International Journal of Pediatric Otorhinolaryngology 75 (2011) 1195–1199

Contents lists available at ScienceDirect

International Journal of Pediatric Otorhinolaryngology

journal homepage: www.elsevier.com/locate/ijporl

Three-dimensional assessment of pharyngeal airway in nasal- and mouth-breathing children

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ARTICLE INFO

Article history:
Received 24 March 2011
Received in revised form 15 June 2011
Accepted 18 June 2011
Available online 20 July 2011

Keywords:
Pharyngeal airway space
Imaging

ABSTRACT

Objectives: The aim of this study was to assess the pharyngeal airway space (PAS) in nasal and mouth-breathing children using cone beam computed tomography (CBCT).
Methods: Volume, area, minimum axial area and linear measurements (PAS-NL, PAS-UP, PAS-OccL, PAS-UT, PAS-Bgo, PAS-ML, PAS-TP) of the pharyngeal airway of 50 children (mean age 9.16 years) were obtained from the CBCT images. The means and standard deviations were compared according to sexes (28 male and 22 female) and breathers patterns (25 nasal breathers and 25 mouth breathers).
Results: There were no statistically significant differences ($p > 0.05$) between all variables when compared by sexes. Comparisons between nasal and mouth breathers showed significant differences only in two linear measurements: PAS-OccL ($p < 0.001$) and PAS-UP ($P < 0.05$). Airway volume ($p < 0.001$), area ($p < 0.001$) and minimum axial area ($p < 0.01$) had significant differences between the groups.
Conclusions: The CBCT evaluation showed that pharyngeal airway dimensions were significantly greater in nasal-breathers than in mouth-breathers.

1. Introduction

Heredity has an important function in determining size and shape of the face, however, environmental factors such as breathing habit is essential to the harmonic and balanced development of the craniofacial complex. In this context, mouth breathing habit has been associated with some dentofacial deformities. According to Moss' functional matrix theory [1], nasal breathing allows proper growth and development of the craniofacial complex interacting with other functions such as masticatory and swallow. On the other hand, when nasal obstruction leads to mouth breathing habit, this could result not only in changes of the tongue and lip positions, but also causes mouth opening posture, downward and backward rotation of mandible, long face, constricted maxillary arch, incompetent lip seal, flat noses, narrow nasal base [1–5]. Predisposing factors of nasal obstruction can include adenoid and tonsil hypertrophy, polyps, allergies, infections, and nasal deformities.

Naso-breathing function and its relation to craniofacial growth are of great interest today, not only because the basic biological relationship of form and function but also because of the great practical concern to pediatricians, otorhinolaryngologists, allergists, speech therapists, orthodontists, and other members of health-care community as well [3].

Traditionally, the airway space has been evaluated by the use of cephalometric radiographs, however, this method results in superimposition of all bilateral structures of the craniofacial complex. Nowadays with the advent of Cone Beam Computed Tomography (CBCT), the airway evaluation became more accurate and reliable, generating information more comprehensive than the 2D radiographs [6,7].

Accordingly, the purpose of this study was to carry out a CBCT evaluation of the pharyngeal airway space (PAS) in nasal-breathing and mouth-breathing children.

2. Materials and methods

This study was revised and approved by the Institute of Collective Health Studies Research Ethics Committee of Rio de Janeiro Federal University. Free informed consent was signed by all the responsible of the patients before they took part in the clinical procedures.

A total of 50 healthy children ranging 8–10 years old (mean age of 9.16 years and standard deviation of 0.64), were selected from a group of 68 children who attended the Orthodontics clinic of the Federal University of Rio de Janeiro. The orthodontic diagnosis of

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doi:10.1016/j.ijporl.2011.06.019

