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Differences in Volume and Area of the Upper Airways in Children with OSA Compared to a Healthy Group

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Study Objectives: The cause of obstructive sleep apnea in children is not fully known. The many risks and predisposing associated factors challenge its diagnosis and treatment. The objective of this research was to verify the differences in the volume and areas of the upper airways between children submitted to adenotonsillectomy for the treatment of OSA, but with persistent/recurrent postoperative OSA complaints, and a sex-age matched healthy control group, assisted by cone beam computed tomographic images.

Methods: The study included a group of 20 children of both sexes, with mean age of 9.5 years, diagnosed with OSA and primary snoring (PS) by polysomnographic exam (AHI ≥ 3), angle class II, and retruded mandible, and a control group of 20 healthy children of both sexes, mean age of 7.4 years, with the same characteristics, but without respiratory complaints. Both groups were submitted to otolaryngological and orthodontic clinical examinations, and to cone beam computed tomography exam (CBCT). Areas and volumes of the nasopharynx and oropharynx and lower axial area were measured. Mean, standard deviation, confidence interval, and Student t-test with a 5% significance between these groups were analyzed.

Results: The results showed a significant difference ($p < 0.05$) in the volume and area of the nasopharynx of patients with OSAS compared to the same parameters in healthy patients. Children with OSA (SG) showed a significant narrowing in the nasopharynx and in the lower area of the upper airway (UA) compared to the control group (CG).

Conclusions: Children with persistent OSA symptoms after adenotonsillectomy present with narrowing of the nasopharynx, and CBCT is a useful complementary test for orthodontic diagnostic and treatment planning of these patients.

Keywords: apnea and hypopnea syndrome, habitual snoring, nasopharynx and oropharynx size, CBCT

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INTRODUCTION

Obstructive sleep apnea (OSA) is a respiratory sleep disorder (RSD) characterized by partial or complete upper airway (UA) obstruction that can affect children in their very early phase of development.[1–6] Children between 2 and 6 years old are the most affected group for the occurrence of upper airway lymphoid tissue hypertrophy, usually presenting with the most severe aspects of OSA. Diagnostic delays of this condition may generate a negative influence on their adult life quality.[3–8] The polysomnographic (PSG) evaluation is considered the gold standard method for the diagnosis of OSA,[1–6,14–16] and surgical removal of lymphoid tissue has been the standard treatment in these cases.[9–13]

Recurrence of OSA can occur after adenotonsillectomy, and (among other causes) is believed to happen due to concomitant craniofacial disorders. Any condition that causes obstruction of the upper airway (UA) or reduces the pharyngeal muscles tonus can provide risk for OSA development.[3,5–7] Some of these conditions may be recognized and treated by the orthodontist.

Orthodontic planning and diagnosis include panoramic radiograph, lateral X-ray, and a X-ray series of the entire mouth, but these 2D tests fail to accurately assess the UA. Recent studies recommend 3D images as diagnostic tools to help identify obstructions in the UA, such as magnetic resonance imaging (MRI) and cone-beam computed tomography (CBCT).[16,17]

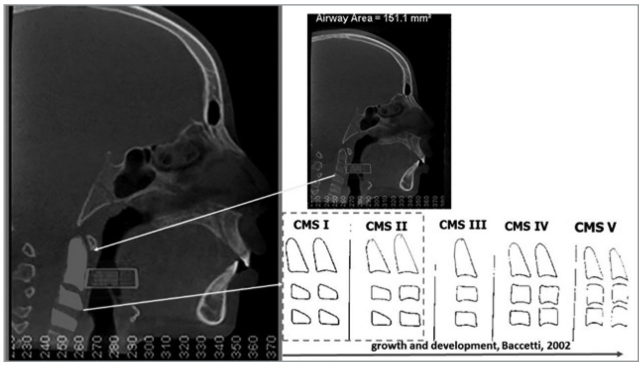
MRI is typically used for evaluating soft tissues, and there is a lack of standardized parameters for hard tissue evaluation.[16] CBCT exposes the child to less ionizing radiation when compared to multiple detector-row spiral CT, but even so, radiation will still be higher than a 2D exam. The individual dose emitted by a single 2D test is low, but the collective dose of all exams that is usually recommended, is equal to or slightly higher than the dose emitted by a single 3D examination.[18–24,26] Furthermore, the 3D image is more reliable than 2D to assess all the head and neck structures as well as the upper airways, and it can be useful to and serve a large multi-professional group.[27–31]

