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Article

# Childhood Obesity and Craniofacial Growth: An Orthodontic Cephalometric Study

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## Abstract

**Background:** Childhood obesity has become a major global health concern and is increasingly recognized as a factor influencing skeletal development. Emerging evidence suggests that excess adiposity may alter craniofacial growth patterns, potentially affecting orthodontic diagnosis, treatment planning, and airway function. However, the extent to which obesity influences craniofacial morphology in growing individuals remains incompletely understood. **Objective:** To evaluate the relationship between body mass index (BMI) and craniofacial morphology in children and adolescents using selected sagittal and linear craniofacial parameters, and to determine the independent effects of age and sex on these associations. **Methods:** This cross-sectional orthodontic study included 130 healthy subjects aged 19 or younger. Anthropometric measurements were recorded, and BMI was calculated to classify participants into normal weight, overweight, and obese groups. Standardized lateral cephalometric radiographs were obtained, and twenty-one skeletal and soft-tissue parameters were analyzed. Statistical evaluation included tests of normality, one-way ANOVA, and post-hoc comparisons to assess differences according to BMI, sex, and age groups. **Results:** Obesity was significantly associated with increased sagittal skeletal dimensions. Mandibular body length, mandibular unit length, SNB angle, and maxillary unit length demonstrated progressive increases across BMI categories ( $p < 0.05$ ). In contrast, vertical growth parameters showed no significant differences. Soft-tissue analysis revealed reduced facial convexity and lower facial height ratios in obese subjects. Age was strongly associated with increases in linear jaw dimensions, whereas sex differences were limited primarily to skeletal size rather than morphological relationships. **Conclusions:** Childhood obesity is associated with enhanced sagittal craniofacial growth, particularly involving mandibular structures, while vertical skeletal patterns remain largely unaffected. These findings highlight the importance of incorporating BMI assessment into orthodontic evaluation and suggest that obesity may influence growth timing, facial morphology, and airway-related risk factors.

**Keywords:** orthodontics; childhood obesity; body mass index; cephalometry; craniofacial growth; mandibular development; skeletal maturation

## Introduction

Childhood obesity has become one of the most significant global public health challenges, with its prevalence increasing substantially over the past several decades [1]. Data from the National

Health and Nutrition Examination Survey (NHANES) indicate that prevalence rose from approximately 5% in the 1960s to 10–12% during 1988–1994, reaching nearly 16% by the early 2000s [2]. This upward trend is accompanied by pronounced ethnic and socioeconomic disparities. For example, a large survey among primary school children in New York City reported that approximately 41% were overweight and 22% obese, with higher rates observed among Hispanic and African-American populations compared to Caucasian and Asian groups [3].

The etiology of childhood obesity is complex and multifactorial. Genetic predisposition, particularly variations affecting leptin metabolism and appetite regulation, plays an important role [4,5]. However, environmental and behavioral factors remain major contributors [6]. Sedentary lifestyles, especially prolonged screen exposure, reduce physical activity while simultaneously increasing exposure to advertising for energy-dense foods, thereby promoting excessive caloric intake [2]. Dietary patterns have also shifted toward increased consumption of refined carbohydrates, sugar-sweetened beverages, and high-glycemic foods, contributing to metabolic imbalance and fat accumulation. Psychosocial determinants such as chronic stress, family instability, depression, and low socioeconomic status further increase obesity risk, while parental obesity strongly predicts childhood obesity [2,3].

Childhood obesity is associated with numerous systemic and psychosocial complications. Cardiometabolic consequences include hypertension, dyslipidemia, insulin resistance, and type II diabetes, with approximately 80–85% of pediatric diabetes cases occurring in overweight or obese children [4,5]. Other associated conditions include polycystic ovarian syndrome, fatty liver disease, gallstones, orthopedic abnormalities such as Blount's disease, asthma, and obstructive sleep apnea related to airway narrowing and craniofacial anatomical factors [6,7]. Beyond physical morbidity, obese children frequently experience reduced self-esteem, social stigmatization, and long-term socioeconomic disadvantages [8].

In recent years, increasing attention has been directed toward the potential relationship between obesity and craniofacial development. Orthodontic research suggests that obesity is associated with measurable differences in craniofacial morphology that may influence airway dimensions and susceptibility to obstructive sleep apnea [9]. Cephalometric studies report that obese individuals often exhibit longer cranial bases, reduced ANB angles, and more anterior mandibular positioning compared with normal-weight peers, indicating a tendency toward altered sagittal skeletal relationships [9,10]. Three-dimensional soft-tissue analyses further demonstrate increased facial widths, larger mandibular dimensions, and deeper facial profiles in obese adolescents, with similar tendencies observed even in mildly overweight individuals [10].

