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The relationship between upper airways and craniofacial morphology studied in 3D. A CBCT study

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Structured Abstract

Objectives – To assess whether morphology and dimension of the upper airway differ between patients characterized by various craniofacial morphology.

Setting and Sample Population – Ninety young adult patients from the Postgraduate Clinic, Section of Orthodontics, Department of Dentistry, Health, Aarhus University, Denmark, with no obvious signs of respiratory diseases and no previous adeno-tonsillectomy procedures. Thirty patients were characterized as Class I ($-0.5 < \text{ANB} < 4.5$), 30 as Class II ($\text{ANB} > 4.5$), and 30 as Class III ($\text{ANB} < -0.5$).

Material and Methods – Cone-beam computed tomography (CBCT) scans obtained in a supine position for all patients. Cephalometric landmarks were identified in 3D. Sagittal and transversal dimensions, cross sections, and partial and total volumes of the upper airway were correlated with the cephalometric measurements in all three planes of space. The cross-sectional minimal area of the upper airway was assessed as well.

Results – No statistical significant relationships between dimension and morphology of upper airways and skeletal malocclusion were found.

Conclusion – Differences in craniofacial morphology as identified by the sagittal jaw relationship were not correlated with variation in upper airway volumes. A clinical significant relation was detected between minimal area and total upper airway volume.

Key words: Cone-beam computed tomography; Orthodontics; Pharynx; Upper airway

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Introduction

The upper airway is a complex structure which involves bone, cartilage, and soft tissues adapted to functions related to respiration, deglutition, and phonation. The influence of the mode of breathing on facial growth was in the focus of the orthodontic community in the seventies and significant, but clinical irrelevant changes in transversal growth were seen following adenoidectomy (1, 2). Removal of tonsils and adenoids was frequently recommended with the purpose of changing the mode of breathing (3, 4). The impact of the mode of breathing and head posture on the facial growth pattern was described in the 'soft-tissue stretching hypothesis' by Solow and Kreiborg (5) who claimed that a change in jaw posture caused by mouth breathing could lead to stretching of the lips, cheeks, and musculature resulting in upright incisors and narrower dental arches, as observed in patients with long face and open bite growth pattern. Harvold (6), on the other hand, demonstrated a variety of skeletal, dental, and muscular alterations in animals with artificially obstructed nasal airway. Elongation of the face and cross-bite developed in the animals that maintained oral respiration by persistent lowering of the mandible, whereas the opposite pattern was observed in the animals that rhythmically grasped for air by opening and closing the mouth in a cyclic manner. Warren and Spalding (7) stated that the relationship between nasorespiratory function and dentofacial development is anyhow controversial; moreover, they did draw the attention to the shortcomings of two-dimensional (2D) cephalometrics measurements as the solely indicators for the dimensions of the upper airways. Indeed, the controversial results about the relationships between craniofacial morphology and airway dimension and morphology could be ascribed to the methods applied and the parameters chosen for the establishment of the breathing pattern. Recognizing the inaccuracies related to 2D headfilms (8, 9), other spirometric techniques (e.g. inductive plethysmography and pneumotachograph) for the assessment of airways were thus recommended (10, 11). These techniques are, however, rarely available for the orthodontist when deciding for the treatment plan to follow. With the introduction of 3D imaging, the possibility for a quantification of the dimension of the airways has broadened. A reproducible method for establishment of areas and volume have been developed by Lenza et al. (12) who also demonstrated that singular linear measurements obtained on 2D images were only weakly correlated with cross-sectional area and volume of the upper airway. Given the 3D complex structure of the airway, van Vlijmen et al. (13), in their systematic review, concluded that the use of CBCT represents a more valuable diagnostic tool in studying upper airway when compared to conventional plane radiography.

Despite this, the relationship between upper airway dimensions and skeletal malocclusion is still not elucidated: In a study based on 60 adult subjects characterized by skeletal Class II and III malocclusion, no difference was found in the retropalatal and retroglossal airway volume (14), while others studies are claiming the existence of a relationship between malocclusion and airway morphology (15–17). The controversy of these outcomes may be related to the parameters chosen to characterize the craniofacial morphology. Indeed, many CBCT's studies are limited to assessment of sagittal and vertical craniofacial dimensions and do not take the transversal dimension into account (14–16, 18). In addition, it is likely that the hyoid bone position may be related to the lower oropharyngeal morphology of the airway. The characteristics of the sample studied might have a role too: El and Palomo (19) mentioned that the groups studied were divided only according to Angle's classification, which may not fully depict the skeletal characteristics of the patients.