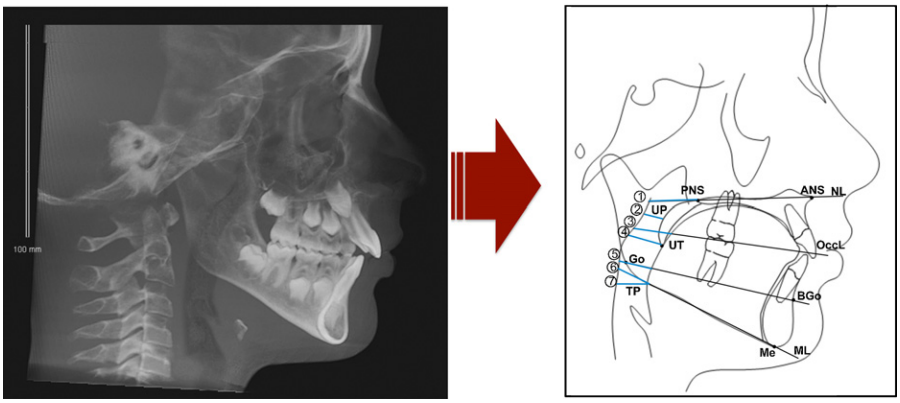

Fig. 1. 2D-lateral cephalometric image with the use of a ray-sum technique (*Dolphin Imaging® software, version 11.0*/Orientation function) and linear distances: 1, PAS-NL; 2, PAS-UP; 3, PAS-OccL; 4, PAS-UT; 5, PAS-BGo; 6, PAS-ML; 7, PAS-TP.

the respiratory function was realized through clinical evaluation of the habitual posture of the lips, size and shape of the nostrils, control reflex muscle alares and Glatzel mirror test [8]. In addition, all the patients were evaluated in the Otorhinolaryngology sector of the University Hospital Clementino Fraga Filho. All the rhinoscopy examination were conducted by the same otorhinolaringologist and the respiratory pattern of the subjects was confirmed according to the degree of adenoid hypertrophy. Patients with more than 60% airway obstruction due to adenoid hypertrophy were considered mouth breathers.

Twenty-five subjects were diagnostic as nasal breathers (mean age of 8.94 years) and 25 as mouth breathers (mean age of 9.27 years). Eighteen patients that had symptoms of upper respiratory infection at the time, pharyngeal pathology or a history of adenoidectomy or tonsillectomy were excluded.

All CBCT scans were taken with the same cone beam machine (i-CAT, Imaging Sciences International, Hatfield, PA, USA), according to a standard protocol (120 kV, 5 mA, 13 × 17 cm FOV, 0.4 mm voxel and scan time of 20 s) used for orthodontic records in this University.

Because the volume of the airway is influenced by head posture [9], all patients seated in the upright position with Frankfort Horizontal (FH) plane paralleled to the floor, maximum intercuspation and lips and tongue in position of filling the oral cavity. The patients were instructed not to swallow and not to move the head and tongue during the scanning.

Data were imported in DICOM (Digital Imaging and Communications in Medicine) format and handled by Dolphin Imaging® software, version 11.0 (Dolphin Imaging, Chatsworth, California, USA). Once the image head 3D-reconstructions of each patient were oriented [10,11], the airway analysis tool in Dolphin 3D Imaging software was used to define the superior [12,13] and inferior [14,15] border of the airway. The update volume was generated and the airway volume, airway area and minimum axial area were obtained (Fig. 1).

Furthermore, the software was used to create a 2D lateral cephalometric image (ray-sum technique). These lateral cephalometric images were printed by HP colorjet (HP Color LaserJet 2600n, Hewlett-Packard Company, Palo Alto, Califórnia, USA) and seven linear measurements (PAS-NL, PAS-UP, PAS-OccL, PAS-UT, PAS-BGo, PAS-ML, PAS-TP) were realized in different levels of the PAS (Fig. 2, Table 1) as previously described by Pracharktam et al. [16] and Hochban and Brandenburg [17]. The linear measurements were hand-traced and calculated by the same author.

The intra-class correlation test (ICC) was applied in order to assess the intraexaminer concordance (95% confidence interval) for all variables (airway volume, airway area, minimum axial area and linears measurements). Sixteen CBCT were randomly selected and all measurements were repeated within a 1-week interval. Descriptive statistical analysis (mean and standard deviation) was carried out for all variables. Differences between sexes were tested with the independent *t*-test. Kolmogorov–Smirnov's test confirmed normal sample distribution and independent *t* test was used to compare the airway volume, airway area, minimum axial area and the linear distance between the nasal and mouth breathers group. $p < 0.05$ was considered statistically significant.

