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Three-Dimensional Upper Airway Analysis of Different Craniofacial Skeletal Patterns in Vietnamese Adults

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Abstract: Introduction: This study aimed to investigate differences in the three-dimensional (3D) upper airway dimensions in Vietnamese participants. **Methods:** This study included 341 Vietnamese participants grouped based on the vertical growth pattern (ANB angle) (skeletal Class I, 123; Class II, 124; Class III, 94). The patients were categorized into subgroups based on the horizontal growth pattern according to the Frankfort mandibular angle (hypodivergent, 35; normodivergent, 175; hyperdivergent, 131) to compare the frequency distribution of the three growth patterns in each skeletal class. The airway dimensions of the three skeletal classes were divided into four volumes using 3D virtual software (In VivoDental Software 6.0). The height, width, and cross-sectional area (CSA) of each part, as well as the total volume and minimum CSA, were measured and analyzed. **Results:** The airway space was reduced in hyperdivergent Class II individuals, underscoring an important connection between upper airway dimensions and vertical skeletal patterns, which suggests that vertical growth patterns contribute to pharyngeal narrowing and subsequent upper airway obstruction. Significant differences ($p < 0.001$) in the minimum CSAs and volumes of the middle and inferior pharyngeal airways were observed based on Angle's skeletal classification. **Conclusions:** Our insights are valuable for orthodontics, especially in diverse populations, such as the Vietnamese, due to differences in the influence of genetic and environmental factors on skeletal and airway characteristics.

Keywords: upper airway dimensions; vertical skeletal class; facial types; cross-sectional area

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1. Introduction

The dimensions of the upper airway can vary significantly among individuals owing to various factors, including skeletal patterns. These patterns can influence the shape and size of the upper airway, potentially affecting respiratory health by causing issues such as obstructive sleep apnea (OSA) and craniofacial anomalies. Understanding the upper airway dimensions and their relationship with craniofacial growth and surrounding structures has been a priority for ear, nose, and throat (ENT) specialists; healthcare professionals; surgeons; and dentists, especially orthodontists.

Numerous extensive studies have been conducted on craniofacial factors and their influence on upper airway dimensions; however, most of these studies are based on airway landmarks in two-dimensional (2D) images, which not only incorrectly depict complex shapes but also lack precision for evaluating the volume of the airway and most constricted cross-sectional area (CSA) [1]. To overcome the limitations of evaluations using 2D images, new cone-beam computed tomography (CBCT) systems with higher-quality images and accurate measurement software were developed, specifically for the head and neck region. The introduction of three-dimensional (3D) airway models derived from CBCT scans represents a significant advancement in the objective evaluation of the efficacy of surgical treatments for OSA, orthognathic surgeries, and maxillary expansion by assessing their effects on airway dimensions [2]. However, ensuring the accuracy and reliability of the methods used to generate these models is crucial because they serve as a fundamental baseline for treatment planning. Therefore, proper scientific validation of the generation method is necessary to maintain the integrity and effectiveness of evaluation tools [3].

The orthodontic literature has long discussed the correlation between the pharyngeal airway space and various craniofacial skeletal patterns in patients, encompassing both anteroposterior (skeletal Classes I, II, and III) and vertical (hyperdivergent, normodivergent, hypodivergent) dimensions. In 1907, Angle observed that Class II, division 1 malocclusions were characterized by narrow upper pharyngeal airways and a tendency for mouth breathing, resulting in dentofacial changes such as a narrow upper arch, protruded upper incisors, and abnormal lip function. This early insight highlights the connection between airway characteristics and dental alignment [4]. This discussion highlights the close relationship and intimate association between these factors. Several studies have shown that different skeletal patterns affect the upper airway size (UAS); however, these results are controversial. These conflicting results could be attributed to various factors, such as patient age, sex, ethnicity, head position during radiography, method of measurement, and area of measurement [5].

Studies examining ethnic differences in the UAS have been conducted in various populations, such as Korean, Lebanese, Chinese, and Brazilian populations [6–8]. However, there is a lack of specific reports focusing on upper airway dimensions in the Vietnamese population, which originates from a homogeneous ethnic background in Southeast Asia; consequently, the upper airway dimensions in this group remain poorly understood. We hypothesize that vertical growth patterns significantly impact upper airway dimensions, particularly in hyperdivergent individuals, and that these patterns are associated with an increased risk of airway obstruction.

