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Full Length Article

Influence of cranial base angle on craniofacial morphology in growing orthodontic patients: A retrospective cephalometric study

Angelo Michele Inchingolo [a,b,1], Alessio Danilo Inchingolo [a,1], Rosalba Lagioia [a], Paola Bassi [a], Daniela Di Venere [a], Cinzia Maspero [b,c], Francesco Inchingolo [a,*], Andrea Palermo [d], Grazia Marinelli [a,2], Gianna Dipalma [a,b,**,2]

[a] Department of Interdisciplinary Medicine, University of Bari "Aldo Moro", 70121, Bari, Italy
[b] Department of Biomedical, Surgical and Dental Sciences, Milan University, 20122, Milan, Italy
[c] Fondazione IRCCS Cà Granda, Ospedale Maggiore Policlinico, 20100, Milan, Italy
[d] Department of Experimental Medicine, University of Salento, 73100, Lecce, Italy

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ABSTRACT

Background/objectives: This retrospective cephalometric study evaluated the association between cranial base flexure, measured by the NSAr angle, and sagittal and vertical craniofacial morphology in growing orthodontic patients.

Methods: Forty patients aged 11-17 years who underwent orthodontic examination and pre-treatment lateral cephalometric radiography at the Orthodontics Department of the Policlinico of Bari were included after ethics committee approval (No. 2377/CEL, September 29, 2025) and written parental informed consent. Participants were classified according to NSAr values into Group A (>125°), Group B (120°-125°), and Group C (<120°). Eight angular and seven linear cephalometric parameters were measured using Delta-Dent software. Statistical analysis was performed with StataMP17, including normality testing, between-group comparisons, and Pearson or Spearman correlation analyses, with significance set at $p < 0.05$.

Results: In the total sample, NSAr showed significant positive correlations with SN-GoGn ($r = 0.35$, $p = 0.02$) and NAPg ($r = 0.31$, $p = 0.04$), indicating that a wider cranial base angle was associated with greater mandibular plane inclination and increased facial convexity. A non-significant trend was observed for SNB ($r = -0.28$, $p = 0.08$), whereas no significant associations were found with the remaining parameters. NSAr explained approximately 12% of the variability in SN-GoGn, and sensitivity analysis confirmed the robustness of the findings.

Conclusions: Cranial base angle was significantly associated with selected sagittal and vertical craniofacial parameters in growing orthodontic patients. NSAr assessment may provide useful adjunctive information for early diagnosis, growth prediction, and individualized orthodontic treatment planning.

1. Introduction

Craniofacial morphology results from the complex and dynamic interaction of genetic, environmental, functional, and structural factors that guide skeletal development throughout growth.

The cranial base serves as a key determinant in this integrated system, providing both a structural foundation and a developmental template for the facial skeleton [1–7].

Its configuration influences the spatial orientation of the maxilla and mandible and, consequently, the overall balance of craniofacial form and occlusal relationships.

The cranial base angle, defined by the cephalometric landmarks

* Corresponding author.
** Corresponding author. Department of Interdisciplinary Medicine, University of Bari "Aldo Moro", 70121, Bari, Italy.
E-mail addresses: angelomichele.inchingolo@uniba.it (A.M. Inchingolo), alessiodanilo.inchingolo@uniba.it (A.D. Inchingolo), rosalba.lagioia@uniba.it (R. Lagioia), paola.bassi@uniba.it (P. Bassi), daniela.divenere@uniba.it (D. Di Venere), cinzia.maspero@unimi.it (C. Maspero), francesco.inchingolo@uniba.it (F. Inchingolo), andrea.palermo@unisalento.it (A. Palermo), graziamarinelli@live.it (G. Marinelli), gianna.dipalma@uniba.it (G. Dipalma).
[1] These authors contributed equally to this work as co-first.
[2] These authors contributed equally to this work as co-last.

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Nasion, Sella, and Articulare (NSAr) or alternatively Nasion, Sella, and Basion (NSBa), represents an objective measure of cranial base flexure. Variations in this angle have been consistently associated with sagittal skeletal discrepancies [8–14]. A more acute angle tends to correspond to anterior mandibular positioning and Class III skeletal morphology, whereas a wider angle correlates with mandibular retrusion and Class II patterns. Since the early descriptions by Young and the pioneering works of Björk, Moss, and Coben, the morphogenetic influence of the cranial base on craniofacial growth has been extensively investigated in orthodontics, anthropology, and developmental biology[15–20].

