Original Article

Three-dimensional study of the upper airway in different skeletal Class II malocclusion patterns

Fernando C. Brito[a]; Daniel P. Brunetto[b]; Matilde C. G. Nojima[c]

ABSTRACT

Objectives: To characterize upper airway volume and morphology in patients with different skeletal patterns of Class II malocclusion compared to Class I.

Materials and Methods: A total of 197 individuals who had cone-beam computed tomography were allocated into groups according to ANB, SNA, and SNB angles (Class I, Class II maxillary protrusion, Class II mandibular retrusion), each subdivided into hypodivergent, normal, and hyperdivergent. Nasopharynx (NP), oropharynx (OP), and hypopharynx (HP) were assessed with three-dimensional image reconstruction software.

Results: Intergroup comparison did not detect significant differences in volume and morphology of NP, OP, and HP. The males displayed larger OP and HP volume than the females. Positive correlations between age and NP, OP, HP volume and between craniocervical angle and OP and HP volume were observed. Linear regression analysis detected a tendency for OP and HP volume to increase as maxillary and mandibular length increased.

Conclusions: Upper airway volume and morphology were similar in different skeletal patterns of Class II malocclusion. Actual upper and lower jaw lengths were more closely related to upper airway volume and morphology than the angles that reflected their position relative to the cranial base. (*Angle Orthod.* 2019;89:93–101.)

KEY WORDS: Class II; Upper airway; Vertical patterns; Sagittal patterns

INTRODUCTION

Previous studies have aimed to elucidate the possible relationship between upper airway (UA) morphology and growth of the craniofacial complex because of the important role that respiratory function has in orthodontic diagnosis and treatment planning.[1–3] As early as 1907, Angle stated that Class II, division 1 malocclusions were characterized by narrow upper pharyngeal airways and mouth breathing with dentofacial alterations such as narrow upper arch, upper incisor protrusion, and abnormal lip function.[4] According to Moss[5] functional matrix theory, a deviation in the respiratory or masticatory pattern could disturb normal craniofacial development of an individual, assuming soft tissue might affect hard tissue morphology. However, there has been controversy regarding this subject. Some authors could not establish an association between narrow airways and dentofacial morphology,[3,6] whereas others found evidence to support that UA influences growth and development of the craniofacial complex.[1]

Among all craniofacial disharmonies, skeletal Class II is the most frequently associated condition with narrowing of the UA.[7–9] There seems to be a consensus that maxillary protrusion increases UA length,[10,11] and mandibular retrusion is related to its constriction.[7,8,12] Vertical craniofacial disharmonies are also related to UA morphology and respiratory function.[13,14]

It is hard to establish a cause–effect relationship between UA morphology and a specific facial pattern

[a] Postgraduate Professor, Department of Orthodontics and Pediatric Dentistry, Universidade de Itaúna, Minas Gerais, Brazil.
[b] Postgraduate Professor, Department of Orthodontics and Pediatric Dentistry, Universidade Federal do Paraná, Paraná, Brazil.
[c] Associate Professor, Department of Orthodontics and Pediatric Dentistry, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil.
Corresponding author: Matilde da Cunha Gonçalves Nojima, Associate Professor, Department of Orthodontics and Pediatric Dentistry, Universidade Federal do Rio de Janeiro, Avenida Professor Rodolpho Paulo Rocco, 325, Ilha do Fundão, 21941-617, Rio de Janeiro, RJ, Brazil
(e-mail: matildenojima@uol.com.br)

Accepted: July 2018. Submitted: November 2017.
Published Online: September 19, 2018

Table 1. Sample Division According to the Sagittal Position of the Maxilla and Mandible to the Cranial Base (SNA and SNB Angles) and the Vertical Pattern of Facial Growth (FMA Angle)[a]

Sagittal Skeletal Groups	Hypodivergent FMA $\leq$ 19	Normal 19 $<$ FMA $<$ 30	Hyperdivergent FMA $\geq$ 30
CI 80 $\leq$ SNA $\leq$ 84 and 78 $\leq$ SNB $\leq$ 82 0$\leq$ANB$\leq$4	Group I Male (n = 13)/Female (n = 10)	Group II Male (n = 9)/Female (n = 15)	Group III Male (n = 13)/Female (n = 9)
CII MaxP SNA $>$ 84 and 78 $\leq$ SNB $\leq$ 82 ANB $>$ 4	Group IV Male (n = 10)/Female (n = 10)	Group V Male (n = 10)/Female (n = 10)	Group VI Male (n = 13)/Female (n = 9)
CII MandR 80 $\leq$ SNA $\leq$ 84 and SNB $<$ 78 ANB $>$ 4	Group VII Male (n = 9)/Female (n = 10)	Group VIII Male (n = 7)/Female (n = 17)	Group IX Male (n = 7)/Female (n = 16)

[a] N = 197 (94 males; 103 females). CI, Class I; CII MaxP, Class II maxillary protrusion; CII MandR, Class II mandibular retrusion.

because of their innate multifactorial origin.[15] Previous studies analyzed this subject on lateral cephalometric radiographs that, despite providing relevant data, presented limitations as a result of anatomical variations in the three-dimensional (3D) complex that constitutes the upper airway, such as highly constricted transverse areas.[16,17] With the evolution of 3D diagnosis, this study aimed to evaluate, on cone-beam computed tomography (CBCT) scans and image reconstructions, the volume and morphology of nasopharynx (NP), oropharynx (OP), and hypopharynx (HP) in different sagittal and vertical skeletal patterns of Class II malocclusions when compared with Class I patients.

