The Influence of Population Variation and Obesity on Facial Growth
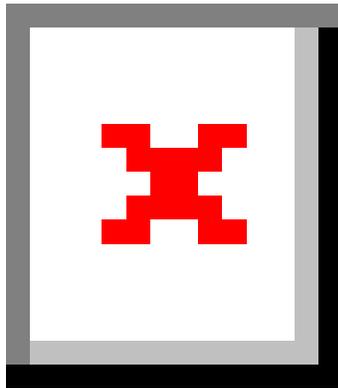
2023 Research Aid Awards (RAA)

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FollowUp Form

Award Information

In an attempt to make things a little easier for the reviewer who will read this report, please consider these two questions before this is sent for review:

- *Is this an example of your very best work, in that it provides sufficient explanation and justification, and is something otherwise worthy of publication? (We do publish the Final Report on our website, so this does need to be complete and polished.)*

- *Does this Final Report provide the level of detail, etc. that you would expect, if you were the reviewer?*

Title of Project:*
The Influence of Population Variation and Obesity on Facial Growth

Award Type
Research Aid Award (RAA)

Period of AAOF Support
July 1, 2023 through June 30, 2024

Institution
The Board of Trustees of the University of Illinois

Names of principal advisor(s) / mentor(s), co-investigator(s) and consultant(s)
Dr. Suzanne Abreu, Dr. Christina Nicholas, Dr. James Sciote

Amount of Funding
$4,800.00

Abstract
(add specific directions for each type here)

Timing and pattern of facial growth varies by ancestry and likely also key environmental factors. For example, insufficient nutrient intake is known to delay puberty, create stunted growth, and delay dental development. Much of the literature now indicates that childhood obesity can affect timing of dental development, with obese children showing accelerated dental maturation. Currently, the relative impact of diet, obesity, and ancestry on timing of facial growth remains unclear. Several recent studies indicate that children with obesity may experience precocious facial growth, and perhaps also differences in mandibular dimensions, especially condylion-pogonion. A pilot study in Puerto Rico found increased frequency of class III dental malocclusions in children with obesity. Timing of facial skeletal growth has implications for timing of orthodontic treatment. Furthermore, differences in the direction/pattern of facial growth may impact orthodontic needs. Current data on this topic has not differentiated between individuals of different ancestries, nor has it considered differences in diet and food security. The primary aim of this project is to investigate the relative influence of ancestry and body mass index on timing and pattern of human craniofacial growth.

Clinical Implications/Significance: The information obtained from this study will allow us to examine the relative impact of demographic characteristics (e.g., sex, ancestry) and environmental factors (e.g., BMI, food security) on facial skeletal growth of modern-day American children. Obtaining information from diverse populations will foster greater understanding of how factors such as BMI, diet, food security, and socioeconomic status can affect a child's dental and skeletal development which is pertinent to the field of orthodontics.

Overall Objective and Specific Aims: We aim to examine the interaction of demographic characteristics (e.g., ancestry, sex) and environmental factors such as BMI and food insecurity on the timing and pattern of facial skeletal growth. Our null hypotheses are: (1) children with obesity and those without do not differ in timing or pattern of facial growth; and (2) variation in facial shape related to obesity is not mediated by self-reported ancestry.

Long-term Objectives: The PI will use this project to develop skills in the area of clinical/translational research. Data from this study will be used to develop future work on the influence of environmental factors on facial growth. The questionnaires collected for this study will also be used for a related study working to develop more sophisticated dental age estimation techniques.

Respond to the following questions:

Detailed results and inferences:*

If the work has been published, please attach a pdf of manuscript below by clicking "Upload a file".
<u>OR</u>
Use the text box below to describe in detail the results of your study. The intent is to share the knowledge you have generated with the AAOF and orthodontic community specifically and other who may benefit from your study. Table, Figures, Statistical Analysis, and interpretation of results should also be attached by clicking "Upload a file".

Suzanne Abreu Tables_Fig_Stats.pdf
The BMI percentile for each subject was determined using the age- and sex-specific growth charts from the Centers for Disease Control and Prevention (CDC) (Figure 1). Lateral cephalograms taken during the standard "records" appointment were retroactively obtained from the patient's electronic health record (EHR) and were utilized to assess craniofacial size and shape using traditional osteometric landmarks (Figure 2, Table 1). A total of twenty-two coordinate landmarks were selected for identification on each subject's lateral cephalometric radiograph (LCR).

Descriptive Statistics

After applying inclusion and exclusion criteria, our final sample included 97 subjects: n=43 females (44%) and n=54 males (56%) (Figure 3), with a median age of 13.2 years and an interquartile range from 11.5 to 15 years of age (Figure 4). The most common ancestry group in our sample was Hispanic (n=66, 73%), followed by non-Hispanic Black (n=16, 18%), and Asian (n=9, 9.9%) (Figure 5). Three individuals did not answer the ancestry questions in the questionnaire, so they were omitted from the analysis. Our results indicate that n=74 (80%) subjects were classified as having low socioeconomic status (SES), n=15 (16%) were identified as middle SES, and n=3 (3.3%) were classified as high SES (Figure 6) according to the Chicago and Philadelphia median household incomes for families of 4 in 2023 (Table II). Five individuals did not answer the questions relating to SES, so they were omitted from the analysis. Additionally, n=56 (66%) subjects reported no experience of food insecurity, while n=29 (34%) reported experiencing food insecurity. Twelve participants did not answer the questions relating to food insecurity, so they were omitted from the analysis (Figure 7). Our results show that n=41 (44%) of the subjects were classified as normal weight, while the overweight and obese categories were combined for a total of n=52 (56%) (Figure 8). The median BMI percentile was 86, with an interquartile range from 57 to 96, suggesting that more than half the subjects in this sample were considered overweight (Figure 9). Four participants did not have a BMI percentile value calculated, so they were omitted from the analysis.

