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Growth Pattern Analysis of Facial Types Using Geometric Morphometric Methods

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ABSTRACT

Vertical facial divergence patterns are clinically significant due to their strong association with malocclusion and orofacial functional imbalances. Gaining insight into how these divergence types develop throughout growth is essential for tailoring effective orthodontic interventions. This research explores and contrasts craniofacial growth behavior from childhood through adulthood among three vertical facial divergence categories using a longitudinal series of lateral cephalograms derived from the Craniofacial Growth Consortium Study. The study examined 371 participants (183 females, 188 males), who were grouped based on their adult mandibular plane angle (MPA): hyperdivergent (MPA > 39°, n = 40), normodivergent (28° ≤ MPA ≤ 39°, n = 216), and hypodivergent (MPA < 28°, n = 115). Each subject contributed five cephalograms spanning ages 6–20. Thirty-six anatomical landmarks were digitized on each radiograph, aligned using five stable reference points from the anterior cranial base, and normalized by centroid size. Growth patterns for each facial type and sex were modeled through multivariate regression analysis. Analysis revealed distinct developmental trajectories among facial types, with normodivergent and hypodivergent individuals following comparable growth paths, while the hyperdivergent group exhibited a markedly different pattern. Geometric morphometric evaluation uncovered unique features of vertical facial development: hyperdivergent subjects displayed a downward rotation of the maxilla–mandible complex relative to the cranial base and pronounced elongation of the lower anterior facial region. Conversely, normodivergent and hypodivergent participants maintained a stable maxillary orientation accompanied by forward mandibular rotation. Additionally, in hyperdivergent cases, both the maxilla and mandible tended to be shorter and positioned more posteriorly with advancing age. The findings suggest that the distinctive characteristics of hyperdivergent craniofacial growth—particularly the limited forward development of the maxilla—may increase susceptibility to Class II malocclusion. Further studies are needed to refine the understanding of internal growth variations within each vertical facial divergence category.

Keywords: Geometric morphometrics, Vertical facial divergence, Craniofacial growth pattern, Mandibular plane angle (MPA)

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Introduction

In orthodontic diagnosis, treatment planning, and prognosis, classifying facial and dental morphology is a fundamental practice. Schudy [1] was the first to define the relationship between vertical and anteroposterior facial growth as distinct patterns of facial divergence—namely hyperdivergent, normodivergent, and hypodivergent types. Since then, various terminologies have been introduced to describe similar morphologic characteristics. The hyperdivergent skeletal pattern has also been referred to as “open bite” [2–4] or “long face syndrome” [5–7], whereas the hypodivergent form has been described as “deep bite” [2–4] or “short face syndrome” [6, 8]. Although Schudy’s [1] classification relied on the mandibular plane angle (MPA), alternative parameters have been used to categorize vertical facial divergence, such as the anterior-to-posterior facial height ratio [6], the ratio of lower anterior to total anterior facial height [2–4], and the angle formed between the mandibular and Frankfort horizontal planes [6].

The clinical relevance of these classifications lies in their association with malocclusion, as well as aesthetic and functional concerns. Hyperdivergent facial types are frequently linked to anterior open bite, characterized by minimal or absent vertical overlap of the upper and lower incisors [9]. Additionally, skeletal hyperdivergence is correlated with diminished masticatory efficiency [10–13] and restricted airway dimensions [14]. Conversely, hypodivergent facial patterns often correspond to deep bites or excessive vertical overlap of the incisors, which may impede mandibular movement and contribute to temporomandibular joint dysfunction [15, 16].

Recognizing how morphology and growth vary across vertical divergence types is essential for effective clinical management and accurate prognostic assessment. Differences in skeletal morphology are typically observable as early as 5–6 years of age [6, 17–20]. Although most research agrees that facial divergence primarily affects the lower face and mandible, the specific morphometric variables distinguishing these facial types differ among studies [6, 17–19, 21,22].

Past cephalometric investigations utilizing linear and angular measurements to assess craniofacial growth across facial divergence patterns have produced inconsistent findings. Bishara and Jakobsen [6] reported parallel growth trajectories for most craniofacial dimensions between ages 5 and 25, suggesting that intergroup differences were established early and maintained during subsequent growth. In contrast, Karlsen [17, 18] observed variations in growth until around age 12, whereas Nanda [2] identified differences emerging during the adolescent growth spurt, resulting in increased divergence among facial types. Such inconsistencies may stem from variations in sample selection, classification criteria, or the age at which participants were categorized, emphasizing the need for standardized comparative studies.