MATERIALS AND METHODS

This study was approved by the research ethics committee of the Institute of Collective Health Studies of the Universidade Federal do Rio de Janeiro in Brazil. All patients signed a consent form prior to orthodontic treatment, allowing the use of their orthodontic records for this study. Sample size was calculated based on the average standard deviation of a previous study.[8] According to Pandis,[18] to detect differences of 2500 mm^3 in oropharyngeal volume, with a test power of 0.80 (α = 0.05), at least 19 cone-beam computed tomography (CBCT) scans would be necessary in each group.

The sample was composed of 197 CBCT scans selected from a total of 1446 that comprised the initial records of patients starting treatment in the Orthodontic Clinics of the Postgraduate Program in the Universidade Federal do Rio de Janeiro in Brazil. The following inclusion criteria were used: age range between 13 and 23 for both genders, no previous orthodontic therapy, skeletal Class I or Class II malocclusions (0 $\leq$ ANB $\leq$ 4; ANB $>$ 4, respectively), good state of general health, CBCT scans that included the fourth cervical vertebrae, Digital Imaging and Communications in Medicine (DICOM) files, and Craniocervical angle (CCA) ranging from 90° to 110° during CBCT acquisition. Exclusion criteria were restricted to the presence of syndromes, Class I bimaxillary protrusion cases, and scans with artifacts.

The CBCT scans were performed on one device (KODAK 9500 Cone Beam 3D System; Carestream

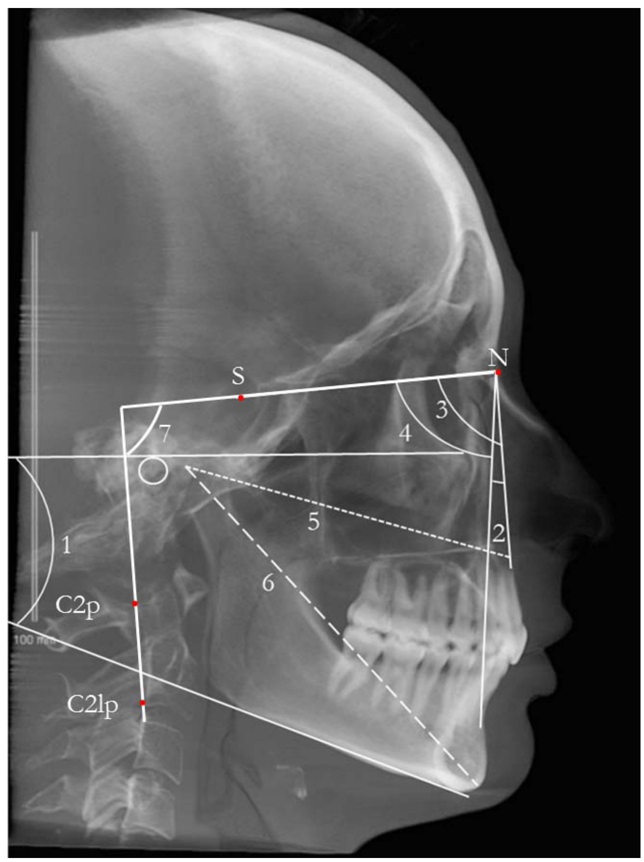

Figure 1. Lateral two-dimensional projection from a cone-beam computed tomography scan used for sample selection: 1 = FMA angle; 2 = ANB angle; 3 = SNA angle; 4 = SNB angle; 5 = linear length of maxilla – dotted line Condylion-A Point (Co-A); 6 = linear length of mandible – dashed line Condylion-Gnathion (Co-Gn); 7 = CCA angle - intersection of line formed by points S and N, and line formed by C2p (upper most posterior point of C2) and C2lp (lower most posterior point of C2).