All statistical analyses were performed by using SPSS software (18.0 version).

3. Results

The orthodontic diagnostic of the respiratory function and rhinoscopy examination became possible to classify the patients according to the respiratory pattern (25 nasal breathers and 25 mouth breathers). Some authors emphasize that rhinoscopy examination should always be performed because it allows the visualization of the entire nasopharynx, providing reliable data the relationship between content and the continent [18].

Concordance index was greater than 0.98 for all variables analyzed, except for minimum axial area (0.91) and PAS-UP (0.92).

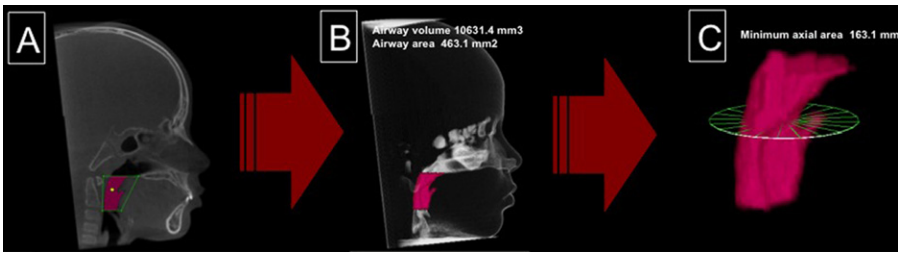

Fig. 2. (A) Pink area denotes defined airway portion of interest; (B) obtainment of airway volume and airway area; (C) obtainment of minimum axial area (*Dolphin Imaging® software, version 11.0*/Orientation function). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Table 1
Linear measurements (mm) of the pharyngeal airway space.

PAS-NL	Pharyngeal airway space on nasal line
PAS-UP	Minimal pharyngeal airway space between the uvula and the posterior pharyngeal wall
PAS-OccL	Pharyngeal airway space on occlusal line
PAS-UT	Minimal pharyngeal airway space between the uvula tip and the posterior pharyngeal wall
PAS-BGo	Pharyngeal airway space on B-Go line
PAS-ML	Pharyngeal airway space on mandibular line
PAS-TP	Minimal pharyngeal airway space between the back of the tongue and the posterior pharyngeal wall

Table 2
Comparison between sexes of the descriptive analysis (mean and standard deviation) of linear measurements, airway volume, airway area and minimum axial area.

Variables	Male ($n=28$)		Female ($n=22$)		p
	Mean	*SD*	Mean	*SD*	
PAS-NL (mm)	11.48	5.70	14.20	5.81	0.172
PAS-UP (mm)	6.39	2.67	6.46	2.18	0.928
PAS-OccL (mm)	8.34	3.59	8.93	2.21	0.547
PAS-UT (mm)	8.43	2.84	10.12	2.33	0.074
PAS-Bgo (mm)	9.53	2.85	11.13	2.84	0.106
PAS-ML (mm)	9.62	2.52	11.46	4.09	0.105
PAS-TP (mm)	8.81	2.95	9.62	3.17	0.447
Airway volume (mm^3)	6898.07	2646.24	6775.02	1399.93	0.855
Airway area (mm^2)	383.48	108.26	405.49	38.04	0.388
Minimum axial area (mm^2)	106.01	51.45	119.44	45.89	0.422

In our study, there was no difference in the airway measurements between sexes. Initially means and standard deviations for all variables were compared by sex, which showed (Table 2) no statistical significant differences ($p > 0.05$) and, therefore, the groups were divided according to the respiratory pattern (nasal and mouth) for subsequent analysis.

Table 3 showed that among the linear measurements, only the PAS-OccL and PAS-UP variables were statistically significant ($p < 0.05$) between nasal and mouth breathers. The others variables, PAS-NL, PAS-UT, PAS-BGo, PAS-ML and PAS-TP, showed no statistically significant differences ($p > 0.05$). The airway volume, airway area and minimum axial area showed statistically significant differences ($p < 0.05$) between the groups. Volumetric size variability was seen in our children sample. This result shows

Table 3
Comparison between nasal and mouth breathers of the descriptive analysis (mean and standard deviation) of linear measurements, airway volume, airway area and minimum axial area.