In the present research, geometric morphometric methods (GMM)—a multivariate, landmark-based analytical technique—were employed to investigate craniofacial morphology and growth differences among three skeletal facial divergence types. Unlike conventional cephalometric approaches that rely on isolated linear and angular measurements, GMM retains the spatial configuration of landmarks, enabling the assessment of integrated vertical and anteroposterior growth patterns. This methodology was applied to reconcile discrepancies among earlier findings concerning hyperdivergent, normodivergent, and hypodivergent facial growth. The study aimed to (1) describe and compare growth trajectories among these three facial divergence categories and (2) identify age-related shape differences across facial types.

Materials and Methods

The Craniofacial Growth Consortium Study (CGCS) comprises a collection of longitudinal lateral cephalograms derived from six historical craniofacial growth studies conducted in the United States between 1930 and 1982, primarily involving participants of European ancestry [19, 20, 23]. For the present investigation, 1,855 cephalograms from 371 individuals (183 females and 188 males) were analyzed. Each participant contributed one cephalogram from five distinct age intervals—6–8, 9–11, 12–14, 15–17, and 18–20 years—resulting in five images per person. In cases where multiple cephalograms existed within an age group, the film taken closest to the median age of that interval was selected for analysis.

The 6–20-year age range was chosen to encompass the primary developmental period relevant to clinical interventions targeting facial growth and to maximize data availability. Although several prior investigations have emphasized the potential importance of facial changes occurring after adolescence [24–31], the extent and clinical impact of such modifications remain debatable [24, 25, 28]. The most noticeable postadolescent change typically occurs in anterior facial height, yet this increase rarely exceeds 1 mm over a decade, a level generally regarded as the threshold for clinical relevance [25].

Facial type classification was determined based on adult craniofacial morphology, using cephalograms captured between 18 and 20 years of age. These classifications were then applied retrospectively to all earlier age records for the same individuals. The mandibular plane angle (MPA)—defined by the intersection of the sella–nasion and gonion–menton planes—served as the criterion for grouping participants into three categories: hypodivergent (MPA $< 28°$), normodivergent ($28° \leq$ MPA $\leq 39°$), and hyperdivergent (MPA $> 39°$) **(Table 1)**.

A total of 36 cephalometric landmarks **(Table 2; Figure 1)** were digitized on each radiograph to characterize craniofacial skeletal and anterior dental morphology. All datasets were complete, with no missing landmark information. Ethical approval for the study protocol was granted by the University of Missouri Institutional Review Board.

Table 1. Summary of sample by sex and adult facial type classification

Classification	Females		Males	
	Participants	Cephalograms	Participants	Cephalograms
Hyperdivergent	21	105	19	95
Normodivergent	113	565	103	515
Hypodivergent	49	245	66	330
Total	183	915	188	940

Table 2. Description of Landmarks Collected for This Study

No.	Landmark	Definition
1	Sella	Center point of the pituitary fossa
2	Nasion	The most forward and downward point on the frontal bone at the nasofrontal junction
3	Orbitale	Lowest point on the orbital rim of the more forward orbital image
4	Upper Incisor Apex	Intersection of the long axis of the most forward maxillary central incisor with its root-end contour
5	Point A	Deepest point on the maxillary bone surface curve between ANS and the maxillary central incisor's alveolar crest
6	Upper Incisor Edge	Tip of the incisal edge of the most forward maxillary central incisor
7	Lower Incisor Edge	Tip of the incisal edge of the most forward mandibular central incisor
8	Point B	Deepest point on the anterior mandibular curve between pogonion and the mandibular central incisor's alveolar crest
9	Lower Incisor Apex	Intersection of the long axis of the most forward mandibular incisor with its root-end contour
10	Pogonion	Most forward point of the bony chin at the midline
11	Menton	Lowest point on the mandibular symphysis
12	Condyle	Point on the condyle's posterior-superior contour farthest from pogonion
13	PNS	Intersection of the posterior extension of the palate's superior surface and the downward pterygomaxillary fissure extension
14	Basion	Lowest point on the anterior margin of the foramen magnum in the midsagittal plane
15	Porion	Highest point of the right ear's external auditory meatus
16	ANS	Most forward point of the anterior nasal spine
17	Glabella	Most forward point on the bony forehead
18	SE*	Midpoint between the intersections of the sphenoid bone's two great wings with the sphenoid plane
19	Point P*	Point of greatest convexity between the sella turcica's anterior contour and the sphenoid plane
20	PTM	Intersection of the foramen rotundum's inferior border with the pterygomaxillary fissure's posterior wall
21	Sigmoid	Deepest point of the sigmoid notch
22	Posterior Ramus	Point where the inflection begins on the posterior ramus
23	Coronoid	Tip of the coronoid process
24	Anterior Ramus	Deepest point in the anterior ramus
25	Infradentale	Most superior and anterior point of the mandibular alveolar process

