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Effects of surgically assisted rapid maxillary expansion on the modification of the pharynx and hard palate and on obstructive sleep apnea, and their correlations

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ABSTRACT

Purpose: To investigate the changes induced by surgically assisted rapid maxillary expansion (SARME) on palate and pharynx morphology as well as the correlation of these changes with the improvement of obstructive sleep apnea (OSA).

Materials and methods: The study was conducted in 16 patients, seven women and nine men, aged on average 40.23 ± 10.23 years, all of them with OSA confirmed by polysomnography (PSG) and with posterior crossbite. All participants underwent computed tomography (CT) and PSG before and after SARME. The CT scans were used to determine the dimensions of the palate and pharynx before and after surgery. Data were analyzed statistically by the paired t-test, Wilcoxon test and Pearson correlation, with the level of significance set at $P < 0.05$.

Results: A 56.24% reduction in apnea and hypopnea index was detected (from 33.23 ± 39.54 to 14.54 ± 19.48: $P = 0.001$). The total airway area increased on average by 23.99% ($P = 0.016$), although in a more expressive manner in its lower half (28.63%, $P = 0.008$). A 24% transverse bone increase was observed in the palate in the region of the first premolars and an 18% increase in the region of the first molars (from 2.42 ± 0.31 to 2.99 ± 0.26. $P < 0.001$, and from 3.11 ± 0.32 to 3.70 ± 0.41, $P < 0.001$, respectively), and a mean 15% reduction of its depth (from 1.07 ± 0.33 to 0.89 ± 0.18, $P = 0.014$). A moderate correlation was detected between palate depth and width and OSA severity, as well as a correlation of the reduction of palate depth and its transverse increase with the improvement of OSA, especially among patients with severe OSA.

Conclusion: It appears that narrowing of the palate, especially in the premolar region, and its greater depth may be related to the severity of OSA. SARME promotes transverse maxillary widening and lowering of palate depth, thus reducing OSA among adults and expanding the airway, especially in its lower half.

1. Introduction

Affecting almost one-third of the adult population (Tufik et al., 2010), obstructive sleep apnea (OSA) is becoming an increasingly relevant problem. The syndrome due to this condition has already been correlated with many diseases, ranging from an increased incidence of myocardial infarction to hypertension, type 2 diabetes (Barbé et al., 2012; Botros et al., 2009) and various cognitive and behavioral complications. All of these factors may reduce the duration and quality of life of affected persons (Young et al., 2008).

The multifactorial etiology of OSA greatly impairs the treatment of this condition, since it may be related to facial skeletal alterations, to the soft tissues of the upper airways, and also to functional factors (Patil et al., 2007). Skeletal changes involving maxillomandibular retrusion have been well established (Flores-Mir et al., 2013). Among the factors related to the soft parts, obesity stands out, although hypertrophy of the palatine tonsils and of the tongue may also contribute to the condition (Schwab et al.,

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2003). Regarding the functional factors, the mechanisms of control of muscle tonus during sleep may change the resistance of the pharyngeal walls (Eckert et al., 2013). A new skeletal factor, lack of transverse development of the maxillary arch, has been described only recently (Vinha, Eckeli, et al., 2016; Liu et al., 2017), possibly having a direct impact on OSA by modifying the dimensions of the airways (Vinha, Faria, et al., 2016).

In addition to affecting occlusion, transverse maxillary deficiency may cause increased nasal resistance to airflow (Zeng et al., 2008) and posterior tongue displacement that compromises tongue support and facilitates pharyngeal collapse.

The treatment of transverse maxillary atresia for adults is surgically assisted rapid maxillary expansion (SARME) or distraction osteogenesis maxillary expansion (DOME) (Liu et al., 2017). The first report of SARME dates back to 1938 (Koudstaal et al., 2006), and the procedure has since become universally accepted as a safe and effective technique for maxillary expansion with few complications (Koudstaal et al., 2006). SARME was used in 2016 for the treatment of OSA in adult patients (Vinha, Eckeli, et al., 2016), with a good result regarding the improvement of the condition. In a recent systematic review and meta-analysis (Abdullatif et al., 2016), the mean apnea–hypopnea index (AHI) of patients who underwent SARME was reduced from 24.3 ± 27.5 to 9.9 ± 13.7, representing a mean reduction of 59.3% from the initial to the final value. However, in addition to the small number of cases, the literature is not clear about the mechanism whereby SARME promotes an improvement of OSA. Our hypothesis is that the change in the transverse dimension of the maxilla and the increase in the intrabuccal volume may provide a better support and anteriorization of the tongue, resulting in an increased pharyngeal volume with a positive impact on OSA (Vinha, Faria, et al., 2016). On this basis, the objective of the present study was to assess the effects of SARME on the modifications of the palate and airways and its consequent effects on OSA.

2. Materials and Methods

2.1. Patients and procedures

This was a prospective clinical trial that was approved by the Ethics Committee of the University Hospital, Faculty of Medicine of Ribeirão Preto, University of São Paulo (HC-FMRP-USP), protocol no. 01270004000-10. All patients gave written informed consent to participate.

This study used the same sample and some statistical data from another publication by our research group (Vinha, Faria, et al., 2016). However, in the present study, other parameters with totally unpublished information were evaluated.