The aim of this study was to assess the relationship between sagittal, vertical, and transversal measurements of the craniofacial complex including hyoid bone position with morphology and dimensions of oropharynx and lower nasopharynx in young adults using CBCT scans.

Materials and methods

Subjects

Pre-treatment CBCT scans of 90 young adults, consisting in 32 male and 58 female (13–43 years of age), were obtained from the available records from the Clinic of the Orthodontic Section at Aarhus University, Denmark. Informed consent was obtained from all the patients. The patients were selected to represent the 3 different skeletal patterns: 30 subjects were Class I ($-0.5 < \text{ANB} < 4.5$); 30 Class II ($\text{ANB} > 4.5$); and 30 as Class III ($\text{ANB} < -0.5$) (20, 21). The inclusion criteria were the existence of a 12″ CBCT scan (NewTom 3G, QR s.r.l., Verona, Italy) taken in occlusion and with patients in a supine position. The CBCT scanner used in this study is provided with a bed, where the patient is lying and his head is fitted in a molded pillow, making the patient positioning procedure highly reproducible. The exclusion criteria were patients with previous orthodontic treatment, orthognathic surgery, syndromes, pathology involving the upper airway, previous adeno-tonsillectomy procedure, and subjectively perceived respiratory problems, as retrieved from the patients' records.

3D image processing

All CBCT scans were reconstructed with an isotropic voxel dimension of 0.36 mm. The original datasets were checked and, if needed, re-oriented using as references the upper orbits, Frankfurt plane, the 'Dens' of the second cervical vertebrae, and the anterior nasal spine. Then, the CBCT data were exported via the DICOM format and imported into a specific software program (Mimics 15.0, Materialise, Leuven, Belgium). In case the head orientation was still not satisfactory, the function in Mimics named 'Change of Sagittal Plane' was applied to finely correct the orientation.

The reconstructed images were processed following a method previously described (12): The proper threshold levels for segmenting the airway were determined manually for each CBCT dataset on the basis of a profile line drawn through the upper airway. The gray values along this profile line could be visualized, and the threshold levels could thus be determined. Based on the minimal and maximal threshold values, a multislices mask of the relevant structures were defined (i.e. skeletal and upper airways) and color-coded. Based on these masks, the corresponding 3D objects were generated (Fig. 1).

Determination of landmarks and skeletal analysis

In MIMICS, a specific set of 33 landmarks defined for analyzing the skeletal and airway dimensions was defined (Table 1). All the landmarks were identified on the most appropriate view, and their position was checked on all the orthogonal planes (22). Sagittal (Fig. 2), transversal (Fig. 3), and vertical linear and angular measurements have been assessed to describe the morphology of the facial skeleton (Table 2). For the upper airway analysis, 8 well-established anteroposterior landmarks were selected (Fig. 4 and Table 1) (23–27). Four planes passing through 2 of the previously defined points at a time and perpendicular to the sagittal plane were generated. Corresponding to the location of the above-mentioned planes, four cross sections of the airway could be defined and their corresponding areas computed. The anteroposterior

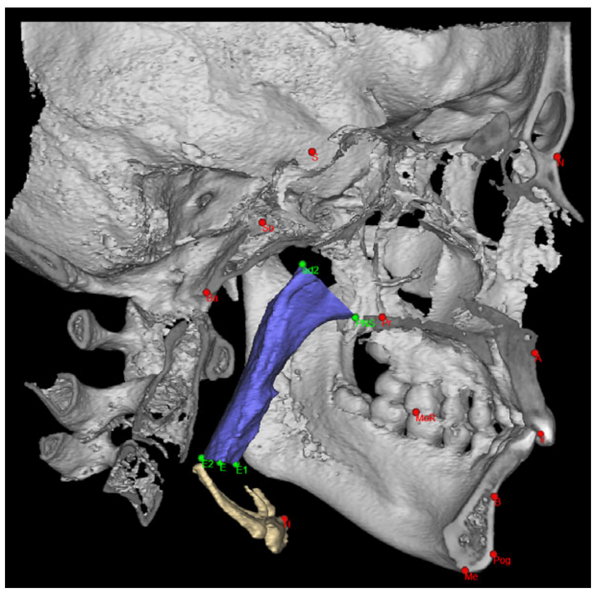

Fig. 1. Airway three-dimensional reconstruction. In violet, the total volume (TV).