Additional evidence indicates that obesity may be associated with craniofacial development through endocrine pathways, including alterations in growth hormone activity. Cephalometric investigations have reported increased linear measurements of the mandible, maxilla, and anterior cranial base in obese subjects, with the most pronounced differences involving mandibular length [9–11]. These findings support the concept that obese children may exhibit differences in skeletal growth timing and maturation patterns during development [9–11].

Beyond systemic health implications, childhood obesity has important relevance for orthodontic diagnosis and treatment planning [9–12]. Because orthodontic patients are typically evaluated during active growth periods, variations in skeletal maturation can substantially influence diagnostic interpretation, treatment timing, and therapeutic outcomes [13]. Obesity-related differences in craniofacial growth may affect sagittal jaw relationships, facial profile harmony, and airway morphology, thereby increasing susceptibility to sleep-disordered breathing [6,7,14].

Despite growing interest in this field, the association between excess body weight and craniofacial morphology remains incompletely understood. Existing studies are often limited by small sample sizes, methodological heterogeneity, and inconsistent evaluation of both skeletal and soft-tissue structures [9]. These limitations highlight the need for integrated investigations combining anthropometric assessment with cephalometric analysis to clarify the extent to which obesity is associated with craniofacial growth patterns [15].

Therefore, this orthodontic study aimed to evaluate the relationship between body mass index and craniofacial morphology using selected cephalometric parameters, while also examining the influence of age and sex on these associations [11,12].

## 2. Materials and Methods

### 2.1. Study Design and Ethical Approval

This cross-sectional observational study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee of the participating university hospital (Approval No. 2709/27.12.2023). Written informed consent was obtained from all participants and their parents or legal guardians before inclusion.

### 2.2. Study Population and Sample Selection

The study sample consisted of 130 consecutively recruited subjects aged between 4 and 19 years who presented for orthodontic evaluation at a university orthodontic department over six months.

Inclusion criteria were:

- Age  $\leq$  19 years at the time of examination
- Absence of craniofacial syndromes or congenital anomalies
- No history of previous orthodontic treatment
- Availability of high-quality standardized lateral cephalometric radiographs

Exclusion criteria included:

- Systemic conditions known to affect growth or bone metabolism
- History of craniofacial trauma or surgery
- Radiographs with positioning errors or insufficient diagnostic quality

Because participants were recruited from an orthodontic population, the sample represents individuals seeking orthodontic care rather than the general pediatric population.

### 2.3. Anthropometric Assessment and BMI Classification

Body weight was measured to the nearest 0.1 kg using a calibrated digital scale, and height was measured to the nearest 0.1 cm using a stadiometer under standardized conditions. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared ( $\text{kg}/\text{m}^2$ ).

Participants were categorized according to World Health Organization (WHO) BMI-for-age percentile standards:

- Normal weight: BMI between the 5th and 85th percentile
- Overweight: BMI between the 85th and 95th percentile
- Obesity: BMI  $\geq$  95th percentile

BMI percentiles were calculated using WHO AnthroPlus software based on the WHO 2007 growth reference [16].

### 2.4. Cephalometric Imaging and Analysis

Standardized lateral cephalometric radiographs were obtained using the same digital cephalometric unit under identical exposure parameters. All images were acquired with subjects positioned in natural head posture, teeth in centric occlusion, and lips at rest.

Cephalometric tracing and measurements were performed using Dolphin Imaging software (Version 11.95, Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) by a single calibrated examiner under standardized conditions.

The following skeletal and soft-tissue variables were analyzed:

Sagittal skeletal parameters

- SNA angle ( $^{\circ}$ )

- SNB angle (°)
- ANB angle (°)
- Linear skeletal measurements
- Maxillary unit length (mm)
- Mandibular unit length (mm)
- Mandibular body length (mm)
- Soft-tissue parameters
- Facial convexity angle (°)
- Lower-to-total facial height ratio (%)

### 2.5. Measurement Reliability

To assess intra-observer reliability, 20 randomly selected radiographs were retraced after a two-week interval. Intraclass correlation coefficients (ICCs) ranged from 0.92 to 0.97, indicating excellent measurement reproducibility.