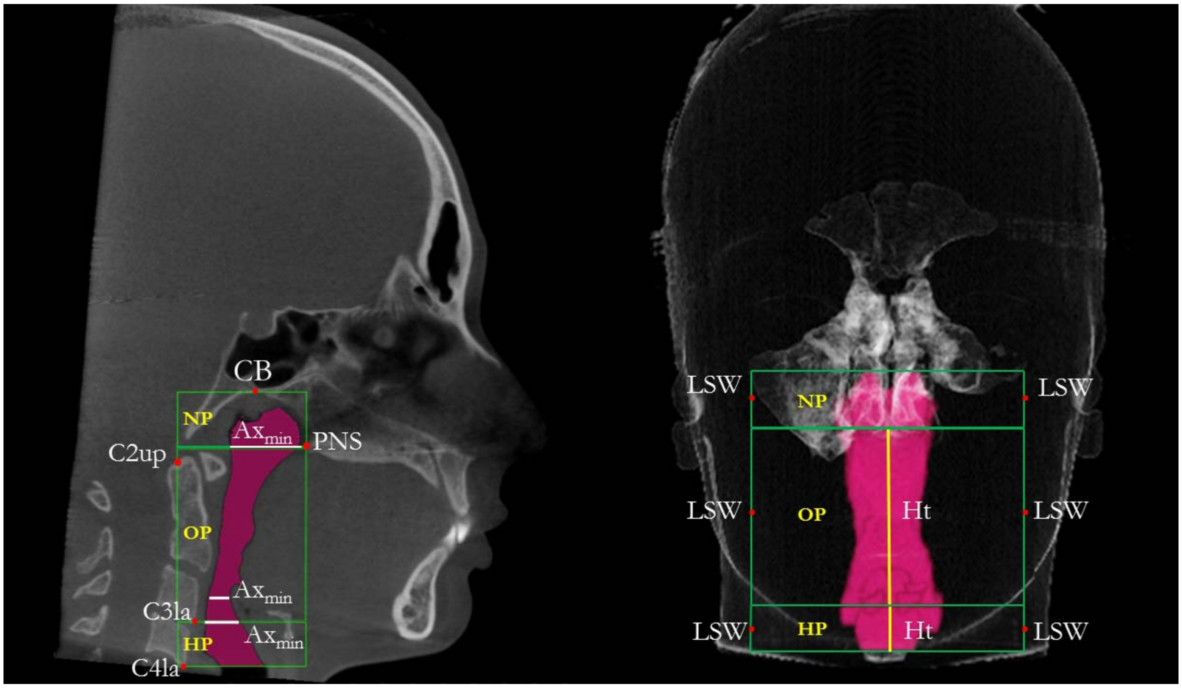

Figure 2. Upper airway analysis: nasopharynx (NP), oropharynx (OP), and hypopharynx (HP). Landmarks: PNS, posterior nasal spine; CB, clivus base; C2up; C3la; C4la; LSW, lateral sinus wall; Ax_{min}, minimal axial area (white line); Ht, height (yellow line). Limits of the NP, OP, HP (green lines).

Health, Rochester, N.Y.) according to a standard protocol (90 kV, 10 mA, Field of View (FOV) of 18.4 $\times$ 20.6 cm, 0.3 mm voxel size, and 24-second scan). During scanning, the patients were instructed to be in maximum intercuspation and to position the tongue against the palate and not to swallow. The Frankfurt horizontal plane (FHP) was kept parallel to the ground and perpendicular to the sagittal plane.

DICOM files were exported for 3D reconstruction using Dolphin Imaging software version 11.7 (Dolphin Imaging & Management Solutions, Chatsworth, Calif), and measurements were made by an experienced operator. The head was positioned virtually in space according to the axial, coronal, and sagittal reference planes.[19] Linear and angular measurements were taken on the two-dimensional lateral cephalometric radiographs created from the CBCT scans in the software to characterize skeletal patterns (Figure 1).

The patients were divided into one of the following three groups according to SNA and SNB angles: Class I (CI), Class II maxillary protrusion (CII MaxP), and Class II mandibular retrusion (CII MandR). Each of these groups was reallocated into one of the following three subgroups according to the vertical pattern of mandibular growth based on the FMA angle: hypo-divergent (Hpo), normal, and hyperdivergent (Hpr).The sample was therefore divided into nine groups (Table 1).

Total volume and minimal axial area were determined for NP, OP, and HP. Total height values were obtained at the OP and HP. Anatomical limits for UA analysis were used as proposed by Guijarro-Martínez and Swennen.[19,20] The anterior limit was set by the intersection of the coronal plane perpendicular to FHP, passing through the Posterior Nasal Spine (PNS). The soft tissue contour of the posterior pharyngeal wall established the posterior limit, defined by the intersection of the coronal plane perpendicular to FHP, passing through point C2up (midpoint between the upper and most posterior points of the second cervical vertebrae). The soft tissue contour of the lateral pharyngeal walls established the lateral limits, defined by the sagittal plane intersecting perpendicular to FHP, touching the lateral walls of the maxillary sinuses.

At NP, the upper limit corresponded to the soft tissue contour of the upper pharyngeal wall, defined by a transverse plane parallel to the FHP passing through the clivus base, and its lower limit was set by a plane parallel to the FHP intersecting the PNS and extended to the posterior pharyngeal wall. At OP, the upper limit was established as the lower limit of NP, and the lower limit was defined by a plane parallel to the FHP intersecting point C3la (lower most anterior point of the third cervical vertebrae). At HP, the upper limit was set as the lower limit of OP, and the lower limit was established by a plane parallel to the FHP joining the

Table 2. Descriptive Statistics and Intergroup Comparison Considering Age and Cephalometric Pattern of All Participants[a]

Sagittal Vertical Skeletal Groups	Age	ANB (°)	FMA (°)
Hypodivergent			
CI Hpo (n = 23), average ± SD	17.17 ± 3.37[a]	1.61 ± 0.61[a]	18.00 ± 1.36[a]
CII MaxP Hpo (n = 20), average ± SD	16.10 ± 3.85[a]	5.35 ± 1.18[b]	18.18 ± 1.72[a]
CII MandR Hpo (n = 19), average ± SD	15.15 ± 2.75[a]	5.18 ± 1.40[b]	17.68 ± 1.81[a]
Normal			
CI Nor (n = 24), average ± SD	15.50 ± 2.62[a]	2.42 ± 0.75[a]	25.02 ± 1.67[b]
CII MaxP Nor (n = 20), average ± SD	14.55 ± 2.58[a]	5.72 ± 1.73[b]	25.71 ± 1.64[b]
CII MandR Nor (n = 24), average ± SD	16.37 ± 3.53[a]	6.07 ± 1.40[b]	26.15 ± 1.96[b]
Hyperdivergent			
CI Hpr (n = 22), average ± SD	17.45 ± 3.69[a]	2.11 ± 0.92[a]	33.33 ± 4.17[c]
CII MaxP Hpr (n = 22), average ± SD	14.86 ± 2.41[a]	6.39 ± 1.98[b]	31.45 ± 1.52[c]
CII MandR Hpr (n = 23), average ± SD	16.08 ± 3.65[a]	6.00 ± 1.00[b]	32.53 ± 4.19[c]

[a] N = 197. Analysis of variance and Tukey (post hoc) test; $P < .05$. Different superscript letters indicate statistically significant difference (same column). CI, Class I; CII MaxP, Class II maxillary protrusion; CII MandR, Class II mandibular retrusion; Hpo, hypodivergent; Nor, normal; Hpr, hyperdivergent; CCA, craniocervical angle; SD, standard deviation.

base of epiglottis to point C4la (lower most anterior point of the fourth cervical vertebrae; Figure 2).