Geometric Morphometric Analysis
To control for size-related shape differences (allometry) we regressed our initial GPA shape data on centroid size and ran all subsequent analyses on these allometrically-scaled regression residuals. A second GPA of this allometrically-scaled data yielded 40 principal components (PCs), the first four of which each represented greater than 5% of the total variation and thus were most likely to be clinically relevant. In the figures below, each wireframe shows the extremes of the range of variation of the PC beside it. The grey dots and outline are the average shape of the whole sample. The black dots and outlines are the extremes of variation. All PC figures were re-oriented to the Frankfurt Horizontal plane for standardization.
Data analysis (linear regression models) was initially run using our most fine-grained data categories (e.g., ancestry was broken down by both race and ethnicity). These analyses failed to find statistically significant relationships. Due to our small sample size, we then elected to use broader, combined categories for ancestry (Hispanic, Black, and Asian) and we removed the Underweight BMI and combined the Overweight and Obese BMI categories. For ancestry, non-Hispanic multiracial (sample size n= 2, (2.1%)) and Non-Hispanic White (sample size n= 3, (3.2%)) were removed due to their small sample sizes. For BMI category, the

"underweight" category (sample size n=4, (4.1%)) was removed while "overweight" and "obesity" were combined into one category (n=52, (56%)).

PC1 represented 31.67% of the total variation in the sample, and PC2 explained 20.36% of the variation. PC1 depicts variation in relative facial height, midfacial prognathism, and mandibular shape. PC2 depicts variation in lower midfacial prognathism, mandibular rotation, and chin prominence (Figure 10). After controlling for age and sex, we failed to identify statistically significant associations between our demographic or BMI variables with PC1 and PC2. PC3 (9.87% of variation) depicts midfacial prognathism and gonial angle.

For PC3, there were statistically significant differences by age (p=0.001), sex (p=0.013), non-Hispanic Asian (p=0.048), and Black self-reported ancestry (p<0.001). Subjects who identified as non-Hispanic Asian were more likely to have lower PC3 scores, characterized by relatively more obtuse gonial angles, more projecting chins, and less subnasal alveolar prognathism. In contrast, those who identified as Black were more likely to have higher PC3 scores, characterized by greater subnasal alveolar prognathism and more acute gonial angles (Figure 11). PC4 (5.36% of total variation) depicts nasal bridge protrusion, ramus length, and midfacial protrusion. For PC4, we found a statistically significant difference by age (p=0.005). Older individuals tended to have lower PC4 scores, corresponding to increased upper facial height and anterior expansion of the frontal bone, increased ramus height, and relatively less subnasal alveolar prognathism.

Centroid size, as a proxy for the timing of facial growth, was compared across BMI and demographic variables using linear regression models, which controlled for age and sex. Age (p<0.001) was statistically significant in all models, while sex approached significance (p=0.084) in the regression of food insecurity and was statistically significant (p=0.011 – p= 0.008) in all other models. In most regression models, variables of interest were approaching significance but did not reach significance (SES Middle p=0.068; food insecurity p=0.168; BMI percentile p=0.058; BMI category overweight/obese p=0.251). For ancestry, a self-reported ancestry of Black/African American was statistically significantly different (p=0.014), with these individuals showing a trend toward larger facial centroid sizes relative to their chronological ages.

Were the original, specific aims of the proposal realized?*

Overall, we accomplished the goals of this research project. We successfully prospectively recruited participants and examined the relationship between BMI and facial morphology. Our key results are summarized below.

Our study failed to reject the null hypotheses:
1. Children with obesity and those without do not differ in timing or pattern of facial growth.
2. Variation in facial shape related to obesity is not mediated by self-reported ancestry.

While this study did not find statistically significant differences in facial skeletal growth timing or shape between children with and without obesity, the findings contribute valuable insight and suggest that further investigation—particularly with larger, more diverse samples—may help uncover subtle associations and clarify the role of ancestry in obesity-related shape variation.

Study Limitations
Our sample size is relatively small and under-powered, and the University of Illinois Chicago (UIC) Orthodontic Clinic population does not represent the general population. The shape differences we see in the first 2 PCs seem to be more associated with Class II and Class III skeletal relationships, which may not be typical of the broader population. There is also existing controversy about whether BMI is accurate as a 'one-size fits all' metric for obesity (Gutin, 2018; Flegal, 2023). BMI does not account for important biological differences such as muscle mass and is at best a rough proxy for actual obesity (Gutin, 2018, Keys et al., 1972).