Therefore, given the evolution of 3D diagnosis, the aim of our cross-sectional study was to determine the dimensions of the upper airway and most constricted CSA and to compare these values among various craniofacial skeletal patterns in healthy Vietnamese adults using CBCT.

2. Methods

This study included 341 Vietnamese participants (skeletal Class I, 123; Class II, 124; Class III, 94), including 126 male and 169 female individuals, aged between 17 and 25 years (mean age, 22 years), who were recruited from the Department of Orthodontics of Hanoi Medical University (Hanoi, Vietnam).

Participants with a full set of permanent dentition were included in this study. Participants who had previously undergone orthodontic or surgical treatments, had a BMI exceeding 22.9 and had symptoms or a history of upper respiratory infections, adenoid hypertrophy, tonsillitis, adenoidectomy, or tonsillectomy were excluded from the study. This study focused on investigating the natural progression and potential associations between vertical skeletal patterns and the upper airway space in a more controlled manner. This approach was implemented to reduce confounding factors that may affect outcomes and to facilitate a clearer understanding of the association between skeletal morphology and airway dynamics among the study participants. This study was reviewed and approved by the Institutional Review Board of the authors' institution (HMU IRB675).

CBCT volume scans of all the patients were obtained with maximum intercuspation to minimize variability in the mandibular and soft tissue measurements [9] using the Sirona DS Plus [Sirona Dental Systems, Bernsheim, Germany]. The imaging protocol included a 12-inch field of view to encompass the entire craniofacial anatomy. The axial slice thickness was set at 0.3 mm, and the voxels were isotropic. The scanning time ranged from 6 to 20 s, with resolutions varying between 0.25 mm and 0.6 mm and voxel sizes between 3.5 × 3.5 pixels and 1024 × 1024 pixels. The information was transmitted directly to the researchers' computer and saved in Digital Imaging and Communications in Medicine format. To account for the influence of head posture on the airway volume, the craniocervical inclinations of all the patients were examined to confirm that they fell within the standard range [10]. A 3D coordinate system and image were constructed using the In Vivo Dental software 6.0 (Anatomage, San Jose, CA, USA), a medical image analysis tool. This software allows the precise construction of a 3D representation, enabling researchers to accurately analyze anatomical structures. The system provides a standardized framework for measurements and comparisons across subjects. With advanced features for image processing and analysis, InVivo Dental 6.0 facilitates detailed visualization and manipulation of dental and skeletal structures derived from imaging data, such as CBCT data. This approach offers valuable insights into the relationships among skeletal patterns, dental alignment, and upper airway anatomy, which are essential for enhancing orthodontic diagnosis and treatment planning.

To minimize errors and standardize the measurements, the 3D image was reoriented using the nasion point as the origin of the 3D coordinate system (Figure 1).

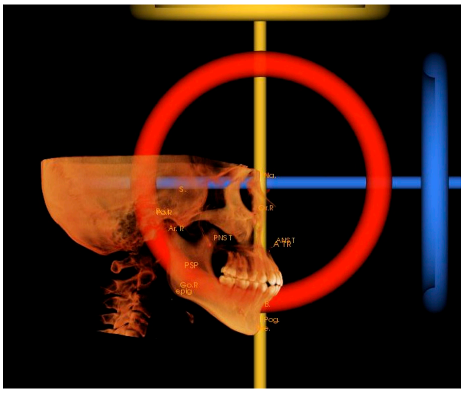

Figure 1. The right porion, the left located in the most laterosuperior points of the external auditory meatus, and the right orbitals defined the standard Frankfort horizontal plane. A frontal plane was constructed through origin points.

In contrast to other studies that employed 2D cephalometric analysis, our study used a 3D analysis system derived from CBCT volumetric images. This involved establishing a set of landmarks, reference lines, and reference planes to conduct comprehensive 3D assessments. Serafin et al. conducted a study indicating that deep learning algorithms demonstrated exceptional accuracy in automatically identifying 3D cephalometric landmarks [1]. The landmark identifications and physical measurements were performed by the same orthodontist (V.T.T.T). For the 3D cephalometric analysis, we identified 16 hard tissue landmarks and performed seven anteroposterior and five vertical measurements. These are defined in Table 1 and illustrated in Figure 2.

