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Original Article

Cephalometric Analysis of Upper Airway Variations Across Skeletal Classes: A Retrospective Study

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ABSTRACT

This study aimed to assess the upper airway measurements in adult patients without prior orthodontic treatment, categorized equally according to their skeletal classification. Methods: In this retrospective cross-sectional investigation, lateral cephalometric radiographs from adults seeking orthodontic consultation were analyzed. Cephalometric tracings were carried out using specialized software, and descriptive statistics were computed for each parameter. Comparisons of cephalometric values across skeletal classes were performed, followed by linear regression analyses examining the relationship between airway dimensions, cephalometric variables, sex, and age. A p-value of < 0.05 was considered statistically significant. Results: Radiographs from 120 subjects were evaluated. The nasopharyngeal length (NL) and depth (PD) were markedly shorter in individuals with skeletal class III patterns ($p < 0.05$). The superior pharyngeal airway space (SPAS) was significantly reduced in class III compared to class II participants ($p < 0.05$), while class I subjects showed a smaller mean airway space (MAS) than those in class II ($p < 0.05$). Palatal length (PL) was notably greater in class I ($p < 0.05$). Regression analysis revealed that both the sella-nasion-A point angle (SNA) and Riedel's A–N–B angle (ANB) significantly influenced NL and PD values ($p < 0.05$). Conclusions: Individuals with class III skeletal patterns present shorter nasopharyngeal dimensions, indicating that sagittal skeletal variations may be associated with changes in upper airway anatomy.

Keywords: Orthodontics, Upper airway, Cephalometry, Malocclusion, Angle classification, Caucasian

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Introduction

Evaluating upper airway structure remains an important concern in orthodontic diagnostics. Numerous studies have explored the connection between cephalometric airway parameters and craniofacial or occlusal features [1–3]. Although cone-beam computed tomography (CBCT) has become widely adopted for precise imaging, lateral cephalograms continue to be routinely used for orthodontic evaluation [4, 5], forming part of standard diagnostic records and providing useful information about airway morphology [6]. According to Moss's "form follows function" principle [7], a functional relationship exists between proper occlusion and airway development.

In a study by Di Carlo *et al.* [8], 3D imaging was employed to determine whether airway shape and volume differed among adults with various skeletal profiles. Ninety subjects without respiratory issues or prior nasal surgery were grouped as Class I ($-0.5 <$ ANB < 4.5), Class II (ANB > 4.5), and Class III (ANB < -0.5). CBCT scans were taken with subjects in a supine position, and 3D cephalometric landmarks were identified. Relationships were analyzed across sagittal, transverse, and volumetric dimensions of the upper airway. No significant associations were found between skeletal class and total or sectional airway volumes, although a meaningful link was observed between minimal cross-sectional area and total airway volume.

Past research has also examined airway variations in specific conditions such as craniofacial syndromes [9], mandibular trauma [10], and obstructive sleep apnea (OSAS), a major focus in recent years [11]. Additionally, morphological airway changes have been studied in response to interventions such as functional appliances [12, 13], orthodontic treatments [14, 15], and orthognathic procedures [16, 17]. A systematic review by Bucci *et al*. [18] evaluated the influence of maxillary expansion on airway dimensions, revealing that most reviews were of low or critically low quality, with only one rated as high. Despite this, results indicated short- and long-term increases in nasal dimensions, supported mainly by low-quality evidence, while an enlargement of nasal cavity volume was confirmed by the higher-quality review. Long-term follow-up data post-rapid palatal expansion remain scarce.

To date, few investigations have analyzed upper airway morphology using cephalometry in untreated adult Caucasian patients with no history of orthodontic, orthopedic, or surgical procedures. Therefore, this study aimed to establish baseline upper airway dimensions across the three skeletal classes in this population. The null hypothesis proposed that there would be no significant differences in airway cephalometric measurements among the three Angle classifications.