Clinically, cephalometric analysis remains an indispensable method for quantifying skeletal relationships and assessing growth direction. Evaluation of the cranial base angle has gained importance not only as a diagnostic descriptor but also as a prognostic marker for predicting skeletal growth tendencies[21–32]. A reduced NSAr may indicate a predisposition toward mandibular prognathism and skeletal Class III development, while an increased angle may be associated with maxillary protrusion and a skeletal Class II pattern. Such relationships are particularly relevant in growing patients, where early orthopedic and orthodontic intervention can modulate growth direction to achieve functional and aesthetic harmony. Differentiating skeletal discrepancies from dentoalveolar compensations through precise cephalometric evaluation enhances diagnostic accuracy and supports evidence-based treatment planning [33–42].

Beyond orthodontics, cranial base morphology plays a crucial role in craniofacial and orthognathic surgery. Understanding cranial base geometry allows for more accurate prediction of postoperative skeletal stability and facial balance following maxillomandibular repositioning. Moreover, cranial base flexure has been implicated in influencing mandibular rotation, occlusal plane inclination, and airway configuration, factors that can affect both function and aesthetics [43–51].

Despite numerous investigations, the literature on cranial base morphology remains heterogeneous. Reported associations vary across studies due to methodological differences, sample size, ethnic variability, and cephalometric techniques used. Some authors have emphasized a strong morphogenetic role of the cranial base, whereas others have suggested that compensatory mechanisms of the jaws and dentoalveolar complex can mitigate its influence [52–57]. Recent advances in cone-beam computed tomography (CBCT) and three-dimensional cephalometry have provided more precise tools for evaluating the cranial base and its relationships with facial structures, fostering new perspectives in predictive and personalized orthodontics [58–61].

In this context, the present study aims to investigate the correlation between the cranial base angle (NSAr) and craniofacial morphology in a sample of growing individuals using standardized cephalometric analysis. The objectives are to clarify the morphogenetic role of the cranial base in shaping sagittal and vertical skeletal relationships and to evaluate its potential as an early diagnostic and prognostic indicator in orthodontic practice. Ultimately, this research seeks to contribute to more individualized, predictive, and biologically guided approaches to craniofacial assessment and treatment planning.

2. Materials and methods

2.1. Study population

This retrospective observational study was conducted at the Orthodontics Department of the Policlinico of Bari and included a total of 40 patients (aged 11–17 years) who had undergone orthodontic examination and lateral cephalometric radiography for diagnostic purposes. The study received approval from the University Ethics Committee (No. 2377/CEL dated September 29, 2025), following an assessment of methodological compliance and adherence to ethical guidelines.

Inclusion criteria were:

- Clinical indication for orthodontic treatment;
- Availability of pre-treatment lateral cephalograms;
- No previous orthodontic or orthopedic functional therapy;
- Absence of craniofacial anomalies secondary to systemic diseases or trauma.

Exclusion criteria comprised prior orthodontic/orthopedic treatment, presence of systemic conditions, congenital or acquired craniofacial syndromes, inadequate or non-diagnostic radiographs, and lack of informed consent.

The study population was subdivided into three groups based on the cranial base angle (NSAr):

- **Group A**: NSAr >125°
- **Group B**: NSAr 120°–125°
- **Group C**: NSAr <120°

2.2. Measuring tool

For each subject, a pre-treatment lateral cephalometric radiograph, obtained under standardized conditions (natural head position, lips at rest, eyes open, horizontal gaze), was analyzed. Digital images were imported into Delta-Dent software, a certified medical device compliant with EU Regulation 2017/745 (MDR) and GDPR (EU 2016/679). The software allows calibration of images to minimize distortions and provides validated cephalometric measurement tools.

All tracings and measurements were performed by a single experienced operator to ensure consistency and reproducibility. Cephalometric evaluation included eight angular parameters (SNA, SNB, NPg-FH, ANB, NAPg, SN-GoGn, Y-axis, ArGo-SN) and seven linear parameters (N-S, S-Ar, Ar-N, Ar–Pt A, Ar–Gn, Wits appraisal, N-Pt A). These variables were selected to investigate the role of cranial base flexure in determining sagittal and vertical jaw position. A summary of the cephalometric landmarks, reference lines, and angular measurements included in the analysis is provided in Tables 1–3.