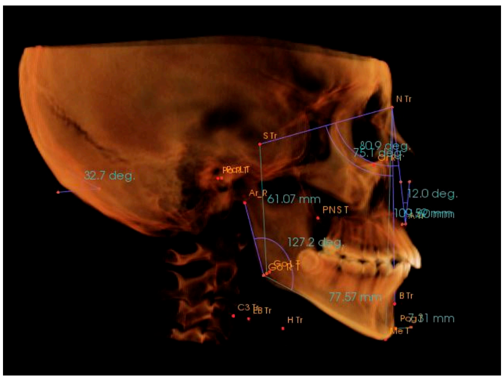

Figure 2. Landmarks, anteroposterior measurements, and vertical measurements were used in this study.

Table 1. Three-dimensional cephalometric variables used in this study.

Variable	Definition
Vertical skeletal pattern	
Gonial angle	The angle formed by the junction of the posterior and lower borders of the mandible
AFH	Distance between nasion and menton
PFH	Distance between sella and gonion
AFH/PFH	The ratio of AFH and PFH
FMA	The angle formed by the FH plane and the mandibular plane
Anteroposterior skeletal pattern	
SNA	The angle formed by sella, nasion, point A
SNB	The angle formed by sella, nasion, point B
A to N perp	The linear distance from point A to nasion perpendicular
Pog to N perp	The linear distance from point pogonion to nasion perpendicular
ANB	The difference between SNA and SNB
Mand length	The linear distance of the mandibular plane (Go-Me)
Facial convexity	The angle formed by nasion, point A, and pogonion

The participants were classified into the following three groups according to the anteroposterior skeletal relationship: Class I ANB angle (0° < ANB < 4°, 123), Class II (ANB ≥ 4°, 124), and Class III (ANB ≤ 0°, 94). Based on the study by Anh et al. [11], the participants were categorized into subgroups according to the Vietnamese norms of the horizontal growth pattern based on FMA angles between 15° and 24° (hypodivergent, normodivergent, hyperdivergent) to compare the upper airway dimensions among the three patterns in each skeletal class. Overall, nine subgroups, combining patients in the anteroposterior and vertical craniofacial groups, were created. The age, sex, and distribution stratified by the ANB and FMA angles are shown in Figure 3.

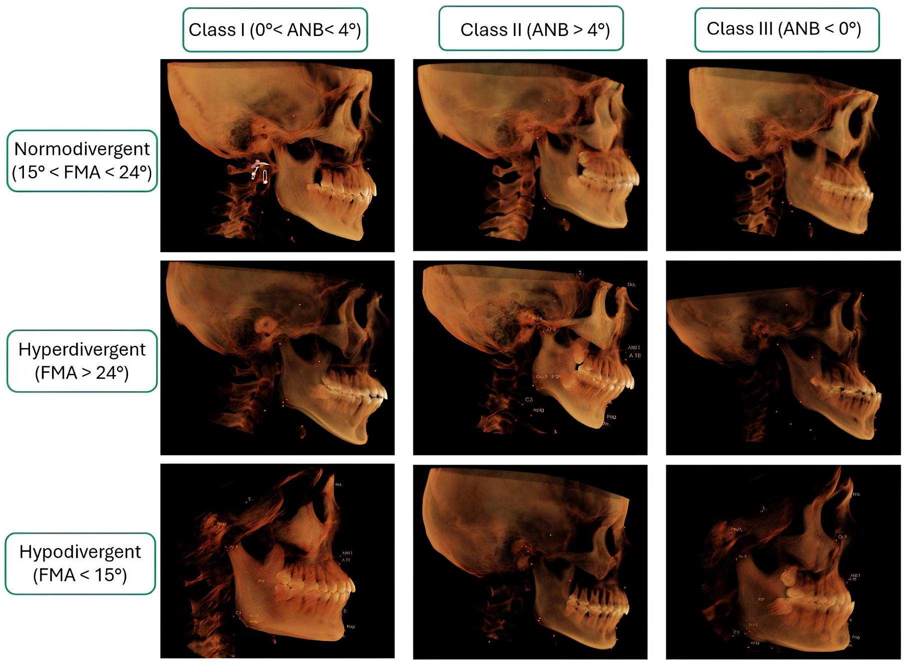

Figure 3. Nine subgroups, combined with anteroposterior and vertical craniofacial groups.

Four cross-sectional planes (one frontal and three axial sections) and four volume measurements of the pharyngeal airway were designed based on a previous study [6] (Figure 4).