The participants were selected consecutively at the Integrated Center of Face Defects (CIEDEF as the Portuguese acronym) of HC-FMRP-USP according to the following inclusion criteria: subjects aged 21 years or older with transverse reduction of the maxilla and unilateral or bilateral posterior crossbite, with a sufficient number of healthy teeth that would support the devices and with an AHI of >5 confirmed by full-night polysomnography. Exclusion criteria were individuals with systemic diseases that would prevent surgery, with significant craniofacial alterations, and individuals who would not agree to participate.

Before the installation of the device, all subjects underwent multi-slice computed tomography (CT) covering the entire upper airway starting from the hyoid bone. The procedure was carried out at HC-FMRP-USP using a Phillips 16-channel Brilliance CT Big Bore. For image acquisition, the patient lay in dorsal decubitus with his head positioned in a standard manner by previously trained operators. All subjects selected had transverse maxillary deficiency (Fig. 1).

Type 1 polysomnography (PSG) was performed in the laboratory of Clinical Neurophysiology using BioLogic equipment (BioLogic Vision. Inc. Natus, San Carlos, CA, USA). The following were acquired: electroencephalogram, electrocardiogram, electrooculogram, electromyography of the chin and lower limbs, pulse oximetry, recording of abdominal and thoracic effort (inductance plethysmography belts), and recording of oronasal flow (thermocouple and nasal pressure). All technical parameters used were based on the guidelines of the 2007 Manual of the American Academy of Sleep Medicine, using 4B criteria for hypopnea (IBER et al., 2007). The neurologist responsible for the PSG analysis did not know whether the examinations had been carried out before or after the intervention.

The following PSG parameters were used for the present study: AHI, respiratory disturbance index (RDI), total sleep time (TST), percent sleep staging on TST, and supine position quantity. Anthropometric data and dental arch molds were obtained before and at the end of the intervention. A Hyrax-type maxillary expander was installed in each participant, usually banded to the first premolars and first molars (Fig. 2).

All subjects underwent the same surgical technique performed by the same team. The surgical technique applied to the maxilla was a variation of the one described by Bell and Epker in 1976, and consisted of Le Fort I type osteotomy with separation of the pterygoid apophysis from the sphenoid bone and another osteotomy between the upper central incisors. The osteotomy for the separation of the maxilla from the pterygoid plate was performed in order to promote a median bone disjunction of the anterior and posterior regions of the maxilla. This method creates a more parallel opening between the maxillae and, if it is not used, the maxillary opening tends to be more anterior (Seeberger et al., 2010; Suri and Taneja, 2008; Laudemann et al., 2009), possibly compromising the results.

The appliance started to be activated 5 days after the surgery, with half a turn of the screw (0.4 mm) every 12 h according to the protocols for the activation of facial osteogenic distraction (Koudstaal et al., 2006). The total period of activation was determined individually for each patient. At the end of the opening, the screws were locked in place, and the appliance was removed after an average of 5 months.

A new full-night PSG was then carried out approximately 1 year after surgery. This more delayed PSG was for the purpose of obtaining complete stability of the moved structures and to incorporate eventual losses or relapses. For the same reason, CT was also carried out with a greater delay, approximately 9 months after surgery.

The second CT was carried out on average 241 days after surgery (8.05 months), corresponding to 65 days after removal of the expander (2.16 months). CT could be performed in only 14 of the 16 patients studied. Pre- and postoperative images in DICOM format were examined with the OSIRIX software, version 3.9. 4.32 bits. This is an open-access software that has already been validated as reliable in various publications (Weissheimer et al., 2012), in addition to having several resources for tomographic analysis (Rosset et al., 2004).

Despite the standardized positioning of the head for tomographic acquisition, it is impossible to obtain sections with 100% precision. Thus, the first procedure executed in the DICOM files was a correction of the images obtained based on the basic series. Areas that would not be affected by the appliance were used as reference (except on the palatal plane), i.e., the upper margins of the orbits centered on the Galli crest on the coronal plane (Fig. 3a). The lateral margins of the orbits in the transverse direction (Fig. 3b), and the palatal plane on the sagittal plane, so that its complete visualization

Fig. 1. Transverse maxillary deficiency.

Fig. 2. Maxillary distractor installed before surgery.

would be possible (Fig. 3cd) (Guijarro-Martínez and Swennen, 2011). This standardization of the series is exactly equal to that published by Vinha, Faria, et al. (2016), as shown in Fig. 3.

Once the planes were corrected, a new DICOM series was saved, and the mean values were obtained from this previously corrected series. All measurements were made twice, with an interval of at least 1 month between them. For the second measurement, the basic tomographic series was again corrected, i.e., two correction series were performed for each tomography in order to determine the reliability of the measurements acquired and of the preparation of the tomographic series. The mean value of the two acquired measurements was used for statistical analysis.

For the hard palate measurements, height and width were standardized using as reference the premolars or the first tooth after the upper canines and the first molars or the teeth that were in its place. Palate width was measured from the root of the teeth mentioned above involved in the table of alveolar bone, as can be seen in Fig. 4. Palate depth was measured from the width line to the lowest region of the hard palate (see Fig. 5).