Table 1
Points.

Points	Location
Sella (S)	The centre of the shadow of the pituitary fossa (sella turcica)
Nasion (N)	The deepest point of the frontonasal suture
Articulare (Ar)	It is the point of intersection of the images of the posterior border of the mandible and the inferior border of the basilar part of occipital bone
Gonion (Go)	The point formed by the intersection of the mandibular plane and the posterior border of the ascending ramus of the mandible. It is a constructed point
Gnathion (Gn)	A point formed by the intersection of the mandibular plane with the facial plane. It is a constructed point
Subspinale or Point A	The deepest midline point on the pre maxilla between anterior nasal spine and the crest of the maxillary alveolar process
Supramentale or Point B	The deepest midline point on the mandible between the pogonion and the crest of the mandibular alveolar process
Pogonion (Pg)	The most anterior point on the bony chin in the median plane
Porion (Po)	The superior point of the external acoustic meatus
ANS	Anterior nasal spine; this is the tip of the bony anterior nasal spine
PNS	Posterior nasal spine; the intersection of a continuation of the anterior wall of the pterygopalatine fossa and the floor of the nose marking the dorsal limit of the maxilla
Menton (Me)	The most inferior midline point on the mandibular symphysis (unilateral)
Orbitale (Or)	The lowest point on the inferior margin of the orbit

Table 2
Lines.

Planes	Connecting Points
S–N plane	Line connecting Sella (S) and Nasion (N); represents the anterior cranial base
S–Ar line	Line connecting Sella (S) and Articulare (Ar); represents the posterior cranial base length
Ar–N line	Line connecting Articulare (Ar) and Nasion (N); represents the total cranial base length
Ar–Go line	Line connecting Articulare (Ar) and Gonion (Go, constructed); represents the vertical ramus length of the mandible
Mandibular plane	Plane connecting Gonion (Go) and Gnathion (Gn)
Facial plane	Plane connecting Nasion (N) and Pogonion (Pg)
S–Gn line	Line connecting Sella (S) and Gnathion (Gn, constructed)
Frankfort horizontal plane	Line connecting Porion (Po) and Orbitale (Or)
N–A line	Line connecting Nasion (N) and Point A
A–Pg line	Line connecting Point A and Pogonion (Pg)
N–B line	Line connecting Nasion (N) and Point B

Table 3
Angles and measurements.

Angles/Distance (mm)	Connecting Point
NSAr angle (saddle angle)	Angle formed by Nasion (N), Sella (S), and Articulare (Ar); represents cranial base flexure
SNA	Angle between SN line and NA line
SNB	Angle between SN line and NB line
ANB	Angle between NA and NB lines
NA–Pg	Angle between NA line and APg line
NPg–FH	Angle between the facial plane (NPg) and the Frankfort horizontal (FH) plane
SN–GoGn	Angle between SN plane and mandibular plane; represents mandibular plane inclination
Y-axis	Angle formed between S–Gn line and FH plane
ArGo–SN	Angle formed between Ar–Go and SN plane
N–S	Linear distance between Nasion (N) and Sella (S)
S–Ar	Linear distance between Sella (S) and Articulare (Ar)
Ar–N	Linear distance between Articulare (Ar) and Nasion (N)
Ar–Pt A	Linear distance between Articulare (Ar) and Point A
Ar–Gn	Linear distance between Articulare (Ar) and Gnathion (Gn)
Wits appraisal	Linear distance between Points A and B projected onto the occlusal plane
N–Pt A	Linear distance from Point A to a perpendicular dropped from Nasion (N) to the FH plane

2.3. Statistical analysis

Data were organized in Microsoft Excel® and analyzed using StataMP17®.

Normality of data distribution was assessed with the Shapiro–Wilk test, which confirmed normal distribution for most variables ($p > 0.05$).

Between-group comparisons were performed with independent-samples t-tests or Mann–Whitney tests; one-way ANOVA with Bonferroni correction was used for >2 groups, and categorical variables were analyzed with Chi-square tests. Correlations between continuous variables were assessed with Pearson's or Spearman's correlation coefficients. A two-tailed p-value <0.05 was considered statistically significant.