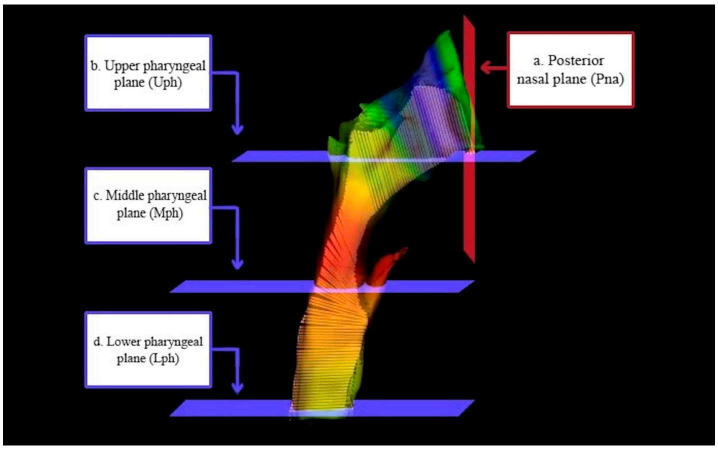

Figure 4. Four cross-sectional planes of the pharyngeal airway. Pna plane: frontal plane perpendicular to the FH plane passing through the PNS; Uph plane: axial plane parallel to the FH plane passing through the PNS; Mph plane: axial plane parallel to the FH plane passing through the caudal margin of the soft palate; Lph plane: axial plane parallel to the FH plane passing through the superior margin of the epiglottis; abbreviations: PNS, posterior nasal plane; FH, Pna, Uph, Mph, Lph.

The CT scans were processed using the InVivo Dental software 6.0 to create volumetric renderings, followed by a volumetric analysis of the specified airways. The threshold values were fine-tuned to remove imaging artifacts and to enhance the delineation of the airway region. Subsequently, measurements of the airway volume, CSA, width, and height were recorded in cubic millimeters (mm^3), cubic centimeters (cc), and millimeters (mm), respectively, Figure 5.

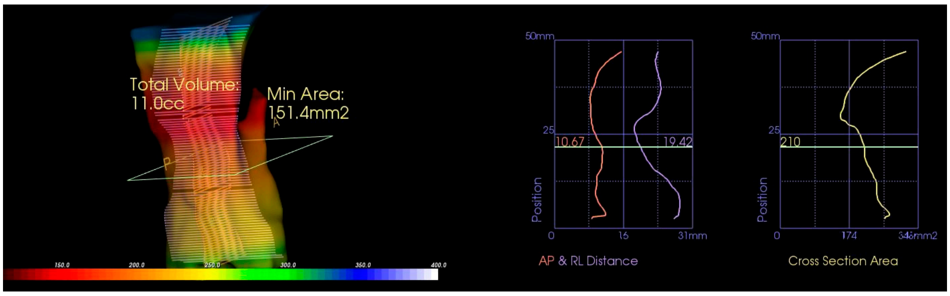

Figure 5. Volume, cross-sectional area, width, and height of the designated airway calculated in mm^3, cc, and mm, respectively. Abbreviations: AP: Anteroposterior, RL: Right Left.

Statistical Analysis

To assess the reliability, 60 randomly selected CBCT scans of participants were digitized by the same operator. Differences between two measurements were evaluated using the intraclass correlation coefficient (ICC), which indicated excellent reliability (ICC > 0.98).

Multivariate analysis of covariance (MANCOVA) was performed to compare the adjusted means of the upper airway dimensions between the three anteroposterior skeletal classification groups separately according to the FMA. A two-way MANCOVA was performed with sex as a covariate and anteroposterior skeletal classification and facial growth pattern as fixed factors.

3. Results

3.1. Association Between Sex and Facial Growth Pattern

Table 2 shows the frequency distribution of the anteroposterior skeletal classes between the two sexes. The skeletal classification and sex exhibited significant main effects ($p = 0.027$ and $p < 0.05$, respectively).

Table 2. Association between sex and anteroposterior skeletal classification.

		Skeletal Classification			Total
		Class I	**Class II**	**Class III**	
Sex	**Male**	49	44	50	143
	Female	74	80	44	198
Total		123	124	94	341

Chi-square test: $p = 0.027$.

3.2. Association Between Sex and Facial Growth Type

Based on a study by Anh et al. [11], given the cephalometric norms in the Vietnamese population, the normodivergent group included patients with FMAs between 15° and 24°.

Table 3 shows the frequency distribution of the facial growth patterns between the two sexes. The facial growth pattern and sex exhibited significant main effects ($p = 0.03$ and $p < 0.05$, respectively).

