full, convex profile. This is not a state of disharmony; it is a different, but equally valid and stable, state of biological and aesthetic harmony. The clinical lesson is clear: to view this profile through the lens of a Caucasian-based cephalometric analysis is to fundamentally misinterpret a normal anatomical variation as a pathology. The "protrusion" is not a malocclusion to be "corrected" but is an integral feature of this specific, coordinated craniofacial type.

Figure 5 masterfully provides the visual evidence to support it. It teaches us to look beyond the surface—the soft tissue—and to understand the intricate and logical biological pathways that create it. It reframes our clinical perspective, moving away from a prescriptive mindset that seeks to make all patients conform to a single, arbitrary ideal. Instead, it encourages a descriptive and analytical approach, where the goal is to understand the patient's unique, inherent pattern of growth and to work within that framework to achieve health, function, and an aesthetic outcome that is in harmony with their own biology and identity. Figure 5 is more than just a summary of results; it is a didactic tool of immense value. It translates complex, multi-layered concepts from craniofacial genetics, developmental biology, and clinical orthodontics into a clear, accessible, and scientifically rigorous visual narrative. It provides the crucial pathophysiological context for the statistical findings of our meta-analysis, illustrating the "why" behind the numbers. For the student, researcher, or clinician, this figure offers a profound lesson in appreciating the beauty and logic of human diversity, a lesson that is essential for the ethical and effective practice of dentistry in our multicultural global society. This study is not without its limitations. The primary limitation, as discussed, is the necessary but imperfect grouping of diverse populations into broad ethnic categories. The number of included studies was small, which prevented a more granular analysis and a formal assessment of publication bias. The data is cross-sectional and does not capture the longitudinal dynamics of growth. Finally, the analysis is based on two-dimensional cephalometry, which cannot fully capture the complexity of three-dimensional facial structures.

4. Conclusion

Statistically significant differences in the central tendencies of soft tissue facial profiles exist among pediatric populations of different broad racial and ethnic backgrounds. These variations are not anomalies but represent normal, genetically-determined morphological patterns. The continued application of a single, universal cephalometric standard for facial aesthetic diagnosis is not supported by high-level evidence and is clinically inappropriate, carrying a significant risk of misdiagnosis of normal ethnic variations as pathology. The extremely high statistical heterogeneity found in this analysis is a critical finding, demonstrating that there is immense variance in facial profiles even within broadly defined ethnic groups. This meta-analysis provides a preliminary quantitative exploration of this global variance. Its primary clinical implication is to caution against a rigid, numbers-based approach to diagnosis

and to strongly advocate for an individualized assessment that respects the wide spectrum of normal human facial variation and is sensitive to the patient's unique ethnocultural background.