3. Results

Results showed significant positive correlations between NSAr and SN-GoGn ($r = 0.35$, $p = 0.02$) as well as NSAr and NAPg ($r = 0.31$, $p = 0.04$), indicating that an increased cranial base angle was associated with a steeper mandibular plane and greater facial convexity. A negative but non-significant trend was observed between NSAr and SNB ($r = -0.28$, $p = 0.08$). No significant correlations were found for the remaining parameters (r range: −0.12 to 0.24; $p > 0.05$).

The coefficient of determination (R^2) for the NSAr–SN-GoGn correlation was 0.12, suggesting that 12% of the variability in mandibular plane inclination is explained by cranial base flexure. Sensitivity analysis, performed after exclusion of potential outliers, confirmed the robustness of the findings. All results were interpreted within a 95% confidence interval.

Mean and standard deviations of angular and linear variables for the three groups are presented in Table 4.

Pearson's correlation analysis identified two statistically significant associations between the cranial base angle (NSAr) and cephalometric variables in the whole sample. NSAr correlated positively with SN-GoGn ($r = 0.35$; $p = 0.02$), indicating that a larger cranial base angle is associated with greater mandibular plane inclination, and with NAPg ($r = 0.31$; $p = 0.04$), suggesting an association with increased facial convexity (Table 5).

The coefficient of determination for the NSAr–SN-GoGn association was $R^2 \approx 0.12$, indicating that ~12% of the variability in SN-GoGn is explained by NSAr. Sensitivity analyses excluding potential outliers did not materially alter the estimates. All analyses were performed in StataMP17 with a 5% significance level and 95% confidence intervals.

Group means and standard deviations highlighted systematic differences across the three groups. NSAr decreased from Group A (129.6° ± 2.05) to Group B (121.8° ± 1.94) and Group C (113.9° ± 4.64). SNA was highest in C (84.1°), while SNB increased from A (78.3°) to C (81.8°). ANB was greatest in A (3.52°), lowest in B (1.94°), and intermediate in C (2.08°). NPg-FH was comparable in A and B (~89.2°) and lower in C (86.4°). NAPg decreased from A (32.1°) to B (30.1°) to C (28.5°). Vertical indices (SN-GoGn, Y-Axis) varied minimally between groups, whereas ArGo-SN was lower in C (50.1°). For linear measures, N-S was smaller and S-Ar larger in C; Ar-Gn was largest in A. Wits was positive in A (+1.92 mm) and negative in B and C (−1.21 mm; −1.40 mm).

No within-group correlations between NSAr and the examined variables reached statistical significance (all $p > 0.05$) (Table 6). Notable trends included:

- Group A: positive tendencies with SN-GoGn ($r = 0.321$; $p = 0.210$) and N-S ($r = 0.318$; $p = 0.213$); negative with ANB ($r = -0.385$; $p = 0.127$);
- Group B: positive tendencies with N-Pt A ($r = 0.457$; $p = 0.158$) and Ar-N ($r = 0.401$; $p = 0.222$); negative with Wits ($r = -0.583$; $p = 0.060$);
- Group C: positive tendencies with NPg-FH ($r = 0.492$; $p = 0.104$), NAPg ($r = 0.397$; $p = 0.202$) and S-Ar ($r = 0.342$; $p = 0.276$).

Pairwise t-tests demonstrated multiple significant between-group differences. Compared with Group A, Group C showed higher SNA and SNB ($p = 0.018$; $p < 0.001$), lower ANB and NAPg (both $p < 0.001$), higher SN-GoGn and Y-Axis (both $p < 0.001$), lower ArGo-SN, N-S and S-Ar ($p = 0.006$; 0.042; 0.027), and lower Wits ($p < 0.001$). Between B and C, significant differences were found for Y-Axis ($p = 0.012$), ArGo-SN ($p = 0.021$), Ar-Gn ($p = 0.015$) and Wits ($p = 0.005$).

Table 7 also reported, at the whole-sample level, a positive correlation between NSAr and ANB ($r = 0.35$; $p = 0.028$) and between NSAr and N-Pt A ($r = 0.36$; $p = 0.021$); within Group B, NSAr correlated inversely with SNA ($r = -0.63$; $p = 0.039$) and strongly positively with SNB ($r = 0.84$; $p = 0.001$) (Tables 7 and 8).

4. Discussion

The present study investigated the relationship between the cranial base angle (NSAr) and a series of cephalometric parameters describing sagittal and vertical craniofacial morphology. The findings revealed significant positive correlations between NSAr and both SN-GoGn and NAPg in the total sample, suggesting that an increased cranial base angle is associated with a steeper mandibular plane and greater facial

Table 4
Mean and SD of all parameters in three groups.