The objective of this research was to verify the differences in the volume and areas of the UA among children with OSA who have had adenotonsillectomy but continue to have persistent OSA, and a control group of healthy children, in order to plan the best orthodontic treatment.

Table 1—PSG parameters.

Abbreviation	Term	Unit
A	Arousals	n
AI	Awakenings index	n/h
PMIM	Periodic movement of the lower limbs	n/h
PMA	PMIM associated with awakenings	n/h
ER	Respiratory events	n
AO	Obstructive apnea	n
H	Hypopnea	n
MA	Mixed apnea	n
AHI	Apnea and hipoapnea index	n/h
CA	Central apnea	n
RERA	Respiratory events related to apnea	n
OSAI	Obstructive sleep apnea index	n/h
RDI	Respiratory disorder Index	n/h
SpO_2	Oxyhemoglobin saturation	%
Mean O_2	SpO_2 average	%
NADIR	Minimum SpO_2	%
DRI	Desaturation index REM	n/h
DnRI	Desaturation index NREM	n/h
RDI	Respiratory disturbance index	n/h
ISL	Initial sleep latency	min
LRS	Latency to REM sleep	min
TST	Total sleep time	min
SE	Sleep efficiency	%
N1	NREM stage 1	%
N2	NREM stage 2	%
N3	NREM stage 3	%
RYM	Rapid eye movement	%
TAAS	Time awake after sleep	min
$SO_2 < 90\%$	SO_2 less than 90%	n/h

Figure 1—Bone maturation rating.



METHODS

This observational case-control study was approved by the Ethics Committee of the Federal University Sao Paulo – UNIFESP under the number: 1739/11 02/12/2011, by the Ethics Committee of FOUSP-Dentistry College State University of Sao Paulo under the number 170/2010. Financed by the Research Foundation-FAPESP under the Protocol 2012/15715-2 November 2, 2012.

To accomplish this case-control study, a multidisciplinary team was enrolled. ENT examination was performed by an experienced otolaryngologist. Children suspected to have PS and OSA underwent a polysomnographic test to confirm the diagnosis, and the report was certified by a professional expert in sleep medicine. Orthodontic evaluations were carried out by 3 orthodontists in 2 different clinics. All selected patients underwent orthodontic planning examination with CBCT, and these images were evaluated by 2 imaging studies experts.

A total of 397 patients, ages ranging between 7–14 years, presenting with PS and OSA complaints were evaluated at the Oral breathing clinic at the Otorhinolaryngology Pediatric Division, Federal University of Sao Paulo (UNIFESP) from 2013 to 2014. All the patients had undergone adenotonsillectomy or had been excluded of having hypertrophic tonsils; but they all had OSA symptoms. After otorhinolaryngological and nasofibroscopic examinations, patients suspected of having OSA were referred for PSG. Patients with syndromes or obesity were excluded.

PSG was performed at the Sleep Apnea Institute-UNIFESP/SP. Patients stayed overnight and were evaluated with an electroencephalogram (EEG), electrooculogram (EOG), electromyogram (EMG) mental and/or submental muscle, electrocardiogram (ECG), airflow (nasal and oral), respiratory effort (thoracic and abdominal), other body movements (tibial EMG), oxygen saturation, and carbon dioxide concentration (precision oximeter). The parameters evaluated in PSG are described in **Table 1**

Twenty patients were selected for the study group (SG)—13 girls and 7 boys, with an average age of 9.5 years. The average apnea-hypopnea index of the patients included was 3.1, Angle Class II, short and retruded mandible and CMS I or II (**Figure 1**).[14] Sexual dimorphism analysis in the PSG data was performed by Student t test, with 95% reliability.