### 2.6. Age Stratification and Growth Phase Classification

Participants were stratified into four age groups representing biologically relevant developmental stages:

- 4.0–10.9 years: prepubertal growth phase
- 11.0–12.9 years: pubertal onset phase
- 13.0–14.9 years: peak pubertal growth phase
- 15.0–19.9 years: post-pubertal maturation phase

This classification was based on established associations between chronological age ranges and cervical vertebral maturation (CVM) stages described in orthodontic growth studies [17,18].

Age stratification was designed to reflect biologically relevant skeletal maturation stages based on established cervical vertebral maturation (CVM) protocols. Chronological age ranges were selected to approximate the developmental phases corresponding to CVM stages described by Baccetti, Franchi, and McNamara [17,18], thereby enabling biologically meaningful evaluation of obesity-related craniofacial growth differences. The youngest group (4.0–10.9 years) predominantly represented prepubertal development (CVM stages 1–2), characterized by relatively stable craniofacial growth rates. The 11.0–12.9-year group corresponded to the onset of the pubertal growth spurt (CVM stage 3), during which acceleration of mandibular growth typically begins. Participants aged 13.0–14.9 years reflected the peak pubertal growth phase (CVM stage 4), associated with maximum mandibular elongation and pronounced sagittal skeletal changes. The oldest group (15.0–19.9 years) represented post-pubertal maturation stages (CVM stages 5–6), during which craniofacial growth progressively stabilizes as skeletal development approaches completion [17,18].

This classification allowed the present study to evaluate obesity-related craniofacial differences in relation to biologically meaningful growth phases rather than relying solely on chronological age, thereby improving the interpretability and orthodontic relevance of the findings.



**Figure 1.** Developmental phases aligned with Cervical Vertebrae Maturation CVM.

### 2.7. Statistical Analysis

Statistical analysis was performed using SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA).

The analytical workflow included:

1. Normality assessment using the Shapiro–Wilk test
2. Descriptive statistics reported as mean  $\pm$  standard deviation
3. One-way ANOVA to evaluate differences among BMI groups
4. Tukey post-hoc testing for pairwise comparisons
5. Independent t-tests to assess sex differences
6. Two-way ANOVA to examine independent effects of age and BMI
7. Multivariate linear regression analysis to determine independent predictors of craniofacial parameters after adjustment for age and sex. Ninety-five percent confidence intervals were calculated for all regression coefficients.

Effect sizes were evaluated using partial eta squared ( $\eta^2$ ) for ANOVA models.

Statistical significance was set at:  $p < 0.05$

### 2.8. Sample Size Considerations

Based on post-hoc power analysis, the sample size provided >80% statistical power to detect moderate effect sizes at  $\alpha = 0.05$ .

## 3. Results

### 3.1. Sample Characteristics

The study included 130 participants, of whom 73% were classified as normal weight, 14% overweight, and 13% obese. Females represented a slightly larger proportion of the sample. The largest age group corresponded to early-to-mid adolescence (Table 1).

**Table 1.** Distribution of participants.

Variable	Category	n
BMI	Normal weight	95
	Overweight	18
	Obese	17
Sex	Male	53
	Female	77
Age group	4–10.9 yrs	26
	11–12.9 yrs	39
	13–14.9 yrs	42
	15–19.9 yrs	23

Most participants were of normal weight (73%), with a slightly higher female representation. The largest proportion belonged to early-to-mid adolescence.

### 3.2. Data Distribution

All cephalometric variables demonstrated normal distribution according to the Shapiro–Wilk test, allowing the use of parametric statistical methods (Table 2).

**Table 2.** Shapiro–Wilk normality testing for key cephalometric variables.

Parameter	W value	p value	Distribution
SNA	0.972	0.118	Normal
SNB	0.968	0.094	Normal
ANB	0.955	0.061	Normal
Maxillary unit length	0.979	0.164	Normal
Mandibular unit length	0.966	0.083	Normal
Mandibular body length	0.971	0.107	Normal
Facial convexity angle	0.963	0.072	Normal
Facial height ratio	0.976	0.149	Normal

All primary variables demonstrated normal distribution, allowing parametric statistical testing.

### 3.3. Craniofacial Differences According to BMI

Significant associations were observed between BMI and sagittal craniofacial dimensions (Table 3). Mandibular unit length, mandibular body length, SNB angle, and maxillary unit length progressively increased across BMI categories ( $p < 0.05$ ).

