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Research Article

Reliability of Björk's Structural Signs Compared with Vertical Cephalometric Measurements: A Cross-Sectional Study

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Abstract

Background: Mandibular growth rotation influences vertical facial development and orthodontic diagnosis. Björk described structural signs on lateral cephalograms that may reflect anterior or posterior mandibular rotation, but their discriminatory value varies across studies and population-specific cephalometric data remain limited.

Objective: To compare the reliability of variations in Björk's structural signs of mandibular rotation with variations in vertical cephalometric measurements.

Methods: This retrospective descriptive cross-sectional study analyzed 30 pretreatment lateral cephalograms from patients attending the Dentofacial Orthopedics Department of the Center for Dental Consultation and Treatment, Ibn Rochd University Hospital, Casablanca. Three normodivergent subjects were excluded from the structural-sign analysis, leaving 27 patients (23 hyperdivergent and 4 hypodivergent). Tracings were performed manually on acetate with a 0.5-mm pencil by a single experienced operator. Seven structural signs were assessed. Statistical analyses were performed using Student's t-test, with statistical significance set at $p < 0.05$.

Results: Seventeen patients (56.7%) were female and 13 (43.3%) were male; 23 (76.7%) were hyperdivergent, 4 (13.3%) hypodivergent, and 3 (10.0%) normodivergent. Significant associations with vertical pattern were observed for mandibular canal shape ($p = 0.017$), mandibular angle ($p < 0.001$), lower mandibular border morphology ($p = 0.007$), cortical bone thickness ($p = 0.029$), and lower facial height ($p < 0.001$). Condylar-neck direction ($p = 0.613$) and symphysis thickness ($p = 0.422$) were not significant. Compared with Björk-Steiner references, SN/Ba, SN/Frankfort, SN/GoGn, SN/ANS-PNS, ANS-PNS/GoGn, and chin angle differed significantly, whereas overbite, ANS-PNS/OcS, GoGn/OcI, and gonial angle did not.

Conclusion: In this small Moroccan orthodontic sample, five Björk structural signs were significantly associated with hyperdivergent versus hypodivergent patterns, whereas condylar-neck direction and symphysis thickness did not. The findings support selective use of structural signs as adjunctive morphological information rather than as stand-alone predictors of future growth rotation.

Keywords: Björk Structural Signs; Mandibular Growth Rotation; Vertical Facial Pattern; Cephalometry; Hyperdivergence; Hypodivergence

Introduction

The direction and magnitude of mandibular growth are central to orthodontic diagnosis because growth includes both translation and rotation, and the rotational component can substantially modify lower facial height, mandibular projection, and occlusal relationships [1,2].

Björk's longitudinal implant studies established a framework for distinguishing total mandibular rotation from the surface remodeling that may mask it on conventional cephalograms. Structural features of the condyle, mandibular canal, lower border, symphysis, dentoalveolar relationships, and lower facial height were subsequently used to infer extreme anterior or posterior rotation patterns [1,3].

The clinical appeal of this structural approach is its simplicity, but its reproducibility and predictive performance have been questioned. An observer study found that hyperdivergent morphology was not consistently recognized from Björk structural signs, and longitudinal validation of the Skieller-Björk-Linde-Hansen prediction method explained only a limited proportion of subsequent mandibular rotation [4,5].

Contemporary three-dimensional investigations nevertheless confirm that vertical facial patterns are associated with measurable differences in mandibular and temporomandibular morphology, including condylar dimensions, ramus height, gonial angle, symphyseal proportions, and alveolar bone architecture [6-10].

Population-specific norms are also relevant. A Moroccan cephalometric study reported a greater vertical dimension than conventional reference standards in carefully selected young adults, emphasizing that norms derived from European or North American samples may not be directly transferable [11].

The objectives of the present study were therefore: comparing the reliability of variations in Björk's structural signs of mandibular rotation with variations in vertical cephalometric measurements.

Materials and Methods

Study design and setting

This was a retrospective, descriptive, cross-sectional study based on archived clinical records of patients attending the Dentofacial Orthopedics Department of the Center for Dental Consultation and Treatment, Ibn Rochd University Hospital, Casablanca, Morocco. Data collection lasted three months, from September through November 2021.