For the volumetric measurement of the airway, the distance between the posterior nasal spine (PNS) was determined, marking the upper limit of the pharynx and the fundus of the vallecula as the lower limit. The total organ thus described is called total pharynx (TP).

In order to minimize errors of measurement, we opted for a linear division of the pharynx. Thus, the area studied was divided into an upper portion, now denoted upper pharynx (UP) and a lower portion, now denoted LP. For volume determination, each section (about 1 mm thick) was treated with the software cited above using the segmentation tool of the software itself, with sensitivity for image density standardized in all measurements. In other words, the software determined the area automatically according to image density. Once all sections were filled out, the volume obtained was calculated as the sum of the area of each previously demarcated level.

The position of the head at the time of the tomographic take was evaluated in order to increase the reliability of the pharyngeal measurements obtained, since head extension or flexion can cause a significant change in the upper airway (Ota et al., 2011). For this purpose, it was necessary to transport a radiographic measurement to the tomography. Habitually used in lateral skull radiographs in order to assess head rotation in relation to the cervical spine, this measure is known as O–C2 or vertebral angle. It consists of an angle formed by the McGregor line (a line determined by the end of the hard palate, PNS) and the opisthion point (the midpoint of the posterior margin of the occipital bone) with the lower terminal plate of the second cervical vertebra, as shown in Fig. 6.

2.2. Statistical analysis

In view of the large amount of data measured and of the behavior of the measurements, we applied paired t-test to data of normal distribution and the nonparametric Wilcoxon test for data with non-normal distribution when the two time points were analyzed in the same sample. The analyses used are described in the tables. The Pearson correlation test was used to determine the correlation between various factors. All values are reported as mean ± SD, with the level of significance set at $P < 0.05$.

3. Results

The study was conducted in 16 subjects, seven women and nine men, on average 40.23 ± 10.23 years of age (range: 24.6–62.2 years). Five subjects had severe OSA, four had moderate OSA, and seven had mild OSA. Among these subjects, CT could not be performed in one individual with severe OSA and in one with moderate OSA. The second PSG was performed, on average, 334.76 days after surgery.

Table 1 lists the mean values and the pre- and post-SARME differences for the total sample and according to the severity of OSA.

AHI showed a mean reduction of 56.24% (pre: 33.23 ± 39.54; post: 14.54 ± 19.48, $P < 0.001$) and RDI was also reduced by 54% ($P < 0.001$), as can be seen in Table 1.

The PSG values obtained before and after intervention are shown in Table 2.

Anthropometric data, BMI, and neck and abdominal circumferences were also measured before and after SARME and did not show significant differences, as demonstrated in Table 3.

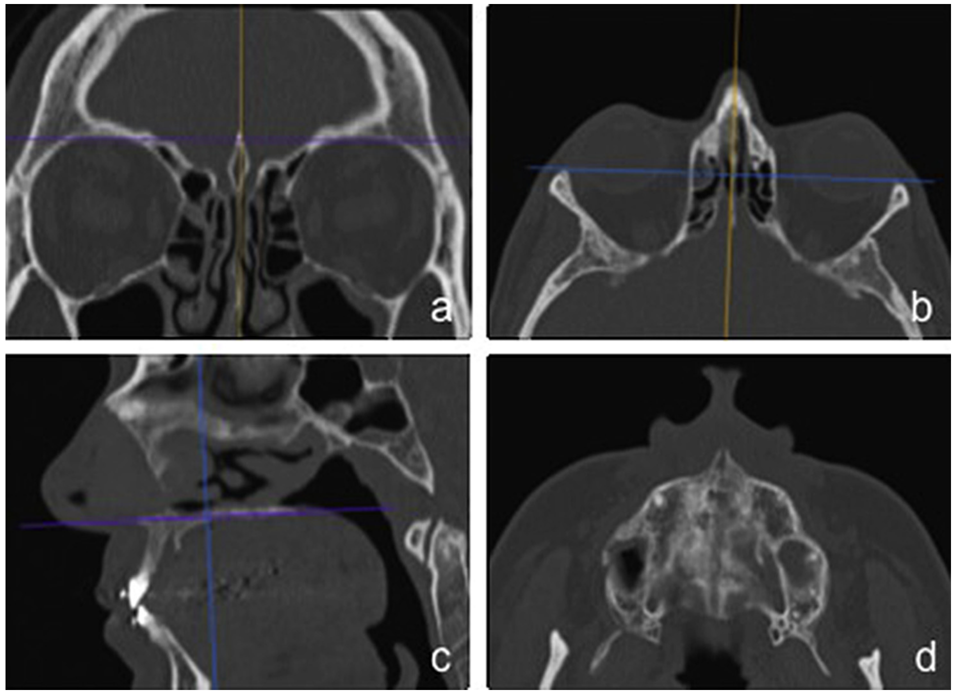

Fig. 3. Orientation for the correction of the orthogonal planes (Vinha, Faria, et al., 2016).

The second CT was carried out on average 241 days after the surgical intervention (8.05 months). i.e., 65 days after removal of the expander (2.16 months). Tomography could not be performed in 14 of the 16 patients studied.

Table 4 presents the measurements and the behavior of the airway before and after SARME.