Additionally, the study of craniofacial growth should ideally be designed as a longitudinal study, and due to the cross-sectional nature of this study, we were limited in our ability to estimate the relationship of our variables of interest through time. While we present data as statistically significant if it reaches the threshold of $p<0.05$, due to the application of multiple testing (i.e. 5 tests for 5 sets of data, totaling 25 tests), Bonferroni correction would set the cut-off at $p<0.002$. At this significance threshold, only age + centroid size ($p<0.001$) and the association between Black ancestry and PC3 shape ($p<0.001$) remain statistically significant.

Future Directions
ANB angle and Wits appraisal are both utilized to assess the anteroposterior (AP) relationship between the maxilla and mandible, which determines the skeletal classification of an individual. Factors such as the rotation of the Sella-Nasion (SN) plane and jaw rotation during growth can affect the ANB angle, whereas variations in the occlusal plane may influence the Wits appraisal (Paddenberg et. al., 2023). Since our sample seems more closely associated with Class II and Class III skeletal relationships (as seen in our PC1 analysis), it would be valuable to explore how ANB and Wits values are influenced by BMI and ancestry group. Future studies related to this project should also control for skeletal growth patterns as that is the primary axis of difference in this sample.

PC2 (20.36% of total variation), which accounted for the second greatest variation, highlighted differences in anterior facial height and mandibular rotation. It would also be valuable to examine how BMI and ancestry influence the Frankfort mandibular plane angle (FMA) values, as this could provide insights into vertical versus horizontal mandibular growth patterns in patients of different ancestry groups.
We categorized subjects as children if they were under 18 years of age. However, it could be beneficial to analyze the breakdown of BMI percentiles by CVM stage and age group. This may help identify the prevalence of individuals with high BMI who have not yet reached their growth spurt. Furthermore, larger sample sizes are necessary to conduct more robust testing of our hypotheses.

Were the results published?*
No

Have the results of this proposal been presented?*
Yes

To what extent have you used, or how do you intend to use, AAOF funding to further your career?*
The AAOF funding has played a pivotal role in supporting the early stages of my academic and research career. To date, I have used $1,000 of the $4,800 award to cover travel expenses to the AAO 2025 Annual Session, where I had the opportunity to present my research findings. An additional $200 was used to pay for statistical consultation from the UIC Center for Clinical and Translational Science; this amount was less than originally anticipated based upon what CCTS originally estimated. My mentor was awarded a grant from the National Institute of Justice after I had received the AAO Research Aid Award, so the NIJ grant was used to cover participant incentive costs. This has meant we came in under budget for the AAOF RAA, However, the AAOF funding has still been instrumental.

Beyond financial support, the award has served as a meaningful stepping stone in my pursuit of an academic career. It has enabled me to share my work with colleagues and experts in the field—an experience that would have been more difficult without this support. Most importantly, it has further ignited my passion for

research and academia. I am sincerely grateful to have been selected as a recipient of the AAOF Research Aid Award, and I look forward to building on this foundation as I continue contributing to the field of orthodontics.

Accounting: Were there any leftover funds?

$3,600.00

Not Published

Are there plans to publish? If not, why not?*

Yes, there are plans to publish. This project served as a pilot study to assess feasibility and establish preliminary findings. We plan to publish the final manuscript once we have recruited a larger sample size to strengthen the statistical power and generalizability of the results. We anticipate that continued data collection over the next few years will allow us to meet this goal.

Presented

Please list titles, author or co-authors of these presentation/s, year and locations:*

Abreu, S., Harb, I., Carr, S., Echeumuna, O., Nicholas, C. L. The Influence of Population Variation and Obesity on Facial Growth. AAO 2025 Annual Session. Philadelphia Convention Center, PA. April 25-26, 2025.

Was AAOF support acknowledged?

If so, please describe:

Yes, it was listed in the acknowledgments portion of the presentation.

Internal Review

Reviewer comments

Reviewer Status*

Approved

2023 Research Aid Awards (RAA)

File Attachment Summary

Applicant File Uploads
- Suzanne Abreu Tables_Fig_Stats.pdf

TABLES SECTION

TABLE I

CEPHALOMETRIC LANDMARKS AND DESCRIPTIONS

Landmark number	Anatomical Structure	Descriptions
1	Porion (Po)	The midpoint of the upper contour of the external auditory meatus
2	Sella (S)	The midpoint of the cavity of the sella turcica
3	Nasion (N)	The most anterior point of the intersection between the nasal and frontal bones
4	Rhinion	The most inferior anterior point where the nasal bone meets the cartilage
5	Condylion (Co)	The most posterior superior point of the mandibular condyle
6	Orbitale (Or)	The lowest point on the inferior margin of the orbit
7	Posterior Nasal Spine (PNS)	The tip of the posterior spine of the palatine bone, at the junction of the hard and soft palates
8	Anterior Nasal Spine (ANS)	The tip of the anterior nasal spine
9	A-point, Subspinale (Ss)	The innermost point on the contour of the premaxilla between the anterior nasal spine and the incisor
10	Prosthion, Supradentale (Pr)	The most inferior anterior point on the maxillary alveolar process between the central incisors
11	Upper Incisor Lingual Gingival Border	Lingual cemento –enamel junction of the upper incisor