Sample and selection criteria

Thirty pretreatment lateral cephalograms were analyzed. No age limit was applied. Inclusion required a complete orthodontic record comprising clinical examination, radiographs, photographic documentation, diagnosis, and an exploitable pretreatment lateral cephalogram. Patients who were candidates for orthognathic surgery, had undergone orthognathic surgery, had an evident craniofacial anomaly or asymmetry, had a syndrome, or had special needs were excluded. For analysis of Björk structural signs, the 3 normodivergent subjects were excluded, leaving 27 patients: 23 hyperdivergent and 4 hypodivergent.

Data collection and cephalometric tracing

Two investigators were involved in the study (a sixth-year dental student and a third-year orthodontic resident), with assistance from a faculty member. Anatomical tracings were performed by a single experienced practitioner using transparent acetate, a 0.5-mm pencil, and a viewing box. The vertical skeletal diagnosis was established from the Björk-Steiner bio-dynamic cephalometric analysis. The cephalometric landmarks, reference lines/planes, and angular or linear measurements are summarized in Tables 1-3.

Björk structural signs

Each structural sign was classified into one of two predefined categories according to the morphology attributed to anterior versus posterior mandibular rotation in the study: condylar neck (stout/forward vs slender/backward); mandibular canal (curved vs straight); mandibular angle (closed vs open); lower mandibular border (rocking-chair outline vs antegonial notch); symphysis thickness (thick vs thin); mandibular cortical bone (thick vs thin); and lower facial height (decreased vs increased).

Statistical analysis

Data were entered in Microsoft Excel 2021 and analyzed with Jamovi version 1.8. Student's t-test was used to evaluate the studied variables. A p value < 0.05 was considered statistically significant.

Landmark	Definition
Sella (S)	Center of the sella turcica.
Nasion (Na)	Most anterior point of the frontonasal suture.
Basion (Ba)	Most inferior point of the basi-occipital image.
Orbitale (Or)	Most inferior point of the orbital floor.
Porion (Po)	Most superior point of the external auditory meatus.
Gnathion (Gn)	Point on the symphysis at the bisector of the Na-Pog line and the mandibular plane according to Downs.
Gonion (Go)	Point at the mandibular angle at the bisector of the posterior ramus tangent and mandibular plane.
Anterior nasal spine (ANS)	Most anterior point of the anterior nasal spine.
Posterior nasal spine (PNS)	Most posterior point of the posterior nasal spine.
Pogonion (Pog)	Most anterior bony point of the symphysis.
Articulare (Ar)	Radiographic intersection of the posterior condylar border with the cranial base.
Lower incisor edge (i)	Most occlusal point of the lower central incisor image.
Upper incisor edge (I)	Most occlusal point of the upper central incisor image.

Table 1: Cephalometric landmarks used in the study.

Line/plane	Definition
S-Na	Anterior cranial-base line through Sella and Nasion.
Frankfort horizontal	Line joining Porion and Orbitale.
ANS-PNS	Palatal/bispinal plane joining the anterior and posterior nasal spines.
Upper and lower occlusal planes	Occlusal planes used for the upper and lower dentitions.
Na-Pog	Facial plane through Nasion and Pogonion.
GoGn	Mandibular plane used for vertical skeletal measurements.

Table 2: Reference lines and planes.

Measurement	Definition
SN/Ba (Ba-S-Na)	Cranial-base angle formed by Na-S-Ba.
SN/Frankfort	Inclination of Frankfort horizontal relative to the anterior cranial base.
SN/GoGn	Inclination of the mandibular plane to the anterior cranial base.
SN/ANS-PNS	Angle between the palatal plane and the anterior cranial base.
ANS-PNS/GoGn	Angle between the palatal and mandibular planes.
Overbite (mm)	Vertical overlap between the upper and lower incisor edges.
ANS-PNS/OcS	Angle between the palatal plane and upper occlusal plane.
GoGn/OcI	Angle between the mandibular plane and lower occlusal plane.
Gonial angle	Angle between the mandibular-plane tangent and posterior ramus tangent.
Chin angle	Angle between the facial plane (Na-Pog) and tangent to the lower mandibular border.

Table 3: Cephalometric measurements.

