Original Article

The influence of craniofacial morphology on the upper airway dimensions

Iveta Indriksone[a]; Gundega Jakobsone[b]

ABSTRACT

Objective: To evaluate the influence of craniofacial morphology on the upper airway dimensions in healthy adult subjects.

Materials and Methods: The records of 276 healthy 17- to 27-year-old patients were extracted from the cone-beam computed tomography image database of the Institute of Stomatology, Riga Stradins University. Dolphin 11.7 software was used to evaluate craniofacial anatomy and semiautomatic segmentation of the upper airway. Measurements of oropharyngeal airway volume (OPV), minimal cross-sectional area (CSAmin), and nasopharyngeal airway volume (NPV) were obtained. The presence of adenoid tissues was recorded. Associations between variables were analyzed by Spearman's correlation coefficients, and multivariate linear regression analysis was used to identify factors that had a possible influence on upper airway dimensions.

Results: The following factors were identified as influencing the variability of NPV (23%): SNA angle, gender, and presence of adenoids. Statistically significant, although weak, correlations were found between SNB angle and OPV ($r = 0.144$, $P < .05$) and CSAmin ($r = 0.182$, $P < .01$).

Conclusion: The results suggest that craniofacial morphology alone does not have a significant influence on upper airway dimensions. (*Angle Orthod.* 2015;85:874–880.)

KEY WORDS: Airway; Cone-beam computed tomography

INTRODUCTION

Respiratory function and upper airway morphology are greatly relevant to orthodontic diagnosis and treatment planning as altered breathing function could influence facial growth and morphology.[1] More importantly, breathing disturbances could lead to increased morbidity and mortality in a condition like obstructive sleep apnea (OSA).[2] The posterior airway space (PAS) of patients with OSA has been shown to be smaller than that of healthy persons.[3] Evidence suggests that one of the reasons for this could be related to craniofacial morphology features, such as the retro position of the mandible and increased upper and/or lower face heights.[4] Because a close relationship is found between the pharyngeal airway patency and craniofacial structures in patients with OSA,[5] an association could be expected to exist between the upper airway dimensions and the craniofacial pattern.

Although many studies have reported changes in the dimensions of the upper airway after surgical repositioning of the mandible and the maxilla, estimates about the changes in the upper airway after orthognathic surgery operations remain controversial.[6] Despite a few case reports in which mandibular setback surgery in patients with skeletal Class III malocclusion induced OSA associated with airway narrowing,[7,8] prospective studies[9,10] have failed to demonstrate disturbances of respiration during sleep after mandibular setback even though retro palatal airway size was reduced. These disagreements might be explained by the suggestion that preoperative airway size in patients with Class III malocclusion is larger than that of the clinically normal population.[10,11]

Several studies have used lateral cephalometry (LC) to explore whether upper airway size is associated with a specific craniofacial pattern.[12–20] Although some of these studies have representative samples and a sophisticated design, LC is limited by its two-dimensional nature. Since the advent of cone-beam computed tomography (CBCT), more accurate evaluation of the airway has become possible, giving more complete information than LC[21,22] with a significantly

[a] PhD student, Department of Orthodontics, Riga Stradins University, Riga, Latvia.

[b] Associate Professor and Head of the Department, Department of Orthodontics, Riga Stradins University, Riga, Latvia.

Corresponding author: Dr Iveta Indriksone, Department of Orthodontics, Riga Stradins University, 20 Dzirciema, Riga LV-1007, Latvia
(e-mail: iveta.indriksone@gign.lv)

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Table 1. Cephalometric Measurements

	Measurement (Degrees)	Description
Sagittal skeletal pattern	SNA	Angle between the anterior cranial base (SN) and NA line
	SNB	Angle between the anterior cranial base (SN) and NB line
	ANB	Difference between SNA and SNB
Vertical skeletal pattern	MP-SN	Angle formed by the cranial base plane (SN) and the mandibular plane (Go-Me)
	MM	Angle formed by the maxillary (ANS-PNS) and the mandibular plane (Go-Me)
	FMA	Angle formed by the FH plane and the mandibular plane (Go-Me)

reduced radiation dose compared with conventional computed tomography.[23] Nevertheless, three-dimensional (3D) studies that have aimed to find pharyngeal size differences among various skeletal patterns have provided inconsistent results.[24–31] Therefore, the aim of the present study was to investigate whether upper airway dimensions in healthy adult subjects are influenced by craniofacial morphology.