12	Inferior Prosthion, Infradentalale (Id)	The most anterior superior point on the mandibular alveolar process
13	B- point, Supramentale (Sm)	The innermost point on the contour of the mandible between the incisor and the bony chin
14	Pogonion (Pg)	The most anterior point on the contour of the chin.
15	Gnathion (Gn)	The most inferior anterior point on the mandibular symphysis – the point of the chin (midpoint between menton and pogonion)
16	Menton (Me)	The most inferior point on the mandibular symphysis
17	Lower Incisor Lingual Gingival Border	Lingual cemento–enamel junction of the lower incisor
18	Gonion (Go)	The midpoint of the contour connecting the posterior ramus and the inferior boarder of the mandible.
19	R1 Point	The deepest point on the curve of the anterior border of the ramus of the mandible
20	R2 Point	Point located on the posterior border of the ramus of the mandible directly lateral to R1 point (along the same axis)
21	R3 Point	Point located at the center and most inferior aspect of the sigmoid notch
22	R4 Point	Point on the border of the mandible directly inferior to R3 point (along the same axis)

TABLE II

SOCIOECONOMIC STATUS BASED ON HOUSEHOLD INCOME AND PARENTAL EDUCATION

Income	Parental/Guardian Education Level		
	Up to 2 years of college	4-yr College Degree	Graduate/Professional School
< $30,000	Low	Low	Low
$30,000 - $69,999	Low	Middle	Middle
$70,000 – $109,999	Middle	Middle	High
$110,000 – $150,000	Middle	High	High
> $150,000	High	High	High

FIGURES

Figure 1. CDC sample charts of height/weight illustrating the ranges for underweight, normal, overweight, and obese BMI in children (left: girls, right: boys). [Kuczmarski et al., 2002]

Figure 2. Example of a digitally landmarked lateral cephalometric radiograph.

SEX

Figure 3. Pie chart of demographics summary for sex. The sex distribution was uneven, with n=54 males (56%) and n=43 females (44%).

AGE

Figure 4. Histogram of distribution of age. The median age of participants was 13.2 years with an interquartile range of 11.5 to 15 years of age.

ANCESTRY

Figure 5. Pie chart of demographics by self-reported ancestry. The most common ancestry group in our sample was Hispanic (n=66, 73%), followed by non-Hispanic Black (n=16, 18%), and Asian (n=9, 9.9%).

Figure 6. Pie chart of demographics by socioeconomic status. N=74 (80%) subjects were categorized as having a low socioeconomic status (SES), n=15 (16%) subjects were identified as having middle SES, and n=3 (3.3%) were classified as having high SES.

FOOD INSECURITY

Yes, n=29
(34%)

No, n=56
(66%)

Figure 7. Pie chart of demographics by food insecurity. A total of n=56 (66%) subjects reported no experience of food insecurity, while n=29 (34%) reported experiencing food insecurity.

BODY MASS INDEX

Figure 8. Pie chart of demographics summary for body mass index. A total of n=41 (44%) of the subjects were in the normal weight category, while the overweight and obese categories were combined for a total of n=52 (56%) subjects.

Figure 9. Histogram of distribution of BMI percentile. More than half of the subjects in this sample were overweight, with a median BMI percentile of 86 and an interquartile range from 57 to 96.

Figure 10. Scatterplot depicting allometrically-scaled PC1 and PC2. Wireframe figures depict the corresponding ends of the range of variation for each PC. Grey dot = consensus shape; Black dots = shape at the extremes of variation. We can see that PC1 (31.67% of variation) primarily describes relative facial height, midfacial prognathism, and mandibular shape. PC2 (20.36% of variation) depicts variation in lower midfacial prognathism, mandibular rotation, and chin prominence.

Figure 11. Scatterplot depicting allometrically-scaled PC3 and PC4. Wireframe figures depict the corresponding ends of the range of variation for each PC. Grey dot = consensus shape; Black dots = shape at the extremes of variation. PC3 (9.87% of total variation) depicts midfacial prognathism and gonial angle. PC4 (5.36% of total variation) depicts nasal bridge protrusion, ramus length, and midfacial protrusion.

STATISTICAL ANALYSIS

Data analysis (linear regression models) was initially run using our most fine-grained data categories (e.g., ancestry was broken down by both race and ethnicity). These analyses failed to find statistically significant relationships. Due to our small sample size, we then elected to use broader, combined categories for ancestry (Hispanic, Black, and Asian) and we removed the Underweight BMI and combined the Overweight and Obese BMI categories. For ancestry, non-Hispanic multiracial (sample size n= 2, (2.1%)) and Non-Hispanic White (sample size n= 3, (3.2%)) were removed due to their small sample sizes. For BMI_Cat, the "underweight" category (sample size n=4, (4.1%)) was removed while "overweight" and "obesity" were combined into one category (n=52, (56%)). The data tables may be seen below.