Materials and Methods

Study design, setting, participants, and variables

This investigation followed a retrospective cross-sectional observational format, sanctioned by the institutional ethics committee (approval code: 2022-0209) and listed in the ClinicalTrials.gov registry (NCT05725980). The study was prepared following STROBE recommendations for observational research. Between February and March 2023, digital lateral cephalometric radiographs were selected from adult patients who attended orthodontic assessments between 2021 and 2023. Participants met the following inclusion criteria: 18–50 years of age, complete permanent dentition, Caucasian ancestry, and natural head posture (with relaxed lips and occluded teeth) during imaging. Excluded were subjects with any previous orthodontic or orthopedic treatment, jaw surgery, facial trauma, or nasopharyngeal disorders.

Radiographs were obtained during routine diagnostic sessions, ensuring compliance with clinical and ethical norms. Each image was analyzed with DeltaDent software (v2.2.1, Outside Format, Spino d'Adda, Italy).

Skeletal classification relied on Riedel's ANB angle [19], using the following parameters:

- ANB = 2° ± 2° → Class I
- ANB > 4° → Class II
- ANB < 0° → Class III

Vertical skeletal divergence was categorized through Steiner's SN^GoGn angle [20]:

- SN-GoGn = 32° ± 5° → Normal divergence
- SN-GoGn < 27° → Hypodivergent
- SN-GoGn > 37° → Hyperdivergent

Facial biprotrusion was recorded if SNA > 84° and SNB > 82°, while biretrusion corresponded to SNA < 80° and SNB > 78°.

Table 1 details the skeletal reference points and planes used in tracing, and **Table 2** lists those associated with the airway region.

Table 1. Standard anatomic landmarks and planes for the cephalometric tracing.

Landmarks and Measurements (Abbreviation)	Description
Nasion (N)	Foremost point on the frontonasal suture in the midsagittal plane
Sella (S)	Central point of the sphenoid bone's pituitary fossa
Point A (A)	Deepest point on the anterior maxillary border's curve
Point B (B)	Most posterior point in the concavity along the anterior mandibular symphysis
Gonion (Go)	Point at the mandibular angle, equidistant from the mandible's lower border and the ascending ramus's posterior border
Gnathion (Gn)	Most forward and lowest point on the chin, located between pogonion and menton
Basion (Ba)	Most forward point of the foramen magnum
Anterior nasal spine (ANS)	Anterior tip of the maxilla's sharp bony process at the lower edge of the nasal aperture

Posterior nasal spine (PNS)	Posterior endpoint of the palatine bone
SNA	Angle formed by sella, nasion, and point A
SNB	Angle formed by sella, nasion, and point B
ANB	Angle formed by point A, nasion, and point B
SN	Plane connecting sella and nasion
Sna-Snp	Bispinal plane connecting anterior and posterior nasal spines
GoGn	Plane of the mandible

Table 2. Anatomical reference points and planes utilized in the evaluation of the upper airway.

Landmarks and Measurements (Abbreviations)	**Description**
Soft Palate	
MPP	Midpoint of the posterior surface of the soft palate
MPA	Midpoint of the anterior surface of the soft palate
PT	Thickness of the soft palate
PL	Length of the soft palate
Nasopharynx	
Ad1	Point where the posterior pharyngeal wall intersects with the PNS-Ba line
NL (Nasopharynx Length)	Distance from Ad1 to PNS
PD (Nasopharynx Depth)	Line parallel to the bispinal plane, connecting PNS to the posterior pharyngeal margin
Oropharynx	
SPAS (Point)	Projection of the MPP point onto the pharyngeal wall
SPAS (Superior Pharyngeal Airway Space)	Distance from the midpoint of the posterior soft palate border (MMP) perpendicular to the nearest point on the posterior pharyngeal wall
U1	Terminal tip of the uvula
U2	Projection of the U1 point onto the posterior pharyngeal wall
MAS (Mean Airway Space)	Distance between U1 and U2
T1	Intersection of the tongue base with the line connecting point B and Go
T2	Projection of T1 onto the posterior pharyngeal wall along a line parallel to Go-B
PAS min (Pharyngeal Airway Space Minimum)	Distance between T1 and T2 along the line parallel to Go-B
Ph1	Intersection of the tongue base and the epiglottic vallecula
Ph2	Projection of Ph1 onto the posterior pharyngeal wall
IAS (Inferior Airway Space)	Distance from the superior epiglottic margin (Ph1) to the closest perpendicular point on the posterior pharyngeal wall
Hypopharynx	
Va1	Base of the epiglottic vallecula
Va2	Projection of Va1 onto the posterior pharyngeal wall
LPW (Lateral Pharyngeal Wall)	Distance from the epiglottic vallecula (Va1) to the posterior pharyngeal wall, perpendicular to Va1
Hyoid Bone	
H1	Most superior point of the hyoid bone body
H2	Projection of H1 onto a line perpendicular to the mandibular inferior margin (Go-Gn)
MPH (Mandibular Plane—Hyoid Bone)	Distance from the most anterior and superior hyoid bone point (H1) perpendicular to the mandibular plane