The control group (CG) consisted of 12 girls and 8 boys, mean age of 7.4 years old, CVMS I or II,[14] without respiratory complaints, Class II malocclusion, and retruded mandible, who sought orthodontic treatment at the Dentistry College, State University of Sao Paulo-FOUSP, SP for other reasons. Children of both study and control groups were referred to orthodontic planning studies (cephalometric and study models) and CBCT examinations. The selected patients and legal guardians signed the consent form.

For the CBCT, the participants were placed in the tomography room in a sitting position with their head parallel to the Frankfurt plane (FP), and the CBCT sensor was positioned

Figure 2—Orientation of cranial positioning.

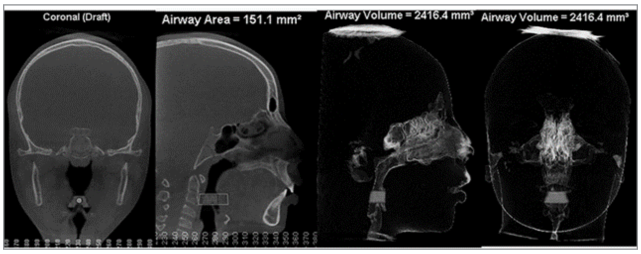


Figure 3—Orientation of the cranial positioning by Frankfurt plane and cephalometrics points (N, ANS, N. Or).

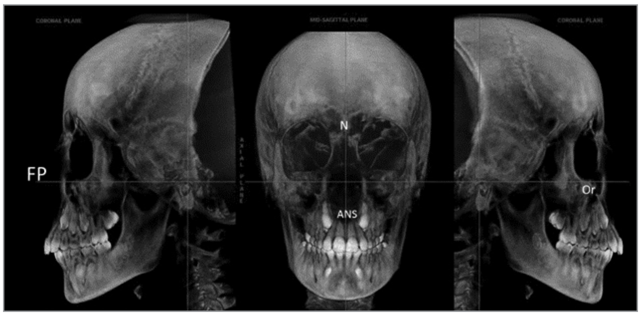


Figure 4—Demarcation of the area in the nasopharynx through the cephalometric points, to get the volume.

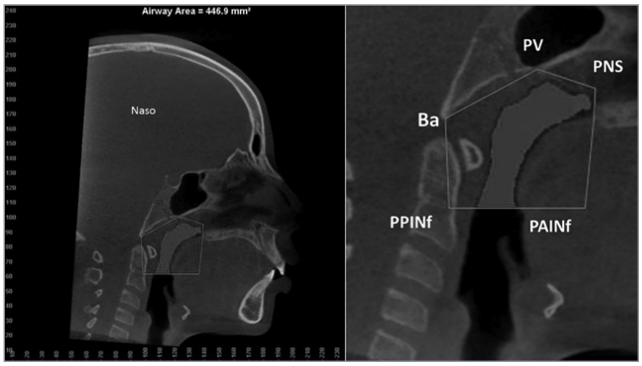
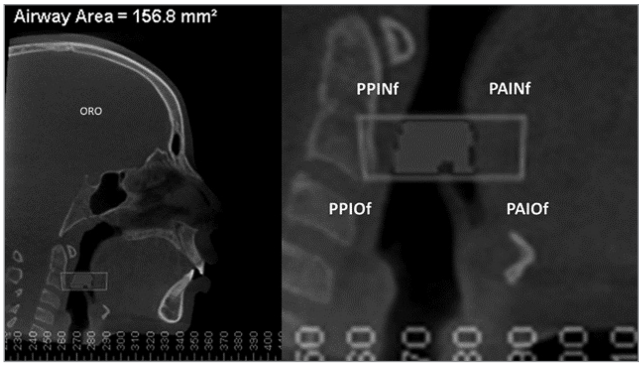