As shown in Table 4, there was a 17.49% increase between the initial and final UP volume (from 3.58 ± 1.03 to 4.34 ± 2.32). However, although it was considerable, this increase was not statistically significant ($P = 0.325$). On the other hand, the LP was the pharyngeal region showing the most significant increase, from 5.03 ± 1.52 μm before surgery to 7.05 ± 2.58 μm after surgery, i.e., a 28.63% increase ($P = 0.008$).

Thus, TP behavior was intermediate, with the initial mean volume (cm^3) increasing from 8.66 ± 1.77 to 11.40 ± 4.29, reflecting a 23.99% increase in the organ ($P = 0.016$). Fig. 7 illustrates the behavior of the pharynx at the upper, lower and total level.

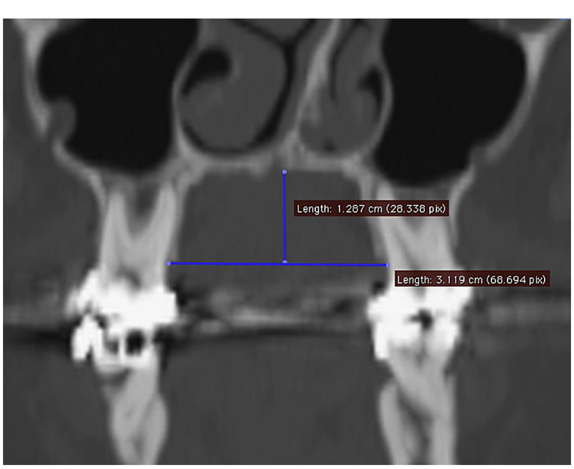

Fig. 4. Computed tomographic section showing the measurement of the transverse distance between the molars (at the height of alveolar bone) and of palate depth.

This marked increase in the LP ended up being reflected on an increase of the pharynx, observed in Fig. 8.

Statistical analysis showed no correlation between AHI and the airways, or between the increase in the airways and a reduction of AHI values (Table 5).

A moderate correlation between AHI reduction and increased LP and TP was observed in subjects with severe OSA ($r = 0.691$ and $r = 0.548$, respectively). AHI reduction was strongly correlated with UP ($r = 0.864$), but not with LP, in subjects with moderate OSA.

The vertebral angle formed by the base of the second cervical vertebra and the McGregor line was measured in both the pre- and post-SARME topographies, varying (in degrees) from 26.78 ± 7.27

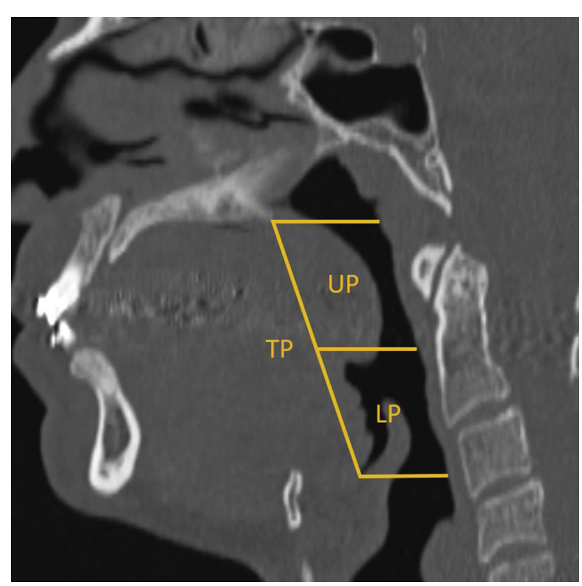

Fig. 5. Computed tomographic section of the median sagittal plane showing the divisions of the pharynx used in the present study.

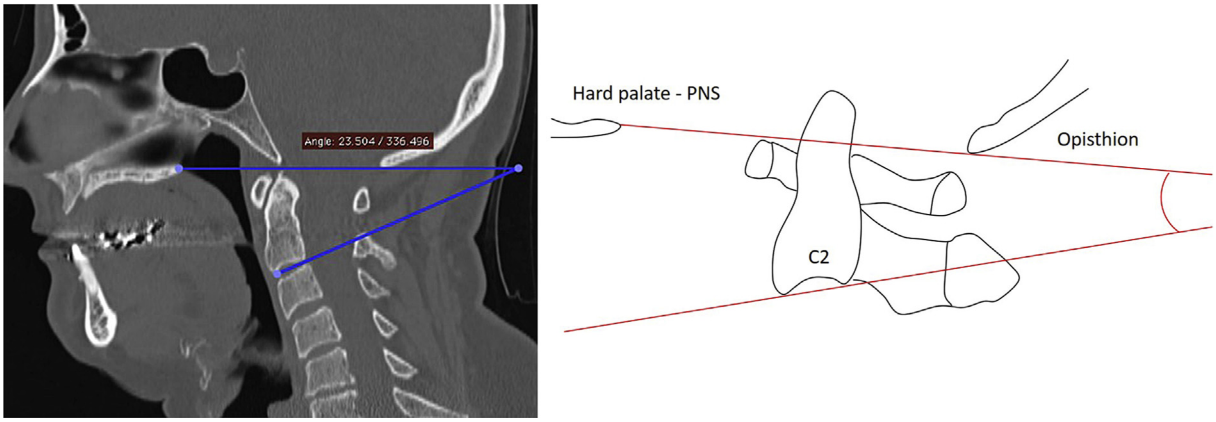

Fig. 6. O–C2 angle fromed by the base of the second cervical vertebra with the McGregor line (adapted figure) (Ataka et al., 2010).