Table 1. **Cephalometric landmarks**

	Measurements	Description
Skeletal	A	Position of the deepest concavity on anterior profile of the maxilla
	ANS	Tip of anterior nasal spine
	B	Most posterior point on the anterior contour of the lower alveolar process
	Ba	Most postero-inferior point on the clivus
	GH-l	Greater horn of the hyoid bone left
	GH-r	Greater horn of the hyoid bone right
	GoL	The most inferior-posterior point on the left angle of the mandible
	GoR	The most inferior-posterior point on the right angle of the mandible
	H	Upper most point of the hyoid bone
	ii	A point midway between the incisal edges of the maxillary and mandibular central incisors
	Me	The most inferior point of the bony symphysis anteriorly
	MoL	The distal tip of the first left molar in the jaw of interest
	MoR	The distal tip of the first right molar in the jaw of interest
	N	The intersection of the internasal and frontonasal sutures in the midsagittal plane
	OrR	The most inferior–anterior point on right orbit's margin
	OrL	The most inferior–anterior point on left orbit's margin
	PNS	The most posterior point on the bony hard palate
	Pl	Centroid of the greater palatine foramen left
	Pr	Centroid of the greater palatine foramen right
	PoL	Most superior point of the outline of the external auditory meatus left
	PoR	Most superior point of the outline of the external auditory meatus right
	PoG	The most anterior point of the bony chin in the midsagittal plane
	S	Midpoint of the sella turcica
	So	Midpoint of the sella-basion line
	Zs-L	The most inferior point of the left zygomaticomaxillary suture
	Zs-R	The most inferior point of the right zygomaticomaxillary suture
Airway	ad1	Intersection of the line PNS-Ba and the posterior nasopharyngeal wall
	ad2	Intersection of the line PNS-So and the posterior nasopharyngeal wall
	P3	Intersection between the posterior pharyngeal wall and the bisected Occlusal plane (OP)
	T2	Intersection between the contour of the tongue and the bisected OP
	E	Most superior point of epiglottis
	E1	Frontal wall of pharyngeal airway over E1-E2 line
	E2	Posterior wall of pharyngeal airway over E1-E2 line

and transversal dimensions of these cross sections were assessed as well. Using the previously described planes, the upper airway could then be divided into three parts and their volumes (*partial volumes*) could be calculated: lower nasopharynx volume (LNP), the velopharynx volume (VLP), and oropharynx volume (ORP) (Table 3). The total volume of the upper airway (TV) was calculated as well.

Statistical analysis

Statistical analysis was performed using SPSS (version 13.0; SPSS Inc., Chicago, IL, USA). Descriptive analysis for all the data, and for each skeletal class including means, standard deviation, minimum, and maximum values were performed (Tables 4 and 5). Q-Q plot, Kolmogoronov–Smirnov test, and Box-Plots

Fig. 2. Linear distance between A point, B point, Pog to Frankfurt perpendicular line passing through Sella point.

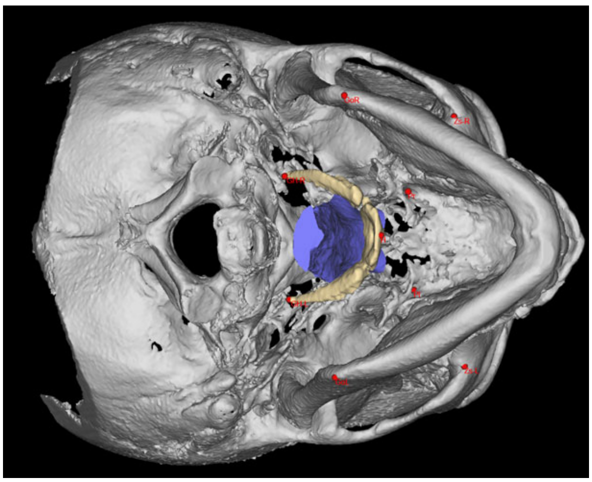

Fig. 3. Landmarks (in red) used to assess transversal measurements: Hyoid width, Gonial width, Palatal width, and Zygomatic width.