Figure 5—Demarcation of the area in the oropharynx through the cephalometric points, to get the volume.



in order to cover the entire head. Patients were instructed to remain still, with relaxed lips, avoiding swallowing, and keeping a smooth breathing pattern during image acquisition.[31]

The equipment used for CBCT was the i-Cat (Cone beam 3-D Dental Imaging System, Imaging Sciences International, Hatfield, PA). After capturing the X-rays, the tomography sensors attenuated and digitalized the images through algorithm reconstruction, converting the data in medicine digital image for communication (DICOM).[30] After an accurate reconstructed digital image was obtained, participants were released.

The reconstruction of the primary image was performed at the workstation. The Dolphin 3D software (Imaging Dolphin/ Patterson Dental, Chatsworth, CA, USA) was used for the proposed measurements. Before measuring the volume, area and lower area of the upper axial way, the pictures were standardized according to the orientation of the cranial positioning (**Figure 2**).[26]

For the orientation of the cranial positioning, the axial plane coincides with the orbital points (Or); in the lateral, the coronal plane coincides with the porion (Po) on the left and right sides, and an axial plane is superimposed on the FP; the median sagittal plane joins the nasion (N) and the anterior nasal spine (ANS) (**Figure 3**).[27,31]

For evaluating the nasopharynx (NP) area and volume, the points were placed at the posterior nasal spine (PNS), posterior vomer (PV), point of horizontal and vertical extent of PV, point of PNS extension, basion (Ba), PPINf (located 15 mm after the lower limit of the uvula), and PAINf (marked 15 mm above the lower limit to the uvula) (**Figure 4**).[31]

For the evaluation of the oropharynx (OP), the upper limit of the epiglottis was seen in the coronal plane, cut at its greatest length, and its highest portion was landmarked. In the image in sagittal view, this area was limited by the union of PPINf' and PAINf', and the points were created in PAIOf' and PPIOf located 15 mm front and rear, respectively, of the uvula point. Sensitivity was determined using the same criteria that was used for the NP (**Figures 5, 6**).[31] In **Figure 7**, regions of oropharynx are highlighted by software tools.

Data from all measurements, the areas of the nasopharynx and oropharynx, the volumes of the oropharynx and nasopharynx, and lower axial area of the SG and CG, were measured with CBCT tools, and registered in a 2007 Excel table. The means, standard deviations, confidence intervals, and Student t-test with a 95% confidence level were calculated for all the obtained values.

RESULTS

No significant differences of the major values obtained in the PSG examination were observed between genders. A significant difference ($p = 0.04$) was only found for the hypopnea parameter (H): girls had a higher number of events than boys. The remaining parameters did not show significant differences between genders (**Table 2**).

Figure 6—Measurements of the lower axial area of the SG and CG.

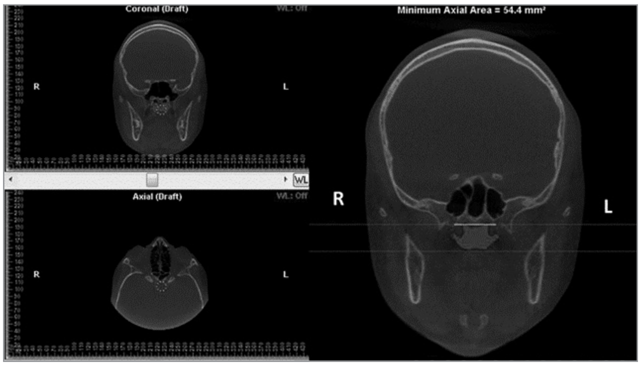


Figure 7—Nasopharynx and oropharynx volumes.