26	Lingual L1	Most superior and anterior point of alveolar bone on the lingual surface
27	Lingual Point B	Intersection of a posterior extension of point B, parallel to the mandibular plane connecting gonion and menton, on the lingual cortical plate of the symphysis
28	Lingual Symphysis	Intersection of a posterior extension of pogonion, parallel to the mandibular plane connecting gonion and menton, on the lingual cortical plate of the symphysis
29	Antegonion	Deepest point of the antegonial notch
30	Prosthion	Most inferior and anterior point of the maxillary alveolar process
31	Front	Intersection of the orbit roof line and the frontal bone's internal cortical plate
32	Roof*	Highest point of the orbit roof, midway between Front and SE-S
33	SE-S*	Intersection of the sphenoid bone's greater wing and the orbit roof (midpoint between the two greater wings)
34	Ethmoid*	Intersection of the ethmoid bone's lateral border and the vertical extension of the most forward Key ridge
35	Zygoma	Lowest point of the most forward key ridge
36	Gonion	Average of the upper and lower gonion points

∗Anterior cranial base landmarks used for superimposition.

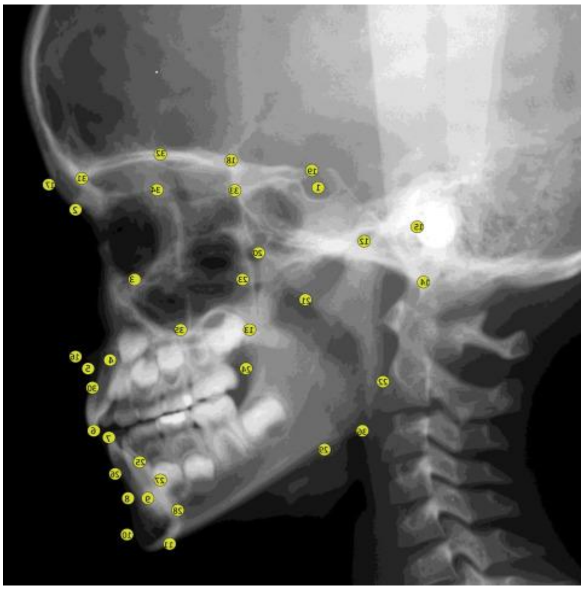

Figure 1. Illustration of the cephalometric landmarks utilized in this study, with numbers corresponding to descriptions in Table 2. Landmarks 18, 19, 32, 33, and 34 mark homologous points of the anterior cranial base used for superimposition

For each sex, landmark configurations were aligned using a modified generalized Procrustes analysis, removing differences in position, rotation, and scale so that only shape variation remained [32, 33]. Alignment was based on five anterior cranial base landmarks and scaled to the unit centroid size of the full landmark set **(Table 2; Figure1)**, producing shape coordinates for subsequent analyses.

To model craniofacial growth, multivariate regressions of shape variables on age [34, 35] were conducted separately for each adult facial type and sex. Here, growth trajectories represent age-related changes in landmark configuration. For each sex–facial type combination, four models (linear through fourth-order polynomial) were tested, with leave-one-out cross-validation and mean squared error determining the optimal fit. Predicted shapes were then generated at 1-year intervals from ages 6 to 20, providing annual mean shape estimates for each trajectory. Pairwise permutation tests [34] with 10,000 iterations assessed whether growth trajectories differed among facial types, using residual sums of squares as the test statistic.

Comparisons of growth trajectories by sex were further performed through principal component analysis (PCA) of age-shape space, which incorporates both age and predicted shape coordinates [36]. Shape changes were

visualized at ages 6, 10, 14, and 18 using wireframe plots [37]. Morphological differences between hyperdivergent and hypodivergent individuals were also highlighted at these ages.
To examine anteroposterior skeletal relationships, SNA (sella–nasion–point A), SNB (sella–nasion–point B), and ANB (point A–nasion–point B) angles were measured for each cephalogram. While GMM captures relative maxillomandibular positioning, these angles provide clinically meaningful measures for assessing Class I, II, and III skeletal relationships. Significant differences across facial types were tested using one-way ANOVA with Tukey's post-hoc comparisons. All analyses were performed in R using the Morpho, geomorph, and stats packages [38–40].

Results and Discussion

Quadratic models were selected for all six sex–facial type combinations in the multivariate regressions of shape on age **(Table 3)**. For both sexes, the first principal component (PC1) in age-shape space reflected the primary age-related changes, whereas the second principal component (PC2) distinguished hyperdivergent and hypodivergent trajectories, with the normodivergent trajectory positioned in between **(Figure 2)**. These results indicate distinct average craniofacial growth patterns for each facial type.
In females, trajectories gradually become more parallel with increasing age, whereas in males, hyperdivergent and hypodivergent growth paths continue to diverge from the normodivergent pattern. Projecting individual data onto the age-shape axes shows variability within each facial type, and although some overlap exists, permutation tests confirmed that growth trajectories differed significantly among all facial types ($P \leq 0.0003$; **Table 4**).