Statistical Analysis

Measurement confidence and intrarater reliability were performed using 30% of the sample with random selection of CBCT scans. All measurements were repeated after a 2-week interval under similar conditions.

Descriptive analysis characterized all quantitative variables. A Shapiro-Wilk test was applied to evaluate data normality. Once the normal distribution of all variables was confirmed, a Levene test and then an analysis of variance test were used to assess statistically significant differences among groups, followed by a Tukey (post hoc) test to detect which groups differed ($P < .05$). The correlations between NP, OP, and HP volume with other variables were tested by Pearson correlation coefficient ($P < .05$; $P < .01$). The correlations between jaw length (Condylion-A Point (Co-A), Condylion-Gnathion (Co-Gn)) and NP, OP, HP volume were evaluated by linear regression, with the gender variable as a subgroup ($P < .05$; $P < .01$; $P < .001$). An independent *t*-test was used to assess statistical significance between the UA subregions (NP, OP, HP) and gender ($P < .01$; $P < .001$).

RESULTS

Intraclass correlation coefficient results for intrarater reliability were above 0.93 for all analyzed variables, thus certifying operator calibration. Sample normality was confirmed separately for each variable, considering distinct groups. Descriptive statistics and intergroup comparison analysis for all variables are presented in Tables 2 and 3. All sample groups were compatible for participant age without significant differences. Statistical significant differences were found between groups regarding ANB, FMA, SNA, and SNB angles, supporting the inclusion criteria employed (Table 2).

Table 3. Descriptive Statistics and Intergroup Comparison of Upper Airway Analysis for All Study Groups[a]

	Nasopharynx		Oropharynx
Sagittal Vertical Skeletal Groups	NP Vol (mm^3)	NP Ax_{min} (mm^2)	OP Vol (mm^3)
Hypodivergent			
CI Hpo (n = 23), average ± SD	4296.50 ± 1787.72[a]	48.59 ± 38.97[a]	12988.68 ± 4755.63[a]
CII MaxP Hpo (n = 20), average ± SD	5235.03 ± 2187.83[a]	46.75 ± 43.87[a]	12808.56 ± 6092.48[a]
CII MandR Hpo (n = 19), average ± SD	4600.41 ± 1394.40[a]	35.37 ± 27.71[a]	12098.38 ± 3487.24[a]
Normal			
CI Nor (n = 24), average ± SD	4267.61 ± 1546.10[a]	32.43 ± 26.67[a]	11937.16 ± 3726.56[a]
CII MaxP Nor (n = 20), average ± SD	4771.36 ± 1456.06[a]	46.27 ± 41.91[a]	15155.09 ± 5637.77[a]
CII MandR Nor (n = 24), average ± SD	4677.50 ± 1550.72[a]	43.29 ± 28.92[a]	12864.60 ± 4247.02[a]
Hyperdivergent			
CI Hpr (n = 22), average ± SD	4958.21 ± 1955.48[a]	39.14 ± 21.25[a]	13690.29 ± 4783.87[a]
CII MaxP Hpr (n = 22), average ± SD	4805.92 ± 2133.10[a]	42.40 ± 35.94[a]	12394.94 ± 4311.77[a]
CII MandR Hpr (n = 23), average ± SD	4798.40 ± 2260.02[a]	51.18 ± 39.87[a]	11514.50 ± 3907.02[a]

[a] N = 197. Analysis of variance and Tukey (post hoc) test; $P < .05$. Different superscript letters indicate statistically significant difference (same column). NP, nasopharynx; Vol, volume; Ax_{min}, minimal axial area; OP, oropharynx; Ht, height; HP, hipopharynx; CI, Class I; Hpo, hypodivergent; CII MaxP, Class II maxillary protrusion; CII MandR, Class II mandibular retrusion; Nor, normal; Hpr, hyperdivergent; SD, standard deviation.

Table 2. Extended

SNA (°)	SNB (°)	CoA (mm)	CoGn (mm)	CCA (°)
82.66 ± 1.12[b]	81.04 ± 1.41[c]	85.82 ± 4.74[ab]	115.23 ± 7.89[a]	96.85 ± 5.50[a]
86.14 ± 1.09[c]	80.76 ± 0.82[c]	87.82 ± 5.33[b]	111.70 ± 7.75[a]	95.85 ± 5.82[a]
81.34 ± 0.99[a]	76.15 ± 1.10[a]	89.05 ± 5.23[b]	112.00 ± 7.87[a]	99.38 ± 6.69[ab]
81.85 ± 1.21[ab]	79.44 ± 1.55[b]	85.48 ± 6.88[ab]	114.98 ± 7.67[a]	99.23 ± 6.41[ab]
86.21 ± 1.75[c]	80.47 ± 1.35[bc]	89.01 ± 5.69[b]	114.13 ± 7.86[a]	99.53 ± 6.56[ab]
81.96 ± 1.16[ab]	75.87 ± 1.32[a]	86.58 ± 5.26[ab]	110.37 ± 7.77[a]	100.55 ± 6.18[ab]
82.66 ± 1.19[b]	80.54 ± 1.33[bc]	80.93 ± 5.65[a]	112.35 ± 2.07[a]	97.66 ± 6.43[a]
86.37 ± 1.91[c]	79.98 ± 1.15[bc]	87.72 ± 4.61[b]	113.17 ± 5.39[a]	98.53 ± 5.05[ab]
81.44 ± 1.33[ab]	75.44 ± 1.25[a]	83.75 ± 4.46[ab]	111.09 ± 8.90[a]	103.83 ± 5.00[b]