MATERIALS AND METHODS

In this retrospective study, the CBCT image database collected at the Institute of Stomatology, Riga Stradins University, from December 2008 to December 2012 was inspected. The study was reviewed and approved by the Ethics Committee of Riga Stradins University, Riga, Latvia. All CBCT scans were taken with an ICAT Scanner (Imaging Sciences International, Hatfield, Pa) as part of the initial diagnostic records for the patients according to orthodontic, prosthetic, or surgical indications. The CBCT images were taken according to a standard protocol with the subject seated in a chair with the following parameters: 120 kV, 5 mA, 0.4 mm voxel, and scan time of 20 seconds.

The following criteria were formulated to select the images for inclusion in this investigation: scans of 17- to 27-year-old patients, full field of view images (13 cm × 17 cm) that allowed clear visualization of the craniofacial structures from the cranial base to the upper border of the epiglottis, and images with the patients' teeth in the central occlusion. The inclusion criteria were met by 396 scans. Full records of these subjects were inspected and the subsequent exclusion criteria were applied: medically compromised patients (OSA, syndromes and arthritis), previous orthognathic surgery, patients with facial clefts and severe craniofacial asymmetries, and subjects with altered craniocervical inclination. As the measurements of airway size are influenced by head posture,[32] craniocervical inclinations of all subjects were examined to ensure that they were between 90° and 110°. After applying the exclusion criteria, 276 patients (100 men and 176 women) remained and were further investigated.

The Dolphin 11.7 software (Patterson Dental Supply Inc, Chatsworth, Calif) was used to analyze CBCT images. Conventional hard-tissue landmarks were identified for the cephalometric analysis, and six

Figure 1. Limits for upper airway segmentation and examples of virtual surface models. Oropharyngeal airway: superior, the edge of the soft palate to the posterior of the pharynx (parallel to FH); inferior, the plane from the tip of the epiglottis to the posterior of the pharynx (parallel to FH); lateral, anterior and posterior, the internal walls of the pharynx, including the full extensions of the lateral projections, and limited by the posterior surfaces of the tongue and the soft palate. Nasopharyngeal airway: superior, the highest point of the nasopharynx, coinciding and consistent with the anterior limit; inferior, the superior border of the oropharyngeal airway; anterior, a coronal plane through the posterior nasal spine perpendicular to the sagittal plane at the lowest border of the vomer; posterior, the posterior wall of the pharynx; lateral, the lateral walls of the pharynx, including the full extensions of the lateral projections.

Table 2. Descriptive Statistics of the Sample

	Mean	SD	Minimum	Maximum
Age (years)	21.0	3.2	17.0	27.0
ANB (°)	1.5	4.4	−9.9	13.6
SNA (°)	80.7	3.5	66.0	91.0
SNB (°)	79.2	4.7	66.3	93.8
MM (°)	28.1	7.1	9.7	50.6
FMA (°)	25.4	6.7	9.2	45.1
SN-MP (°)	34.8	7.0	18.8	53.9

angular measurements were collected (SNA, SNB, ANB, MP-SN, MM, FMA) for the craniofacial relationships (Table 1). The same software was used to obtain the airway measurements. Once the CBCT data sets were imported in the format of single-file DICOM (Digital Imaging and Communications in Medicine) files, the reconstructions were reoriented as close as possible to the guidelines suggested by Haskel et al.[33] The airway analysis tool was used to obtain the desired portions of the nasopharyngeal (NP) and the oropharyngeal (OP) airway. The area of interest was defined by a clipping box and seeds in the airway space. The limits for segmentation of the upper airway and examples of the virtual surface models are presented in Figure 1. Measurements of the oropharyngeal airway volume (OPV), minimal cross-sectional area (CSAmin), and nasopharyngeal airway volume (NPV) were calculated by the software. The presence of adenoid tissues was recorded. All data were collected by one operator.

