AJO-DO

Three-dimensional airway changes after adenotonsillectomy in children with obstructive apnea: Do expectations meet reality?

André Pinheiro de Magalhães Bertoz,[a] Bernardo Q. Souki,[b] Roberta Lione,[c,d] Silke Anna Theresa Webber,[e] Renato Bigliazzi,[a] Paula Moreira Oliveira,[b] Alexandre Moro,[f] and Paola Cozza[c,d]
Araçatuba, Belo Horizonte, Botucatu, and Curitiba, Brazil, Rome, Italy, and Tirana, Albania

Introduction: The assessment of the volumetric changes of the airways after adenotonsillectomy has gained popularity among orthodontists, but the validity of such evaluation is not clear. **Methods:** Thirty patients with obstructive sleep apnea diagnosed with the use of polysomnography (PSG) were evaluated according to the Apnea and Hypopnea Index (AHI), the obstructive apnea index (OAI), the oxygen desaturation index (ODI), the lowest oxygen saturation ($LSpO_2$), and the average oxygen saturation ($ASpO_2$). The volume and the minimal cross-section of lower (oropharynx and velopharynx) and upper (nasopharynx) spaces of the airways were calculated. Patients were adenotonsillectomized; posttreatment data were collected after 12 months. Thirty comparison patients also had the volume of airways evaluated. **Results:** A statistically significant improvement ($P < 0.05$) of most PSG parameters was observed after adenotonsillectomy: AHI from 14.5 to 5.2, OAI from 9.4 to 5.5, ODI from 14.6 to 6.5, and $LSpO_2$ from 77% to 94%). A significant increase in airway volume of the lower space (from 2571.5 mm^3 to 5276.3 mm^3) and the upper space (from 726 mm^3 to 1056.9 mm^3), as well as in the minimal cross-section of the airways (from 98.5 mm^2 to 335.8 mm^2) was found in adenotonsillectomy patients. No significant volumetric changes of the airways were observed in the comparison patients. No significant correlation was found between PSG parameters and the dimensions of the airways before adenotonsillectomy. No significant correlation was found between changes of the PSG parameters and changes of the dimensions of the airways 12 months after the adenotonsillectomy. **Conclusions:** Adenotonsillectomy contributed to the increase of the airway volume and minimal cross-section, and to the improvement of the PSG parameters, but there was no correlation between the magnitude of the anatomic changes and the improvement of the breathing mode. (Am J Orthod Dentofacial Orthop 2019;155:791-800)

Obstructive sleep apnea (OSA) is a disorder condition that affects 1%-4% of children.[1,2] In growing individuals, OSA might be associated with cor pulmonale,[3] growth failure,[4] behavioral problems,[5,6] neurocognitive deficit,[6] secondary enuresis,[7] mouth breathing,[8] and poor quality of life.[9] Owing to the association between pediatric mouth breathing and dentofacial abnormalities,[10,11] OSA has awakened interest among orthodontists.[12,13] Although it seems reasonable to think that a more severely obstructed child would present a more severe apnea condition, and that the greater the volumetric improvement of the airway after adenotonsillectomy, the greater would be the improvement of the polysomnographic (PSG) parameters, that assumption has not been validated.

In growing individuals, OSA is primarily caused by naso- and/or oropharynx obstruction due to hypertrophic adenoids and tonsils,[14] which are most prominent

[a]Department of Pediatric and Social Dentistry, School of Dentistry, São Paulo State University, Araçatuba, Brazil.
[b]Graduate Program in Orthodontics, Pontifical Catholic University of Minas Gerais, Belo Horizonte, Minas Gerais, Brazil.
[c]Department of Clinical Sciences and Translational Medicine, University of Rome "Tor Vergata," Rome, Italy.
[d]Department of Dentistry, Universita Nostra Signora del Buon Consiglio, Tirana, Albania.
[e]Department of Ophtalmology, Otolaryngology, and Head and Neck Surgery, Botucatu Medical School, São Paulo State University, Botucatu, Brazil.
[f]Graduate Program in Clinical Dentistry, Positivo University; Associate Professor, Department of Anatomy and Orthodontics, Federal University of Parana, Curitiba, Parana, Brazil.
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Address correspondence to: Bernardo Q. Souki, Pontifical Catholic University of Minas Gerais, Av Dom Jose Gaspar 500, Predio 46, Sala 101, Belo Horizonte, Brazil, CEP 30535-901; e-mail, souki.bhe@terra.com.br.
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during childhood, when the size of the pharyngeal space is not yet fully developed.[15] The involution of the lymphoid tissue begins around puberty, and in old age there is very little lymphoid tissue remaining.[15] But despite the physiologic regression of the size of the lymphatic tissues along the aging process, in cases of recurrent throat infections and OSA, the American Academy of Otolaryngology–Head and Neck Surgery clinical practice guideline[16] recommends adenotonsillectomy. Thus, adenotonsillectomy is considered to be a common procedure during childhood[17,18] and represents one of the most frequent indications for surgery in children,[19] with more than a half-million procedures performed annually.[20]

In nonobese children, high clinical therapeutic effectiveness for OSA has been reported after adenotonsillectomy,[21] and there is evidence of improvements of oximetry as well. Because the treatment of OSA in children is mainly focused on the surgical removal of the tonsils and adenoids, the visualization of the airways before and after adenotonsillectomy is an intuitive method to quantify the morphologic changes provided by adenotonsillectomy and thus to infer that corresponding improvements of the breathing parameters are likely to happen. Recently,[22] it was shown that the gain of volume and of the area of the smallest cross-section of the airways after the use of removable mandibular advancement devices in adults, despite providing clinical improvement for the sleeping disorder, did not correlate well with the Apnea and Hypopnea Index (AHI).