Table 3. Association between sex and facial growth type.

		Facial Growth Type			Total
		Hypodivergent (≤15)	**Normodivergent (>15, <24)**	**Hyperdivergent (≥24)**	
Gender	Male	22	70	51	143
	Female	13	105	80	198
Total		35	175	131	341

Chi-square test $p = 0.030$.

3.3. Effects of Age According to Anteroposterior Skeletal Classification Groups

Table 4 shows the frequency distribution of the facial growth patterns among the three skeletal classes. The facial growth type and skeletal class exhibited significant main effects ($p = 0.03$ and $p < 0.05$, respectively.

Table 4. No significant difference in skeletal classification was observed based on age.

	Mean	**SD**	***p*-Value**
Class I	22.28	3.355	0.102
Class II	22.53	3.358	
Class III	21.59	3.140	

ANOVA test.

3.4. Comparison of Variables According to Angle's Classification and Facial Growth Pattern

The MANCOVA showed that the anteroposterior skeletal classification and facial growth pattern exhibited significant main effects ($p < 0.001$), with a significant interaction between them ($p = 0.001$); the covariate "sex" exhibited a significant effect ($p < 0.001$).

4. Discussion

The selection criteria for our study included the absence of clinical signs and symptoms associated with pharyngeal pathology and no history of treatment interventions. The selection process relied on information extracted from clinical charts at the time of orthodontic diagnosis. Individuals with severe adenoid or tonsillar hypertrophy, indicative of infection or allergies, were excluded from the study to ensure a more homogeneous sample. A systematic review of the upper airway dimensions in different sagittal craniofacial patterns was conducted by Iveta et al. [3]; they highlighted that 75% of the included studies did not identify differences in nasopharyngeal dimensions among different craniofacial patterns.

They also reported that automatic or semi-automatic 3D segmentation of the upper airway was considerably challenging, particularly in terms of the intricate anatomy of the nasal airway. The measurement method we used in our study was the same as that suggested by Kim et al. [6]. However, we excluded the nasal area because a deviated septum, a narrow nasal cavity, and turbinate hypertrophy [12] could lead to artifact reconstruction and, therefore, could affect the resolution of the airway boundaries or CSA measurement. To effectively investigate the potential relationship between airway restriction and craniofacial growth using CBCT imaging, the reconstructed upper airway model must be reliable and valid. Reliability ensures consistent measurements over time and across different observers, and validity ensures the accuracy and appropriateness of a model's representation. Achieving reliability and validity involves careful image acquisition, segmentation, and validation using established standards and expert consensus [3].

While the majority of studies on the upper airway size reported no significant sex-based differences [6,13], Alves et al. [14] reported variations in the retropalatal and retrolingual areas among patients with Class III malocclusion. Additionally, Chiang et al. [15] found that boys not only possess longer and wider airways but also exhibit a more rapid increase in size compared to girls. In line with these findings, our study also revealed a significant influence of sex on differences in anteroposterior and facial growth patterns.

Pharyngeal structures exhibit rapid growth until the age of 13 years [16]. Between 14 and 18 years of age, a phase of relative stability is noted in pharyngeal development [17–19]. Long-term follow-up studies have confirmed that from 20 to 50 years of age, the soft palate undergoes elongation and thickening, while there is a narrowing of the pharyngeal region [20]. The optimal time frame for assessing oropharyngeal maturity is determined based on these findings.

There are ongoing debates regarding the clinical significance and reliability of the ANB angle in determining anteroposterior jaw relationships [21]. Despite these discussions, ANB angle measurement remains a widely employed method for characterizing anteroposterior dentofacial discrepancies; therefore, this was the method of choice in several studies [6,14,22]. Furthermore, the SNA and SNB angles, commonly used to establish the position of the maxilla and mandible relative to the cranial base [23,24], were also incorporated into the analysis.

Kim et al. [6] reported that while the minimum CSA and volumetric measurements of the pharyngeal airway subregions were higher in skeletal Class I than in Class II, the differences were not significant. This suggests that the segmental airway capacity may not be associated with mandibular deficiency. Conversely, our study found a significant difference ($p < 0.001$) in the minimum CSA and volume of the middle and inferior pharyngeal airway based on Angle's skeletal classification. This difference may be attributed to a larger sample size.