For sagittal skeletal base length, the maxilla (Co-A) displayed statistically significant lower average values in CI Hpr when compared with groups CII MaxP Hpr, CII MaxP normal, CII MaxP Hpo, and CII MandR Hpo. Variable Co-Gn, representative of mandibular length, was not statistically different among the groups. The CCA angle was significantly greater in CII MandR Hpr when compared with CI Hpr, CI Hpo, and CII MaxP Hpo (Table 2).

Regarding UA analysis, all NP, OP, and HP variables were equivalent in intergroup comparisons (Table 3).

The correlation test results are shown in Table 4. Age had a significant positive correlation with NP, OP, and HP volumes. The variables FMA, ANB, and SNA were not significantly correlated to NP, OP, and HP volumes. SNB angle was significantly correlated only with OP volume. Similar significant correlations were observed between CCA and OP and HP volumes. The variables related to NP, OP, and HP morphology (minimal axial area and total height) were significantly positively correlated with their respective volumes (Table 4).

Linear regression graphs are shown in Figure 3 and depict positive correlations between NP, OP, and HP with maxillary and mandibular length. A significant difference was found in males regarding NP volume and Co-Gn as well as when OP and HP volumes were related to Co-A and Co-Gn in males and in total gender averages.

The comparisons of average and standard error values of NP, OP, and HP volumes between males and females are shown in Figure 4. The males displayed significantly greater OP and HP volumes when compared with females.

DISCUSSION

The age range established for this research made it possible to evaluate the relationship between growth and UA morphology in individuals with different dento-facial patterns. Previous retrospective 3D studies showed an increase in UA length and volume between the ages of 8 and 18[21,22] as well as increasing airway area and length until the age of 20.[23] Similar data were found in the present study, demonstrating positive and statistically significant correlations with an increase in

Table 3. Extended

Oropharynx		Hypopharynx		
OP Ax_{min} (mm^2)	OP Ht (mm)	HP Vol (mm^3)	HP Ax_{min} (mm^2)	HP Ht (mm)
55.63 ± 25.02[a]	54.66 ± 6.61[a]	3719.57 ± 1278.36[a]	68.55 ± 29.95[a]	15.73 ± 1.82[a]
70.15 ± 56.76[a]	53.41 ± 5.37[a]	4245.27 ± 1660.52[a]	69.92 ± 40.38[a]	15.24 ± 1.81[a]
60.58 ± 25.10[a]	53.37 ± 5.32[a]	3964.56 ± 1157.77[a]	72.62 ± 25.56[a]	15.14 ± 1.37[a]
66.10 ± 19.99[a]	52.29 ± 6.76[a]	4001.29 ± 1489.16[a]	66.10 ± 27.24[a]	14.84 ± 2.11[a]
79.31 ± 39.73[a]	53.18 ± 6.57[a]	3697.91 ± 1062.35[a]	75.15 ± 28.64[a]	14.52 ± 1.60[a]
60.42 ± 27.16[a]	55.35 ± 5.95[a]	4099.37 ± 1450.22[a]	71.00 ± 40.45[a]	15.36 ± 1.21[a]
62.23 ± 28.73[a]	55.09 ± 5.38[a]	4179.47 ± 1771.02[a]	79.68 ± 40.67[a]	15.82 ± 1.79[a]
62.31 ± 21.64[a]	53.26 ± 6.14[a]	4206.81 ± 1529.33[a]	71.84 ± 35.93[a]	15.26 ± 1.99[a]
60.22 ± 27.08[a]	51.91 ± 5.64[a]	3870.24 ± 1531.54[a]	78.39 ± 41.58[a]	14.60 ± 1.50[a]