Variable	Nasal breathers ($n=25$)		Mouth breathers ($n=25$)		p
	Mean	*SD*	Mean	*SD*	
PAS-NL (mm)	14.49	6.20	10.93	5.05	0.067
PAS-UP (mm)	7.90	2.39	5.09	1.62	0.000***
PAS-OccL (mm)	9.84	3.48	7.46	2.18	0.018*
PAS-UT (mm)	10.01	2.58	8.35	2.71	0.075
PAS-Bgo (mm)	10.61	2.76	9.83	3.07	0.431
PAS-ML (mm)	11.25	3.19	9.62	3.37	0.145
PAS-TP (mm)	10.07	3.09	8.35	2.81	0.095
Airway volume (mm^3)	8171.31	1710.28	5594,70	1878.76	0.000***
Airway area (mm^2)	446.35	57.31	341.30	79.1	0.000***
Minimum axial area (mm^2)	137.42	44.91	86.85	39.97	0.001**

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

that the assessment by 3D reconstruction were more sensitive than linear distances to detect differences between the two groups.

Fig. 3 shows the comparison of the airway volume between two subjects, a nasal breather and a mouth breather. In this specific case, the volume shown in the nasal breather was almost twice greater than in the mouth breather.

4. Discussion

It is known that breathing pattern is of great importance in orthodontic diagnosis and treatment planning, as well as in the stability of the treatment results. When breathing function undergoes throw significant changes, it may have negative impact on the stages of facial growth, and also in the occlusion development [1,17,19–21]. Despite there are a lot of studies on the different patterns of breathing and its influence on pharyngeal airway space and development, the majority used only two-dimensional analysis, evaluating the lengths and areas. Kluemper et al. [22] suggested that cephalometric analyses are poor indicators of nasal impairment and should not be used as clinical decision-making.

CBCT is widely accepted diagnostic tool for this purpose. Differently from the radiographic methods which structures are projected onto one-dimensional plane through X-ray, CBCT scan provides cross-sectional images while structural relationships can be investigated through 2D scrolling or 3D volume rendering [23,24]. In our study, the CBCT allowed not only the actual view of

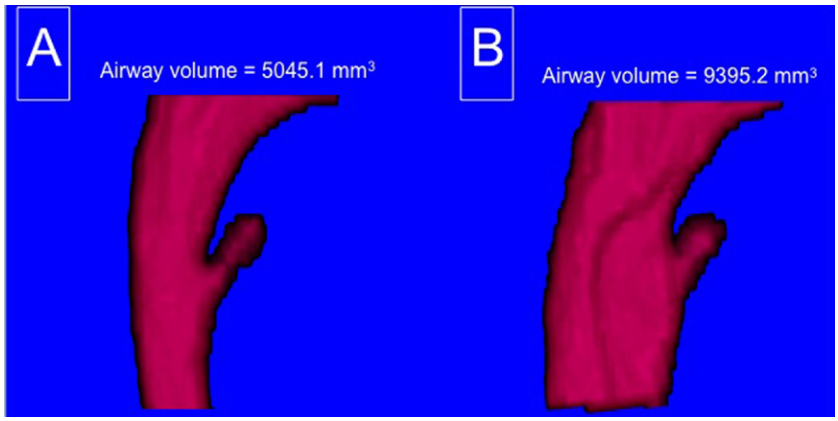

Fig. 3. Digital image reconstructed and measured by means of *Dolphin Imaging software*, demonstrating the differences in volume between a mouth (A) and nasal (B) breather.

the airways, as well as measuring of the airway volume, airway area and minimum axial area.

In Table 2, no statistically significant differences between sexes ($p > 0.05$) were found. Juliano et al. [25] evaluating 27 children and also did not find difference between mouth and nasal breathers regarding sex ratios. Sheng et al. [26] also showed no statistically significant differences ($p > 0.05$) between sexes in four linear measures localized in PAS between the hard palate and the epiglottis tip. They evaluated 239 Taiwanese subjects during mixed dentition stage. In other study, Martin et al. [27] assessed nasopharyngeal soft-tissue patterns in patients with ideal occlusion and showed no statistically significant differences ($p > 0.05$) for measurements similar to PAS-UP and PAS-UT.