Reports have indicated that the malocclusion type does not influence the pharyngeal airway width [14,25,26]. In line with this finding, when considering anteroposterior skeletal classification, de Freitas et al. [25], Dalmau et al. [27], Di Carlo et al. [28], and Brito et al. [29] observed no significant differences in the volume and morphology of the nasopharynx (NP), oropharynx (OP), and hypopharynx (HP) between different vertical and sagittal facial patterns. However, the upper airway morphology can be affected by different sagittal malocclusions. Most authors have observed smaller OP and NP dimensions in skeletal Class II patterns [30–32]. Akcam et al. [33] studied the upper and lower pharyngeal airways in preadolescents based on various rotation types and found that individuals classified as hyperdivergent had narrower lower pharyngeal airways. Wang et al. [34] showed that adult patients with skeletal Class II who exhibit vertical growth patterns have significantly narrower pharyngeal airways than patients with normal or horizontal growth patterns; the same measurement technique was used in our study and the findings clearly revealed a significant tendency toward reduced pharyngeal airway measurements in hyperdivergent participants in the Class II skeletal group. Accordingly, the minimum CSA in the hyperdivergent group was significantly lower than that in the normodivergent or hypodivergent group (Table 5). The relationship between facial growth and airway function remains controversial, partly due to conflicting research findings. Although some studies have suggested a correlation between certain facial features and airway dimensions, others have reported inconclusive or contradictory results [35]. Studies have indicated that 3D imaging offers superior reliability and accuracy compared to conventional cephalometry, particularly in assessing the dimensions of both hard and soft tissues, as well as in airway measurements, such as volume measurements [13,36]. A systematic review explored the predictability of 3D airway evaluations using lateral cephalograms (LCs) compared with using CT and CBCT scans [37]. This review indicates that although LCs do not reliably predict variability in the hypopharyngeal segment, further robust studies are needed to determine their clinical utility in assessing airway size. Accurate diagnosis forms the cornerstone of any specialty and aids in precise treatment planning and preventive strategies. Therefore, the data and images obtained from CBCT provide valuable insights across various categories of aspects in the craniofacial region [38]. CBCT produces anatomically accurate 3D images without magnification or distortion, enabling precise measurements in all three dimensions (sagittal, frontal, and transverse). This allows for a comprehensive understanding of the pharyngeal morphology in growing children and provides valuable insights that aid in diagnosis and treatment planning. Moreover, 3D imaging has become invaluable for quality control in industrial settings. Traditional methods for assessing facial structures and dentition have become outdated because of their limitations. In medicine, the predominant method used is 3D imaging, which provides detailed information on hard and soft tissues. Techniques, such as CT, CBCT, micro-computerized tomography, 3D laser scanning, structured light techniques, and stereophotogrammetry, and 3D surface imaging modalities, such as 3dMD, 3D facial morphometry, tuned aperture CT, and magnetic resonance imaging, offer precise and problem-specific insights. These advanced imaging modalities significantly enhance diagnostic accuracy and treatment planning in various medical fields [38]. Furthermore, to better evaluate the relationship between respiratory function and airway morphology, Iwasaki et al. [39] utilized fluid-mechanical simulation to assess the ventilation status of the entire upper airway. These cutting-edge technologies open avenues for novel approaches, such as constructing virtual patients by overlaying the soft tissue, facial skeleton, and/or dentition. Future well-designed studies are essential to gain a deeper understanding of airway dynamics and to develop real-time four-dimensional virtual airway models that simulate patients in action [40].

Thus far, there has been no research related to Vietnamese skeletal classification and facial growth type distribution or their impact on the upper airway dimensions. Hence, this study represents an inaugural examination of the upper airway dimensions in the Vietnamese population, adding a novel dimension to existing research. A small nose and protruding upper lip are characteristic features of many East Asian individuals with mandibular prognathism. A common surgical intervention involves clockwise rotation of the maxillomandibular complex and impaction of the maxillary posterior region to achieve an aesthetically pleasing facial profile. However, this procedure can lead to an upward displacement of the tongue, which may exert pressure on the soft palate, resulting in significant narrowing of the airway at this level [41]. Therefore, our study also offers surgeons a comprehensive overview of the pre-esthetic surgical characteristics of Vietnamese patients. Our focus was on analyzing the airway dimensions in adults. However, future studies should also include children. Additionally, comparing our findings with those of studies conducted in other populations could offer valuable insights into potential ethnicity-related differences in upper airway dimensions. This comparative approach may contribute to a more comprehensive understanding of variations in airway anatomy across different demographic groups.