The clearance of the pharynx after adenotonsillectomy of growing patients has been documented in the past with the use of lateral cephalometric radiographs,[23,24] and in the recent years several cone-beam computed tomography (CBCT) reports have illustrated the changes in the volume of the airways and in the minimal constricted area.[25-27] Thus, much commercial interest has been raised in dentistry about the volumetric assessment of the airways. Nevertheless, the validation of the correlation between the 3-dimensional (3D) morphologic changes of the airways with PSG parameters has not been reported yet. Despite the fact that the use of 3D imaging warrants a new horizon of diagnostic possibilities, the need for valid diagnosis of the airways is a must. What we see and measure should represent the truth. Some questions still do not have objective answers: Do children with a greater gain of the volume of the airways after adenotonsillectomy respond better in terms of the OSA condition? Do the various degrees of enlargement of the constricted minimal cross-section passage for the airflow provide a better recovery of OSA signs and symptoms? Is it possible to correlate the adenotonsillectomy-derived morphologic changes of the pharynx with the improvement of OSA?

Therefore, the purpose of the present retrospective study was to correlate the volumetric change of the airways and of the minimal cross-section airflow after adenotonsillectomy with 5 objective PSG parameters: the AHI, the obstructive apnea index (OAI), the oxygen desaturation index (ODI), the lowest oxygen saturation ($LSpO_2$), and the average oxygen saturation ($ASpO_2$).

MATERIAL AND METHODS

Based on the volumetric data of the pharynxes of a population of 8-year-olds provided by Chiang et al,[28] with the power set at 0.8, the effect size at 0.5, and the significance level at 0.05, the required sample size was calculated to be 30 patients.

Therefore, the data of 30 children (15 boys, 15 girls) with a mean age of 8.9 years (ranging from 7.3 to 11 years) treated at the Department of Orthodontics of the São Paulo State University (Araçatuba, Brazil), and who presented with a previous diagnosis of OSA (AHI greater than 5 in the PSG exam before adenotonsillectomy), were collected for the current investigation, and composed the OSA group (OSAG). Ethical approval was given by the Institutional Review Board of the São Paulo State University (89821218.1.0000.5420). Following the clinical guidelines of the university's protocol, the parents of all of the patients signed informed consents at the beginning of the children's dental treatment authorizing the use of the examinations for research purposes.

Records from a group of orthodontic growing patients (23 boys and 7 girls) who had received conventional dental treatments (traction of impacted teeth, marsupialization of cysts, teeth alignment and leveling) were retrieved to compose a comparison group (CG). The mean age before treatment was 10.8 years (ranging from 8 to 15 years). Patients were treated both at the Department of Orthodontics of the Positivo University (Curitiba, Brazil), and at Department of Orthodontics of the Pontifical Catholic University of Minas Gerais (Belo Horizonte, Brazil). A second time-point orthodontic record was available 12-18 months later (T1) for all CG patients.

The inclusion criteria included: (1) clinical symptoms of breathing disorder, such as snoring, respiratory pauses, restless sleep, and mouth breathing; (2) diagnosis of OSA with the aid of PSG examination; (3) AHI >5 before treatment; (4) palatine tonsil hypertrophy classified by means of mouth examination according to the grading criteria of Brodsky[29]; (5) adenoid hypertrophy assessed by means of flexible nasoendoscopy or lateral cephalometric radiographic reconstruction from

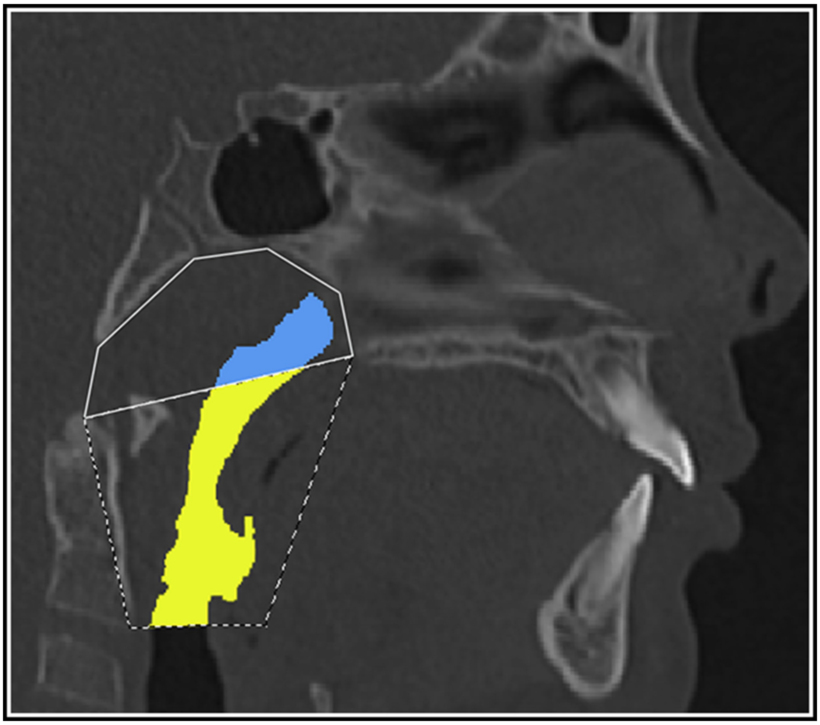

Fig 1. Reconstructed sagittal view of CBCT scan: dashed line limits the anatomic boundaries of the lower space (oropahrynx and velopharynx; *yellow*) and the continuos line limits the anatomic boundaries of the upper space (nasopharynx; *blue*) for the computer identification of the airways based on the preset threshold values.

CBCT scan with a cutoff point of 75%; (6) adenotonsillectomy performed aiming the improvement of the airflow; and (7) CBCTs available before treatment (T0) and 12 months after adenotonsillectomy (T1). Exclusion criteria included (1) craniofacial anomalies, (2) previous orthodontic treatments, and (3) systemic diseases.