Logsize_univ_results (Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	6.86	0.041	165.993	0
Age_Years	0.011	0.003	3.579	0.001
SexM	0.032	0.015	2.121	0.037
ANC1Asian	-0.017	0.025	-0.696	0.488
ANC1Black	0.05	0.02	2.5	0.014
(Intercept)	6.858	0.042	163.419	0
Age_Years	0.012	0.003	3.878	0
SexM	0.039	0.015	2.594	0.011
SESHigh	0.017	0.042	0.405	0.686
SESMiddle	-0.039	0.021	-1.849	0.068
(Intercept)	6.828	0.044	155.945	0
Age_Years	0.014	0.003	4.215	0
SexM	0.028	0.016	1.752	0.084
FINS2Y	0.023	0.017	1.39	0.168
(Intercept)	6.799	0.044	154.99	0
Age_Years	0.013	0.003	4.605	0
SexM	0.037	0.014	2.541	0.013
BMI_Perc	0	0	1.916	0.058
(Intercept)	6.823	0.041	168.161	0
Age_Years	0.013	0.003	4.592	0
SexM	0.039	0.014	2.7	0.008
BMI_CatOverweight	0.017	0.014	1.155	0.251

Allometry_PC1_univ_results (Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	-0.013	0.027	-0.493	0.623
Age_Years	0.001	0.002	0.421	0.674
SexM	0.006	0.01	0.643	0.522
ANC1Asian	-0.009	0.016	-0.566	0.573
ANC1Black	-0.004	0.013	-0.344	0.732
(Intercept)	-0.021	0.027	-0.792	0.43
Age_Years	0.001	0.002	0.615	0.54
SexM	0.007	0.01	0.701	0.485
SESHigh	0.009	0.027	0.324	0.747
SESMiddle	0.016	0.013	1.241	0.218
(Intercept)	-0.013	0.028	-0.464	0.644
Age_Years	0.001	0.002	0.257	0.798
SexM	0.007	0.01	0.677	0.5
FINS2Y	0.003	0.011	0.288	0.774
(Intercept)	-0.021	0.028	-0.764	0.447
Age_Years	0.001	0.002	0.437	0.663
SexM	0.006	0.009	0.661	0.51
BMI_Perc	0	0	0.677	0.5
(Intercept)	-0.022	0.026	-0.835	0.406
Age_Years	0.001	0.002	0.607	0.546
SexM	0.01	0.009	1.039	0.302
BMI_CatOverweight	0.005	0.009	0.548	0.585

Allometry_PC2_univ_results (Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	0.009	0.021	0.444	0.658
Age_Years	-0.001	0.002	-0.453	0.652
SexM	0	0.008	0.042	0.967
ANC1Asian	-0.012	0.013	-0.92	0.36
ANC1Black	-0.003	0.01	-0.299	0.766
(Intercept)	0.008	0.02	0.406	0.686
Age_Years	-0.001	0.001	-0.386	0.7
SexM	0	0.007	0.025	0.98
SESHigh	0.013	0.02	0.636	0.527
SESMiddle	-0.017	0.01	-1.71	0.091
(Intercept)	-0.004	0.021	-0.195	0.846
Age_Years	0	0.002	-0.098	0.922
SexM	0.002	0.008	0.247	0.806
FINS2Y	0.004	0.008	0.487	0.628
(Intercept)	0.006	0.023	0.257	0.798
Age_Years	0	0.001	-0.224	0.823
SexM	-0.002	0.007	-0.3	0.765
BMI_Perc	0	0	-0.024	0.981
(Intercept)	0.008	0.021	0.36	0.72
Age_Years	0	0.002	-0.243	0.809
SexM	-0.002	0.008	-0.302	0.763
BMI_CatOverweight	-0.003	0.008	-0.373	0.71

Allometry_PC3_univ_results (Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	0.045	0.012	3.646	0
Age_Years	-0.003	0.001	-3.519	0.001
SexM	-0.011	0.004	-2.545	0.013
ANC1Asian	-0.015	0.007	-2.003	0.048
ANC1Black	0.027	0.006	4.532	0
(Intercept)	0.036	0.014	2.512	0.014
Age_Years	-0.002	0.001	-2.225	0.029
SexM	-0.009	0.005	-1.827	0.071
SESHigh	-0.016	0.014	-1.109	0.271
SESMiddle	0.002	0.007	0.301	0.764
(Intercept)	0.034	0.014	2.369	0.02
Age_Years	-0.002	0.001	-1.984	0.051
SexM	-0.01	0.005	-1.84	0.069
FINS2Y	0.002	0.005	0.326	0.745
(Intercept)	0.04	0.015	2.702	0.008
Age_Years	-0.002	0.001	-2.37	0.02
SexM	-0.01	0.005	-1.995	0.049
BMI_Perc	0	0	-0.765	0.446
(Intercept)	0.04	0.014	2.877	0.005
Age_Years	-0.003	0.001	-2.513	0.014
SexM	-0.012	0.005	-2.363	0.02
BMI_CatOverweight	-0.002	0.005	-0.433	0.666

Allometry_PC4_univ_results (Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	-0.03	0.01	-2.919	0.004
Age_Years	0.002	0.001	2.888	0.005
SexM	-0.001	0.004	-0.158	0.875
ANC1Asian	-0.004	0.006	-0.646	0.52
ANC1Black	0.005	0.005	1.049	0.297
(Intercept)	-0.024	0.01	-2.42	0.018
Age_Years	0.002	0.001	2.504	0.014
SexM	0.002	0.004	0.618	0.538
SESHigh	-0.003	0.01	-0.301	0.764
SESMiddle	-0.003	0.005	-0.608	0.545
(Intercept)	-0.029	0.01	-2.831	0.006
Age_Years	0.002	0.001	2.704	0.008
SexM	0	0.004	-0.04	0.968
FINS2Y	0.007	0.004	1.85	0.068
(Intercept)	-0.028	0.011	-2.517	0.014
Age_Years	0.002	0.001	2.875	0.005
SexM	0.001	0.004	0.207	0.837
BMI_Perc	0	0	0.029	0.977
(Intercept)	-0.024	0.01	-2.355	0.021
Age_Years	0.002	0.001	2.42	0.018
SexM	0	0.004	-0.008	0.994
BMI_CatOverweight	0	0.004	0.074	0.941