Table 1
Total AHI and AHI stratified according to OSA severity before and after SARME.

	N	Pre-SARME	Post-SARME	% Diff.	*P*
Total AHI	16	33.23 ± 39.54	14.54 ± 19.48	−56.66	0.001
Mild AHI	7	7.14 ± 4.01	5.80 ± 4.71	−18.76	0.468
Moderate AHI	4	21.73 ± 5.74	9.08 ± 6.22	−58.21	0.125
Severe AHI	5	78.96 ± 43.33	31.15 ± 29.19	−60.54	0.062

AHI – apnea and hypopnea index; % Diff. – mean AHI difference before and after SARME.
Wilcoxon test.

(95% CI: 22.58–30.97) to 26.76 ± 9.03 (95% CI: 21.54–31.97), with $P = 0.987$, i.e., a nonsignificant difference.

Tomographic measures of the width and depth of the palate are listed in Table 6. The table reports the transverse values of the palate in the region of the first premolars and between the first premolars before and after SARME, as well as their differences. The table also shows the height of the palate in relation to the level of alveolar bone, the same as used to measure the width of the palate, as well as the relation between palate width and height. Since this value is the ratio between height and width, this means that, the lower the ratio, the greater the width in relation to the height. For example, a 0.5 ratio means that the height is exy half the width (see Table 7).

It can be seen that palate width increased by approximately 24% in the region of the first premolars and by 18% in the region of the first molars (from 2.42 ± 0.31 to 2.99 ± 0.26, $P < 0.001$, and from 3.11 ± 0.32 to 3.70 ± 0.41, $P < 0.001$, respectively), with statistical significance in both cases. Palate height was reduced by approximately 15% in the region of the first premolars and by approximately 9% in the region of the molars, with statistical significance in both cases (from 1.07 ± 0.33 to 0.89 ± 0.18, $P = 0.014$, and from 1.49 ± 0.22 to 1.36 ± 0.20, $P < 0.001$, respectively).

Table 2
Polysomnographic values obtained before and after SARME.

	Pre-SARME	Post-SARME	% Diff.	*P*
TST (min)	363.18 ± 50.03	336.98 ± 101.16	−7.21	0.519
% Sleep efficiency	82.03 ± 11.58	86.68 ± 8.16	5.67	0.216
N1 (% TST)	12.44 ± 5.84	11.81 ± 6.84	−5.06	0.404
N2 (% TST)	46.43 ± 12.29	47.49 ± 7.20	2.28	0.606
N3 (% TST)	20.97 ± 8.80	23.74 ± 8.92	13.21	0.433
REM (%TST)	20.12 ± 9.92	17.04 ± 6.95	−15.31	0.252
Supine (% do TST)	44.49 ± 26.27	42.51 ± 39.85	−4.45	0.413

TST – total sleep time. Supine – percent of supine position during PSG in relation to TST; % Diff. – percent difference between pre- and post-SARME values.
Wilcoxon test.

The ratio between palate height and depth also decreased by 31% in the premolar region and by approximately 23% in the molar region (from 0.45 ± 0.17 to 0.30 ± 0.07, $P < 0.001$, and from 0.48 ± 0.08 to 0.37 ± 0.07, $P < 0.001$, respectively).

A moderate correlation was detected between the initial AHI and the initial palate width in the region of the first premolars ($r = 0.624$) and between the first molars ($r = 0.661$) and was also observed between the initial palate height/width ratio in the premolar region and the initial AHI ($r = 0.539$). No correlation was detected between the initial AHI and palate width in the premolar or molar region or between the initial AHI and the palate height/width ratio.

The correlation between OSA improvement and palate measurements was also determined, as shown in Table 8.

No important correlation was detected between reduced AHI and palate measurements in any subject. However, new correlations were detected when the sample was stratified according to OSA severity. In patients with severe OSA, the reduction of AHI showed a moderate correlation with increased palate width at the level of the first premolars ($r = 0.577$) but not at the level of the molars. A very strong correlation was detected between the reduction of AHI and palate depth, with $r = 0.940$ in the premolar region and $r = 0.994$ in the molar region (Fig. 9).

Table 3
Anthropometric data obtained before and after SARME.

	Pre	Post	% Diff.	*P*
BMI	29.8 ± 4.46	29.97 ± 5.31	0.57	0.667
Cervical circumference (cm)	40.81 ± 3.31	40.5 ± 3.48	−0.76	0.415
Abdominal circumference (cm)	103.81 ± 11.2	105.5 ± 11.44	1.63	0.235

BMI – Body mass index; Pre – mean pre-SARME values; Post – mean post-SARME values; % Diff. - percent difference between pre- and post-SARME values.
Paired t-test.

Table 4
Values of airway volume (cm^3) before and after SARME.

	Pre	Post	% Diff.	*P*
UP	3.58 ± 1.03	4.34 ± 2.32	17.49%	0.325
LP	5.03 ± 1.52	7.05 ± 2.58	28.63%	0.008
TP	8.66 ± 1.77	11.40 ± 4.29	23.99%	0.016

Pre – mean pre-SARME values; Post – mean post-SARME values; UP –upper pharynx volume (cm^3); LP – lower pharynx volume (cm^3); TP – total pharynx volume (cm^3).
Paired t-test.