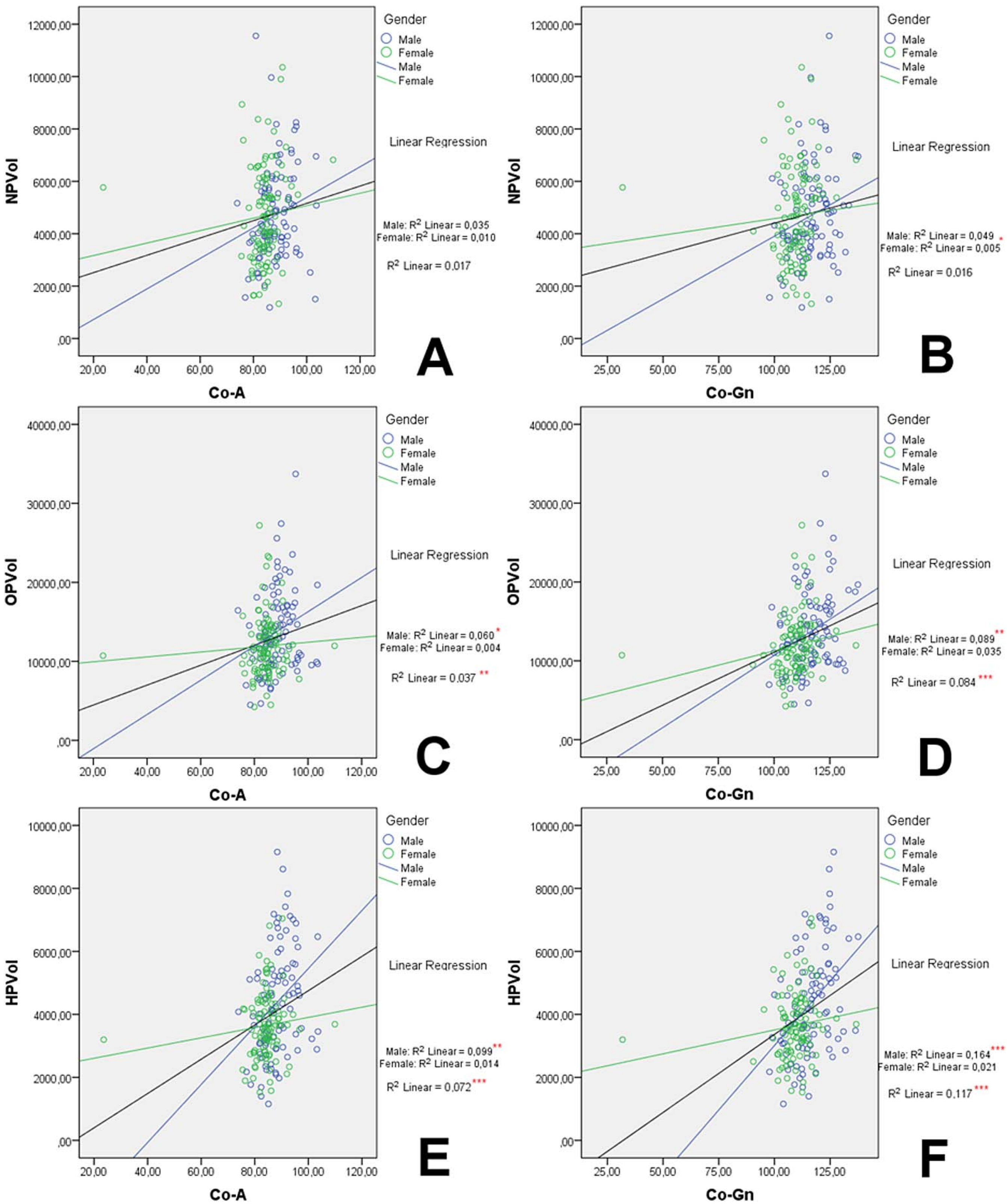

Figure 3. Linear regression analysis comparing nasopharynx (NP), oropharynx (OP), and hypopharynx (HP) volume with actual length of the maxilla (Co-A) and mandible (Co-Gn). Blue and green circles represent males and females, respectively. Black, blue, and green lines represent the average correlations for the total sample, males and females, respectively. Correlations between (**A**) NP volume and Co-A, (**B**) NP volume and Co-Gn, (**C**) OP volume and Co-A, (**D**) OP volume and Co-Gn, (**E**) HP volume and Co-A, (**F**) HP volume and Co-Gn. **P* < .05; ***P* < .01; ****P* < .001.

Table 4. Pearson Correlation Coefficient for NP, OP, and HP Volume Compared to Age, Cephalometric Variables, and Upper Airway Morphological Variables[a]

Airway Volume	Age	FMA	ANB	SNA	SNB	CCA	NP Ax_{min}	OP Ax_{min}	OP Ht	HP Ax_{min}	HP Ht
OP Vol											
r	0.184**	0.058	−0.038	0.137	0.162*	0.200**	0.327**	0.480**	0.396**	0.217**	0.257**
P	.010	.417	.597	.055	.023	.005	<.01	<.01	<.01	.002	<.01
NP Vol											
r	0.455**	0.077	0.109	0.104	0.003	−0.056	0.242**	0.169*	0.077	0.253**	0.221**
P	<.01	.282	.127	.145	.969	.433	.001	.018	.281	<.01	.002
HP Vol											
r	0.311**	0.042	0.035	0.046	0.012	0.260**	0.188**	0.516**	0.516**	0.548**	0.564**
P	<.01	.559	.625	.519	.866	<.01	.008	<.01	<.01	<.01	<.01

[a] N = 197. NP, nasopharynx; OP, oropharynx; CCA, craniocervical angle; Ax_{min}, minimal axial area; Ht, height; HP, hipopharynx; Vol, volume. *$P < .05$; **$P < .01$.

NP, OP, and HP volumes between the ages of 13 and 23. This result is supported by the homogeneous distribution in all groups when it came to age. As age increases and soft tissue around the UA develops, there is clearly an actual increase in UA dimensions.

The majority of authors evaluated UA using linear measurements taken on lateral cephalometric radiographs.[1,3,7,13,14] As further research evolved, 3D studies on UA analysis were performed, but without considering it as a complete structure.[2,8] Considerable obstacles still need to be surpassed to make 3D UA analysis more precise, among which is the need for better anatomical boundary definition, which has been highly variable in the literature.[7,9,20] Due to its importance, the anatomical limits in the current study were used as recently published.[19] By standardizing the anatomical limits used, more accurate comparisons among studies may be achieved.