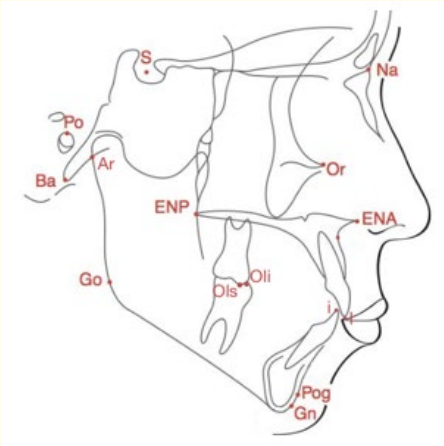


Figure 1: Cephalometric landmarks used by the operator in the study.

Results

Sample characteristics

The sample comprised 17 female patients (56.7%) and 13 male patients (43.3%). The vertical skeletal distribution was 23 hyperdivergent patients (76.7%), 4 hypodivergent patients (13.3%), and 3 normodivergent patients (10.0%). The 3 normodivergent patients were excluded from the structural-sign analysis, which therefore included 27 patients.

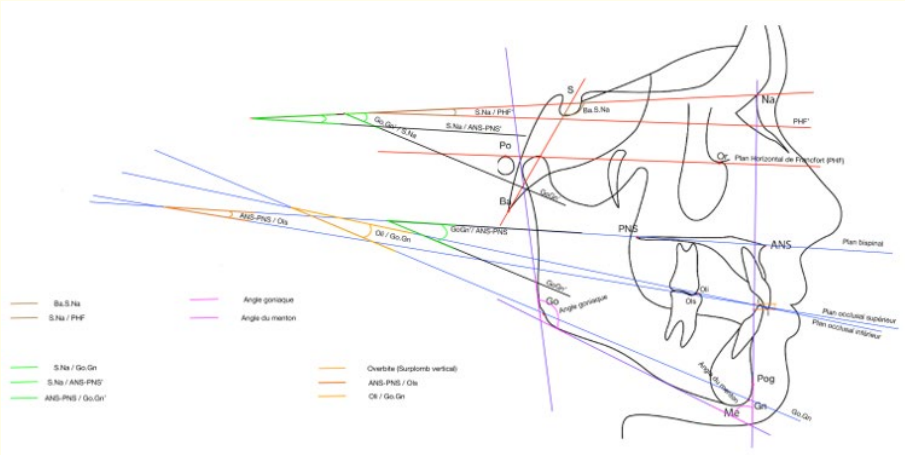


Figure 2: Cephalometric angles and planes used in the study.

Structural signs according to vertical skeletal pattern

Five of the seven evaluated signs were significantly associated with vertical skeletal pattern. A straight mandibular canal was observed in 91.3% of hyperdivergent patients, compared with 50.0% of hypodivergent patients ($p = 0.017$). All hyperdivergent patients had an open mandibular angle, whereas the hypodivergent group was evenly divided between open and closed angles ($p < 0.001$). An antegonial notch occurred in 78.3% of hyperdivergent and 25.0% of hypodivergent patients ($p = 0.007$). Thin cortical bone occurred in 69.6% and 25.0%, respectively ($p = 0.029$). Increased lower facial height was present in all hyperdivergent patients and in none of the hypodivergent patients ($p < 0.001$). Condylar-neck direction ($p = 0.613$) and symphysis thickness ($p = 0.422$) were not significantly associated with vertical pattern.

Comparison with Björk-Steiner reference values

The whole-sample cranial-base angle SN/Ba was 132.78 ± 5.15°, compared with the reference value of 131 ± 4.5° ($p = 0.017$). SN/Frankfort was 10.66 ± 3.19° versus 6 ± 6° ($p < 0.001$). The vertical skeletal measurements SN/GoGn (40.96 ± 6.46° vs 33 ±

Structural sign	Category	Hyperdivergent n = 23	Hypodivergent n = 4	p
Condylar neck	Stout/forward	8 (34.8%)	2 (50.0%)	0.613
	Slender/backward	15 (65.2%)	2 (50.0%)	
Mandibular canal	Curved	2 (8.7%)	2 (50.0%)	0.017
	Straight	21 (91.3%)	2 (50.0%)	
Mandibular angle	Closed	0 (0.0%)	2 (50.0%)	<0.001
	Open	23 (100%)	2 (50.0%)	
Lower mandibular border	Rocking chair	5 (21.7%)	3 (75.0%)	0.007
	Antegonial notch	18 (78.3%)	1 (25.0%)	
Symphysis thickness	Thick	10 (43.5%)	3 (75.0%)	0.422
	Thin	13 (56.5%)	1 (25.0%)	
Cortical bone	Thick	7 (30.4%)	3 (75.0%)	0.029
	Thin	16 (69.6%)	1 (25.0%)	
Lower facial height	Decreased	0 (0.0%)	4 (100%)	<0.001
	Increased	23 (100%)	0 (0.0%)	

Table 4: Distribution of Björk structural signs according to facial divergence (n = 27).