Table 5. Comparison of variables according to Angle's classification and the facial growth pattern. Two-way MANCOVA: gender as a covariate; anteroposterior skeletal classification and facial growth pattern as fixed factors.

Variables	Class I						Class II						Class III						Gender Sig. (Co-variate)	Angle Class Sig.	Facial Growth Sig.	Interaction Sig. (Angle and Facial)
	Hypodivergent		Normodivergent		Hyperdivergent		Hypodivergent		Normodivergent		Hyperdivergent		Hypodivergent		Normodivergent		Hyperdivergent					
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD				
FMA	12.24	1.91	20.09	2.48	27.14	2.17	13.57	0.84	20.32	2.45	29.67	4.73	12.57	2.34	19.93	2.49	27.28	2.89	0.227	0.038	<0.001	0.083
SNA	84.25	4.15	81.75	3.54	81.93	3.53	85.94	3.81	83.95	3.69	82.90	3.42	81.04	3.83	81.02	3.96	81.52	4.43	0.558	<0.001	0.076	0.178
SNB	82.56	3.87	79.67	3.68	79.77	3.53	80.39	3.43	78.60	4.02	76.65	3.54	83.69	4.25	84.08	3.83	84.51	4.93	0.722	<0.001	0.048	0.024
ANB	1.69	1.04	2.09	1.03	2.16	0.95	5.54	0.82	5.35	1.13	5.93	1.42	−2.65	1.36	−2.60	1.83	−2.60	1.89	0.501	<0.001	0.319	0.473
Gonial angle R	111.47	3.64	118.51	5.11	122.83	6.97	112.12	3.26	117.83	4.16	122.51	5.77	115.61	6.09	119.93	5.38	125.57	6.37	0.013	0.001	<0.001	0.701
A to N perp	3.67	3.81	2.60	2.90	1.44	3.29	4.82	2.61	4.69	3.13	2.85	3.16	1.51	2.31	0.85	3.50	0.43	3.87	0.068	<0.001	0.002	0.463
Pog to N perp	6.15	5.49	1.97	5.00	−1.16	5.83	1.53	4.79	−0.30	5.81	−7.15	6.44	9.37	4.67	8.90	5.80	7.59	8.47	0.038	<0.001	<0.001	0.003
Mand length	87.68	4.61	83.79	4.17	83.72	4.59	84.58	4.10	82.83	4.19	81.41	4.64	88.15	5.92	86.74	4.17	88.39	4.57	<0.001	<0.001	0.103	0.471
Facial convex angle	1.85	2.52	3.72	2.50	4.36	2.16	9.07	2.54	10.52	2.78	12.72	3.49	4.02	7.00	0.92	8.68	3.44	7.89	0.157	<0.001	0.008	0.102
AFH	112.20	6.17	113.36	7.31	115.96	6.34	108.52	7.27	112.18	7.07	115.97	6.02	116.28	5.25	115.02	6.16	121.20	6.24	<0.001	<0.001	<0.001	0.364
PFH	85.46	6.20	76.97	7.01	73.57	6.19	80.79	7.05	76.04	5.89	72.43	6.49	86.28	5.02	78.60	7.03	79.02	6.79	<0.001	0.003	<0.001	0.976
AFH/PFH	1.32	0.05	1.48	0.09	1.58	0.08	1.35	0.04	1.48	0.08	1.61	0.12	1.35	0.08	1.47	0.10	1.54	0.12	<0.001	0.624	<0.001	0.464
Pna plane height	16.24	6.17	13.55	6.96	12.85	6.50	8.52	5.28	12.53	5.86	11.86	5.33	16.27	6.35	14.44	6.84	12.93	6.84	0.212	0.007	0.411	0.226
Pna plane width	20.54	6.61	19.78	8.83	19.77	8.07	16.85	6.91	18.47	8.11	17.64	7.73	17.81	7.19	17.64	8.18	18.00	8.08	0.018	0.128	0.91	0.995
Pna plane CSA	366.20	136.66	336.46	119.90	347.10	123.31	302.86	126.14	339.46	152.02	343.50	151.60	428.93	150.39	394.10	173.29	354.88	162.00	0.167	0.068	0.838	0.475
Uph plane height	20.17	4.12	19.52	4.22	19.22	5.14	18.29	3.42	19.14	4.81	18.26	4.78	20.04	3.28	19.71	4.39	18.15	4.24	0.314	0.379	0.212	0.886
Uph plane width	28.23	3.67	26.87	4.32	28.08	3.71	23.91	4.94	27.25	4.36	27.59	4.08	29.14	3.79	27.31	4.88	28.32	4.26	0.673	0.041	0.227	0.172
Uph plane CSA	562.21	164.31	523.59	140.08	518.29	138.65	434.43	128.37	513.70	162.37	470.27	155.51	578.64	156.00	526.50	157.69	501.70	136.57	0.816	0.039	0.355	0.436
Mph plane height	10.88	3.19	11.17	3.25	11.93	2.96	10.57	2.58	10.85	2.93	9.78	3.02	13.04	4.05	11.75	3.45	13.35	3.59	0.07	0.001	0.564	0.078
Mph plane width	25.70	5.58	26.12	5.91	26.80	5.87	21.19	7.32	24.66	5.63	24.14	6.64	27.29	6.53	25.15	7.17	27.63	6.88	0.009	0.022	0.31	0.509
Mph plane CSA	255.79	146.02	267.44	123.84	290.74	104.87	203.43	100.18	245.04	99.42	229.39	114.88	297.60	110.03	256.11	105.18	317.58	108.45	0.078	0.014	0.184	0.264
Lph plane height	14.06	5.04	12.48	3.87	14.19	3.45	12.40	4.02	13.97	4.00	11.80	3.99	14.13	3.72	14.07	4.45	15.93	4.28	<0.001	0.095	0.523	0.009