were applied to check data distribution. One operator (G.D.C.), previously calibrated, performed all the measurements. The error of the method was calculated on double measurements of seven randomly selected cases: Fifteen representative linear, angular, areal, and volume measurements were considered, and the Dahlberg's formula ($s = \sqrt{\sum d2/2n}$) applied. The coefficient of reliability ($CoR = 1 - s2/SD2$) was calculated as well. The analysis of variance (ANOVA) was applied to compare intra-examiner differences. The Student–Newman–Keuls *post hoc* test was used to determine which measurements were different. One-way ANOVA was used to assess differences in age, sex, total volume, and minimal cross section area among the different skeletal class group. Analysis of variance was performed to establish whether the mean total volume and partial volume differ in the three groups identified by ANB angle (Table 6). Regression analysis was chosen to test whether 3D airways measurements depend on linear and angular facial skeletal characteristics. After preliminary data analysis to check for data entry errors, outliers, and skewness of the data, total and partial airway volumes were explained by all the available linear and angular measurements (Full Models), previously described in Table 2. In case the Full Models show very high variance inflation factors (VIF) (28), the presence of multicollinearity among variables is sure. In this scenario, the best strategy consists of dropping out one variable at a time choosing among the ones with higher VIF. At each further step, the non-significant variable with the highest p-value need to be dropped until a restricted model with only significant variables is reached. To assess the adequacy of each model, diagnostic plots of residuals, White's test for constant variance, and Ramsey's RESET test for linearity were performed. At last, the analysis of variance between the full and the restricted model was performed to test the null hypothesis that the two models explain the same amount of variability. For all the tests, the significance level was set at 0.05.

Results

The error of the method was found to be in percentage small for all the measurements except for the measurements of ORP volume; the coefficient of reliability confirmed the validity of the method used (Table 5). All data were normally distributed. The three groups did not differ with respect to age and sex. The mean values in the three groups identified by ANB do not differ significantly for all the volume variables (p-value > 0.05) (Table 6).

Table 2. **Linear and angular measurements of facial skeleton**

	Measurements		
Sagittal	S-N-Pog	deg	Angle comprise Sella, Nasion, and Pogonion
	SNA	deg	Angle measuring the anteroposterior relationship of the maxillary basal arch on the anterior cranial base
	SNB	deg	Angle measuring the anteroposterior relationship of the mandibular basal arch in relation to the anterior cranial base
	ANB	deg	Angle showing the anteroposterior relationship between the maxillary and mandibular apical bases
	S-Pog	mm	Distance from Sella point to Pogonion
	PNS-Ba	mm	Sagittal depth of the bony nasopharynx
	Ba-Me	mm	Distance between Ba point and Me point
	A-Frank perp	mm	Distance from A point to Frankfurt perpendicular line passing through Sella point
	B-Frank perp	mm	Distance from B to Frankfurt perpendicular line passing through Sella point
	Pog-Frank perp	mm	Distance from Pog to Frankfurt perpendicular line passing through Sella point
Vertical	H to palatal	mm	Distance between H point to palatal plane
	ANS-Me	mm	Distance between Anterior nasal spine and Menton
	N-Pog	mm	Distance between N point to Pogonion
	PFH	mm	Posterior facial height, distance between Sella point and plane comprising: Gor, Gol, B point
Transverse	Gonial width	mm	Distance between Gonion right and Gonion left
	Palatal width	mm	Distance between Palatal right and Palatal left
	Hyoid width	mm	Distance between Greater horn right and left
	Zygomatic width	mm	Distance between Zs-R to Zs-L
Others	S-N-Ba	deg	Angle comprise Nasion Sella and Basion

The TV regression model explains about 60% of the total variability of the data (Table 7). TV regression estimates show the following results:

1. if Min_Area increases by 1 mm^2, then TV is expected to increase on average by 49 mm^3;
2. if PNS_Ba increases by 1 mm, then TV is expected to increase on average by 111 mm^3;
3. if SNA increases by 1 degree, then TV is expected to decrease on average by 149 mm^3;
4. if PFH increases by 1 mm, then TV is expected to increase on average by 80 mm^3.

The LNP model explains about 40% of the total variability of the data (Table 8).

The VLP regression model explains about 50% of the total variability of the data (Table 8).

The ORP regression model explains only 33% of the total variability of the data (Table 8).

For the three last regression models, the results can be explained as showed for the TV regression model.