A certified radiologist from the São Paulo State University Radiology Department acquired all of the OSAG CBCT scans with the use of a Scanora 3D device (Soredex, Tuusula, Finland) under an extended field of view mode (14.5 cm × 13.0 cm). The overall effective radiation dose was 125 mSv, with a 0.35-mm isotropic voxel size, a total scanning time of 20 seconds, and an effective radiation time of 4.5 seconds. CG individuals had their scans acquired by certified radiologists with the use of an iCat machine (Imaging Sciences International, Hatfield, Pa), with a 40-second scan, a 23 × 17-cm field of view, and a voxel size of 0.3 mm. Patients sat upright with a natural head position. Mandible position was stabilized with the use of a chin holder, keeping the Frankfort plane horizontal to the ground. The teeth were occluded in centric occlusion, with facial muscles relaxed. The patients were asked to breathe normally and to not swallow. The CBCT images were saved as DICOM files and then transferred to Dolphin 3D Imaging software (version 11.0; Dolphin Imaging and Management Solutions, Chatsworth, Calif). The patient's head was oriented with the palatal plane parallel to the horizontal plane in the sagittal view and centered on the coronal and axial axes. This established a reference plane so that all scans could be standardized to this position before measuring the airway. Then the best parasagittal view of the airway that allowed clear visualization of the posterior nasal spine and of the second cervical vertebra was identified. The patient's airway was identified by viewing sequential slices of the volume and placing seed points in the voids on the image that are part of the patient's airway. Based on the seed points, the software automatically selected the adjacent empty areas and identified the patient's airway. The airway was divided into 2 spaces: the lower space, corresponding to the oropharynx and velopharynx, and the upper space, corresponding to the nasopharynx (Fig 1). The most inferior boundary of the lower space of the airway was determined to be the plane drawn through the most anterior-inferior point of the second cervical vertebra and parallel to the Frankfort plane. The most superior boundary of the lower space of the airway, and the

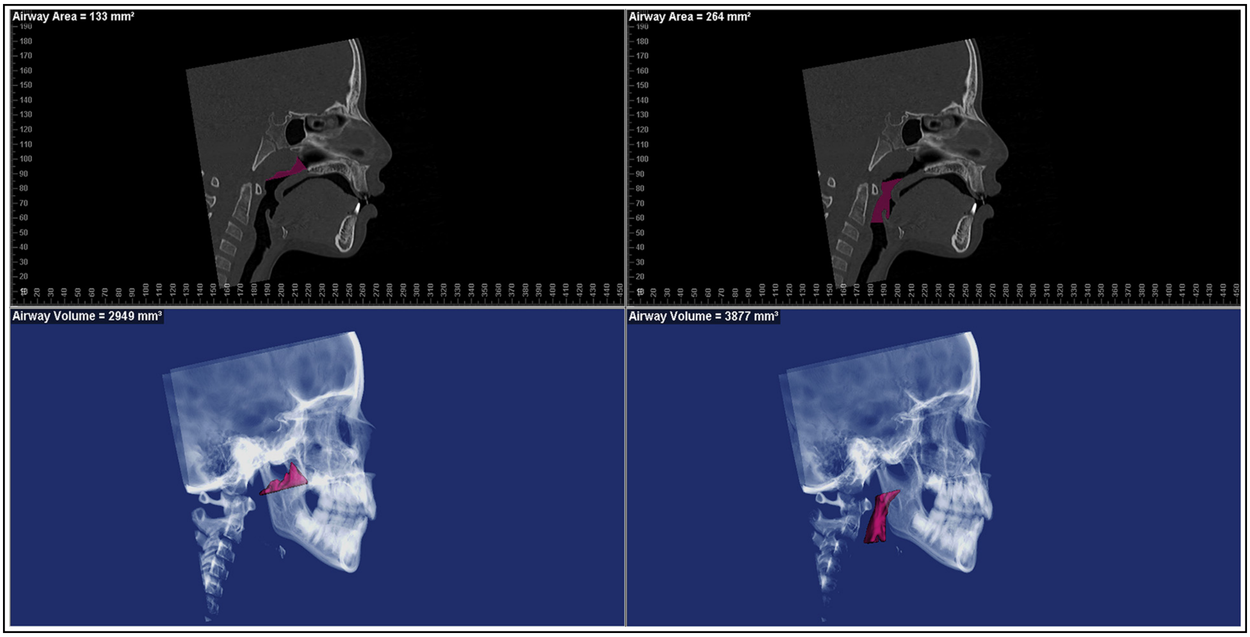

Fig 2. Measurement of the volume and minimal cross-section of the upper and lower spaces of the airways with the use of Dolphin Imaging software.

most inferior boundary of the upper space, was determined to be a plane connecting the posterior nasal spine and the most superior point of the anterior arch of Atlas. The posterior-superior-anterior boundaries of the upper space of the airway was defined by lines connecting the Atlas, basion, spheno-occipital synchondrosis, superior and anterior edges of the Vomer bone, and posterior nasal spine, as illustrated in Figure 1.

To ensure that the anteroposterior and lateral borders of the airway were identified and measured, axial and coronal views were opened and the field-of-interest airway was always fully highlighted. The threshold ranges were arbitrarily standardized to 60 units after observing consecutively that this provided the most comprehensive airway selection for OSAG and to 33 for CG patients. Once the portion of the field of interest was selected, the software automatically calculated the pharyngeal volume in cubic millimeters and the cross-sectional area in square millimeters (Figure 2). In the cross-sectional sagittal view it is possible to visualize the airway shape and the smallest area of the airway (Figure 3). Figure 2 illustrates the volumetric assessment of the upper and lower airway spaces.

Trained and calibrated investigators (A.P.M.B. and P.M.O.) identified the 3D landmarks on the axial, sagittal, and coronal planes. To improve accuracy and to test agreement, all measurements were repeated at least 1 week later. A third reader assessed the data of 20 randomly selected patients for the test of interrater agreement.