In contrast, vertical skeletal parameters did not differ significantly among BMI groups.

Soft-tissue analysis demonstrated reduced facial convexity and lower facial height ratios in obese subjects, indicating a tendency toward a less convex facial profile.

### 3.4. Sex-Related Differences

Male participants exhibited significantly larger linear skeletal dimensions, including anterior cranial base length, maxillary unit length, and mandibular unit length ( $p < 0.01$ ). However, no significant sex differences were observed in angular skeletal relationships or soft-tissue parameters.

### 3.5. Age-Related Craniofacial Changes

Age was strongly associated with increases in maxillary and mandibular linear dimensions. The most pronounced growth occurred between the prepubertal and early pubertal groups, corresponding to the onset of accelerated skeletal development.

Smaller increments were observed during later adolescence, indicating stabilization of craniofacial growth as skeletal maturity approached.

Table 3 shows clearly: progressive mandibular dominance with BMI, reduced ANB in obesity, thus sagittal prognathic tendency, increased skeletal linear dimensions, decreased facial convexity, and reduced vertical proportional balance

The results demonstrate that BMI is primarily correlated with sagittal craniofacial development, especially mandibular growth and positioning, while vertical skeletal relationships remain largely unaffected. Age mainly impacts linear skeletal growth, and sexual dimorphism is predominantly related to skeletal size rather than morphology.

**Table 3.** Cephalometric parameters by BMI category.

Parameter	Normal weight	Overweight	Obese	p value
SNA (°)	82.4 ± 3.0	85.0 ± 3.3	84.1 ± 3.1	0.010
SNB (°)	79.2 ± 2.9	81.5 ± 3.0	82.4 ± 3.2	0.003
ANB (°)	3.2 ± 1.8	3.5 ± 1.7	1.7 ± 1.6	0.012
Maxillary unit length (mm)	97.0 ± 4.1	98.6 ± 4.4	100.1 ± 4.3	0.017

Mandibular unit length (mm)	123.0 ± 6.6	126.4 ± 7.0	129.6 ± 6.7	0.002
Mandibular body length (mm)	74.0 ± 5.1	76.5 ± 5.0	78.2 ± 5.3	0.013
Facial convexity angle (°)	15.3 ± 4.1	12.8 ± 3.8	10.1 ± 3.4	0.005
Facial height ratio (%)	95.4 ± 3.6	91.1 ± 4.0	87.2 ± 4.3	0.007

### 3.6. Age–BMI Interaction Results

Two-way ANOVA analysis demonstrated significant independent effects of both age and BMI on craniofacial morphology (Table 4). Age exerted a strong influence on linear skeletal parameters, with progressive increases observed in maxillary and mandibular dimensions across developmental stages. The most pronounced growth occurred between the prepubertal and early pubertal groups, followed by smaller increments and near stabilization in late adolescence.

BMI showed a significant independent association primarily with sagittal skeletal relationships. Higher BMI values were correlated with increased SNB angle, greater mandibular body and unit lengths, and reduced facial convexity, indicating a tendency toward enhanced mandibular prognathism in overweight and obese subjects. Vertical proportional relationships remained relatively stable, although facial height ratio demonstrated modest reductions in older and higher-BMI groups.

No significant interaction effect between age and BMI was identified, suggesting that obesity primarily amplifies normal growth patterns rather than altering their developmental timing.

A significant difference was observed among BMI groups for mandibular length ( $F = 8.45$ ,  $p < 0.001$ ,  $\eta^2 = 0.12$ ), indicating a moderate effect size.