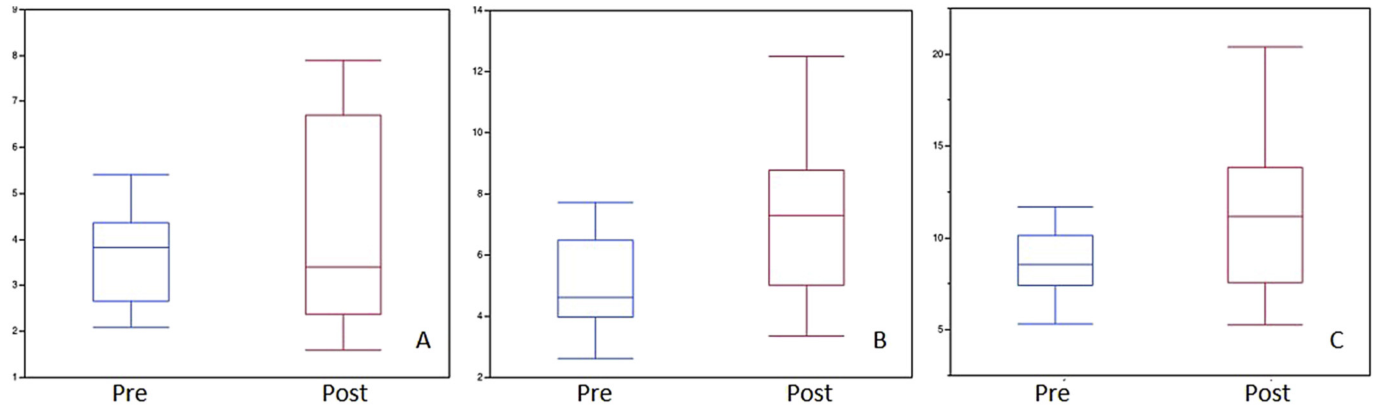

Fig. 7. (A) Box-plot* of upper pharynx; (B) lower pharynx; (C) total pharynx in cm^3 before and after SARME. *Graphs on different scales.

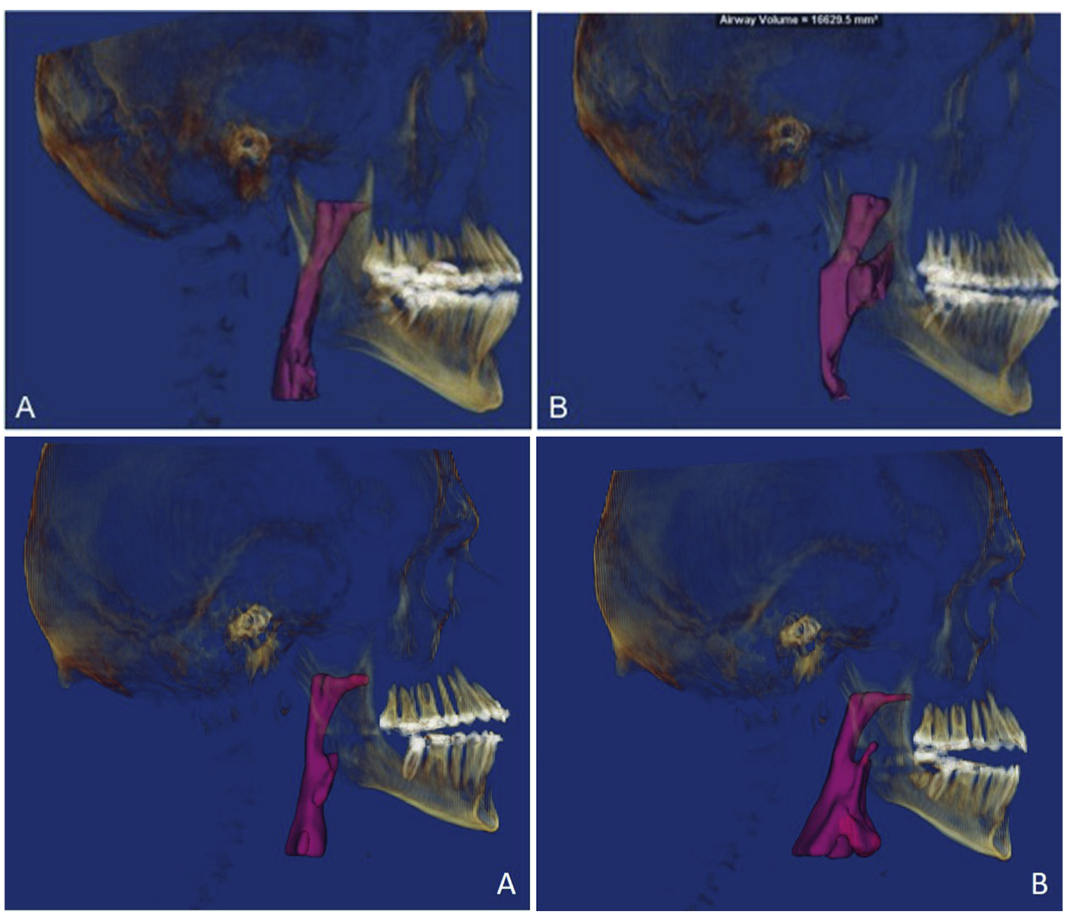

Fig. 8. Total pharynx after SARME in 2 different patients (A – Pre-SARME and B – Post-SARME).