Figure 1 presents the cephalometric tracing employed in the analysis of upper airway morphology.

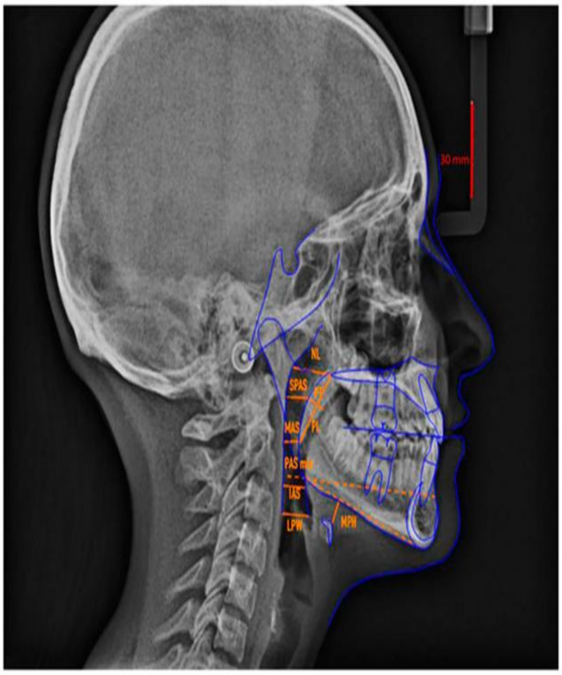

Figure 1 visually demonstrates the landmarks employed for the airway cephalometric analysis.

Data reliability and bias control

Two trained evaluators independently completed the tracings. To determine intra-examiner consistency, 20% of the radiographs (n = 24) were reassessed after a two-week interval. The intraclass correlation coefficients (ICC) reached 0.93 and 0.92, confirming excellent repeatability. For inter-examiner reliability, the agreement level was 0.91, indicating strong concordance between observers.

Sample size

The soft palate length (PL) served as the reference parameter for determining the minimum sample. Based on prior data (mean = 31.05, SD = 4.16), with $\alpha = 0.05$, power = 95%, and an expected mean difference of 3.34 [21], the required sample was 40 individuals per skeletal group—corresponding to Class I, II, and III malocclusions.

Statistical procedures

Descriptive statistics (mean and SD) were calculated for all cephalometric variables. Kolmogorov–Smirnov tests verified data distribution. Non-normally distributed interclass comparisons were analyzed with the Kruskal–Wallis test, followed by Dunn's post hoc test. Parameters exhibiting normal distribution, such as divergence and protrusion, were tested via ANOVA, complemented by Tukey's multiple comparison test.

Linear regression models explored associations between upper airway diameters and cephalometric measures (SNA, SNB, ANB, SN^GoGn, ANSPNS^GoGn, PT, PL), along with sex and age. Statistical significance was defined as $p < 0.05$.

All computations were performed in R® (version 3.1.3; R Foundation for Statistical Computing, Vienna, Austria).

Results and Discussion

For the sample estimation, data from 40 individuals per group were analyzed, classified into three skeletal categories, totaling 120 subjects (comprising 71 females and 49 males). The participants' initial demographic information for each category is detailed in **Table 3**.

Table 3. Baseline demographic characteristics of the study cohort. N = number of subjects; age is presented as mean ± SD.