Demographic Summary (Combined Variables)

Characteristic	N	N = 97[1]
Age_Years	97	13.20 (11.50, 15.00)
Sex	97	
F		43 (44%)
M		54 (56%)
ANC1	91	
Hispanic		66 (73%)
Asian		9 (9.9%)
Black		16 (18%)
Unknown		6
SES	92	
Low		74 (80%)
High		3 (3.3%)
Middle		15 (16%)
Unknown		5
FINS2	85	
N		56 (66%)
Y		29 (34%)
Unknown		12
BMI_Perc	97	86 (57, 96)
BMI_Cat	93	
Normal		41 (44%)
Overweight		52 (56%)
Unknown		4

[1] Median (IQR); n (%)

Logsize_univ_results (Before Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	6.858	0.042	161.563	0
Age_Years	0.011	0.003	3.637	0
SexM	0.034	0.015	2.212	0.03
ANC2Asian	-0.022	0.025	-0.857	0.394
ANC2Hispanic Black	0.035	0.033	1.051	0.296
ANC2Hispanic Multiracial	-0.018	0.043	-0.422	0.674
ANC2Hispanic Native	-0.022	0.027	-0.825	0.412
ANC2Non-Hispanic Black	0.049	0.024	2.018	0.047
ANC2Non-Hispanic Multiracial	-0.04	0.052	-0.758	0.451
ANC2Non-Hispanic White	-0.052	0.043	-1.217	0.227
(Intercept)	6.858	0.042	163.419	0
Age_Years	0.012	0.003	3.878	0
SexM	0.039	0.015	2.594	0.011
SESHigh	0.017	0.042	0.405	0.686
SESMiddle	-0.039	0.021	-1.849	0.068
(Intercept)	6.828	0.044	155.945	0
Age_Years	0.014	0.003	4.215	0
SexM	0.028	0.016	1.752	0.084
FINS2Y	0.023	0.017	1.39	0.168
(Intercept)	6.799	0.044	154.99	0
Age_Years	0.013	0.003	4.605	0
SexM	0.037	0.014	2.541	0.013
BMI_Perc	0	0	1.916	0.058
(Intercept)	6.814	0.039	174.633	0
Age_Years	0.014	0.003	5.063	0
SexM	0.038	0.014	2.735	0.008
BMI_CatObesity	0.005	0.016	0.297	0.768
BMI_CatOverweight	0.034	0.018	1.882	0.063
BMI_CatUnderweight	-0.092	0.036	-2.587	0.011

Allometry_PC1_univ_results (Before Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	-0.014	0.027	-0.524	0.601
Age_Years	0.001	0.002	0.435	0.665
SexM	0.006	0.01	0.632	0.529
ANC2Asian	-0.009	0.016	-0.525	0.601
ANC2Hispanic Black	0.003	0.021	0.119	0.906
ANC2Hispanic Multiracial	-0.026	0.028	-0.938	0.351
ANC2Hispanic Native	0.004	0.017	0.217	0.829
ANC2Non-Hispanic Black	-0.007	0.016	-0.432	0.667
ANC2Non-Hispanic Multiracial	0.058	0.034	1.718	0.089
ANC2Non-Hispanic White	0.017	0.027	0.637	0.526
(Intercept)	-0.021	0.027	-0.792	0.43
Age_Years	0.001	0.002	0.615	0.54
SexM	0.007	0.01	0.701	0.485
SESHigh	0.009	0.027	0.324	0.747
SESMiddle	0.016	0.013	1.241	0.218
(Intercept)	-0.013	0.028	-0.464	0.644
Age_Years	0.001	0.002	0.257	0.798
SexM	0.007	0.01	0.677	0.5
FINS2Y	0.003	0.011	0.288	0.774
(Intercept)	-0.021	0.028	-0.764	0.447
Age_Years	0.001	0.002	0.437	0.663
SexM	0.006	0.009	0.661	0.51
BMI_Perc	0	0	0.677	0.5
(Intercept)	-0.017	0.026	-0.657	0.513
Age_Years	0.001	0.002	0.483	0.631
SexM	0.007	0.009	0.756	0.452
BMI_CatObesity	0.009	0.011	0.891	0.375
BMI_CatOverweight	-0.002	0.012	-0.16	0.874
BMI_CatUnderweight	-0.031	0.023	-1.312	0.193