Discussion

Airway dimensions seem to be substantially affected by body posture and head inclination when assessed on lateral cephalograms (29, 30). However, in a study, where OSAS and snoring patients were analyzed, it was demonstrated that linear cephalometric measurements of the airways taken with patients in an awake supine position did not differ from the corresponding measurements taken with the patient in an upright position (31). When the effect of posture on the soft tissues was assessed stereophotogrammetrically in a cohort of mothers and daughters, it was noticed that in young adult girls, gravity has a little effect on the facial soft tissue movement as a result of muscle tone and it was concluded that soft-tissue changes occurring from upright to supine position could not obviously be confirmed

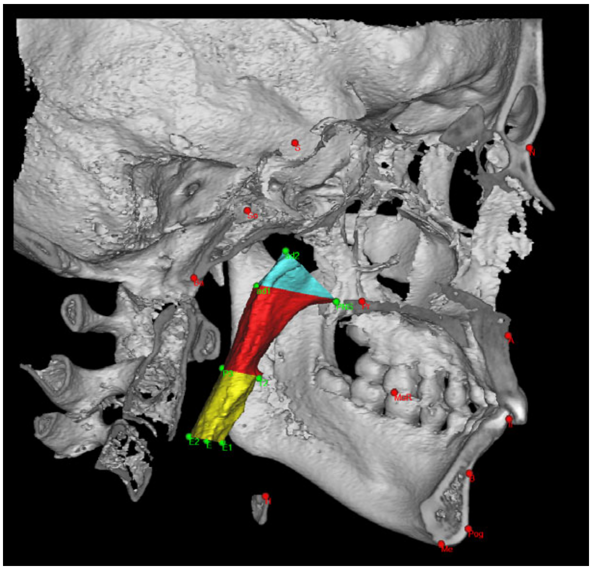

Fig. 4. Total airway and three partial volumes delimited by 8 anteroposterior landmarks. In light blue, the lower nasopharynx (LNP); in red, the velopharynx (VLP); in yellow, the oropharynx (ORP).

Table 3. **3D segments of the upper airways from which volumes were calculated**

Volume	Description
TV	Bounded superiorly by ad2-PNS line and inferiorly by E1-E2 line
LNP	Bounded superiorly by ad2-PNS line and inferiorly by ad1-PNS line
VLP	Bounded superiorly by ad1-PNS line and inferiorly by T2-P3 line
ORP	Bounded superiorly by T2-P3 line and inferiorly by E1-E2 line

(32). CBCT scans have been shown to be accurate in measuring upper airway (12, 14, 16, 17, 19, 33–35). The controversy about using a CBCT-scanning protocol where patients are in either an upright or supine position when studying the upper airway is questionable as no evidence supporting one or the other position is available yet. Indeed, in order to be properly debated, this dispute should be studied three-dimensionally, as only this approach was shown to be appropriate to depict the upper airway (12, 13).

According to Ingman and coauthors, the treatment of patients with obstructive apnea should be mainly targeted at preventing narrowing of the oropharynx during sleep (26). Although it is understood that during sleep, patients present different muscular tone compared to awake, we chose a supine CBCT acquisition as it closely mimics the sleeping position, where collapse of the airway is more prone to occur. Nevertheless, head orientation is a critical point when airway measurements are taken. Therefore, the orientation of the head should always be carried out using craniofacial landmarks to perform a proper analysis. In this study, special care was used to address this issue.

To depict cross sections and volumes in a 3D analysis, the segmentation technique plays an important role. We opted for a manual procedure. Although this method is more time-consuming and might generate errors if not correctly applied, yet it has been shown to be more reproducible when compared to the automatic technique. Indeed, El and Palomo (35, 36), when comparing three automatic procedures vs. a manual segmentation technique, stated that the latter was the method with the greatest accuracy and allows the greatest operator control.

Several two-dimensional studies have been conducted to identify changes of airway morphology during adulthood. Due to the previously mentioned deficiencies of 2D methods, the validity of such studies could be questioned. Tournè (37) stated that nasopharyngeal depth usually remains the same after its growth in the early age and Bondevik (38) found minimal changes between 22 and 33 years old, whereas Johnston and Richardson (39) claim that pharyngeal morphology changes during adulthood. The only available CBCT study conducted on airway growth and development found that airway volume of individuals at 45 years of age was slightly larger than that of 15 years old (40). For this reason, in the present study, we tried to match as closely as possible this age range and therefore only (young-) adult patients with an age comprised between 13 and 43 years old were selected.