5. References

1. Ludwigs L, Pape C, Visse HS, Runte C, Meyer U, Dirksen D. Cross sectional analysis of Eurasian skull anatomy for 3D cephalometry-normative data reveal four different skull types. J Pers Med. 2023; 13(6).
2. Khattiyawittayakun L. Mandibular plane to hyoid in lateral cephalometry as a predictive parameter for severity of obstructive sleep apnea. Chula Med J. 2024; 67(2).
3. Hattori Y, Chien-Jung Pai B, Saito T, Denadai R, Chou P-Y, Lo L-J. Appraising mandibular prognathism in class III malocclusion following orthognathic surgery: Patient-reported and cephalometry-based outcomes. J Craniomaxillofac Surg. 2024; 52(9): 974–82.
4. Hedayatian M, Azarbayejani S, Omrani A, Etemadi Borujeni S. Correlation of clivus length and angle with chronological age, gender, sagittal growth pattern of the jaws, and skeletal maturation using lateral cephalometry. J Dent (Shiraz). 2024; 25(3): 251–61.
5. Bagdy-Bálint R, Szabó G, Zováthi ÖH, Zováthi BH, Somorjai Á, Köpenczei C, et al. Accuracy of automated analysis in cephalometry. J Dent Sci. 2025; 20(2): 830–43.
6. Zilio C, Tel A, Perrotti G, Testori T, Sembronio S, Robiony M. Validation of “total face approach” (TFA) three-dimensional cephalometry for the diagnosis of dentofacial dysmorphisms and correlation with clinical diagnosis. Int J Oral Maxillofac Surg. 2025; 54(5): 420–9.
7. Avdoshenko KE, Strelkova NK, Postnikova EV. Cephalometry and columnmetry in surgical rejuvenation of the lower two-thirds of the face and neck. Plas Surg Aest Med. 2025; (2): 69.
8. Pandey A, Chaturvedi TP, Srivastava A, Shukla S, Priyadarsini S S, Nagvanshi S, et al. Assessing diagnostic accuracy in cephalometry: a comparative study of manual and digital tracing techniques. Cureus. 2025; 17(8): e89412.
9. Tanikawa C, Nakamura H, Mimura T, Uemura Y, Yamashiro T. Development of artificial intelligence-supported automatic three-dimensional surface cephalometry. Orthod Craniofac Res. 2025; 28(4): 636–46.
10. Ed-Dhahraouy M, Riri H, Ezzahmouly M, Bourzgui F, El Moutaoukkil A. A new methodology for automatic detection of reference points in 3D cephalometry: a pilot study. Int Orthod. 2018; 16(2): 328–37.
11. Kumar S, Jayan B, Kumar MPP, Sharma M, Nehra K, Bansal AK. Acoustic pharyngometry vs lateral cephalometry: a comparative evaluation of pharyngeal airway dimensions in patients with skeletal class I and skeletal class II malocclusion. Orthod Waves. 2019; 78(3): 118–25.
12. Tsukiboshi Y, Tanikawa C, Yamashiro T. Surface-based 3-dimensional cephalometry: An objective analysis of cranio-mandibular morphology. Am J Orthod Dentofacial Orthop. 2020; 158(4): 535–46.
13. März K, Chepura T, Plewig B, Haddad D, Weber D, Schmid M, et al. Cephalometry without complex dedicated postprocessing in an oriented magnetic resonance imaging dataset: a pilot study. Eur J Orthod. 2021; 43(6): 614–21.
14. Jayaprakash PK, Mb J, Kumar AM. Topical application of barium sulphate paste for enhancement of soft tissue cheek contours in lateral cephalometry. J Indian Orthod Soc. 2021; 55(2): 209–10.
15. Gu M, Savoldi F, Chan EYL, Tse CSK, Lau MTW, Wey MC, et al. Changes in the upper airway, hyoid bone and craniofacial morphology between patients treated with

headgear activator and Herbst appliance: a retrospective study on lateral cephalometry. Orthod Craniofac Res. 2021; 24(3): 360–9.

16. Ahrari F, Shahabi M, Hosseini-Zarch H, Alavi MJ. Comparison of lateral cephalometry and cone-beam computed tomography techniques for measuring alveolar bone thickness around maxillary incisors. Taiwanese Journal of Orthodontics (TJO). 2023; 35(3).
17. Farronato M, Cenzato N, Crispino R, Tartaglia FC, Biagi R, Baldini B, et al. Divergence between CBCT and optical scans for soft tissue analysis and cephalometry in facial imaging: a cross-sectional study on healthy adults. Int Orthod. 2024; 22(2): 100845.
18. Pittayapat P, Jacobs R, Bornstein MM, Odri GA, Lambrichts I, Willems G, et al. Three-dimensional Frankfort horizontal plane for 3D cephalometry: a comparative assessment of conventional versus novel landmarks and horizontal planes. Eur J Orthod. 2018; 40(3): 239–48.
19. Oh S, Kim C-Y, Hong J. A comparative study between data obtained from conventional lateral cephalometry and reconstructed three-dimensional computed tomography images. J Korean Assoc Oral Maxillofac Surg. 2014; 40(3): 123–9.
20. Adetona MO, Shokunbi MT. The cephalometry of the Yoruba ethnic group of southwestern Nigeria. Niger J Physiol Sci. 2019; 34(2): 115–20.