	Skeletal Class I		**Skeletal Class II**		**Skeletal Class III**	
	n	Age	n	Age	n	Age
Female	27	27.86 ± 8.29	31	27.05 ± 7.59	13	28.36 ± 9.47
Male	13	27.68 ± 8.03	9	27.29 ± 8.09	27	28.38 ± 9.18

The comparative evaluation of cephalometric parameters across the skeletal classifications, jaw positions, and divergence profiles is summarized in **Table 4**. Measurements of the nasopharyngeal region (NL and PD) were markedly lower among Class III patients compared with Class I and Class II participants ($p < 0.05$). Significant distinctions were also recorded between biretruded versus normoposition, and biprotruded versus normoposition groups for PD and IAS metrics ($p < 0.05$). In contrast, no statistically relevant variation was found among hypodivergent, normodivergent, and hyperdivergent subjects ($p > 0.05$); however, hyperdivergent individuals tended to exhibit respiratory and muscular limitations.

Table 4. Mean ± SD for upper airway parameters across skeletal groups and Dunn's post hoc comparisons. Mean ± SD for biretruded/biprotruded cases with Tukey's post hoc analysis. Mean ± SD for divergence categories and respective Tukey's post hoc findings. Identical superscript symbols indicate nonsignificant differences ($p > 0.05$).

Measurement	Skeletal Class I	Skeletal Class II	Skeletal Class III	Biretruded (n = 24)	Normoposition (n = 70)	Biprotruded (n = 26)	Hypodivergent (n = 24)	Normodivergent (n = 70)	Hyperdivergent (n = 26)
NL	19.88 ± 3.30 A	21.07 ± 3.49 A	17.26 ± 3.37 B	18.19 ± 4.17 A	18.62 ± 3.86 A	27.3 ± 37.29 A	19.82 ± 3.23 A	22.36 ± 23.92 A	18.55 ± 3.66 A
PD	21.06 ± 3.22 A	21.97 ± 3.45 A	18.41 ± 3.45 B	18.86 ± 3.95 A	19.73 ± 3.59 A	21.08 ± 3.1 A	20.96 ± 3.16 A	20.55 ± 3.77 A	19.72 ± 3.86 A
SPAS	11.95 ± 2.36 A	12.57 ± 2.96 A	11.25 ± 3.07 A	11.26 ± 1.8 A	11.78 ± 2.94 A	12.27 ± 2.58 A	11.60 ± 2.49 A	11.88 ± 2.73 A	12.04 ± 2.89 A
MAS	8.99 ± 2.37 A	10.19 ± 2.98 A	10.08 ± 3.06 A	8.9 ± 2.07 A	9.64 ± 2.86 A	10.04 ± 2.72 A	10.13 ± 2.4 A	9.51 ± 2.70 A	9.65 ± 2.67 A
PAS min	11.11 ± 2.85 A	11.41 ± 3.40 A	11.19 ± 3.52 A	9.64 ± 2.24 A	11.07 ± 3.25 A,B	11.97 ± 3.2 B	11.90 ± 2.76 A	10.81 ± 3.19 A	11.33 ± 3.12 A
IAS	10.73 ± 2.51 A	10.97 ± 3.39 A	10.30 ± 3.33 A	9.31 ± 2.72 A	10.53 ± 3.17 A	11.32 ± 2.62 A	11.41 ± 2.7 A	10.44 ± 3.12 A	10.02 ± 2.51 A
LPW	14.02 ± 3.24 A	13.89 ± 3.02 A	12.58 ± 3.75 A	12.5 ± 3.44 A	13.20 ± 3.65 A	13.98 ± 3.19 A	14.43 ± 2.81 A	13.23 ± 3.50 A	12.89 ± 3.16 A
PL	33.29 ± 4.33 A	30.93 ± 5.43 A	30.85 ± 5.80 A	29.4 ± 4.74 A	32.22 ± 6.08 A	32.21 ± 4.6 A	32.17 ± 4.76 A	32.23 ± 5.66 A	30.20 ± 4.15 A
PT	9.38 ± 1.64 A	9.37 ± 2.61 A	9.71 ± 2.51 A	8.54 ± 1.83 A	9.37 ± 2.25 A,B	10.19 ± 1.74 B	10.26 ± 1.74 A	9.71 ± 2.51 A	9.21 ± 1.99 A
MPH	12.81 ± 4.72 A	13.18 ± 5.30 A	14.64 ± 4.17 A	12.09 ± 4.94 A	14.20 ± 4.00 A	13.71 ± 4.15 A	13.98 ± 3.84 A	13.65 ± 4.77 A	12.66 ± 5.40 A