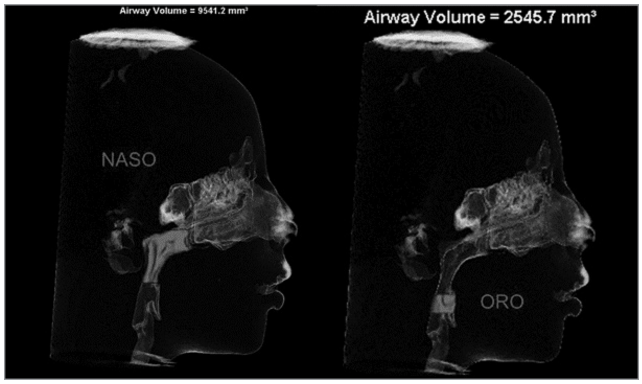


Table 2—Difference between genders (SG).

Gender	n		Age	Weight (KG)	Height (m)	Start	End
M	12	mean	9.56	33.33	1.35	21:48:33	(06:06:13)
F	15	mean	9.50	32.71	1.35	20:58:04	(06:14:56)
Total	27	test t	0.95	0.88	0.60		

Gender	n		ISL	LSS	TST	SE (%)	N1 (%)	N2(%)
M	12	mean	13.14	146.89	453.79	90.01	5.99	47.13
F	15	mean	18.18	161.11	397.76	87.38	7.22	44.83
Total	27	test t	0.43	0.63	0.12	0.88	0.83	0.92

Gender	n		N3(%)	RYM (%)	TAAS	A	AI	PMIM
M	12	mean	29.14	17.76	27.96	47.00	6.63	6.51
F	15	mean	30.20	17.69	38.81	44.07	6.89	4.15
Total	27	test t	0.86	0.89	0.72	0.58	0.79	0.68

Gender	n		PMA	RE	AO	H	MA	AHI
M	12	mean	0.08	21.11	2.34	3.94	0.00	3.10
F	15	mean	0.19	19.79	3.31	7.53	0.43	3.09
Total	27	test t	0.24	0.83	0.57	0.04*	0.25	0.98

Gender	n		RERA	SAI	AO	CA	RDI	SO_2
M	12	mean	0.67	4.23	2.77	7.11	3.10	96.34
F	15	mean	0.07	1.47	2.33	4.43	3.29	84.06
Total	27	test t	0.28	0.41	0.76	0.35	0.87	0.32

Gender	n		Mean SO_2	Nadir	DRI	DnRI	SO_2 < 90%
M	12	mean	95.78	87.44	3.20	1.87	0.08
F	15	mean	96.56	91.84	10.06	1.44	0.17
Total	27	test t	0.55	0.08	0.43	0.76	0.53

*$p < 0.05$.

Regarding the CBCT measurements, the NP volume (4,949.85 mm^3) and NP area (284.79 mm^2) were significantly lower in the SG than in the CG ($p = 0.001$ and $p = 0.002$) (8,100.93 mm^3 and 417.87 mm^2), respectively. The OP volume and area of the SG (1,645.43 mm^3 and 112.88 mm^2) and CG (1,410.81 mm^3 and 100.18 mm^2) did not show significant

Table 3—Mean, standard deviation, confidence interval, and student test-t between control group and study group.