The criteria used for the scoring of the PSG were those of the American Academy of Sleep Medicine.[30] The patients underwent sleep assessment with the use of a level 3 portable monitoring device (Philips Stardust II) at nighttime, without technical supervision at home. Data of the sensors were considered to be valid when there was at least 4 hours of sleeping recording for the report. The device has 7 sensor channels and consists of 2 inductance bands for thoracic and abdomen measurement, a nasal cannula pressure transducer airflow signal, finger pulse oximetry, and a body position sensor. The airflow sensor measures the breath rate. The oximeter measures the pulse rate and oxygen saturation. The effort sensors measure the chest and abdominal effort. The patient's event monitor controls the lighting of the room and visits to the bathroom, and the position monitor controls the supine and nonsupine sleep positioning. The scoring was based on the following criteria. Apnea events were required to show an airflow cessation of $\geq$10 seconds (central, obstructive, or mixed). Hypopnea was defined as a decrease ($>$50%) from baseline in the amplitude of the nasal cannula during sleep or a clear amplitude reduction of the nasal cannula during sleep ($<$50%) but associated with an oxygen desaturation of $>$3%. The hypopnea event lasts $\geq$10 seconds. For

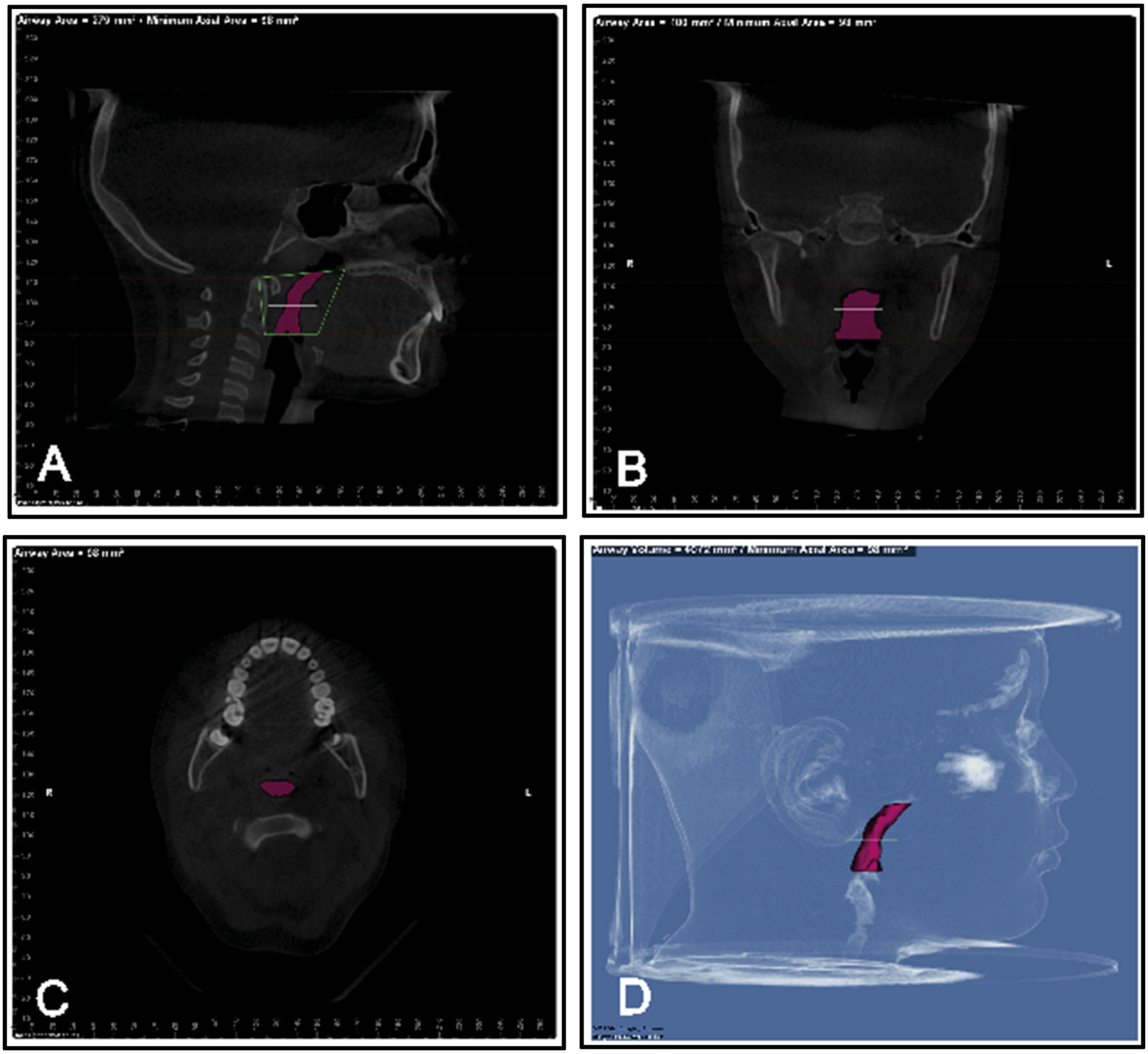

Fig 3. Minimal cross-section of the airways. Most frequent site in **(A-C)** multiplanar views and **(D)** 3D.

the analysis, total recording time, AHI, obstructive apnea index (OAI), oxygen desaturation index (ODI), lowest oxygen saturation ($LSpO_2$), and average oxygen saturation ($ASpO_2$) were considered.