Class I and Class II skeletal malocclusions were stratified on the sagittal norm in the present study, but did not show significant differences in UA morphology according to the skeletal patterns analyzed. The results confirm those of previous studies, all showing no significant association between UA dimensions and different sagittal skeletal patterns.[13,24] However, the literature reports that UA morphology can be influenced by different sagittal malocclusions, and most authors found smaller dimensions in OP and NP in skeletal Class II patterns.[2,7,9] An important difference between the current study and that by El and Palomo[8] was that the CCA angle was used as an inclusion criterion for the sample, decreasing the effect that head posture has on the UA dimensions during a CBCT scan.[9,25] This became quite clear due to the positive significant correlations identified in this research between CCA and OP and HP volumes, which demonstrated that even if CCA was restricted to a standard range,[25] it was capable of significantly influencing UA dimensions.

The sagittal relationship between the maxilla and mandible is usually determined by ANB angle. However, it may be influenced by maxillary rotation, increased vertical distance between points A and B as well as between points N and B, length of the anterior cranial base, and sagittal position of point N.[26] In the present study, no significant correlations were found between ANB angle and NP, OP, or HP volumes, indicating that such influential factors should be carefully considered in future studies. Indriksone and Jakobsone[3] did not detect significant correlations between ANB and NP or OP volume, which supports the current findings. Nevertheless, the positive significant correlation between SNB and OP volume found in the current study was consistent with previous studies.[3,7]

The positive statistically significant correlations between maxillary and mandibular lengths and OP and HP volumes are consistent with other studies that

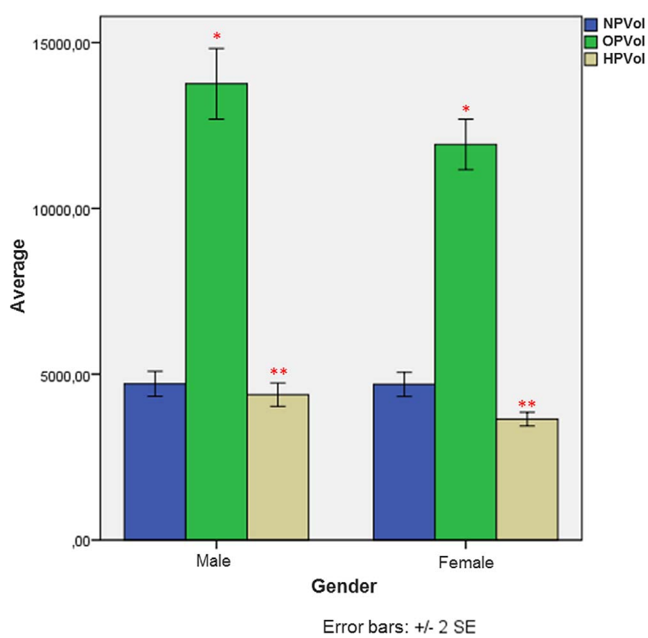

Figure 4. Average and standard error comparisons of nasopharynx (NP), oropharynx (OP), and hypopharynx (HP) volumes between males and females. Independent *t*-test, *$P < .01$; **$P < .001$.

identified a significant correlation between mandibular length and OP volume.[8,12] From these results, it is possible to infer the hypothesis that the actual length of the maxilla and mandible are more determinant of the volume and shape of the UA than is their sagittal position with regard to the cranial base, represented by the SNA and SNB angles. A meta-analysis reported a clinically significant association of mandibular length with an accurate diagnosis of obstructive sleep apnea.[27] Associated with these findings, none of the groups from the current study showed differences in Co-Gn, which could explain in part the low variation of OP and HP volumes of the evaluated groups. Future studies should present results less dependent on the SNA, SNB, and ANB angles.

Regarding the possible influence of vertical craniofacial patterns in UA, Celikoglu et al.[28] found significant differences in UA volume, observing higher values in Hpo and lower values in Hpr patients. The current data support the theory that this issue itself does not cause significant modifications in its morphology, consistent with other research.[2,3]

The high positive correlation between NP, OP, and HP volumes and the respective minimal axial areas is well supported by previous studies.[7,8,24] This is a relevant clinical finding because volume itself cannot provide information about UA shape, but from the current results, it can be inferred that the most constricted area for air to pass through the UA seems to be directly influenced by volume and effective jaw length, as previously discussed.

Larger oropharyngeal and hypopharyngeal volumes were observed in the males in this study and not the females, consistent with previous studies.[2,8,21] Specifics related to the development of males and females within this age range may have contributed to these findings.

The present results highlighted that actual jaw length plays a more determining role on UA volume and morphology. It is a more important risk factor to be considered in an obstructive sleep apnea diagnosis than considering vertical and sagittal skeletal malocclusions separately. Therefore, additional research adopting similar anatomical limits and methodology for UA analysis are recommended to support these findings.

CONCLUSIONS

Regarding skeletal Class II malocclusion patterns, the following conclusions can be drawn:

- Different vertical and sagittal facial patterns showed no significant differences in volume and morphology of the NP, OP, and HP.
- Significant correlations were shown between jaw length and OP and HP volumes in males and in total gender averages.
- Males had larger OP and HP volumes when compared with females.
- Age was significantly correlated with NP, OP, and HP volumes in the sample studied.

ACKNOWLEDGMENTS

We thank the Carlos Chagas Filho Foundation for Research Support of the State of Rio de Janeiro for financial support during the acquisition of the software used in this research and the Coordination of Improvement of Higher Level Personnel for supporting academic and professional development.