A strong correlation was detected between AHI reduction and height/width ratio in the molar region (r = 0.880) and an extremely strong correlation was observed between AHI reduction and height/width ratio in the premolar region (r = 0.922). Important correlations were also detected in the group with moderate OSA, in which the increased palate width was strongly correlated with the improvement of AHI both in the premolar (r = 0.852) and molar (r = 0.979) regions. This correlation was also observed between palate height and AHI although it was less intense, being moderate both in the premolar (r = 0.689) and molar (r = 0.617) regions. Correlations were also detected between palate height/width ratio and AHI, being strong in the premolar region (r = 0.745) and extremely strong in the molar region (r = 0.992). No expressive correlations were observed in the group with mild OSA. The correlation between palate dimensions and airway volume is presented in Table 9.

A moderate correlation was observed between the increase in LP volume and TP and the increase in palate width (r = 0.562 and r = 0.617) in the premolar region. The reduction of palate height appeared to be correlated with UP only in the premolar region (r = 520). A moderate correlation was also observed between UP and the improved palate height/width ratio in the premolar region,

Table 5
Correlation between airway volume and improvement of OSA.

AHI				
Volume	Total	Mild	Moderate	Severe
UP	0.078	0.008	0.864	0.101
LP	0.067	0.012	0.295	0.691
TP	0.098	0.071	0.421	0.548

UP – Upper pharynx; LP – lower pharynx; TP, total pharynx. Total – AHI of all patients; Mild – group with mild OSA; Moderate, group with moderate OSA; Severe, group with severe OSA.
Pearson r values.

Table 6
Comparison of the palate width and height in the region of the first premolars and in the region of the first molars and the relationship between these measurements before and after SARME.

	Pre	Post	% Diff.	*P*
P Width	2.42 ± 0.31	2.99 ± 0.26	1.24	< 0.001
P Height	1.07 ± 0.33	0.89 +- 0.18	0.85	0.014
M Width	3.11 ± 0.32	3.70 ± 0.41	1.18	< 0.001
M Height	1.49 ± 0.22	1.36 ± 0.20	0.91	< 0.001
P Ratio	0.45 ± 0.17	0.30 ± 0.07	0.69	< 0.001
M Ratio	0.48 ± 0.08	0.37 ± 0.07	0.77	< 0.001

P Width – Palate width between the first premolars (cm); P Height – palate height in the region of the first premolars (cm); M Width – Palate width between the first molars (cm); M Height – palate height in the region of the first molars (cm); P ratio– Palate height/width ratio in the region of the first premolars; M ratio – Palate height/width ratio in the region of the first molars.
-Paired t-test.

Table 7
Pearson correlation between palate width and height and palate height/width ratio with AHI improvement.

	P Width	P Height	M Width	M Height	P Ratio	M Ratio
Initial AHI	0.624	−0.026	−0.661	0.214	−0.539	0.017

P Width– Pàlate Width between the first premolars (cm); P Height – Palate height in the region of the first premolars (cm); M Width – Palate width between the first molars (cm); M Height – palate height in the region of the first molars (cm); P Ratio – Palate height/width ratio in the region of the first premolars; M Ratio – Palate height/width ratio in the region of the first molars.

with no important correlations being observed for the remaining regions or measurements (Table 10).

Comparison of the behavior of the airway in patients with severe OSA revealed a strong correlation between LP and palate width and depth in the premolar region (r = 0.860 and r = 0.745). In the molar region, only palate width seemed to have a moderate

Table 8
Pearson correlation between increased palate width, reduced palate height and height/width ratio and OSA improvement in general and according to disease severity.

	% AHI reduction			
	Total	Mild	Moderate	Severe
% P Width	0.054	0.229	0.852	0.577
% P Height	0.420	0.283	0.689	0.940
% M Width	0.197	0.109	0.979	0.430
% P Width	0.419	0.528	0.617	0.994
% P Ratio	0.427	0.287	0.745	0.922
% M Ratio	0.397	0.321	0.992	0.880

%P Width – Percent increase in palate width in the premolar region; %P Height– Percent reduction of palate depth in the premolar region; %M Width – percent increase in palate width in the molar region; %M Height – Percent reduction of palate depth in the molar region; %P Ratio – Percent variation of the height/width ratio in the premolar region; %M Ratio – Percent variation in the palate height/width ratio in the premolar region; Mild – Group with mild OSA; Moderate – Group with moderate OSA; Severe – Group with severe OSA.

correlation (r = 0.621). The correlation with height/width ratio was extremely strong (r = 0.916) in the premolar region but negligible in the molar region. The same behavior was observed for TP, with a strong correlation with the premolar region (r = 0.860 for width and r = 0.634 for height) and only a moderate correlation with width in the molar region (r = 0.518). A strong correlation with palate height/width ratio was observed in the premolar region (r = 0.826), while no important correlation was observed with the molar region.