Statistical analysis

All CBCT and PSG data were analyzed with the use of SPSS software (version 22; IBM, Armonk, NY). Normal distribution of the data was tested with the use of the Kolmogorov-Smirnov test. Because the only variable that showed normal distribution was total nasal volume, Wilcoxon signed rank test was used for the comparison of the changes along the observational period in each patient. Spearman coefficients and scatter plots were used in the correlation analysis between the PSG parameters (AHI, OAI, ODI, SpO_2, $ASpO_2$) and the CBCT volumetric and minimal cross-section changes between T0 and T1 reconstruction of the airways. Intra- and interexaminer reliability coefficients were calculated with the use of the intraclass correlation coefficient (ICC). All analyses were based on a significance level of 0.05.

RESULTS

Intra- and interexaminer agreements (ICC) were >0.81 for the measurements of the volume of the upper space 0.95 for the measurement of the volume

Table I. Descriptive data before surgery (T0) and 1 year after surgery (T1): polysomnographic parameters

	T0					*T1*					
Parameter	*Mean*	*SD*	*Min*	*Max*	*Median*	*Mean*	*SD*	*Min*	*Max*	*Median*	*Wilcoxon P*
AHI	18.2	10.0	7.2	44.3	14.5	5.2	2.4	3.1	13.1	4.1	<0.001
OAI	11.2	8.8	1.6	34.7	9.4	5.5	9.0	2.7	12	5.5	<0.001
ODI	13.9	8.0	2.6	33.2	14.6	6.5	2.8	3.2	13	6.5	<0.001
$LSpO_2$	76.2	9.0	49	93	77	94.2	1.2	49	96	94	0.025
$ASpO_2$	95.0	1.95	89	97	96	95	1.2	90	97	94	0.053

AHI, Apnea And Hypopnea Index; *OAI,* obstructive apnea index; *ODI,* oxygen desaturation index; *$LSpO_2$,* lowest saturation of oxygen; *$ASpO_2$,* average saturation of oxygen.

of the lower space, and 0.91 for the minimal cross-section of the airways.

At baseline, ~50% of the patients had scores at or above the cutoff value of 15 for AHI and ODI, indicating at least a moderate degree of apnea/hypopnea and desaturation of oxygen, respectively[31] (Table I). Twenty-five percent of the patients had at least a moderate degree of apnea itself, as indicated by the OAI. Normal blood oxygen levels in humans are considered to be 96%-99% and ideally should be >94%. If the level is <90%, it is considered to be "low," resulting in hypoxemia. Blood oxygen levels <80% may compromise organ function, such as the brain and heart, and should be promptly addressed. In the present sample, the $LSpO_2$ values were below this cutoff point (mean 76.2% and median 77%). But $ASpO_2$ was within the normal range (96%). One year after adenotonsillectomy, clinically and statistically significant changes were observed ($P < 0.001$). AHI was reduced more than threefold, and OAI and ODI were reduced almost twofold from the original values (medians: AHI 14.5 vs 4.1, AOI 9.4 vs 5.5, ODI 14.6 vs 6.5). $LSpO_2$ improved to normal levels (94%), with a statistically significant change ($P < 0.005$), and $ASpO_2$ was maintained within normal values (Table I).

Table II presents statistically significant changes between T0 and T1 of the 2 airways spaces ($P < 0.001$) of the OSAG patients. The volume of the lower space increased 51.5% (5205.3 mm^3 to 7886.6 mm^3) after tonsil removal, the upper space increased 67.5% (683.6 mm^3 to 1146.9 mm^3) after adenoid removal, and the minimal cross-sectional area increased more than twofold (186.9 mm^2 to 444.2 mm^2). Moreover, the CG patients presented no significant volumetric changes along the observation period ($P > 0.05$) of the lower (9809.5 mm^3 to 8789.2 mm^3)or upper (4465.5 mm^3 to 4468.2 mm^3) spaces. The minimal cross-sectional area of the airways of CG patients did not present statistically significant differences ($P > 0.05$) between T0 and T1 (83.1 mm^2 to 72.4 mm^2).

Table III presents the Spearman correlation coefficients between anatomic measurements and PSG parameters at T0. The volume of upper space at T0 showed moderate negative correlation with ODI ($r = -0.583$; $P < 0.05$). All other interactions between obstructions of the airways at T0 and apnea parameters did not show statistical significance ($r < 0.5$; $P > 0.05$).

Table IV presents the Spearman correlation between the T0 to T1 volumetric changes of the upper and lower spaces and the improvement of PSG parameters. Low negative correlation coefficient was found, with no statistical significance.

DISCUSSION

In the present sample, following adenotonsillectomy a significant improvement in the breathing pattern of all the children was reported by the parents, as well as measured with the use of mean PSG parameters. Reduction of AHI by more than threefold (14.5 vs 4.1), reduction of OAI and ODI by approximately twofold (OAI 9.4 vs 5.5, ODI 14.6 vs 6.5), and increase of $LSpO_2$ by more than 20% (77% vs 94%) are encouraging aspects in the indication of surgery for children with severe airway obstruction. However, it should be noted that some children still had altered PSG parameters 12 months after breathing "normalization." This finding is in agreement with those previously described in the literature. Mitchell and Kelly[21] evaluated adenotonsillectomized children and found a mean reduction of AHI from 23.4 to 3.1 in obese and from 17.1 to 1.9 in non-obese children, although several children remained with some degree of apnea after surgery. Schendel, Broujerdi, and Jacobson[32] reported that patients submitted to orthognathic surgery with maxillary and/or mandibular advancement generally improved their obstructive condition, although some patients remained with some degree of apnea as measured by AHI.