Parameter	Group A Mean	Group A SD	Group B Mean	Group B SD	Group C Mean	Group C SD
NSAr	129.6285	2.049552	121.8218	1.940909	113.8917	4.636159
SNA	81.84912	1.868137	80.822	2.186607	84.08333	2.374353
SNB	78.31176	1.379053	80.486	1.74755	81.84617	1.799185
NPg-FH	89.22941	2.358889	89.27733	3.35437	86.41667	2.073868
ANB	3.522941	0.832412	1.935	1.190909	2.083333	0.654528
NAPg	32.14118	1.779765	30.11986	1.781345	28.46667	1.21222
SN-GoGn	28.49412	2.358495	28.49595	2.40611	28.46667	2.40667
Y-Axis	59.44118	1.567655	58.72773	1.39303	56.6075	2.169899
ArGo-SN	55.38294	3.462102	55.333	2.395602	50.11667	4.096736
N-S	71.01176	4.987365	70.66364	3.246133	68.1975	3.978598
S-Ar	35.45882	2.206553	34.47773	3.249583	38.6667	3.322222
Ar-N	39.94118	2.50567	37.35455	4.594211	37.96333	3.541226
Ar-Pt A	46.8175	2.995195	45.4	4.33016	45.2	2.337564
Ar-Gn	105.7824	7.015782	100.586	6.618028	102.0417	4.773356
Wits appraisal	1.923529	1.391027	−1.214	1.33253	−1.4	1.070488
N-Pt A	49.91118	1.946169	46.95	3.44233	46.45	1.973088

Table 5
Relationship between NSAr and other parameters in the total sample.

NSAr	Frequency	SNA	SNB	NPg-FH	ANB	NAPg	WITTS	SN-GoGn	Y-Axis	N-S	S-Ar	Ar-N	Ar-Pt A	N-Pt A	Ar-Gn	ArGo-SN
106–110	3	85.8	81.6	86.3	1.5	7.0	−2.5	29.2	54.4	67.6	29.5	40.2	44.0	48.6	110.7	48.1
111–115	5	83.3	81.4	86.0	2.2	6.3	−1.9	28.6	55.4	68.3	32.5	37.9	44.9	47.6	104.2	50.2
116–120	8	82.1	80.5	88.1	2.9	8.1	−0.6	30.4	57.8	71.0	34.6	38.6	45.9	48.1	107.4	54.1
121–125	11	81.9	79.8	88.3	3.1	8.3	0.4	29.8	57.9	70.3	35.1	38.3	46.2	48.7	106.8	54.9
126–130	10	82.5	77.8	89.2	3.8	10.1	1.6	32.1	59.4	71.7	35.6	39.7	47.3	50.1	105.3	56.2
131–135	3	83.0	78.0	91.0	3.7	6.2	3.0	36.1	59.1	76.7	39.3	38.0	47.2	51.3	120.0	56.3

Coefficient	p value
• SNA: −0.12	• SNA: 0.45
• SNB: 0.28	• SNB: 0.08
• NPg-FH: 0.18	• NPg-FH: 0.27
• ANB: 0.25	• ANB: 0.12
• NAPg: 0.31	• NAPg: 0.04 *
• WITTS: 0.22	• WITTS: 0.17
• SN-GoGn: 0.35	• SN-GoGn: 0.02 *
• Y-Axis: 0.15	• Y-Axis: 0.35
• N-S: 0.10	• N-S: 0.54
• S-Ar: 0.08	• S-Ar: 0.62
• Ar-N: 0.05	• Ar-N: 0.75
• Ar-Pt A: 0.14	• Ar-Pt A: 0.38
• N-Pt A: 0.20	• N-Pt A: 0.22
• Ar-Gn: 0.24	• Ar-Gn: 0.13
• ArGo-SN: 0.17	• ArGo-SN: 0.29 (* = statistically significant)

Positive but non-significant trends were observed with SNB ($r = 0.28$; $p = 0.08$), ANB ($r = 0.25$; $p = 0.12$), NPg-FH ($r = 0.18$; $p = 0.27$), Wits appraisal ($r = 0.22$; $p = 0.17$), and Ar-Gn ($r = 0.24$; $p = 0.13$). No significant relationships were found with SNA ($r = -0.12$; $p = 0.45$), Y-Axis ($r = 0.15$; $p = 0.35$), or with linear measures (N-S, S-Ar, Ar-N, Ar-Pt A, N-Pt A), nor with ArGo-SN (all $p > 0.05$).

convexity[62–69]. These results provide new evidence supporting the hypothesis that cranial base flexure plays a critical role in shaping the spatial relationships of the facial skeleton.