The statement to be tested was whether 3D airways measures directly depend on some linear and/or angular measurements of the maxillofacial complex (Table 2). Regression analysis was chosen, because: it is a linear model; it allows testing different variables, keeping all the other constant.

Table 4. **Descriptive analysis**

	Level	Mean	SD	Minimum	Maximum
Skeletal					
Angular (deg)	ANB	2.4	4.2	−8.8	11.5
	SNA	81.3	4.0	71.5	93.0
	SNB	78.6	4.6	67.9	97.8
	S-N-Ba	128.8	4.9	117.8	141.2
	S-N-Pog	79.8	4.6	69.4	97.4
Sagittal (mm)	S-Pog	120.6	7.8	100.7	140.2
	PNS-Ba	42.3	4.2	31.3	55.6
	Ba-Me	105.2	7.5	89.2	132.4
	A-Frank perp	91.1	5.3	79.2	102.9
	B-Frank perp	87.4	7.2	72.6	106.5
	Pog-Frank perp	89.1	8.3	68.2	109.3
Vertical (mm)	H to palatal	59.8	7.9	42.3	85.3
	ANS-Me	67.4	6.8	48.1	85.4
	N-Pog	112.0	8.3	86.4	132.5
	PFH	75.4	6.8	59.8	92.9
Transversal (mm)	Gonial width	87.5	6.4	71.7	101.1
	Palatal width	30.0	2.8	24.1	36.7
	Hyoid width	39.7	4.8	30.5	54.0
	Zygomatic width	82.3	5.8	61.6	96.6
Airway					
Linear (mm)	ad2-PNS	17.7	4.5	5.7	25.7
	ad1-PNS	21.3	4.6	6.8	30.3
	T2-P3	17.2	4.0	6.3	28.3
	E1-E2	10.8	2.5	5.0	17.6
Transversal (mm)	ad2-PNS	27.5	3.9	16.5	36.5
	ad1-PNS	27.1	4.6	15.8	37.8
	T2-P2	22.0	5.2	10.1	41.2
	E1-E1	31.5	5.1	19.4	45.3
Area (mm^2)	ad2-PNS	354.2	123.9	83.9	824.7
	ad1-PNS	386.6	113.6	140.4	649.6
	T2-P2	151.0	62.4	50.1	388.3
	E1-E1	274.8	100.7	28.2	655.1
Volume (mm^3)	TV	12647.4	3556.9	6914.4	22177.6
	LNP	2378.4	1128.4	289.2	5763.9
	VLP	4357.8	1554.9	1092.9	9626.0
	ORP	2855.8	1295.5	785.5	8568.3

In this study, when comparing partial and total mean volumes of the airways, there were no significant differences between patients characterized as skeletal Class I, II, and III according to ANB. This contradicted the results obtained by El and Palomo (17), who found that subjects with more retruded mandible tended to have smaller oropharyngeal airway volume. Another study found that in retrognathic patients, the mean total airway volume was significantly smaller than in patients with normal sagittal relationship. However, this study was performed

***Table 5.* Error of the method**

	Level	*s*	CoR
Angular (deg)	ANB	0.6	0.9
	SNA	1.0	1.0
	SNB	0.9	0.9
Linear (mm)	ad2-PNS	1.2	0.9
	ad1-PNS	1.2	0.9
	T2-P3	1.4	0.9
	E1-E2	0.7	1.0
Area (mm^2)	ad2-PNS	16.2	1.0
	ad1-PNS	35.4	0.9
	T2-P2	10.4	0.9
	E1-E1	17.5	0.9
Volume (mm^3)	TV	1314.7	0.9
	LNP	310.1	0.9
	VLP	658.5	0.7
	ORP	596.1	0.9

***Table 6.* Analysis of variance table in the three groups identified by ANB**

	Df	Sum Sq	Mean Sq	*F*-value	*p*-Value
TV					
Groups	2	6 338 310	3 169 155	0.24	0.78
Residuals	87	1 119 653 714	12 869 583		
LNP					
Groups	2	64 71 467	3 235 733	2.61	0.07
Residuals	87	1 119 653 714	12 869 583		
VLP					
Groups	2	9 906 312	4 953 156	2.11	0.12
Residuals	87	203 317 060	2 336 978		
ORP					
Groups	2	5 095 020	2 547 510	0.42	0.65
Residuals	87	520 455 906	5 982 252		

on preadolescent subjects; thus, the results might be related to the fact that the development of the airway morphology due to growth had not yet taken place (15). On the other hand, the findings of the present study did corroborate the findings of Alves and coauthors, who did not find any difference in total oropharyngeal volumes between Class II and Class III adult patients observed in a supine position (14). The lack of differences in the total upper airway volumes measured on CBCT scans in different skeletal groups was also confirmed when the scanning was performed on non-growing patients in an upright position (16).