Although AHI is the criterion standard for the diagnosis of OSA, and some patients present with AHI above

Table II. Descriptive data of presurgery (T0) and 1-year postsurgery (T1) airway measurements of OSA patients and baseline (T0) and 1-year later (T1) for control patients

	OSA								Control group							
	T0			T1					T0			T1				
Parameter	*Mean*	*SD*	*Median*	*Mean*	*SD*	*Median*	*% Change*	*Wilcoxon P*	*Mean*	*SD*	*Median*	*Mean*	*SD*	*Median*	*% Change*	*Wilcoxon P*
Age	8.9	1.4	8	9.9	1.5	9	N/A	N/A	10.8	2.6	12	12.1	2.4	13	N/A	N/A
Lower region	5205.3	4971.8	2571.5	7886.6	6691.1	5276.3	+51.5	<0.001	9809.5	5122.9	8237.0	8789.2	6284.6	7121.0	−10.5	0.993
Upper region	683.6	155.3	726.9	1146.9	371.9	1056.9	+67.5	<0.001	4465.5	2521.9	3993.5	4468.2	2881.7	3724.0	0	0.285
Minimum cross section	186.9	223.4	98.5	444.2	256.4	335.8	+138.5	<0.001	83.1	40.6	75.0	72.4	58.3	58.5	−13.0	0.352

Table III. Spearman correlation coefficients (*r*) between polysomnographic parameters and pharyngeal measurements before adenotonsillectomy (T0)

Parameter	*Lower space*	*Upper space*	*Minimal cross-section*
AHI	−0.054	−0.102	0.264
OAI	−0.248	−0.008	−0.149
ODI	−0.214	−0.583	0.085
$LSpO_2$	0.194	0.195	0.077
$ASpO_2$	0.08	0.053	−0.023

Table IV. Spearman correlation coefficients (*r*) between polysomnographic parameters and pharyngeal measurements 1 year after adenotonsillectomy (T1)

Parameter	*Lower space*	*Upper space*	*Minimal cross-section*
AHI	0.039	−0.070	0.148
OAI	0.092	0.006	0.066
ODI	0.158	0.208	−0.058
$LSpO_2$	0.137	−0.054	0.263
$ASpO_2$	−0.032	0.440*	−0.354

*$P = 0.015$.

the cutoff point for "mild degree of apnea," in daily clinical life the report is practically unanimous from patients' parents that adenotonsillectomy causes an improvement in the breathing pattern and quality of life of their children.[33] Similarly, studies using questionnaires on quality of life and level of daytime sleepiness have shown high sensitivity, indicating that after adenotonsillectomy there is a strong tendency of clinical improvement of patients.[34] There is also evidence that after adenotonsillectomy, patients will gain more weight and will grow more,[35] will behave better,[36] and will improve in oximetry parameters.[37] The fact that AHI has been shown to be a poor indicator of actual clinical changes in young patients in some way helps to explain the absence of moderate or strong correlation between the increase in airway volume after adenotonsillectomy of our patients and the PSG parameters.

In this study, the volume of the airways and the minimal cross-section increased significantly ($P < 0.001$) after adenotonsillectomy, which was expected and has been previously described.[38] On the other hand, in the comparison group of patients, no significant volumetric changes could be observed. We expected an involution of the lymphatic tissues, as well as the increase in the size of the oropharyngeal space with normal growth, leading the growing nonsurgical patients to an increase of the volume of the airways, but that did not happen. Because patients of the comparison group had no obstructed airways due to the increased size of the lymphatic tissues, significant changes of the airways did not take place. Ideally, the comparison group should be composed of untreated OSA patients, but because of the retrospective design of this investigation, and because of ethical issues of collecting prospectively data of impaired subjects, such comparison is unlikely to be possible. However, we think that the volumetric gain in OSAG was achieved not only by the removal of the hyperplastic lymphatic tissues, but also by the extension of the walls of the respiratory tract after increasing the airflow permeability. Di Francesco and Kreibich[39] demonstrated that the objective size of the palatine tonsils is not correlated with the increase in the volume of the pharynx after tonsillectomy. The improvement in patency favors the extension of the walls of the aerial tract, increasing also the minimal cross-sectional area, which is located in the region of greater collapse of the walls. The minimal cross-section is the area where the upper airway is theoretically most constricted. The smallest cross-section of the upper airway is a limiting factor for airflow because it causes maximum resistance to airflow, and it is a site for the greater obstruction of the airway during sleep in patients with OSA.

As upper airway tract is a highly elastic tube; its walls are not rigid and suffer plastic collapse and significant narrowing when there is an internal negative pressure. Such an effect can be compared with that of a very dense milkshake plastic straw. Due to the high resistance to the flow of the milkshake, during the forced suction, a collapse of the straw occurs. But after the milkshake melts, the resistance to flow is greatly reduced and the walls of the straw are extended. Thus, it is suggested that after the adenotonsillectomy, the entire path of the upper respiratory tract undergoes a significant increase, even in regions distant from the adenotonsillectomy site. In the present study, we observed that after adenotonsillectomy the volume of the lower space of the airways (oropharynx and velopharynx) increased twofold; whereas in the upper space the volumetric gain was 1.45-fold.

We observed variability among patients regarding the percentage of improvement of the volume of the airways after adenotonsillectomy. This significant variability has been also reported by Schendel, Broujerdi, and Jacobson,[28] with some patients gaining retroplatal volume by 13% and others showing >1600% increase. This huge interpatient volumetric variation is probably one of the explanations for the low correlation between AHI and airway volumetric changes. The volumetric variations among different patients can be explained not only by the individual response to the patency improvement, but probably also as due to some methodologic bias, such as: (1) the seated position during image acquisition; (2) CBCT being a static examination in a region where dynamism is the main feature; (3) the long time needed to acquire the scan, thus including inspiration and expiration cycles during the capture; (4) the facial type of the individuals, with long-face patients presenting less gain of patency after the adenotonsillectomy than brachycephalic ones; and (5) CBCT volumetric analyses having been shown to vary widely within the same patient from one day to the next and from one moment to the next.[40]

However, contrary to what we had hypothesized, a greater degree of increase in the volume of the upper and lower spaces of the airways did not correspond to a greater improvement of the PSG indices. Alsufyani et al[8] found that conventional measures of the airways, such as the ones we used, did not explain the changes of clinical symptoms. The authors suggested new airway measures.