4.1. Relationship between cranial base angle and sagittal skeletal relationships

The positive association between NSAr and NAPg indicates that subjects with a more obtuse cranial base angle tend to exhibit a more convex facial profile. This is consistent with classical cephalometric theories proposing that increased cranial base flexure allows forward displacement of the maxilla relative to the mandible, leading to Class II skeletal patterns[70–74]. Conversely, a more acute NSAr is often associated with a straighter or even concave profile, typical of Class III relationships.

Although the correlation between NSAr and SNB did not reach statistical significance ($r = -0.28$; $p = 0.08$), the negative trend suggests that as the cranial base angle increases, mandibular prognathism tends to decrease [75–80]. This finding aligns with previous studies reporting that a flattened cranial base promotes anterior mandibular positioning, whereas a more flexed base restricts it [81–86]. The weak correlation with SNA indicates that the maxillary position alone is less influenced by cranial base morphology, and that overall sagittal balance results from the combined positional relationships of both jaws[87–90].

The observed positive correlation between NSAr and ANB ($r = 0.35$; $p = 0.028$) further supports this interpretation, emphasizing the contribution of cranial base architecture to skeletal Class II development [91–100]. Moreover, within Group B, a strong positive correlation between NSAr and SNB ($r = 0.84$; $p = 0.001$) and a negative one with SNA ($r = -0.63$; $p = 0.039$) indicate that cranial base morphology may exert differential effects across subgroups, possibly depending on compensatory growth patterns or adaptive remodeling[101–107].

4.2. Relationship with vertical skeletal pattern

The significant positive correlation between NSAr and SN-GoGn ($r = 0.35$; $p = 0.02$) highlights a link between cranial base flexure and vertical skeletal development. A larger NSAr corresponds to a steeper mandibular plane, indicating a tendency toward a hyperdivergent growth pattern[108–115]. This finding is in agreement with prior

Table 6
Correlations between NSAr and cephalometric variables in the three groups (A, B, C).

Variabile	Gruppo A (r, p)	Gruppo B (r, p)	Gruppo C (r, p)
SNA	0,102 (p = 0,696)	0,106 (p = 0,757)	0,165 (p = 0,607)
SNB	0,078 (p = 0,765)	0,046 (p = 0,894)	0,357 (p = 0,254)
NPg-FH	0,259 (p = 0,315)	−0,585 (p = 0,059)	0,492 (p = 0,104)
ANB	−0,385 (p = 0,127)	−0,266 (p = 0,430)	−0,312 (p = 0,324)
NAPg	−0,088 (p = 0,737)	0,285 (p = 0,396)	0,397 (p = 0,202)
SN-GoGn	0,321 (p = 0,210)	0,127 (p = 0,709)	0,014 (p = 0,965)
Y-Axis	−0,106 (p = 0,685)	−0,329 (p = 0,324)	−0,043 (p = 0,896)
ArGo-SN	−0,185 (p = 0,477)	0,058 (p = 0,865)	−0,455 (p = 0,137)
N-S	0,318 (p = 0,213)	−0,070 (p = 0,838)	0,224 (p = 0,485)
S-Ar	0,091 (p = 0,727)	0,001 (p = 0,997)	0,342 (p = 0,276)
Ar-N	−0,315 (p = 0,218)	0,401 (p = 0,222)	0,030 (p = 0,926)
Ar-Pt A	−0,056 (p = 0,832)	0,094 (p = 0,784)	0,141 (p = 0,662)
Ar-Gn	0,206 (p = 0,427)	−0,057 (p = 0,867)	−0,267 (p = 0,401)
Wits appraisal	0,028 (p = 0,914)	−0,583 (p = 0,060)	0,189 (p = 0,557)
N-Pt A	0,245 (p = 0,343)	0,457 (p = 0,158)	−0,276 (p = 0,385)

research by Kasai et al. (1995) and Riedel (1952), which emphasized the interdependence between cranial base inclination and mandibular rotation. The current data, showing an R^2 of 0.12 for this relationship, suggest that approximately 12% of the variability in mandibular plane inclination can be attributed to cranial base morphology, implying that other factors—such as condylar growth direction, dentoalveolar compensation, and neuromuscular function—also play substantial roles [116–120].