Table 3. Model comparison of the mean squared error using leave-one-out cross-validation

Classification	Linear	Second-order	Third-order	Fourth-order
Females				
Hyperdivergent	0.01048	0.01045	0.01047	0.01045
Normodivergent	0.01204	0.01198	0.01198	0.01199
Hypodivergent	0.01252	0.01241	0.01241	0.01247
Males				
Hyperdivergent	0.01107	0.01107	0.01109	0.01119
Normodivergent	0.01047	0.01039	0.01039	0.01039
Hypodivergent	0.01046	0.01041	0.01043	0.01045

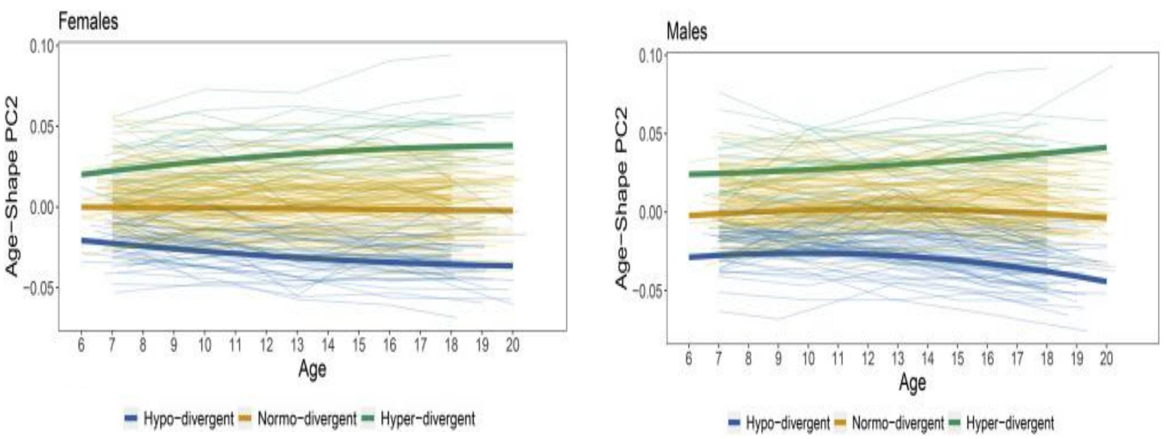

Figure 2. Visualization of the second principal component (PC2) from the age-shape space plotted across chronological age for females (top) and males (bottom). Each line illustrates the evolution of craniofacial shape over time for a given participant, with bold lines representing the mean growth trajectory of each facial type, and thin lines showing individual variations. Colors indicate facial type: blue for hypodivergent, yellow for normodivergent, and green for hyperdivergent

Table 4. P values from pairwise permutation tests with 10,000 iterations

Malesfemales	Hyperdivergent	Normodivergent	Hypodivergent
Hyperdivergent	–	0.0003	0.0001
Normodivergent	0.0001	–	0.0002
Hypodivergent	0.0001	0.0001	–

Note. Females, upper triangle; males, lower triangle.

Figure 3 displays the predicted craniofacial growth patterns for each facial type at ages 6, 10, 14, and 18, separated by sex. In both females and males, the hyperdivergent type shows a slight forward and downward tilting of the maxilla between ages 6 and 10, which stabilizes after age 10. With growth, the maxilla shortens relative to other structures, and the subnasal region (ANS–point A–prosthion) becomes increasingly concave. The mandibular ramus gradually adopts a more vertical orientation, moving the condyle and coronoid process forward, while the mandibular corpus rotates backward, resulting in a taller mandibular symphysis over time.