The volume of the upper space of the airways at T0 had a moderate negative correlation with ODI. This means that the smaller the free nasopharynx airflow, the higher the desaturation index, which is not good for the patient. No other morphologic aspect of the airways showed moderate or strong correlation with PSG parameters at T0. At T1, no correlation was found between volume and minimal cross-section area and the PSG parameters.

A full-night in-laboratory PSG (level 1) is the criterion standard for OSA diagnosis, but it is an expensive and complex procedure. Thus, there is a universal tendency to simplify diagnostic procedures through the use of portable monitors that are classified as level 2, level 3, or level 4 depending on their complexity and the number of signals they record. The diagnostic yield of each of these systems varies compared with the criterion standard. In 2007, the American Academy of Sleep Medicine (AASM) reviewed studies evaluating the use of portable monitoring equipment to diagnose OSA, particularly unattended level 3 monitors. The AASM recommended portable monitors to diagnose OSA in patients with a high pretest probability of OSA and without comorbidities.[30] Level 3 portable monitors are not accepted as a definitive diagnostic tool. Although level 3 portable monitors were developed as a means of preliminary screening patients with suspected OSA, they are now used for specific diagnosis of sleep breathing disorders.[41,42] They offer a number of advantages: they are accessible, they normally perform automatic analyzes, they do not need to be managed by highly skilled personnel, and they can be used to perform sleep disturbance studies at the patient's home. Level 3 monitors accurately identified patients without OSA and had high sensitivity to moderate-to-severe OSA. In the present investigation patients had been evaluated with the use of a level 3 monitor, so the PSG parameters were limited to those offered by these devices. The absolute values of AHI and OAI provided by level 3 monitors are not comparable with those collected from level 1 monitors, and the cutoff points for the classification of apnea are different between methods, but the assessment of the differences from T0 to T1 with the use of the same device in the present investigation showed a dramatic change of values. In the other hand, our data clearly showed that the volumetric changes of the airways did not correlate well with the important parameters AHI, OAI, ODI, and SpO_2.

The present retrospective study has limitations that need discussion. The airway measurements were collected from orthodontic records with the use of conventional dental CBCT equipment while the patients were awake in a seated position, which did not reflect the actual dimensions that are likely to occur during snoring in a sleeping child. The follow-up period was also relatively short. It is possible that, over a period of years, the natural reduction of the size of the lymphatic tissues might affect the volumes of the airways of patients who had a smaller surgical gain. The present sample was extracted from a population of children referred for surgical therapy because of severe OSA, so in an ordinary orthodontic population the findings would be different.

In future studies, the use of new measurements from CBCT scans, or the use of new methodologies using computational fluid dynamics could provide different views about the efficacy of using 3D assessment of airways to quantify improvements. But at this point, based on the findings of the present investigation, as well as those collected previously by other researchers, it is not recommended to use volumetric changes of the airways after adenotonsillectomy of children as a valid and reliable aspect to quantify breathing improvement. If so, most of the patients will show a degree of airway volumetric change that will not correlate to the quantitative breathing improvement.

CONCLUSION

Adenotonsillectomy contributed to the increase of airway volume and minimal cross-section and to the improvement of the PSG parameters, but there was no correlation between the magnitude of the anatomic changes and the improvement of the breathing mode.

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REFERENCES

1. Lumeng JC, Chervin RD. Epidemiology of pediatric obstructive sleep apnea. Proc Am Thorac Soc 2008;5:242-52.
2. Ali NJ, Pitson DJ, Stradling JR. Snoring, sleep disturbance, and behaviour in 4-5 year olds. Arch Dis Child 1993;68:360-6.
3. Lee P-C, Hwang B, Soong W-J, Meng CCL. The specific characteristics in children with obstructive sleep apnea and cor pulmonale. ScientificWorldJournal 2012;2012:757283.
4. Esteller E, Villatoro JC, Agüero A, et al. Obstructive sleep apnea syndrome and growth failure. Int J Pediatr Otorhinolaryngol 2018;108:214-8.
5. Mitchell RB, Kelly J. Behavior, neurocognition and quality-of-life in children with sleep-disordered breathing. Int J Pediatr Otorhinolaryngol 2006;70:395-406.
6. O'Brien LM, Mervis CB, Holbrook CR, et al. Neurobehavioral implications of habitual snoring in children. Pediatrics 2004;114:44-9.
7. Chen J-H, Huang R, Luo J-M, Xiao Y, Zhang Y. Adult monosymptomatic nocturnal enuresis with obstructive sleep apnea syndrome. Chin Med J (Engl) 2016;129:2011-2.
8. Izu SC, Itamoto CH, Pradella-Hallinan M, et al. Obstructive sleep apnea syndrome (OSAS) in mouth breathing children. Braz J Otorhinolaryngol 2010;76:552-6.
9. Goldstein NA, Fatima M, Campbell TF, Rosenfeld RM. Child behavior and quality of life before and after tonsillectomy and adenoidectomy. Arch Otolaryngol Neck Surg 2002;128:770.
10. Malhotra S, Pandey RK, Nagar A, Agarwal SP, Gupta VK. The effect of mouth breathing on dentofacial morphology of growing child. J Indian Soc Pedod Prev Dent 2012;30:27-31.
11. Bresolin D, Shapiro GG, Shapiro PA, et al. Facial characteristics of children who breathe through the mouth. Pediatrics 1984;73:622-5.
12. Banabilh SM. Orthodontic view in the diagnoses of obstructive sleep apnea. J Orthod Sci 2017;6:81-5.
13. Huynh NT, Desplats E, Almeida FR. Orthodontics treatments for managing obstructive sleep apnea syndrome in children: a systematic review and meta-analysis. Sleep Med Rev 2016;25:84-94.
14. Burstein DH, Jackson A, Weedon J, Graw-Panzer KD, Fahmy S, Goldstein NA. Adenotonsillectomy for sleep-disordered breathing in a predominantly obese pediatric population. Int J Pediatr Otorhinolaryngol 2013;77:525-9.
15. Cassalblat ML. What is wrong in chronic adenoiditis/tonsillitis anatomical considerations. Int J Ped Otorhinol 1999;49:S133-5.
16. Baugh RF, Archer SM, Mitchell RB, et al., American Academy of Otolaryngology–Head and Neck Surgery Foundation. Clinical practice guideline: tonsillectomy in children. Otolaryngol Head Neck Surg 2011;144:S1-30.
17. Boudewyns A, Abel F, Alexopoulos E, et al. Adenotonsillectomy to treat obstructive sleep apnea: is it enough? Pediatr Pulmonol 2017;52:699-709.
18. Suen JS, Arnold JE, Brooks LJ. Adenotonsillectomy for treatment of obstructive sleep apnea in children. Arch Otolaryngol Head Neck Surg 1995;121:525-30.
19. Kozak LJ, Hall MJ, Pokras R, Lawrance L, National Center for Health Statistics, Centers for Disease Control. Advance data 283: ambulatory surgery in the United States, 1994. Available at: www.cdc.gov/nchs/data/ad/ad283.pdf.