Statistically significant p values are <0.05.

2.5°), SN/ANS-PNS (9.29 ± 3.61° vs 8 ± 3°), and ANS-PNS/GoGn (32.11 ± 5.61° vs 25 ± 6°) were all significantly higher than the reference values ($p < 0.001$, $p = 0.020$, and $p < 0.001$, respectively). Vertical dental compensation measures did not differ significantly. The gonial angle was 129.03 ± 8.41° versus 131 ± 6° ($p = 0.088$), whereas the chin angle was significantly lower (63.25 ± 4.84° vs 69 ± 5°; $p < 0.001$).

Variable	Whole sample	Hyperdivergent	Hypodivergent	Reference	p
SN/Ba	132.78 ± 5.15	133 ± 5.39	130 ± 2.51	131 ± 4.5	0.017
SN/Frankfort	10.66 ± 3.19	11 ± 3.12	10 ± 3.46	6 ± 6	<0.001
SN/GoGn	40.96 ± 6.46	41 ± 5.934	32 ± 2.44	33 ± 2.5	<0.001
SN/ANS-PNS	9.29 ± 3.61	9.79 ± 3.46	6.75 ± 3.20	8 ± 3	0.020
ANS-PNS/GoGn	32.11 ± 5.61	31.89 ± 5.46	26.75 ± 4.57	25 ± 6	<0.001
Overbite (mm)	2.18 ± 2.53	2.1 ± 2.42	3 ± 2.16	2 ± 2.5	0.656
ANS-PNS/OcS	11.85 ± 3.91	11.51 ± 4.16	10 ± 4.08	10 ± 4	0.066
GoGn/OcI	20.5 ± 5.52	20.6 ± 5.23	16.5 ± 3.31	20 ± 5	0.681
Gonial angle	129.03 ± 8.41	128.51 ± 8.36	118.75 ± 10.21	131 ± 6	0.088
Chin angle	63.25 ± 4.84	63.51 ± 4.75	68.75 ± 3.40	69 ± 5	<0.001

Table 5: Cephalometric values compared with Björk-Steiner references.

Values are mean ± standard deviation; degrees unless otherwise stated. Student's t-test was used to evaluate the studied variables; $p < 0.05$ was considered statistically significant.

Discussion

Principal findings

The present study showed significant associations between vertical skeletal pattern and several Björk structural signs, including mandibular canal morphology, mandibular angle, lower mandibular border, cortical bone thickness, and lower facial height. In contrast, condylar-neck direction and symphysis thickness were not significantly associated with facial divergence. Cephalometric analysis also showed significant differences in cranial-base and vertical skeletal measurements compared with Björk-Steiner reference values, whereas vertical dental compensation measurements remained close to the reference values.

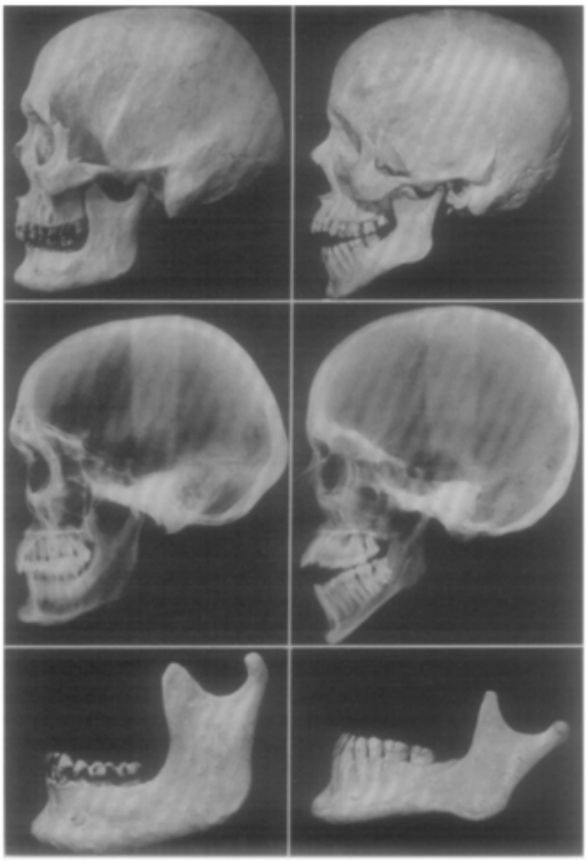


Figure 3: Different mandibular morphologies illustrating variation in mandibular growth pattern.