**Table 4.** Influence of age and BMI on key craniofacial parameters.

Parameter	4–10.9 yrs	11–12.9 yrs	13–14.9 yrs	15–19.9 yrs	Age Effect (p)	BMI Effect (p)
SNA (°)	81.2 ± 2.9	82.5 ± 3.1	83.2 ± 3.3	83.6 ± 3.5	0.039	0.010
SNB (°)	77.8 ± 3.1	79.6 ± 3.2	80.9 ± 3.4	81.3 ± 3.6	<0.001	<0.001
ANB (°)	3.4 ± 1.9	2.9 ± 1.8	2.3 ± 1.7	2.1 ± 1.6	0.021	0.012
Maxillary unit length (mm)	93.5 ± 4.6	96.1 ± 4.4	98.0 ± 4.8	99.0 ± 5.1	<0.001	0.017
Mandibular unit length (mm)	118.3 ± 6.2	123.5 ± 6.6	127.3 ± 7.1	129.0 ± 7.4	<0.001	<0.001
Mandibular body length (mm)	70.0 ± 4.2	73.5 ± 4.6	76.1 ± 5.0	76.9 ± 5.2	<0.001	0.013
Facial convexity angle (°)	16.4 ± 4.6	14.2 ± 4.4	11.9 ± 4.2	11.0 ± 4.3	<0.001	0.005
Facial height ratio (%)	96.6 ± 5.2	92.1 ± 4.9	89.3 ± 4.7	87.7 ± 4.5	<0.001	0.007

Values expressed as mean ± SD. Two-way ANOVA tested the independent effects of age and BMI.

### 3.7. Multivariate Regression Analysis

Multivariate regression analysis confirmed that BMI independently predicted several craniofacial parameters after adjustment for age and sex.

Higher BMI was significantly associated with increased mandibular prognathism, reflected by greater SNB angle and mandibular unit length, as well as reduced ANB angle and facial convexity.

Age remained the strongest determinant of linear skeletal growth, while sex showed a moderate influence primarily related to skeletal size.

**Table 5.** Multivariate Linear Regression Analysis of Factors Influencing Craniofacial Parameters.

Dependent Variable	Predictor	$\beta$ Coefficient	Standard Error	p value
SNB (°)	BMI	0.18	0.05	<0.001
	Age	0.22	0.04	<0.001
	Sex(Male)	0.09	0.03	0.014
Mandibular unit length (mm)	BMI	0.36	0.07	<0.001
	Age	0.48	0.06	<0.001
	Sex (Male)	0.21	0.05	0.002
ANB (°)	BMI	-0.14	0.04	0.001
	Age	-0.09	0.03	0.019
	Sex (Male)	-0.05	0.02	0.087
Facial convexity angle (°)	BMI	-0.31	0.06	<0.001
	Age	-0.28	0.05	<0.001
	Sex (Male)	-0.07	0.03	0.041

*All regression models demonstrated good explanatory power, with adjusted R<sup>2</sup> values ranging from 0.41 to 0.63. Regression coefficients are presented with 95% confidence intervals.*

## Discussion

The present study provides evidence that childhood obesity is associated with measurable differences in craniofacial morphology, primarily involving sagittal skeletal dimensions [9,12]. The findings demonstrate a consistent pattern of increased mandibular and maxillary linear measurements in overweight and obese subjects, accompanied by progressive increases in SNB angle and reductions in soft-tissue convexity [10]. These results collectively suggest a tendency toward greater mandibular prominence and altered sagittal facial relationships in children with elevated body mass index [10,12,19]. Importantly, vertical skeletal parameters remained largely unchanged, indicating that obesity appears to be selectively associated with anteroposterior craniofacial growth rather than vertical facial development. These observations differ from some previous reports suggesting proportionally increased anteroposterior and vertical craniofacial dimensions in overweight children and adolescents [20].

Obesity-related craniofacial differences were most evident during the pubertal growth phase, suggesting a possible interaction between metabolic status and periods of accelerated skeletal maturation [9,21].

The enlargement of mandibular dimensions represented the most pronounced morphological change identified in this investigation. Mandibular unit length showed the strongest association with BMI, displaying a progressive increase across weight categories. This pattern supports the hypothesis

that increased adiposity may be associated with enhanced skeletal growth activity during critical developmental periods [22]. The mandibular condyle, as a major site of endochondral growth, is known to be responsive to systemic metabolic and hormonal influences, and increased growth activity in obese individuals may reflect altered endocrine regulation [23]. Previous studies suggest that hyperinsulinemia and elevated insulin-like growth factor-1 levels, commonly observed in obese children, have been proposed to stimulate chondrocyte proliferation and matrix deposition within condylar cartilage, thereby contributing to increased mandibular growth [24,25]. In addition, leptin and other adipokines secreted by adipose tissue may further modulate bone metabolism and growth plate activity, potentially influencing skeletal enlargement in this population [26,27].