Regression outcomes **(Table 5)** revealed that SNA and ANB significantly predicted nasopharyngeal variables NL and PD ($p < 0.05$). A notable correlation also emerged between PL and SPAS ($p < 0.05$). The parameters MAS, IAS, and PAS min were influenced by sex ($p < 0.05$), being higher in males and lower in females. Moreover, MAS and PAS min were age-dependent ($p < 0.05$), showing reduced values in older adults and elevated ones in younger individuals. The LPW value showed dependence on MPH, while PL displayed a significant association with PT ($p < 0.05$).

Table 5. R^2 and p-values (in parentheses) for significant regressions of upper airway variables. Dependent parameters are listed vertically, independent predictors horizontally. Only significant outcomes ($p < 0.05$) are presented.

	SNA	SNB	ANB	SN^GoGn	ANS-PNS	PL	PT	MPH	Age	Sex
Nasopharynx										
NL	0.043 (0.023)		0.0441 (0.021)							
PD	0.0758 (0.002)		0.1351 (0.001)							
Oropharynx										
SPAS						0.0509 (0.013)				
MAS									0.0528 (0.012)	0.0519 (0.012)
IAS										0.063 (0.012)

PAS min		0.0342 (0.043)	0.038 (0.033)
Hypopharynx			
LPW	0.0337 (0.034)		

The upper airway serves vital roles in breathing, swallowing, and speech production. Its interaction with craniofacial morphology is bidirectional, influencing both respiratory behavior and skeletal development. The "soft-tissue stretching theory" introduced by Solow and Kreiborg [22] explained how airway function and head orientation can affect facial growth. In contrast, Harvold's experiments demonstrated skeletal, muscular, and dental alterations in animals with induced nasal blockage [23], whereas Warren and Spalding [24] argued that the relationship between nasal respiration and craniofacial development remains ambiguous.

Previous literature has extensively examined airway dimensional changes, particularly concerning obstructive sleep apnea syndrome (OSAS) [11, 12], as well as morphological variations following different therapeutic procedures [13–18]. The current investigation aimed to provide an in-depth two-dimensional analysis of the upper airway in untreated Caucasian adults, grouped according to skeletal classification, jaw divergence, and protrusion level. Comparative data from earlier publications were included to enhance analysis consistency [21, 25, 26]. The null hypothesis was partially refuted. Specifically, NL and PD measurements were significantly smaller in Class III participants relative to Classes I and II ($p < 0.05$). PD and IAS values also varied significantly across protrusion categories ($p < 0.05$). Conversely, no notable differences were recorded among hypodivergent, normodivergent, and hyperdivergent groups ($p > 0.05$).

Table 6 compiles the reference benchmarks for the parameters analyzed in this research.

Table 6. Reference standards for the evaluated outcomes derived from previously published sources [21, 25, 26].

Classification	Divergence Type	Gender	NL	PD	SPAS	MAS	PAS Min	IAS	LPW	MPH	PL	PT
Skeletal Class I	/	/	13.1 ± 2.6	9.7 ± 3.1	/	12.3 ± 4.4	/	18.2 ± 4.4	36.8 ± 4	7.4 ± 1.3		
Skeletal Class II	/	/	14 ± 3.8	10.1 ± 3.1	/	12.9 ± 3.9	/	15.8 ± 4.8	37 ± 4	7.4 ± 1.44		
Skeletal Class III	/	/	12.8 ± 4.4	10.6 ± 4.5	/	13.9 ± 4.6	/	18.8 ± 5	34 ± 9.3	7.3 ± 2.1		
Hypodivergence	/	/	12.9 ± 2.74	/	/	/	/	18.95 ± 4.37	34.39 ± 8.42	/		
Normodivergence	/	/	12.64 ± 2.3	/	/	/	/	15.97 ± 4.97	31.07 ± 4.16	/		
Hyperdivergence	/	/	10.64 ± 1.83	/	/	/	/	18.74 ± 5.53	33.12 ± 3.96	/		
Males	/	27.9 ± 2.5	/	10.9 ± 2.8	11.1 ± 3.2	/	19.7 ± 2.6	/	38.3 ± 1.9	11.1 ± 1.4		
Females	/	25.1 ± 1.3	/	10.1 ± 2.4	10.5 ± 2.8	/	16.5 ± 3.1	/	35.6 ± 1.7	9.5 ± 1.4		