Condylar neck

Although 65.2% of hyperdivergent patients had a slender, backward-inclined condylar neck, the association was not significant. The absence of a significant association may partly reflect the limitations of lateral cephalometry, which provides only a two-dimensional assessment of condylar morphology. A three-dimensional study by Santander., *et al*. reported that hyperdivergent adults had smaller condyles and greater anteroposterior condylar inclination than hypodivergent adults [17]. Diwakar., *et al*. also reported smaller condylar dimensions in hyperdivergent subjects compared with other vertical skeletal patterns [6]. These findings indicate that condylar morphology varies with vertical pattern, but the differences are multidimensional and cannot be reduced to a single neck-inclination category.

Biologically, condylar growth contributes to mandibular displacement and rotation, but the apparent contour on a lateral cephalogram is affected by projection, head positioning, bilateral superimposition, and remodeling. Reis., *et al*. reported significant differences in condylar width and ramus-related dimensions between hyperdivergent and hypodivergent individuals, whereas condylar height and symphysis inclination did not differ significantly [7].

Mandibular canal

The mandibular canal was straight in 91.3% of hyperdivergent patients and was significantly associated with vertical pattern. Björk interpreted canal morphology as a relatively stable internal record of mandibular remodeling, because the canal is less affected by surface remodeling than the external lower border. Earlier computed-tomography work demonstrated that mandibular divergence is related to the position of the inferior alveolar canal [1,12]. Oliveira., *et al*. reported a significant association between facial type and mandibular canal trajectory on cone-beam computed tomography [18]. More recently, Selvaraj., *et al*. found a larger curvature radius in hyperdivergent subjects, indicating a less curved mandibular canal than in hypodivergent subjects [19]. This recent result is consistent with the straighter canal observed in the hyperdivergent group in the present study.

The morphology of the mandibular canal may reflect mandibular remodeling during growth. However, because this study was cross-sectional, the observed association does not demonstrate that canal shape can predict future mandibular rotation.

Mandibular angle

In the present study, all hyperdivergent patients presented an open mandibular angle, whereas 50% of hypodivergent patients had a closed angle. This association was highly significant ($p < 0.001$). Similar findings have been reported in recent studies. Rehman., *et al*. found a significantly larger gonial angle in hyperdivergent than in hypodivergent subjects [23]. Similarly, Reis., *et al*. reported significant differences in gonial angle between the two vertical patterns using three-dimensional imaging [7]. The mean gonial angle was also higher in hyperdivergent than in hypodivergent patients in our sample, although the overall mean did not differ significantly from the Björk-Steiner reference value.

The morphology of the gonial region is influenced by mandibular growth and masticatory function. Therefore, an open gonial angle should be interpreted as one component of the vertical skeletal pattern rather than as an isolated finding.

Lower mandibular border and antegonial notch

A marked antegonial notch occurred in 78.3% of hyperdivergent patients compared with 25.0% of hypodivergent patients. This is consistent with the concept that the lower mandibular border records remodeling associated with vertical growth. Manabe., *et al*. reported that antegonial notch area was significantly correlated with ramus inclination and the Y-axis, supporting a relationship between notch formation, mandibular growth direction, and masticatory muscle influences [13].

The antegonial region is influenced by mandibular remodeling and masticatory muscle activity. However, notch morphology is multifactorial and should not be considered a reliable predictor of mandibular growth when assessed alone.

Symphysis

Symphysis thickness was not significantly associated with vertical pattern in the present sample, despite a numerical tendency toward thinner symphyses in hyperdivergent patients. This negative result may reflect the very small hypodivergent group and the reduction of a complex three-dimensional structure to a binary thick/thin judgment. Linjawi., *et al*. reported significant differences in mandibular symphysis dimensions across vertical skeletal patterns [20]. Oh., *et al*. also found narrower symphyseal and pogonion widths in high-angle Class III subjects [21]. These studies indicate that vertical pattern may influence symphyseal morphology, although individual dimensions do not differ consistently across all populations.