Statistical analyses were performed with SPSS 20.0 for Windows (SPSS, Chicago, Ill). The Kolmogorov-Smirnov test was used to check the normality of distribution. For analysis of method error all measurements were repeated for 30 randomly selected subjects by the same operator on two separate occasions at least 2 weeks apart. The intraclass correlation coefficient (ICC) for the volumes and CSA and the Dahlberg formula for the angular measurements were calculated. The statistical significance was set at 0.05. Associations between the variables were analyzed by Spearman correlation coefficients; multivariate linear regression analysis was used to identify the factors that possibly influence upper airway dimensions. The following nine variables were analyzed as possible predictors for pharyngeal airway size: gender, ANB, SNA, SNB, MM, MP-SN, FMA, sum of angles SNA and SNB, and presence of adenoids.

RESULTS

The method error ranged from 0.45° to 0.79° for angular measurements, and ICC values for airway variables varied from 0.97 to 0.99. Demographic and cephalometric characteristics of the sample are summarized in Table 2. This sample had a diversity of craniofacial patterns as revealed by the range of values of cephalometric variables. Of the 276 subjects, 48 (17%) had increased nasopharyngeal adenoid tissues of various degrees.

Bivariate correlations between the variables and the airway measurements are given in Table 3. The NPV correlated negatively with gender, presence of adenoid tissues, and MP-SN and SNB angles; in addition, there were positive correlations with SNA angle and the sum of angles SNA and SNB. Both OPV and CSAmin correlated significantly with SNB angle, sum of angles SNA and SNB, and presence of adenoids. Additionally, OPV had a significant negative correlation with gender, and CSAmin correlated negatively with ANB angle.

Of the nine variables included in the regression analysis, five were significantly associated with NP volume, four with OP volume, and four with minimal CSA. Because of the strong inter-correlations, one variable for the volumes and CSAmin were excluded from the multivariate regression analysis. Thus, the remaining four variables were included in the regression model for NPV (gender, MP-SN, SNA, presence of adenoids), and three were included for OPV (gender, SNB, presence of the adenoids). In the final model, gender, SNA angle, and presence of adenoids explained 23% of the variation in NPV. Only 11% of the OP volume variation was explained by gender, SNB angle, and presence of adenoids. It was possible to explain only 6% of CSAmin variation by two variables (SNB and presence of adenoids).

DISCUSSION

To our knowledge the present 3D study on upper airway dimensions and craniofacial morphology is the most complete in terms of the number of subjects

Table 3. Correlations Between Cephalometric and Anatomic Variables and Volume and Cross-sectional Area Measurements[a]

	Gender	MP-SN	MM	FH-MP	ANB	SNA	SNB	SNA+SNB	Presence of Adenoids
NPV	−0.144*	−0.146*	−0.073	−0.111	0.083	0.238**	−0.098	0.185**	−0.432**
OPV	−0.252**	−0.047	−0.028	−0.035	−0.092	0.078	0.144*	0.136*	−0.157**
CSAmin	−0.071	−0.095	−0.096	−0.084	−0.142*	−0.002	0.182**	0.156**	−0.184**

[a] NPV indicates nasopharyngeal airway volume; OPV, oropharyngeal airway volume; CSAmin, minimal cross-sectional area.
* $P = .05$; ** $P = .01$.

Table 4. Summarized Data from Previous Studies on Upper Airway Dimensions and Craniofacial Morphology