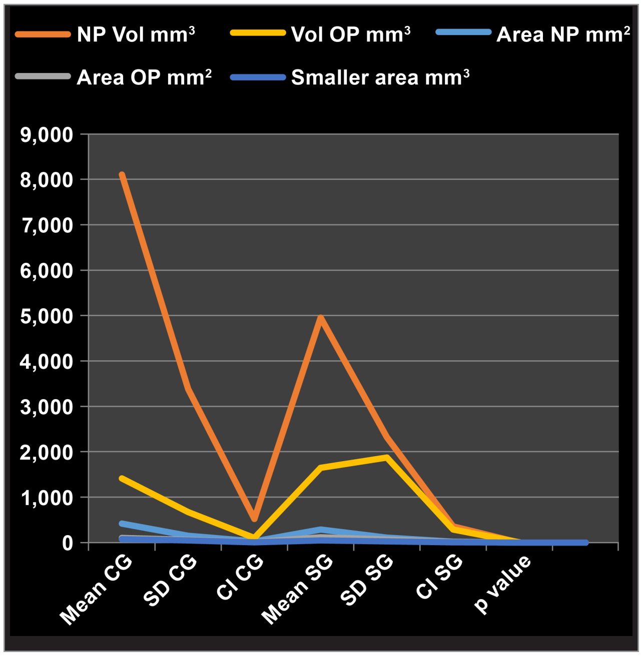
Mean	Age	AHI	NP Area mm²	NP Vol mm³	OP Area mm²	OP Vol mm³	Axial Area mm²
CG	7.4	0	417.87	8,100.93	100.18	1,410.81	74.48
SG	9.5	3	284.79	4,949.85	112.88	1,645.43	44.03
p value			0.002	0.001	0.5	0.6	0.01

differences. Clinical measures of OP were slightly higher in the SG (**Table 2**).

The CTCB cross-sectional areas of the nasopharynx, oropharynx, and hypopharynx in apneic patients were significantly reduced ($p < 0.05$) compared with those in the CG. The lower axial area of the NP was significantly lower ($p = 0.01$) in SG (74.48 mm²) than CG (44.03 mm²). The mean, standard deviation, confidence interval, and Student t-test with a 95% significance between these groups can be seem in **Table 3**.

There was a significant difference between the volume and area of the NP of patients with OSA in comparison to the same parameters of healthy patients, but for OP no significant differences were found. The results can be observed in **Figure 8**.

Figure 8—Differences of means between CG and SG.



DISCUSSION

Sleep apnea is a relatively well understood disorder in adults, but in children it remains controversial, particularly due to the multifactorial nature of the disease in addition to the differences in response to each child growth phase. Our results may have implications to children from 7 to 14 years of age, who had already received some treatment for OSA such as tonsillectomy in early childhood but still present with OSA complaints, as demonstrated by other authors in previous studies.[3–14] Our goal was to understand which sites the upper airways could be involved with the persistence of the disease, in order to develop an effective orthodontic treatment.

The results of our study showed that the upper airway was significantly smaller in SG when compared to healthy subjects mainly at the nasopharynx.[13,14] Regarding the oropharynx, we observed that healthy patients (CG) had a smaller area and volume than the OSA patients; the differences however, were not statistically significant. The axial lower area of the OSA patients was significantly lower than the CG, as already observed by many others.[18–25]

Reports in the literature showed that severe OSA is associated with younger ages (pre-adolescence) due to the increased lymphoid tissues, causing a narrowed pharynx.[1–6,16] In the present study, the OSA patients were slightly older (average age of 9.5 years old), having already undergone a surgical treatment when younger, and mostly had no tonsils at all; even so, they presented with reduced NP volume. This observation demonstrated that other factors, such as craniofacial abnormalities, could play a role in the installation of OSA, in agreement with other studies.[7–12] The CG patients did not have respiratory complaints and had no hypertrophic tonsils, despite their young age.

In addition, chronological age may not represent the real growth phase that can be best evaluated by bone age measurements.[14] In our study, both groups were at the same stage of pubertal maturation (CVM I and II), and in the same age group (5–12 years old).[27] Maybe OSA studies in children assessing also the real phase of growth and children development, determined by bone ossification age, could minimize the chance of erroneous conclusions.

In this study, no differences in AHI were found between males and females of the study group, and the patients were not divided by gender (**Table 1**).