Table 3 shows no statistically significant ($p > 0.05$) differences between the two breathing patterns in the linear measurements variables, except for PAS-OccL ($p = 0.018$) and PAS-UP ($p = 0.000$). However, as only two of the seven linear variables were statistically significant, we suspect that these could have been influenced by the adenoids size, which is located in this region. Despite the patients who had adenoid and tonsillitis hypertrophy had been previously excluded, it is known that the absence of lip seal and lower tongue position, often found in the mouth breathers, interfere the airway permeability [28] and could cause lymphatic-tissue increase of the pharynx and consequently change in such measures.

Juliano et al. [23] reported statistically significant differences ($p < 0.05$) between mouth and nasal breathers in the variable SPAS (similar PAS-UP in our study). This study showed that mouth-breathing children had more oxygen desaturation during sleep. Furthermore, the mouth breathers showed reduced linear measurement of the upper airway space with narrowed area at the level of the nasopharynx, hypopharynx, or both. In the other hand, Gouveia et al. [29] evaluating the relationship between patients with different breathing patterns found no statistically significant differences ($p > 0.05$) in two linear measurements made at PAS. In this study were assessed 88 subjects by lateral cephalograms, which 45 were mouth breathers and 43 nasal breathers.

Recently, some authors have used the 3D reconstruction for different purposes, such as to determine accurate relationship between airway patency and mandibular advancement [14], to compare the 3D pharyngeal airway volume in healthy children with different anteroposterior skeletal patterns [15], Class III malocclusion and to assess the differences in the airway shape [12] and in the volume among subjects with various facial patterns [30]. But, there are no studies that evaluate the pharyngeal airway space in differences breathing patterns using CBCT.

Table 3 showed statistically significant differences between airway volume ($p = 0.000$), airway area ($p = 0.000$) and minimum axial area ($p = 0.001$) between the two groups. Only two of the seven linear distances showed significant statistically differences ($p < 0.05$) while all the 3D variables showed significant statistically differences ($p < 0.05$).

Minimum axial area was greater in nasal breathers than mouth breathers ($p = 0.001$). This effective airway resistance can be great enough to affect nasal airway function. Resistance to airflow is not only related to airway size, but also to airway shape [31–33].

All CBCT scans were realized with the patient seated in upright position and Frankfort Horizontal (FH) plane paralleled to the floor, because the airway volume is influenced by the head posture. Muto et al. [9] reported changes in airway dimensions related to the cranio-cervical inclination. The changes in cranio-cervical inclination produced by head extension were correlated with changes in the variables describing the PAS.

Despite the patients had been instructed not to swallow and not to move the head and tongue during CBCT acquisition, some patients did not follow the instructions and, therefore, new tomography were made. The acquisition times for our iCAT scanner was 20 s; sometimes, this was too long to ask the patient not to move the head and tongue during the scan. Newer scanners have reduced the acquisition time to about 5 s, and allows control of this limitation. Futhermore, reduces the loss of quality for patient movement during scanning and minimizes the radiation dose.

The evaluation of pharyngeal airway space in the present study, indicated that the use of CBCT was an important method of diagnosis, especially when it takes into account the detection and correction of the abnormalities in the airway during development can influence the normal dentofacial growth [34].

5. Conclusion

According to our results, there are differences between nasal and mouth breathers in the measurements PAS-OccL, PAS-UP, airway volume, area and minimum axial area, suggesting that pharyngeal airway dimensions are higher in nasal-breathers than mouth-breathers. The authors believe, that once detected airway constriction, multidisciplinary approach involving pediatricians, physicians, dentists, and ear–nose–throat specialists is required. The treatment aim should be the improvement of the children breathing condition and consequently all its associated medical, social, and behavioral problems.

Acknowledgments

The authors acknowledge the financial support given by CAPES and FAPERJ.

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