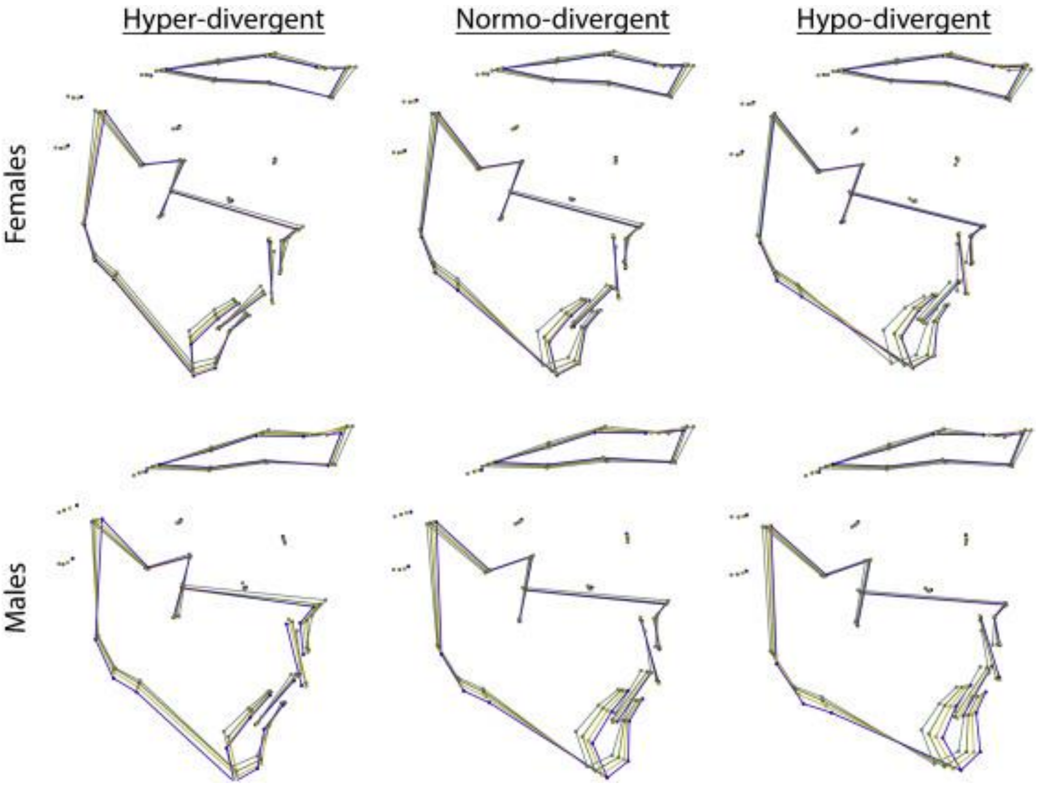

Figure 3. Craniofacial configurations for each facial type and sex at ages 6 (gray), 10 (green), 14 (yellow), and 18 (blue), depicting the evolution of shape along the growth trajectories shown in Figure 2

In the normodivergent and hypodivergent groups, a modest downward tilt of the anterior maxilla is observed between ages 6 and 10. The normodivergent mandible shows a tendency for the ramus to become more vertical, yet the corpus remains largely unrotated; as growth proceeds, the corpus lengthens and the mandibular symphysis advances forward without appreciable change in height. The hypodivergent mandible, by contrast, exhibits forward rotation of the corpus with increased chin prominence, while changes in ramus inclination are minimal. Both of these facial types demonstrate a gradual flattening of the antegonial notch from childhood through late adolescence.

In male participants, the overall growth patterns resemble those of females, but the extent of shape change and skeletal rotation is more pronounced **(Figure 3)**. Female trajectories show minimal change between ages 14 and 18, whereas males continue to undergo noticeable craniofacial remodeling during the same interval, reflecting the earlier completion of growth in females.

Comparing hyperdivergent and hypodivergent facial types at different ages **(Figure 4)** reveals that the structural distinctions are apparent as early as age 6 and persist through age 18. The hyperdivergent face is characterized by a larger gonial angle, a more prominent antegonial notch, reduced posterior facial height, a shorter posterior cranial base, and a narrower mandibular ramus. The ramus rotates forward while the corpus tilts backward, the anterior maxilla rotates downward, and the subnasal region elongates, with increased vertical dimensions of both upper and lower anterior dentoalveolar segments. This vertical ramus orientation positions the condyle and coronoid process higher, and the overall lengths of the maxilla and mandible are shorter and displaced posteriorly compared with hypodivergent faces. Additionally, hyperdivergent incisors display reduced vertical overlap relative to hypodivergent dentition.