In general, male patients have shown to have an increased risk for OSA; the mechanisms underlying this predisposition are unclear.[13] At least one previous study demonstrated a difference, and proposed that to be due to the usual more enlarged UA sizes in adult males than in females, this anatomical feature could let the male UA more likely to collapse.[13]

Recent studies of CBCT, have demonstrated that patients with retruded mandible and class II tend to have the OP volume reduced when compared to patients Class I and III malocclusion, with advanced or standard mandible. According to the authors, the mandibular position may have influence on the volume of the OP. Regarding the NP, significant differences have been shown only in patients presenting with Class I and Class II malocclusion; the volume is usually lower in Class II patients.[17,22,25] We included Class II patients with retruded mandible in both CG and the SG groups, and our results showed a greater and significantly reduced area and volume of the NP in patients with OSA and PS. The nasopharynx is not a region of the airway particularly related to mandible retrusion, but it could be associated with class II malocclusion, oral breathing, or allergic diseases.[8,19,27] The SG patients were all oral breathers, which may have caused the narrowing of NP, even after they had been submitted to a surgical ENT treatment. This agrees with some authors who have shown the influence of the breathing mode on the anatomy of the upper airways.[8,19,27]

The causes of the OSA disorder has not been totally established, particularly in the pediatric population, in which the growth and developmental events, and external factors, such as allergic diseases and habits, can influence the development of the sleep disorders, confusing the correct diagnosis. Due to such a complexity of OSA in children, the treatment should be planned in conjunction with various professionals simultaneously.[3–14] The PSG diagnosis may not be enough for understanding the cause of disease, in order to achieve the best treatment. We should have tools to evaluate the anatomical obstructive site of the patient to plan for the possible treatment.[1–7,15,16]

The MRI[17] and CBCT exams[18–24] have shown to be of good assistance for the OSA understanding. Recent studies recommend considering the cone-beam computed tomographic (CBCT) to identify obstructions in the airways,[18] due to the many advantages, including that as the 3D image is more reliable than 2D.[18–22] CBCT exams[3,15,16] are safely used for diagnosis in orthodontics because they can replace all routinely requested tests in the diagnosis and orthodontic planning, with the same or even lower ionizing radiation than tests routinely ordered.[17,23,24]

Our goal was to understand and build parameters that could help the diagnosis and treatment of the recurrent PS and OSAS. Our sample was just large enough for statistical analysis, but not enough for definitive conclusions. The multifactorial aspects of the disorder and aspects related to childhood growth are a great obstacle in standardizing population samples. The observation of the sites where there is a decrease of size in the upper airways gives us an opportunity to offer the most appropriate orthodontic treatment. Studies involving patients with all patterns of malocclusion such as class I and III angle malocclusion should also be conducted for a comparison with our results.

CONCLUSIONS

Children diagnosed with primary snoring and persistent obstructive sleep apnea after tonsillectomy showed a significant and important narrowing of the upper airway, especially at the nasopharynx region. The sagittal lower area of the upper airway also showed significant reduction. CBCT proved to be a complementary test for diagnostic and treatment planning purposes, and it is available to health professionals of many areas, avoiding the need for potentially harmful orthodontic exams.

ABBREVIATIONS

AHI, apnea-hypopnea index
ANS, anterior nasion spine
AT, adenotonsillectomy
Ba, basion
CBCT, cone bean tomography
CG, control group
DICOM, digital image for communication
FAPESP, Research Foundation of Sao Paolo State
FOUSP, Dentistry College, State University of Sao Paolo
FP, Frankfurt plane
i-Cat, cone beam 3-D dental imaging system
N, nasion
NP, nasopharynx
OP, oropharynx
OSA, obstructive sleep apnea
PAINF, pharynx anterior inferior (15 mm after the lower limit of the uvula)
PAIOF, pharynx anterior (15 mm front of the uvula point)
PNS, posterior nasion spine
PPINF, pharynx posterior inferior (15 mm after the lower limit of the uvula)
PPIOF, pharynx posterior (15 mm rear of the uvula point)
Po, porion
PS, primary snoring
PSG, polysomnography
PV, posterior vomer
RSD, respiratory sleep disorder
SG, study group
UA, upper airway
UARS, upper airway syndrome
UNIFESP, Federal University Sao Paulo

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