Study	N	Age Range (Mean) Years	Method	Sagittal Pattern (Angles Used)	Vertical Pattern (Angles Used)	Findings Regarding Upper Airway Dimensions Among Various Craniofacial Patterns
Ceylan et al. (1995)[12]	90	13–15 (?)	LC	Classes I, II, III (<ANB)	No vertical occlusal discrepancies	OP sagittal area was smaller in Class II compared with Class III and Class I No statistically significant differences were found in other NP and OP sagittal measurements
Joseph et al. (1998)[13]	50	?	LC	Not specified (<ANB, <SNA, <SNB)	Vertical, normal (<FMA)	Several NP and OP sagittal measurements were smaller in vertical compared with normal growth pattern
Trenouth et al. (1999)[14]	70	10–13 (11.8 ± 1.3)	LC	Not specified (<ANB, <SNA, <SNB)	Not specified (<MM, <Go, AFH, PFH)	OP sagittal size had a significant but weak correlation with the length of the mandible
Abu Allhaija et al. (2005)[15]	90	14–17 (?)	LC	Classes I, II, III (<ANB)	No vertical discrepancies (<MM)	No statistically significant differences in OP sagittal measurements Inferior pharyngeal space had a significant but weak correlation with ANB angle
de Freitas et al. (2006)[16]	80	? (11.6 ± 1.9)	LC	Classes I and II (molar relationships)	Vertical, normal (<FMA, <MP-SN)	NP sagittal dimension was smaller in vertical compared with normal growth pattern OP sagittal dimension was not influenced by vertical pattern
Alves et al. (2008)[24]	60	? (18.0 ± 1.8)	CT	Classes II and III (<ANB, <SNA, <SNB)	No vertical discrepancies	No statistically significant differences in most of the NP and OP measurements between Class II and Class III
Muto et al. (2008)[17]	99	17–32 (?)	LC	Retrognathic, prognathic, normal mandible (<SNB)	Not evaluated	OP sagittal measurements decreased from mandibular prognathism to normal mandible to mandibular retrognathism group
Iwasaki et al. (2009)[25]	45	? (8.8 ± 1.0)	CBCT	Classes I and III (<ANB, Wits)	Not evaluated	No statistically significant differences in OPV between Class I and Class III CSA of OP was smaller in Class I compared with Class III
Grauer et al. (2009)[26]	62	17–46 (24.7)	CBCT	Classes I, II, III (<ANB)	Long face, short face, normal (Bony facial index)	OPV was smaller in Class II compared with Class I and Class III No statistically significant difference in NPV
Oh et al. (2011)[27]	60	10–13 (11.8 ± 1.1)	CBCT	Classes I, II, III (<ANB, Wits)	Not evaluated	No statistically significant differences in NPV and OPV
Zhong et al. (2010)[18]	190	11–16 (?)	LC	Classes I, II, III (<ANB)	Vertical, normal, horizontal (<FMA)	OP and HP sagittal dimension was larger in Class III compared with Class I and Class II No statistically significant differences in NP sagittal measurements In Class I subjects NP sagittal measurements decreased with increasing mandibular plane angle
Hong et al. (2011)[28]	60	18–30 (26.0 ± 4.5)	CBCT	Classes I and III (<ANB, <SNA, <SNB)	Not specified (<MP-SN, <Go, <FMA)	NPV and CSA measurements at soft palate plane and the epiglottis plane were larger in Class III compared with Class I No statistically significant differences in OPV
El et al. (2011)[29]	140	14–18 (?)	CBCT	Classes I, II, III (<ANB)	No vertical discrepancies (<FMA)	NPV was smaller in Class II compared with Class I OPV was smaller in Class II compared with Class I and Class III
Ucar et al. (2011)[19]	104	10–17 (?)	LC	Class I (<ANB, <SNA< SNB)	Vertical, normal, horizontal (<MP-SN, <MM, <FMA)	NP sagittal area and oropharyngeal sagittal measurements behind the soft palate were found to be larger in subjects with a horizontal pattern compared with subjects with a vertical pattern

Table 4. Continued

Study	N	Age Range (Mean) Years	Method	Sagittal Pattern (Angles Used)	Vertical Pattern (Angles Used)	Findings Regarding Upper Airway Dimensions Among Various Craniofacial Patterns
Memon et al. (2012)[20]	360	14–20 (15.3 ± 1.3)	LC	Classes I and II (<ANB)	Vertical, normal, horizontal (<MP-SN)	No statistically significant differences in OP sagittal measurements Subjects with vertical pattern had narrower OP spaces behind the soft palate
Alves Jr et al. (2012)[30]	50	8–10 (9.2 ± 0.64)	CBCT	Classes I and II (<ANB, <SNA, <SNB)	No vertical discrepancies (<MP-SN, <FMA)	OPV, minimal CSA and sagittal measurements were smaller in Class II compared with Class I
Abdelkarim (2012)[31]	128	16–35 (?)	CBCT	Classes I, II, III (<SNB, <ANB, <SNA)	No vertical discrepancies (PFH:AFH, <Go)	OPV was largest in the mandibular prognathism, followed by normal mandible, and then the mandibular retrognathism group
Current study (2013)	276	17–27 (21.0 ± 3.2)	CBCT	Classes I, II, III (<ANB, <SNA, <SNB)	Vertical, normal, horizontal (<MP-SN, <MM, <FMA)	Craniofacial morphology in adults was weakly associated with the variability of the upper airway dimensions