20. Ingram DG, Friedman NR. Toward adenotonsillectomy in children. A review for general pediatricians. JAMA Ped 2015;169:1155-61.
21. Mitchell RB, Kelly J. Outcome of adenotonsillectomy for obstructive sleep apnea in obese and normal-weight children. Otolaryngol Neck Surg 2007;137:43-8.
22. Shete CS, Bhad WA. Three-dimensional upper airway changes with mandibular advancement device in patients with obstructive sleep apnea. Am J Orthod Dentofacial Orthop 2017;151:941-8.
23. Souki MQ, Souki BQ, Franco LP, Becker HMG, Araújo EA. Reliability of subjective, linear, ratio and area cephalometric measurements in assessing adenoid hypertrophy among different age groups. Angle Orthod 2012;82:1001-7.
24. Grewal N, Godhane AV. Lateral cephalometry: a simple and economical clinical guide for assessment of nasopharyngeal free airway space in mouth breathers. Contemp Clin Dent 2010;1:66-9.
25. Buchanan A, Cohen R, Looney S, Kalathingal S, de Rossi S. Cone-beam CT analysis of patients with obstructive sleep apnea compared to normal controls. Imaging Sci Dent 2016;46:9-16.
26. Momany SM, AlJamal G, Shugaa-Addin B, Khader YS. Cone beam computed tomography analysis of upper airway measurements in patients with obstructive sleep apnea. Am J Med Sci 2016;352:376-84.
27. Zimmerman JN, Lee J, Pliska BT. Reliability of upper pharyngeal airway assessment using dental CBCT: a systematic review. Eur J Orthod 2016;39:489-96.
28. 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;82:985-92.
29. Brodsky L. Modern assessment of tonsils and adenoids. Pediatr Clin North Am 1989;36:1551-69.
30. Aurora RN, Zak RS, Karippot A, et al. Practice parameters for the respiratory indications for polysomnography in children. Sleep 2011;34:379-88.
31. Povitz M, Kimoff RJ. Use of a level 3 portable monitor for the diagnosis and management of sleep disordered breathing in an inpatient tertiary care setting. Can Respir J 2014;21:96-100.
32. Schendel SA, Broujerdi JA, Jacobson RL. Three-dimensional upper-airway changes with maxillomandibular advancement for obstructive sleep apnea treatment. Am J Orthod Dentofacial Orthop 2014;146:385-93.
33. Tarasiuk A, Simon T, Tal A, Reuveni H. Adenotonsillectomy in children with obstructive sleep apnea syndrome reduces health care utilization. Pediatrics 2004;113:351-6.
34. Goldstein NA, Pugazhendhi V, Rao SM, et al. Clinical assessment of pediatric obstructive sleep apnea. Pediatrics 2004;114:33-43.
35. Katz ES, Moore RH, Rosen CL, et al. Growth after adenotonsillectomy for obstructive sleep apnea: an RCT. Pediatrics 2014;134:282-9.
36. Chung S, Hodges EK, Ruzicka DL, et al. Improved behavior after adenotonsillectomy in children with higher and lower IQ. Int J Pediatr Otorhinolaryngol 2016;80:21-5.
37. Kargoshaie A, Akhlaghi M, Najafi M. Oxygen saturation improvement after adenotonsillectomy in children. Pakistan J Biol Sci PJBS 2009;1:276-80.
38. Alsufyani N, Flores-Mir C, Major P. Three-dimensional segmentation of the upper airway using cone beam CT: a systematic review. Dentomaxillofacial Radiol 2012;41:276-84.
39. Di Francesco RC, Kreibich MS. Is the difference in the volume of the pharyngeal space, as measured by acoustic pharyngometry, before and after tonsillectomy proportional to the volume of the excised tonsils? Clinics (Sao Paulo) 2016;71:285-90.
40. Antosz M. CBCT volumetric analyses have no value in assessing functional airway. Am J Orthod Dentofacial Orthop 2015;147:10-1.
41. Driver HS, Pereira EJ, Bjerring K, et al. Validation of the Medibyte type 3 portable monitor compared with polysomnography for screening of obstructive sleep apnea. Can Respir J 2011;18:137-43.
42. Polese JF, Santos-Silva R, de Oliveira Ferrari PM, Sartori DE, Tufik S, Bittencourt L. Is portable monitoring for diagnosing obstructive sleep apnea syndrome suitable in elderly population? Sleep Breath 2013;17:679-86.