Based on the findings of the present investigation, the most significant observation is that nasopharyngeal dimensions were markedly smaller in patients with skeletal Class III, likely as a consequence of maxillary constriction. This aligns with prior studies demonstrating that maxillary expansion results in an increase in nasal cavity and nasopharyngeal volume. In a related study, Li *et al.* [27] evaluated both dimensional and volumetric modifications of the upper airway before and after mini-implant-assisted rapid maxillary expansion (MARME), and explored correlations between these variations and vertical skeletal patterns in young adults. Their results confirmed that MARME led to an increase in nasal and nasopharyngeal volumes, accompanied by an enlargement of nasal bone and maxillary width. Likewise, Chang *et al*. [28] analyzed 3D cone-beam computed tomography (CBCT) data to assess upper airway changes in individuals with maxillary deficiency treated with rapid expansion. They found that the cross-sectional airway area, extending from the posterior nasal spine to the basion, exhibited a notable enlargement of 99.4 mm (+59.6%), thereby reaffirming the therapeutic advantage of rapid maxillary expansion, consistent with prior reports [29, 30].

According to the outcomes of the current analysis, it is noteworthy that, in addition to the significant reduction of nasopharyngeal dimensions in Class III subjects, the linear regression models identified a significant association between SNA and ANB (predictors) and nasopharyngeal parameters (NL and PD) as dependent variables ($p < 0.05$). Hence, the reduction in nasopharyngeal measurements appears to be directly correlated with the degree of sagittal maxillary deficiency. Although several contemporary studies have reported upper airway volumetric alterations following orthopedic interventions [13, 31], the management of airway disorders should always involve a multidisciplinary approach, integrating otolaryngologists for comprehensive diagnosis and treatment planning.

Previous research has also demonstrated a notable relationship between maxillomandibular imbalance and OSA severity [32]. Additionally, a narrower nasopharyngeal width has been linked with hyperdivergent maxillomandibular growth patterns. These findings reinforce the association between craniofacial morphology and sleep-related breathing disturbances, though a definitive cause-and-effect mechanism remains unconfirmed. Consequently, the authors highlight the critical role of orthodontic assessment in the early detection and management of pediatric obstructive sleep apnea (OSA).

A principal limitation of the present study lies in the fact that airway morphology was assessed through cephalometric (2D) evaluation, rather than three-dimensional CBCT imaging, as used in recent investigations. Although 3D analysis provides more accurate morphological assessment of the airway [33], it is necessary to balance diagnostic precision against the higher biological risks associated with increased radiation exposure, in accordance with current radiological safety guidelines [34]. Furthermore, the observational design of the research imposes inherent methodological constraints typical of this study type.

Considering these aspects, future studies should broaden this evaluation framework to include different classes of malocclusions and functional discrepancies beyond sagittal variations. Expanding knowledge about airway morphology alterations will allow for the earlier identification of individuals at risk of airway dysfunction associated with craniofacial patterns.

Conclusion

The upper airway functions as a highly integrated anatomical system, with a mutual dependency between respiratory patterns and facial development. Individuals with Class III skeletal configurations exhibit notably smaller nasopharyngeal measurements, likely attributable to a reduction in maxillary sagittal width, which influences overall upper airway size. Clinicians should acknowledge that such sagittal discrepancies may correspond to structural alterations in the upper respiratory tract. Furthermore, it is essential to educate and encourage families to seek early orthodontic evaluation for growing patients, aiming to detect skeletal and dental misalignments promptly and prevent secondary complications affecting not only oral health but also airway function.

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