The observed increase in maxillary length in obese subjects, although less pronounced than mandibular changes, indicates that obesity may be associated with broader craniofacial skeletal development rather than isolated mandibular growth alone [9,28]. However, the predominance of mandibular differences suggests a differential sensitivity of craniofacial structures to metabolic and hormonal influences, with the mandible appearing particularly responsive to obesity-related growth variations [29]. This observation is consistent with previous cephalometric and three-dimensional imaging studies reporting larger mandibular dimensions and more prognathic skeletal profiles in overweight adolescents [9,10].

In contrast to sagittal findings, vertical craniofacial parameters did not demonstrate significant differences across BMI groups. This suggests that obesity may not substantially modify vertical growth patterns or facial divergence, reinforcing the concept that the primary craniofacial associations of increased adiposity relate to forward skeletal growth rather than vertical rotational changes [9,30]. The relative stability of vertical measurements across BMI categories also supports the view that intrinsic growth direction is largely genetically determined and less susceptible to metabolic influences [31,32].

Soft-tissue analysis revealed a reduction in facial convexity and lower facial height ratios among obese subjects. These changes likely reflect both underlying skeletal differences and increased soft-tissue thickness associated with adipose deposition [33,34]. The reduction in convexity has clinical relevance, as it may mask or exaggerate underlying skeletal discrepancies, potentially complicating orthodontic diagnosis [35]. Furthermore, altered soft-tissue profiles in obese individuals may contribute to reduced upper airway dimensions and increased susceptibility to obstructive sleep apnea [36]. The interaction between craniofacial morphology and airway patency represents an important interdisciplinary consideration in pediatric orthodontic assessment [36,37].

Age stratification according to biologically defined growth phases represents a methodological strength of this study. By grouping participants according to prepubertal, pubertal transition, peak growth, and late maturation stages, the analysis accounts for known variations in craniofacial growth velocity, particularly mandibular development, thereby reducing age-related confounding and improving the interpretability of BMI-related skeletal associations [38,39].

Sex-related differences observed in this study were limited to linear skeletal dimensions, with males demonstrating larger cranial base and jaw lengths compared to females. These findings are consistent with established patterns of sexual dimorphism in craniofacial growth and reflect overall differences in skeletal size rather than morphological pattern [40]. The absence of significant differences in angular and soft-tissue parameters suggests that obesity-related craniofacial variations occur similarly in both sexes [9,40].

Age-related analysis revealed expected progressive increases in maxillary and mandibular lengths throughout childhood and adolescence, with the most pronounced growth occurring during early developmental stages [17,18]. The attenuation of differences in late adolescence suggests that skeletal maturation eventually reduces variability in craniofacial dimensions, supporting previous observations that obesity may be associated with earlier attainment of peak growth velocity without necessarily altering final adult morphology [10,29].

From a clinical perspective, these findings underscore the importance of incorporating anthropometric assessment into orthodontic diagnostic protocols [41]. Failure to consider BMI may

lead to misinterpretation of skeletal relationships, particularly in cases presenting with apparent mandibular prognathism [19,23,25,28]. Moreover, differences in growth patterns among obese patients may influence the timing and effectiveness of orthopedic treatment interventions, highlighting the need for individualized treatment planning.

Despite its strengths, including standardized radiographic methodology, selected craniofacial parameters, and high measurement reliability, this study has several limitations. The cross-sectional design precludes evaluation of longitudinal growth trajectories and does not allow causal inference. Additionally, BMI does not reflect fat distribution patterns or metabolic status, which may differentially influence skeletal growth [27,32]. Future longitudinal investigations incorporating hormonal assessments and advanced three-dimensional imaging are needed to further clarify the biological mechanisms underlying obesity-related craniofacial differences. Unmeasured confounders such as pubertal status, endocrine variations, and breathing patterns may have influenced craniofacial morphology, and the orthodontic sample limits generalizability to the broader pediatric population.

**Supplementary Materials:** The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

**Author Contributions:** Conceptualization, Sorana Maria Bucur; Methodology, Sorana Maria Bucur; Software, Dorin Ioan Cocos; Validation, Cristian Olteanu and Eugen Bud; Formal analysis, Mioara Decusară; Investigation, Dorin Ioan Cocos, Cristian Olteanu and Mariana Păcurar; Resources, Cristian Olteanu and Mariana Păcurar; Data curation, Dorin Ioan Cocos; Writing – original draft, Sorana Maria Bucur; Writing – review & editing, Sorana Maria Bucur; Visualization, Mioara Decusară and Eugen Bud; Supervision, Eugen Bud. All authors have read and agreed to the published version of the manuscript.

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