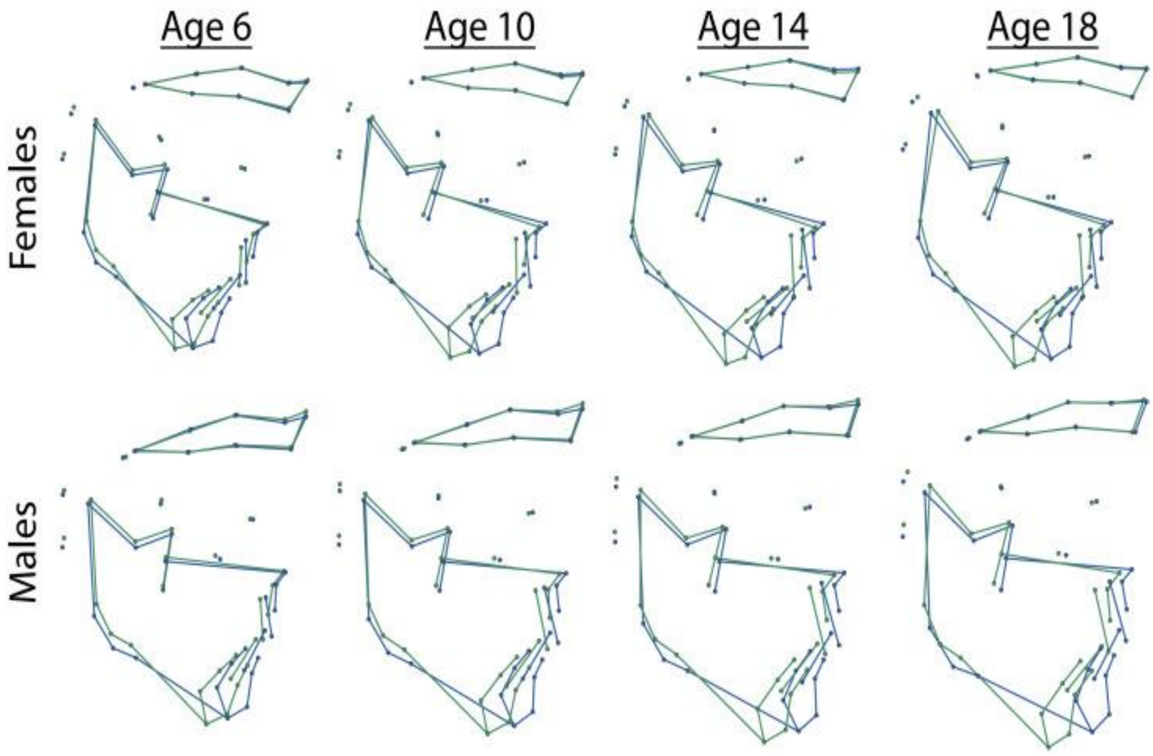

Figure 4. Differences between the average hyperdivergent (green) and hypodivergent (blue) craniofacial configurations at ages six, ten, fourteen, and eighteen. The wireframe plots depict predicted landmark positions based on the mean growth trajectories shown in Figure 2

In the hyperdivergent group, smaller SNA and SNB angles reflect a more posterior (retrognathic) position of both the maxilla and mandible compared with the other facial types **(Figure5; Table 5)**. While SNA and SNB angles increase with age across all groups, the growth-related increase is less pronounced in hyperdivergent individuals than in hypodivergent or normodivergent groups. Additionally, the ANB angle is generally larger in the hyperdivergent type, indicating a relatively more retrognathic mandible compared with the maxilla; however, this difference reaches statistical significance at all ages only in females.