Interestingly, within-group analyses did not identify statistically significant correlations between NSAr and vertical parameters, though Group A demonstrated a positive trend with SN-GoGn and Group C with S-Ar [121–125]. This may reflect the smaller sample size within each subgroup and interindividual variability in growth trajectories.

4.3. Group differences and morphological trends

Intergroup comparisons revealed systematic differences across the three categories of cranial base angle. Group A, characterized by a more obtuse NSAr (~129°), exhibited higher facial convexity (NAPg = 32°) and greater ANB, indicating a predominance of Class II skeletal patterns [126–130]. Group C, with a markedly acute NSAr (~114°), showed reduced convexity and higher SNB, consistent with a more prognathic mandibular configuration. These trends confirm the influence of cranial base flexure on overall craniofacial balance [131–134].

The pairwise *t*-test results reinforce these associations. Significant differences in SNB, ANB, and NAPg between groups highlight the geometric impact of the cranial base on maxillo-mandibular relationships. Additionally, differences in vertical indices (SN-GoGn, Y-Axis) between groups suggest that cranial base shape also contributes to the vertical dimension of facial growth, potentially affecting the divergence pattern [135–141].

4.4. Clinical implications

From a clinical perspective, the findings underscore the diagnostic value of assessing the cranial base angle (NSAr) in orthodontic and orthopedic evaluations, especially in growing patients. An increased NSAr may serve as an early indicator of a skeletal Class II tendency or a hyperdivergent growth pattern, warranting closer monitoring and timely interceptive treatment [142–147]. Conversely, a reduced NSAr may predict a Class III skeletal relationship with a lower mandibular plane angle. Integrating cranial base morphology into growth prediction models could thus enhance the accuracy of orthodontic diagnosis and long-term treatment planning [148–151].

5. Limitations and future perspectives

Several limitations should be acknowledged. The sample size,

Table 8
Pairwise comparison of cephalometric variables between groups (A, B, C) using independent-samples *t*-test.

Variable	A vs B	A vs C	B vs C
SNA	−0.38 (p = 0.707)	−2.59 (**p = 0.018**)	−1.94 (p = 0.066)
SNB	−3.69 (**p = 0.001**)	−4.66 (**p < 0.001**)	−1.27 (p = 0.218)
NPg-FH	0.94 (p = 0.362)	3.27 (**p = 0.003**)	1.35 (p = 0.195)
ANB	1.88 (p = 0.073)	6.21 (**p < 0.001**)	3.49 (**p = 0.003**)
NAPg	4.06 (**p = 0.001**)	4.76 (**p < 0.001**)	0.84 (p = 0.413)
SN-GoGn	3.06 (**p = 0.007**)	4.34 (**p < 0.001**)	0.36 (p = 0.726)
Y-Axis	1.95 (p = 0.064)	4.52 (**p < 0.001**)	2.78 (**p = 0.012**)
ArGo-SN	0.65 (p = 0.522)	3.08 (**p = 0.006**)	2.51 (**p = 0.021**)
N-S	0.25 (p = 0.806)	2.14 (**p = 0.042**)	1.30 (p = 0.214)
S-Ar	1.11 (p = 0.279)	2.41 (**p = 0.027**)	1.37 (p = 0.184)
Ar-N	3.27 (**p = 0.003**)	3.03 (**p = 0.005**)	−0.26 (p = 0.798)
Ar-Pt A	1.20 (p = 0.247)	1.48 (p = 0.155)	0.14 (p = 0.887)
Ar-Gn	−1.05 (p = 0.303)	1.71 (p = 0.098)	2.68 (**p = 0.015**)
Wits appraisal	3.15 (**p = 0.004**)	6.98 (**p < 0.001**)	3.19 (**p = 0.005**)
N-Pt A	2.65 (**p = 0.019**)	4.72 (**p < 0.001**)	0.40 (p = 0.698)

Table 7
Pairwise comparison of cephalometric variables between groups (A, B, C) using independent-samples *t*-test.