Allometry_PC2_univ_results (Before Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	-0.001	0.022	-0.026	0.98
Age_Years	0	0.002	0.135	0.893
SexM	0	0.008	-0.015	0.988
ANC2Asian	-0.013	0.013	-1.03	0.306
ANC2Hispanic Black	0.008	0.017	0.48	0.633
ANC2Hispanic Multiracial	-0.003	0.022	-0.145	0.885
ANC2Hispanic Native	-0.016	0.014	-1.153	0.252
ANC2Non-Hispanic Black	-0.012	0.012	-0.982	0.329
ANC2Non-Hispanic Multiracial	0.011	0.027	0.403	0.688
ANC2Non-Hispanic White	0.008	0.022	0.391	0.697
(Intercept)	0.008	0.02	0.406	0.686
Age_Years	-0.001	0.001	-0.386	0.7
SexM	0	0.007	0.025	0.98
SESHigh	0.013	0.02	0.636	0.527
SESMiddle	-0.017	0.01	-1.71	0.091
(Intercept)	-0.004	0.021	-0.195	0.846
Age_Years	0	0.002	-0.098	0.922
SexM	0.002	0.008	0.247	0.806
FINS2Y	0.004	0.008	0.487	0.628
(Intercept)	0.006	0.023	0.257	0.798
Age_Years	0	0.001	-0.224	0.823
SexM	-0.002	0.007	-0.3	0.765
BMI_Perc	0	0	-0.024	0.981
(Intercept)	0.009	0.021	0.438	0.662
Age_Years	0	0.001	-0.32	0.75
SexM	-0.002	0.007	-0.323	0.747
BMI_CatObesity	0.001	0.009	0.132	0.895
BMI_CatOverweight	-0.009	0.01	-0.904	0.368
BMI_CatUnderweight	0.001	0.019	0.031	0.975

Allometry_PC3_univ_results (Before Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	0.045	0.013	3.501	0.001
Age_Years	-0.003	0.001	-3.513	0.001
SexM	-0.011	0.005	-2.456	0.016
ANC2Asian	-0.014	0.008	-1.77	0.08
ANC2Hispanic Black	0.022	0.01	2.257	0.027
ANC2Hispanic Multiracial	-0.006	0.013	-0.497	0.62
ANC2Hispanic Native	0.013	0.008	1.647	0.103
ANC2Non-Hispanic Black	0.031	0.007	4.215	0
ANC2Non-Hispanic Multiracial	0.029	0.016	1.868	0.065
ANC2Non-Hispanic White	0.004	0.013	0.325	0.746
(Intercept)	0.036	0.014	2.512	0.014
Age_Years	-0.002	0.001	-2.225	0.029
SexM	-0.009	0.005	-1.827	0.071
SESHigh	-0.016	0.014	-1.109	0.271
SESMiddle	0.002	0.007	0.301	0.764
(Intercept)	0.034	0.014	2.369	0.02
Age_Years	-0.002	0.001	-1.984	0.051
SexM	-0.01	0.005	-1.84	0.069
FINS2Y	0.002	0.005	0.326	0.745
(Intercept)	0.04	0.015	2.702	0.008
Age_Years	-0.002	0.001	-2.37	0.02
SexM	-0.01	0.005	-1.995	0.049
BMI_Perc	0	0	-0.765	0.446
(Intercept)	0.036	0.014	2.68	0.009
Age_Years	-0.002	0.001	-2.373	0.02
SexM	-0.01	0.005	-2.107	0.038
BMI_CatObesity	-0.006	0.006	-1.127	0.263
BMI_CatOverweight	0.004	0.006	0.684	0.495
BMI_CatUnderweight	0.017	0.012	1.406	0.163

Allometry_PC4_univ_results (Before Combined Variables)

var	Estimate	Std..Error	t.value	Pr...t..
(Intercept)	-0.024	0.01	-2.298	0.024
Age_Years	0.002	0.001	2.143	0.035
SexM	-0.001	0.004	-0.396	0.693
ANC2Asian	-0.002	0.006	-0.398	0.692
ANC2Hispanic Black	0.005	0.008	0.634	0.528
ANC2Hispanic Multiracial	0.007	0.011	0.662	0.51
ANC2Hispanic Native	0.004	0.007	0.571	0.57
ANC2Non-Hispanic Black	0.009	0.006	1.463	0.147
ANC2Non-Hispanic Multiracial	0.038	0.013	2.994	0.004
ANC2Non-Hispanic White	0.01	0.01	0.965	0.337
(Intercept)	-0.024	0.01	-2.42	0.018
Age_Years	0.002	0.001	2.504	0.014
SexM	0.002	0.004	0.618	0.538
SESHigh	-0.003	0.01	-0.301	0.764
SESMiddle	-0.003	0.005	-0.608	0.545
(Intercept)	-0.029	0.01	-2.831	0.006
Age_Years	0.002	0.001	2.704	0.008
SexM	0	0.004	-0.04	0.968
FINS2Y	0.007	0.004	1.85	0.068
(Intercept)	-0.028	0.011	-2.517	0.014
Age_Years	0.002	0.001	2.875	0.005
SexM	0.001	0.004	0.207	0.837
BMI_Perc	0	0	0.029	0.977
(Intercept)	-0.027	0.01	-2.695	0.008
Age_Years	0.002	0.001	2.771	0.007
SexM	0	0.004	0.101	0.92
BMI_CatObesity	-0.001	0.004	-0.222	0.825
BMI_CatOverweight	0.002	0.005	0.455	0.65
BMI_CatUnderweight	0.012	0.009	1.307	0.194

Demographic Summary (Before Combined Variables)