[a] LC indicates lateral cephalometry; OP, oropharyngeal; NP, nasopharyngeal; CT, computed tomography; CBCT, cone-beam computed tomography; OPV, oropharyngeal airway volume; NPV, nasopharyngeal airway volume; HP, hypopharyngeal; CSA, cross-sectional area.

included. However, the main weakness of the study is its retrospective nature. The records of the patients were included in the investigation based on availability, and important information, such as data on body mass index, smoking status, and assessment of the soft tissues and neuromotor factors, is missing, although these could have a significant influence on upper airway size.[34,35] The influence of aging on upper airway size is well recognized[36]; however, it was assumed that between the ages of 17 and 27 only minor changes would have taken place; therefore, this age range was set as an inclusion criterion.

Several studies using two-dimensional and 3D imaging techniques have tried to find relationships between pharyngeal dimensions and craniofacial morphology.[12–20,24–31] However, the inconsistencies of the findings are found among lateral cephalometric studies and 3D investigations (Table 4). The inconsistencies could be explained by variations in sites of the airway measurements and by the diversity of the study samples. Most of the previous investigations used vertical discrepancies as an exclusion criteria,[12,15,24,29–31] and in other studies vertical skeletal relationships were not evaluated.[17,25,27] Nevertheless, the influence of vertical morphology should not be underestimated. If only the ANB angle is used to measure the relative position of the maxilla and the mandible to each other, the location of points A and B in the vertical plane can influence the value of the angle.[37] Therefore, misleading conclusions could be made without incorporating the vertical growth type in the evaluation of the upper airway.

Several 3D investigations have not found any association between the volume of the nasopharynx and the horizontal position of the maxilla[24,26,27]; however, in some studies significant differences in the nasopharyngeal volume among sagittal malocclusions were reported.[28,29] We found a weak correlation between the value of SNA and the nasopharyngeal volume, although the presence of increased adenoid tissues had a more significant influence. The nasopharyngeal adenoid tissues, which are often present during the childhood, usually spontaneously atrophy by puberty. We found enlarged adenoids in 17% of the patients in our sample. This is an unexpected finding, but Wolford et al.[38] also pointed out the presence of adenoids in many patients undergoing orthognathic surgery.

Retrognathic position of the mandible has been frequently linked with the narrowing of the upper airway in patients with obstructive sleep apnea (OSA).[4,5] Similarly, several studies have found smaller oropharyngeal volumes for subjects with Class II malocclusion compared with subjects with Class I[26,29–31] or Class III[26,29,31] malocclusion. In our study, only a very weak influence of craniofacial morphology was found on the oropharyngeal dimension. This is in agreement with other studies that have reported that OPV[24,25,27,28] or oropharyngeal CSA[24] do not differ among persons with various skeletal patterns, and either weak or insignificant correlations were reported between craniofacial variables and oropharyngeal airway dimensions.[14,15,26–29]

Since the effective dose of CBCT is substantial, the use of this method as a part of the diagnostic records should be fully justified. The ideal way of investigating the upper airways is magnetic resonance imagining (MRI), as it allows the pharyngeal soft tissues to be examined without any radiation exposure[39]; however, because of its affordability, CBCT has overtaken MRI in dentistry. Although CBCT does not show clear delineations between soft tissues, it clearly demonstrates the airway space and related skeletal structures and has been shown to provide precise and clinically relevant information on upper airway dimensions.[40] We used the Dolphin software for airway segmentation, which has been found to be accurate and reliable.[41]

The vastly different findings of previous investigations using CBCT scans[25–31] suggest that the associations between the upper airways and craniofacial morphology are ambiguous. The representativeness of our study sample suggests that the isolated influence of craniofacial morphology on the upper airway dimensions is minor, and clear differences among craniofacial patterns in pharyngeal measurements could only be found in selected extremities. Therefore, orthodontic treatment planning per se should not be an indication for extensive upper airway investigation with CBCT. However, for borderline patients, if clinical investigation has given a reason for it, CBCT investigation could provide additional and valuable information to assess the precise site of obstruction and could justify different treatment options. These reasons include orthodontic patients suffering from OSA and evaluation of the need for maxillomandibular advancement surgery[42] or for orthognathic surgery involving mandibular setback.[6]

CONCLUSION

- Craniofacial morphology has a minor influence on the dimensions of the upper airways.

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