Variable	Correlation with NSAr	Correlation by group	Significant differences between groups (*t*-test)
SNA	−0,28 (p = 0,077)	B: −0,63 (p = 0,039)	A vs C (p = 0,018)
SNB	ns	B: 0,84 (p = 0,001)	A vs B (p = 0,001), A vs C (p < 0,001)
NPg-FH	0,31 (p = 0,050)	ns	A vs C (p = 0,003)
ANB	0,35 (p = 0,028)	ns	A vs C (p < 0,001), B vs C (p = 0,0025)
NAPg	ns	ns	A vs B (p < 0,001), A vs C (p < 0,001)
SN-GoGn	0,31 (p = 0,055)	ns	A vs B (p = 0,0067), A vs C (p < 0,001)
Y-Axis	ns	ns	A vs C (p = 0,00025), B vs C (p = 0,012)
ArGo-SN	ns	ns	A vs C (p = 0,006), B vs C (p = 0,021)
N-S	−0,26 (p = 0,106)	B: −0,58 (p = 0,063)	A vs C (p = 0,042)
S-Ar (NSAr)	–	–	A vs C (p = 0,026)
Ar-N	ns	ns	A vs B (p = 0,003), A vs C (p = 0,005)
Ar-Pt A	ns	ns	ns
Ar-Gn	ns	ns	B vs C (p = 0,015)
Wits appraisal	ns	ns	A vs B (p = 0,004), A vs C (p < 0,001), B vs C (p = 0,0048)
N-Pt A	0,36 (p = 0,021)	B: 0,58 (p = 0,061)	A vs B (p = 0,019), A vs C (p < 0,001)

NS: not significant.

though adequate for exploratory analysis, may not have sufficient power to detect weaker correlations within subgroups. Additionally, the cross-sectional design limits the ability to infer causal relationships or dynamic changes during growth. Future longitudinal studies using three-dimensional imaging techniques, such as CBCT or MRI, could provide deeper insights into the spatial and developmental interplay between the cranial base and facial structures.

Another limitation concerns the potential influence of ethnic and sex-related differences, which were not specifically controlled in the present analysis. Including these variables in future research could refine the understanding of population-specific growth patterns.

6. Conclusions

The findings of this study confirm the presence of a significant correlation between the NSAr and craniofacial morphology, particularly in relation to mandibular plane inclination and facial convexity. An increased NSAr was associated with a steeper mandibular plane and greater facial convexity, supporting the role of cranial base flexure as a determinant of sagittal and vertical skeletal relationships. These results highlight the diagnostic relevance of evaluating the cranial base angle as an early indicator of skeletal growth patterns. Incorporating NSAr assessment into orthodontic diagnosis and treatment planning may enhance the prediction of craniofacial development and guide individualized therapeutic strategies, especially in growing patients.

7. Informed consent statement

As all participants were minors (11-17 years), written informed consent was obtained from a parent or legal guardian before inclusion in the study. The consent form authorized the Dental Clinic of the Policlinico of the University of Bari "Aldo Moro" to perform the required diagnostic procedures, including photographic records, radiographic examinations, and cephalometric tracings, and to process clinical data in accordance with privacy regulations. Consent also covered the use and publication of anonymized clinical information and images for scientific research and scientific articles. No directly identifiable personal information is disclosed in this manuscript.

Informed consent statement

Written informed consent was obtained from the parent or legal guardian of each minor participant before inclusion. Consent covered diagnostic procedures, photographic and radiographic records, cephalometric tracings, processing of clinical data in accordance with privacy regulations, and the use and publication of anonymized data and images for scientific research and scientific articles.

Author contributions

Conceptualization, A.D.I., G.D. and D.D.V.; methodology, G.M., C. M.; G.D. and R.L.; software, A.P., P.B. and F.I.; validation, A.M.I., A.P and R.L.; formal analysis, A.D.I., G.M. and C.M.; investigation, A.D.I.; resources, D.D.V. and F.I.; data curation, A.M.I., G.D. and A.D.I.; writing—original draft preparation, A.P., P.B. and F.I.; writing—review and editing, C.M., G.D., A.M.I. and A.D.I.; visualization, F.I., G.D. and A.P.; supervision, F.I.; project administration, G.D. and D.D.V.; and funding acquisition, C.M. All authors have read and agreed to the published version of the manuscript.

Institutional review board statement

The study was approved by the University Ethics Committee (No. 2377/CEL, September 29, 2025).

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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