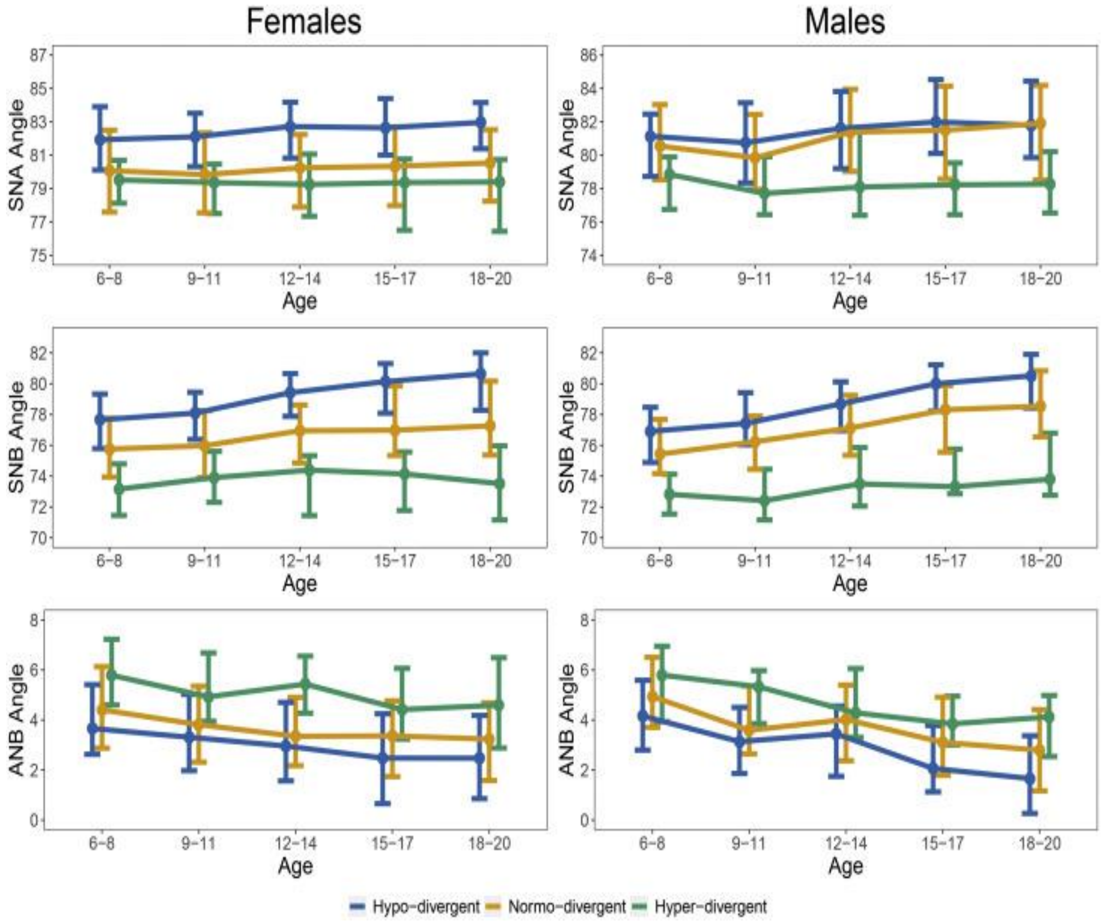

Figure 5. Graphs showing SNA, SNB, and ANB angles across different facial types and age groups. Points represent median values, while whiskers indicate the interquartile range (25th–75th percentiles). Left panels depict females, and right panels depict males

Table 5. Results from the post-hoc Tukey's HSD tests

Empty Cell	Females			Males		
	Hyper-Normo	**Hyper-Hypo**	**Normo-Hypo**	**Hyper-Normo**	**Hyper-Hypo**	**Normo-Hypo**
6-8 y						
SNA	0.413	0.012*	0.025*	0.008*	0.004*	0.868
SNB	0.000*	0.000*	0.000*	0.003*	0.000*	0.028*
ANB	0.008*	0.004*	0.757	0.999	0.213	0.017*
9-11 y						
SNA	0.148	0.000*	0.000*	0.008*	0.001*	0.369
SNB	0.000*	0.000*	0.000*	0.000*	0.000*	0.002*
ANB	0.036*	0.049*	0.988	0.614	0.047*	0.039*
12-14 y						
SNA	0.142	0.000*	0.000*	0.005*	0.002*	0.796
SNB	0.000*	0.000*	0.000*	0.000*	0.000*	0.035*
ANB	0.000*	0.002*	0.982	0.951	0.190	0.045*
15-17 y						
SNA	0.039*	0.000*	0.000*	0.001*	0.000*	0.312
SNB	0.000*	0.000*	0.000*	0.000*	0.000*	0.003*
ANB	0.009*	0.003*	0.613	0.968	0.221	0.049*
18-20 y						
SNA	0.011*	0.000*	0.000*	0.001*	0.000*	0.528
SNB	0.000*	0.000*	0.000*	0.000*	0.000*	0.003*
ANB	0.005*	0.001*	0.423	0.770	0.051	0.016*

*Significant at 0.05 level.

In this research, we applied geometric morphometric methods (GMM) to examine and compare craniofacial growth trajectories across clinical classifications of vertical facial divergence. A key advantage of GMM lies in its ability to preserve the geometric arrangement and orientation of anatomical structures by treating them as configurations of landmarks, which allows for the assessment of coordinated vertical and anteroposterior growth patterns. This landmark-based methodology represents a novel approach for investigating craniofacial development in relation to clinical facial morphology, as prior research primarily focused on modeling changes in linear distances or isolated interlandmark angles. In contrast, GMM captures the spatial relationships among all landmarks simultaneously, providing a more holistic view of craniofacial growth.

While traditional growth models based on linear distances are useful for tracking changes in individual measurements and growth velocity, conventional cephalometric approaches are limited in their ability to evaluate spatial relationships among landmarks. For instance, landmarks may shift in position or orientation without altering the linear distance between them, making shape changes difficult to detect without complex interpretations of multiple measurements. GMM overcomes this limitation by directly analyzing shape as a geometric construct.

Building on earlier studies of vertical facial growth, this research identifies subtle but meaningful differences in the growth patterns and orientation of craniofacial components across skeletal facial types. These newly observed correlations improve our understanding of structural relationships, which can inform more effective strategies for growth modification. Variations in findings among previous studies have often been attributed to differences in sample selection and classification methods. Some prior investigations included only individuals with the most extreme hyperdivergent or hypodivergent phenotypes [2, 6], or limited participants to Class I malocclusion [6]. In contrast, our study incorporates all individuals within the classification ranges, encompassing Class I, II, and III malocclusions, in order to capture the full spectrum of vertical and anteroposterior relationships.

Facial type was determined using cephalograms from the oldest age group (18–20 years), maximizing morphological distinction and enabling assessment of how adult facial structures develop throughout growth. Earlier studies often classified participants during adolescence [2, 4, 17, 18, 41] or childhood [6], which may have limited the ability to discern final adult patterns.