***Table 7.* Regression model of TV, where TV was used as dependent variable**

	Estimate	SE	*t* value	Pr(>|*t*|)
Min_Area	49.114	5.00	9.81	1.38×10^{-15}***
PNS_Ba	111.24	64.43	1.72	0.08795†
SNA	−148.552	68.37	−2.17	0.03264*
H_Palate	97.277	36.81	2.64	0.00982**
PFH	79.936	44.49	1.79	0.07601†
Multiple R^2 = 0.603				

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1 ' '.

***Table 8.* Regression models where partial volumes were used as dependent variable**

	Estimate	SE	*t* value	Pr(>|*t*|)
LNP				
Min_Area	7.40	1.91	3.87	0.000215***
ANB	69.85	25.55	2.73	0.007654**
S_N_Ba	−40.03	22.52	−1.77	0.079185†
H_Palate	−60.36	14.79	−4.07	0.000103***
PFH	38.80	17.53	2.21	0.029625*
Hyoid_Width	50.23	22.94	2.19	0.031340*
Multiple R^2 = 0.401				
VLP				
Min_Area	19.84	2.29	8.63	3.44×10^{-13}***
ANB	−74.50	29.80	−2.50	0.0144*
A_Frank_perp	51.96	23.26	2.23	0.0282*
ANS_Me	34.03	17.79	1.91	0.0593†
Gonial_Width	36.51	20.08	1.81	0.0726†
Hyoid_Width	−57.24	27.02	−2.11	0.0371*
Multiple R^2 = 0.544				
ORP				
Min_Area	20.70	4.05	5.10	1.93×10^{-6}***
H_Palate	146.11	26.30	5.55	2.97×10^{-7}***
Multiple R^2 = 0.369				

Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1 ' '.

The model that explains the highest percentage of the total variability of the data is the total volume's model: When the minimal area increases, the TV is expected to increase as well. This is in agreement with Tso et Al, who indicated the existence of high correlation between the most constricted cross section and total airway volume (41). The importance of this aspect was underlined by Haskell and coworkers, who claimed that an improvement in the cross section area just in a restrictive point of the airway might be already beneficial when treating sleep apnea patients using mandibular advancement devices (42).

We did not find a correlation between ANB angle and total volume. Although controversial results were found regarding ANB angle and partial volumes where if ANB increases: LNP is expected to increase as well and, while contrarily VLP is expected to decrease (Table 8). These data are in disagreement with Claudino and coworkers, who claim that 'the greater the ANB angle, the smaller the airway volume' (43).

Surprisingly, in the TV's model, if SNA increases, then TV is expected to decrease. This was an unexpected result because, from a clinical point if the SNA angle increases, then a stretch of the upper airway is expected, and consequently, an increase of the total volume is expected. These results could be justified by the absence in this study of 'omitted' variables (e.g. BMI, Neck circumference, and respiration phase) that might influence the outcomes. To overcome this drawback, a panel study (44) could be used to get the right answers. However, as our study is retrospective, it was not possible to perform a panel study where two sets of measurements on the same patients with a time interval in between were taken.

Conclusion

An individual skeletal pattern cannot directly be related to the morphology of the overall upper airway. A significant connection was found between minimal area and total upper airway volume, indicating that the airway's most constricted cross section plays an important role in determining upper airway size. From a clinical point of view, the minimal cross section could be an important indicator, when planning orthodontic treatment as well as orthognathic surgical intervention.

Clinical relevance

The possible relationships between upper airway morphology and craniofacial morphology in patients without signs of upper airway obstruction were analyzed in this study. Although the existence of this relationship was debated in the literature for years, the availability of low radiation CBCT technology has renewed the interest in this field. This study does not sustain the existence of any correlations between airway morphology and skeletal patterns in patients with no obvious signs of respiratory problems.

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