REFERENCES

1. McNamara JA. Influence of respiratory pattern on craniofacial growth. *Angle Orthod*. 1981;51:269–300.
2. Grauer D, Cevidanes LS, Styner MA, Ackerman JL, Proffit WR. Pharyngeal airway volume and shape from cone-beam computed tomography: relationship to facial morphology. *Am J Orthod Dentofacial Orthop*. 2009;136:805–814.
3. Indriksone I, Jakobsone G. The influence of craniofacial morphology on the upper airway dimensions. *Angle Orthod*. 2015;85:5, 874–880.
4. Angle, EH. *Malocclusion of the Teeth*. 7th ed. Philadelphia, PA: S.S. White Dental Manufacturing; 1907;28–59.
5. Moss ML. The functional matrix: functional cranial components. In: BS K, ed. *Vistas in Orthodontics*. Philadelphia, PA: Lea and Febiger; 1962:85–98.
6. Kluemper GT, Vig PS, Vig KW. Nasorespiratory characteristics and craniofacial morphology. *Eur J Orthod*. 1995;17: 491–495.
7. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. *Am J Orthod Dentofacial Orthop*. 2011; 139:e511–e521.
8. El H, Palomo JM. An airway study of different maxillary and mandibular sagittal positions. *Eur J Orthod*. 2013;35:262–270.
9. Oh KM, Hong JS, Kim YJ, Cevidanes LS, Park YH. Three-dimensional analysis of pharyngeal airway form in children with anteroposterior facial patterns. *Angle Orthod*. 2011;81: 1075–1082.
10. Kaygisiz E, Tuncer BB, Yüksel S, Tuncer C, Yildiz C. Effects of maxillary protraction and fixed appliance therapy on the pharyngeal airway. *Angle Orthod*. 2009;79:660–667.
11. Lee JW, Park KH, Kim SH, Park YG, Kim SJ. Correlation between skeletal changes by maxillary protraction and upper airway dimensions. *Angle Orthod*. 2011;81:426–432.
12. Hong JS, Oh KM, Kim BR, Kim YJ, Park YH. Three-dimensional analysis of pharyngeal airway volume in adults with anterior position of the mandible. *Am J Orthod Dentofacial Orthop*. 2011;140:e161–e169.
13. de Freitas MR, Alcazar NMPV, Janson G, de Freitas KMS, Henriques JFC. Upper and lower pharyngeal airways in subjects with Class I and Class II malocclusions and different growth patterns. *Am J Orthod Dentofacial Orthop*. 2006;130:742–745.

14. Ucar FI, Uysal T. Orofacial airway dimensions in subjects with Class I malocclusion and different growth patterns. *Angle Orthod*. 2011;81:460–468.
15. Moyers RE. *Ortodontia*. Rio de Janeiro: Guanabara Koogan; 1991:33–63.
16. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2009;135:468–479.
17. Feng X, Li G, Qu Z, Liu L, Nässtrröm K, Shi XQ. Comparative analysis of upper airway volume with lateral cephalograms and cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2015;147:197–204.
18. Pandis N. Sample calculations for comparison of 2 means. *Am J Orthod Dentofacial Orthop*. 2012;141:519–521.
19. Guijarro-Martínez R, Swennen GR. Three-dimensional cone beam computed tomography definition of the anatomical subregions of the upper airway: a validation study. *Int J Oral Maxillofac Surg*. 2013;42:1140–1149.
20. Guijarro-Martínez R, Swennen GR. Cone-beam computerized tomography imaging and analysis of the upper airway: a systematic review of the literature. *Int J Oral Maxillofac Surg*. 2011;40:1227–1237.
21. Li H, Lu X, Shi J, Shi H. Measurements of normal upper airway assessed by 3-dimensional computed tomography in Chinese children and adolescents. *Int J Pediatr Otorhinolaryngol*. 2011;75:1240–1246.
22. Chiang CC, Jeffres MN, Miller A, Hatcher DC. Three-dimensional airway evaluation in 387 subjects from one university orthodontic clinic using cone beam computed tomography. *Angle Orthod*. 2012;82:985–992.
23. Schendel SA, Jacobson R, Khalessi S. Airway growth and development: a computerized 3-dimensional analysis. *J Oral Maxillofac Surg*. 2012;70:2174–2183.
24. Di Carlo G, Polimeni A, Melsen B, Cattaneo PM. The relationship between upper airways and craniofacial morphology studied in 3D. A CBCT study. *Orthod Craniofac Res*. 2015;18:1–11.
25. Muto T, Takeda S, Kanazawa M, Yamazaki A, Fujiwara Y, Mizoguchi I. The effect of head posture on the pharyngeal airway space (PAS). *Int J Oral Maxillofac Surg*. 2002;31:579–583.
26. Hussels W, Nanda RS. Analysis of factors affecting angle ANB. *Am J Orthod*. 1984;85:411–423.
27. Miles PG, Vig PS, Weyant RJ, Forrest TD, Rockette HE. Craniofacial structure and obstructive sleep apnea syndrome—a qualitative analysis and meta-analysis of the literature. *Am J Orthod Dentofacial Orthop*. 1996;109:163–172.
28. Celikoglu M, Bayram M, Sekerci AE, Buyuk SK, Toy E. Comparison of pharyngeal airway volume among different vertical skeletal patterns: a cone-beam computed tomography study. *Angle Orthod* 2014;84:782–787.