Our analysis confirms that certain differences in average morphology among the three facial types are evident by age 6 [6, 19]. Importantly, each facial type follows a distinct growth trajectory into adulthood, indicating unique patterns of adolescent development [2, 4, 17, 41]. Notably, hypodivergent and normodivergent growth trajectories are more similar to each other than either is to the hyperdivergent trajectory **(Figure 2)**. These results highlight the importance of a nuanced approach to growth prediction, one that considers both early-established morphological differences and the distinct trajectory of growth for each facial type, as both factors contribute to the ultimate adult craniofacial form.

Sex differences in growth trajectories were evident in this study. In males, craniofacial growth patterns continued to diverge through age 20, whereas in females, the trajectories largely aligned by age 18 **(Figure 2)**. This earlier convergence in females likely reflects the faster completion of adolescent craniofacial development, with only minimal changes occurring afterward [42]. In males, ongoing divergence indicates continued differential growth of craniofacial structures, which is expected to eventually approach the parallel pattern seen in females during postadolescence.

Our findings indicate that the distinct morphologies of hyperdivergent and hypodivergent faces result from combined changes in the orientation of the maxilla and mandible relative to the anterior cranial base, together with differences in anterior facial height. Compared with hypodivergent faces, the hyperdivergent maxilla and mandible are rotated downward and backward, causing the mandibular condyle to sit higher and more forward, the anterior palatal plane to tilt downward, and the mandibular corpus to rotate backward, with the corpus showing the largest angular change **(Figure 4)**. This backward rotation in hyperdivergent faces is associated with increased lower anterior facial height, while hypodivergent faces display forward rotation of the mandible and a relative decrease in lower anterior facial height. These patterns of coordinated rotation and differences in anterior and posterior facial heights align with prior findings [17, 22], though they contrast with studies [2, 4, 41, 43] that attributed such differences primarily to changes in anterior vertical facial dimensions, with little variation in posterior height.

When facial type is classified using the lower-to-total anterior facial height ratio rather than MPA, Enoki *et al.* [43] reported that individuals with shorter lower anterior facial heights exhibited downwardly rotated palatal planes, but MPA did not differ across facial types. In contrast, our study shows hyperdivergent faces with

downward palatal plane rotation accompanied by increased lower anterior facial height, highlighting how differences in classification methods (MPA versus facial height ratio) can influence observed growth patterns.
Both geometric and traditional morphometric analyses **(Figure 3 and 5)** reveal that the hyperdivergent maxilla and mandible are shorter and positioned more posteriorly than in hypodivergent faces, with these differences becoming more pronounced over time. In hyperdivergent individuals, mandibular anterior positioning remains largely stable, while the maxilla shortens with age. Hypodivergent faces, by contrast, show progressive mandibular elongation with no significant change in maxillary length. These findings differ from those of Bishara and Jakobsen [6] and Opdebeeck *et al.* [8], who found no variation in maxillary or mandibular lengths across facial types. Our results are consistent with Joseph *et al.* [14] and Opdebeeck *et al.* [8], who observed a more retruded maxilla in hyperdivergent individuals, as reflected in SNA and SNB angles.
The patterns observed in this study provide important insights into when and how traits linked to vertical facial divergence emerge. Detecting these morphological indicators at an early age can improve clinicians' ability to anticipate and manage future facial development. While earlier research highlighted gonial angle and dentoalveolar height as early predictors of adult facial morphology [19], our findings show that antegonial notch depth and subnasal maxillary height also distinguish hyperdivergent from hypodivergent patterns by 6 years of age.
Vertical facial divergence also correlates with specific malocclusion tendencies. Across growth, the anteroposterior relationship between the maxilla and mandible changes differently depending on facial type. In normodivergent and hypodivergent individuals, the mandible rotates forward and elongates while maxillary growth remains proportional, gradually reducing the ANB angle. Conversely, in hyperdivergent faces, mandibular growth slightly outpaces maxillary growth but the overall A-P alignment remains largely unchanged, promoting a higher ANB angle and a greater likelihood of Class II malocclusion.

Conclusion

This research demonstrates that craniofacial growth follows unique trajectories in hyperdivergent, normodivergent, and hypodivergent types. Trajectories of normodivergent and hypodivergent faces are relatively similar, though the degree of change is generally greater in hypodivergent individuals. Many distinguishing features are already present by age 6 and become more pronounced throughout adolescence. While differences are most evident in mandibular shape and growth, variations in maxillary orientation and relative anteroposterior dimensions indicate coordinated maxillomandibular development. Notably, the downward and backward rotation of both the maxilla and mandible, combined with limited relative maxillary growth in hyperdivergent faces, may elevate the risk for Class II malocclusions. Further investigation is warranted to determine how vertical hyperdivergence influences anteroposterior growth outcomes under different conditions. Overall, these findings provide a framework for future studies exploring growth trajectories within facial types and their relationship to vertical and A-P malocclusion patterns.

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