Characteristic	N	N = 97[1]
Age_Years	97	13.20 (11.50, 15.00)
Sex	97	
F		43 (44%)
M		54 (56%)
ANC2	94	
Hispanic White		53 (56%)
Asian		9 (9.6%)
Hispanic Black		5 (5.3%)
Hispanic Multiracial		3 (3.2%)
Hispanic Native		8 (8.5%)
Non-Hispanic Black		11 (12%)
Non-Hispanic Multiracial		2 (2.1%)
Non-Hispanic White		3 (3.2%)
Unknown		3
SES	92	
Low		74 (80%)
High		3 (3.3%)
Middle		15 (16%)
Unknown		5
FINS2	85	
N		56 (66%)
Y		29 (34%)
Unknown		12
BMI_Perc	97	86 (57, 96)
BMI_Cat	97	
Normal		41 (42%)
Obesity		31 (32%)
Overweight		21 (22%)
Underweight		4 (4.1%)

[1] Median (IQR); n (%)

INTERPRETATION OF RESULTS

While this study did not find statistically significant differences in facial skeletal growth timing or shape between children with and without obesity, the findings contribute valuable insight and suggest that further investigation—particularly with larger, more diverse samples—may help uncover subtle associations and clarify the role of ancestry in obesity-related shape variation.

Demographics

We observed a slight discrepancy in the number of male (n=54, 56%) and female (n=43, 44%) participants. However, this is unlikely to have influenced our results as we controlled for age and sex in our data analysis. Most subjects were of Hispanic ancestry (73%) and had low socioeconomic status (80%), which aligns with the typical patient population we treat at the UIC Department of Orthodontics. However, according to the 2020 U.S. Census, the representation of Hispanic subjects in our sample (73%) was much greater than the national average (18.7%). Similarly, our study displayed a higher percentage of Black (18%) and Asian (9.9%) subjects compared to the national average (12.1% Black; 6.1% Asian) (Frey, 2021). These demographic characteristics suggest that our study focused mainly on minority adolescent health, particularly Hispanic youth, which may limit the generalizability of our findings to the broader U.S. population. Our sample also displayed higher rates of low SES (80%) and food insecurity (34%) compared to national averages (low SES 15%; food insecurity 13.9%) ("Today's Low-Income America."; Fleming et al., 2021). However, this finding is consistent with some studies focusing particularly on vulnerable youth populations which highlight food insecurity among adolescents (25% for ages 11-14y and 30% for ages 15-18y) (Fram et al., 2022).

The overall prevalence of overweight and obesity in our sample (56%) and median BMI percentile (86) was higher than what has been reported in national studies. According to Ogden and colleagues, 31.7% of children and adolescents between the ages of 2-19 years were at or above the 85th percentile (Ogden et al., 2010), which is much lower than the 56% reported in our sample. Vora and colleagues reported a subtle yet significant difference in cranial skeletal morphology between children and adolescents with and without obesity (Vora et. al., 2022). However, our study did not find any significant differences in size or shape between subjects with obesity and those without. We did, however, observe a higher percentage of obese subjects (32%) in our sample compared to what has been reported in previous studies. For example, in the 2010 study by Ogden et al., only 16.9% of children were classified as obese. Our data are also higher than what has been seen in other studies of retrospective data from the UIC Departments of Orthodontics (Gordon et al., 2021) and Pediatric Dentistry (Strumpf et al., 2023). In the former study, data was retrospectively collected for adolescent patients (n=181) seen between January 1, 2000 – October 16, 2018. Among that sample, 45% of subjects had overweight or obesity (Gordon et al. 2021). In the latter study, retrospective data from patients (n=281) seen at the UIC Pediatrics or Orthodontics clinics between January 2012 – August 2018 was collected. In this somewhat younger sample (mean age = 8.84 years), 43.7% of individuals had overweight

or obesity (Strumpf et al, 2023). This could be indicative of a recent rise in childhood obesity since the COVID-19 pandemic. This finding is supported by a recent study by Wang et al that reported a rise in pediatric obesity rates from 19.3% in 2019 to 22.4% in 2020 (Wang et al., 2024).

Geometric Morphometrics Analysis (PCA)

Our key findings suggest that BMI and ancestry are not associated with PC1 (31.67% of total variation). Instead, PC1 shape is likely related to variation in clinical presentation, i.e., Class II or Class III skeletal relationships, especially considering that our sample consisted of subjects with orthodontic needs. BMI and ancestry were also not associated with PC2 (20.36% of total variation), which describes anterior facial height and mandibular rotation. We hypothesize that, again, aspects of clinical presentation are driving variation in the sample, such as horizontal (hypo-divergent) or a vertical (hyper-divergent) mandibular growth pattern (steep/high and flat/low Frankfort mandibular plane angles (FMA)).

For PC3 (9.87% of total variation), older, and Black male subjects had a tendency towards having a more positive PC3, while non-Hispanic Asians were represented on the other end of the range of variation. The positive end of the range of variation is characterized by greater midfacial prognathism and a more acute gonial angle. For PC4 (5.36% of total variation), older subjects had greater nasal bridge protrusion, ramus length, and midfacial protrusion. While it is not surprising to see age-related differences in shape, it should be noted that these data are allometrically scaled, meaning that the influence of size on shape has been controlled for. Therefore, what is depicted in PC4 represents pure, non-allometric shape variation across ages. This could represent differences in ancestry or sex composition across age groups; larger sample sizes will be needed to examine this further.