Table 5. *Cont.*

Variables	Class I						Class II						Class III						Gender Sig. (Co-variate)	Angle Class Sig.	Facial Growth Sig.	Interaction Sig. (Angle and Facial)
	Hypodivergent		Normodivergent		Hyperdivergent		Hypodivergent		Normodivergent		Hyperdivergent		Hypodivergent		Normodivergent		Hyperdivergent					
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD				
Lph plane width	29.38	4.62	28.02	4.44	29.50	3.27	27.74	4.98	28.81	3.87	28.74	4.87	31.07	5.33	28.85	4.85	30.46	4.56	<0.001	0.368	0.19	0.562
Lph plane CSA	369.93	164.54	302.46	109.52	367.43	105.28	325.14	108.40	355.86	131.85	298.95	130.25	358.26	103.34	343.85	136.12	424.17	151.68	<0.001	0.349	0.161	0.006
Superior pharyngeal airway	9.13	1.82	7.82	2.68	8.09	2.57	8.34	3.99	7.87	2.56	7.37	2.80	9.10	2.26	8.50	2.49	7.96	2.27	0.186	0.461	0.165	0.768
Middle pharyngeal airway	8.15	2.28	8.58	3.15	8.71	2.79	7.16	4.36	7.82	2.83	7.60	3.11	10.12	3.38	8.46	3.50	9.33	3.58	0.067	0.019	0.816	0.49
Inferior pharyngeal airway	*5.70*	2.32	6.10	2.55	7.05	2.90	*4.76*	2.34	6.19	2.69	5.33	2.57	*7.72*	2.09	6.21	3.22	8.97	3.30	<0.001	<0.001	0.005	0.004
Total volume	22.98	4.46	22.51	6.61	23.85	6.27	20.26	8.46	21.87	5.83	20.30	6.49	26.95	6.00	23.18	7.24	26.26	6.51	<0.001	0.002	0.529	0.219
CSA	205.74	71.99	197.69	72.55	209.83	69.31	183.34	106.17	190.52	85.07	171.64	73.72	237.19	98.60	195.04	87.13	236.46	91.75	0.126	0.036	0.461	0.206

Ultimately, this study faces two primary limitations. Firstly, it lacks a functional assessment of the upper airway. Secondly, we were unable to control for every individual factor of each participant. Moreover, the observational nature of this design introduces the potential for residual confounding. Consequently, we suggest that future research delve into upper airway during activities, like swallowing, speech, and breathing, and expand the sample size for a more comprehensive understanding [42].

5. Conclusions

This study of Vietnamese adults found reduced airway space in skeletal high-angle Class II individuals, confirming a link between pharyngeal airway dimensions and vertical skeletal patterns. Significant differences ($p < 0.001$) were observed in the minimum cross-sectional area (CSA) and volume of the middle and inferior pharyngeal airways.

Our findings emphasize the relationship between vertical growth patterns and pharyngeal narrowing, which may lead to upper airway obstruction. These insights are important for optimizing orthodontic treatment and guiding airway management in clinical practice.

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