Chen., *et al*. reported a slimmer mandibular cross-section in subjects with increased vertical dimension,[9] whereas Reis., *et al*. found no significant difference in symphysis inclination between hyperdivergent and hypodivergent groups [7].

Cortical bone thickness

Thin cortical bone was significantly more frequent in hyperdivergent patients. Hasani., *et al*. reported thinner cortical bone at selected sites in hyperdivergent patients [15]. In contrast, Akbulut and Bayrak found no significant differences in buccal or lingual cortical thickness between vertical patterns, although hypodivergent subjects showed greater trabecular and total alveolar widths [10]. Eto., *et al*. reported greater buccal shelf bone thickness in hypodivergent patients at the first molar region [22]. These findings show that the relationship between cortical bone morphology and vertical pattern is site-dependent.

These differences may reflect the interaction of skeletal geometry, muscle loading, and bone adaptation. They are clinically relevant when planning tooth movement and temporary anchorage because available cortical thickness and alveolar width can constrain safe mechanics and primary stability [10,15].

Lower facial height

Lower facial height perfectly separated the two analyzed groups: all hyperdivergent patients had increased lower facial height and all hypodivergent patients had decreased lower facial height. This was therefore the strongest discriminator in the dataset. Its apparent performance must, however, be interpreted carefully because lower facial height is closely embedded in the clinical definition of vertical facial pattern and is not independent of the diagnostic construct being classified.

Reis., *et al*. and Chen., *et al*. reported coordinated differences in maxillomandibular morphology according to vertical facial pattern, supporting the concept that vertical divergence reflects changes across several craniofacial structures rather than a single local feature [7,9].

Cephalometric values and Moroccan reference context

The whole sample showed significantly higher SN/GoGn, SN/ANS-PNS, and ANS-PNS/GoGn values than the Björk-Steiner references, indicating a strong vertical skeletal component. In contrast, overbite and the upper and lower occlusal-plane measurements did not differ significantly. This suggests that the greater skeletal divergence observed in the sample was not accompanied by marked changes in the selected vertical dental measurements.

The population context is important. Ousehal., *et al*. reported a mean GoGn/SN of 35.4 ± 5.3° in 98 Moroccan young adults selected for balanced faces and Class I occlusion, already higher than conventional Steiner-type norms. The present sample mean of 40.96 ± 6.46° is higher still, which is plausible because the current sample was drawn from orthodontic patients and contained 76.7% hyperdivergent subjects [11].

In this sample, facial divergence appeared to be more closely associated with the orientation of the mandible relative to the cranial base than with gonial angle morphology. This interpretation is supported by the significant cranial-base and vertical skeletal measurements, whereas the gonial angle did not differ significantly from the reference value. However, because the study was cross-sectional, this finding should be interpreted as an association rather than a causal relationship.

Clinical implications

The most clinically useful message is not that Björk structural signs can predict future growth with certainty, but that several signs can enrich morphological assessment when they converge with standard cephalometric findings. In a hyperdivergent patient, a straight mandibular canal, open gonial region, antegonial notch, thin cortical appearance, and increased lower facial height may reinforce the diagnosis of a vertical phenotype. Conversely, discordant signs should reduce confidence in a categorical interpretation.

Longitudinal assessment using serial images is preferable for evaluating mandibular growth. Franco., *et al*. reported good agreement between three-dimensional voxel-based superimposition and Björk's structural superimposition method, showing that contemporary imaging can assess growth changes more directly than a single baseline radiograph [16].

Limitations and future research

The main limitations of this study were the small sample size, the absence of a specific age restriction, potential measurement bias, and the lack of standardized radiographic acquisition, as the cephalograms were not obtained by the same operator. Future studies should include larger samples, different age groups and skeletal classes, and anteroposterior skeletal characteristics to further investigate the relationship between Björk structural signs and facial divergence.

Conclusion

In this Moroccan orthodontic sample, several Björk structural signs were significantly associated with vertical skeletal pattern, whereas condylar-neck direction and symphysis thickness were not. Cephalometric findings also showed greater vertical skeletal divergence than the Björk-Steiner reference values. Overall, Björk's structural signs should be interpreted individually and used as complementary indicators of vertical morphology rather than as predictors of future mandibular growth rotation.

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