Among the patients with mild apnea, the correlation between increased pharynx and palate measurements were moderate in all three levels of the pharynx in relation to palate width in the premolar region (r = 0.550 for UP, r = 0.515 for LP and r = 0.677 for TP). The reduction of palate height also showed a moderate correlation with the increase in UP (r = 0.662). A moderate correlation was observed between increased palate width in the molar region and LP (0.512) and between increased palate width and UP and LP (r = 0.695 and r = 0.064), although a strong correlation was observed between increased TP and increase palate height/width ratio in the premolar region.

4. Discussion

In the present study, even though tomographic images were not obtained with induced sleep (Faria et al., 2013), the examinations were carried out with the patients in dorsal decubitus, a position similar to that during which most of the obstructive episodes occur.

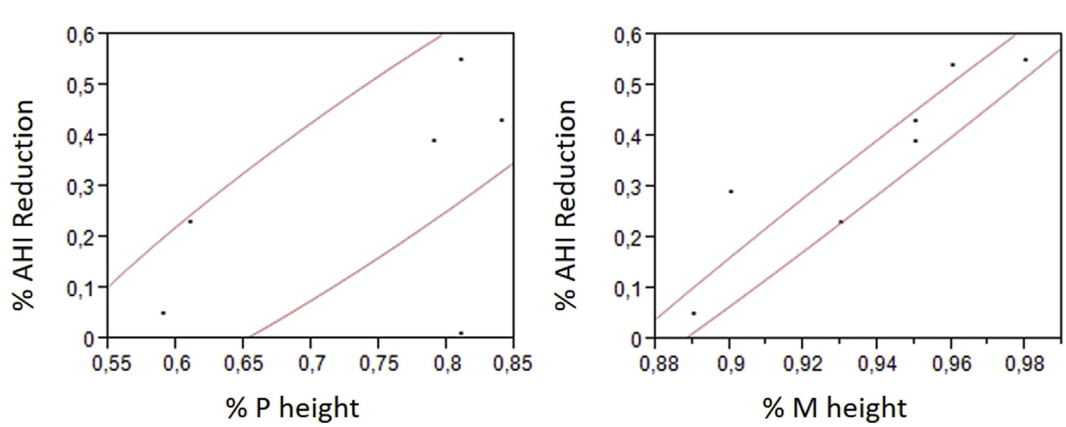

Fig. 9. Correlation between AHI reduction and palatal height reduction before and after SARME in the premolar region (left) and in the molar region (right).

Table 9
Correlation between the difference in palate width, height and height/width ratio and the amount of airway increase.

	% P width	% P Height	% M Width	% M Height	% P Ratio	% M Ratio
% UP	0.312	0.520	0.111	0.301	0.569	0.284
% LP	0.562	0.019	0.274	0.026	0.203	0.140
% TP	0.617	0.177	0.144	0.116	0.361	0.022

%UP – Percent increase of the upper pharynx; %LP – Percent increase of the lower pharynx; %TP – percent increase of the total pharynx; %P width – percent increase in palate width in the premolar region; %P height – percent reduction of palate depth in the premolar region; %M width – Percent increase in palate width in the molar region; %M Height – Percent reduction of palate depth in the molar region; %P Ratio – percent variation in palate height/width ratio in the premolar region; %M Ratio – percent variation in palate height/width ratio in the premolar region.

This differential approach was important, since a possible bias may have been involved in other studies in which the airway of the patients was evaluated in the vertical position during image acquisition (El and Palomo, 2014; Kurt et al., 2010).

Despite the transverse increase of the maxilla resulting from SARME, the upper level of the pharynx was the region that showed the least volumetric changes. Although there was an expressive increase of 17.49%, this change was not statistically significant. The most significant increase was observed in the lower half of the pharynx, with a mean value of 28.63%. This result clearly shows that, even though the bone effect occurred on the maxilla, the major result was detected in the lower portion of the pharynx, mainly in the retrolingual. region, which has been pointed out in several studies to play a relevant role in the obstruction occurring during sleep (Bachar et al., 2008; Kavcic et al., 2015). In general, the TP studied here was increased by approximately 24%.

One of the factors that may be questioned regarding the increase in the airway observed in the present study is the position of the patient's head during tomography. This questioning is correct, since the objective of this positioning is to prevent the position of the head from changing the tomographic results obtained since head flexion induces closure of the airway, especially in its lower region (Walsh et al., 2008; Strohl et al., 2012; Ota et al., 2011). In the present study, the vertebral angle was used for the first time for tomography in order to measure possible changes in head position during tomography. The values obtained clearly showed that there was no variation in head position, guaranteeing fidelity of the results obtained. The same applies to the anthropometric measurements, which did not show significant changes.

No correlation was observed between the reduction of apnea and the increase in the airway of patients with mild OSA, but a moderate correlation was observed between the reduction of AHI and the increase in LP and TP in subjects with severe OSA and a strong correlation between UP and the reduction of AHI in subjects with moderate OSA.

After SARME, the hard palate showed an expected transverse increase (24% in the first premolar region and 18% in the first molar region), although its depth was reduced by 15% in the more anterior region and by 9% in the posterior region. The height/width ratio was also changed, from 0.45 ± 0.17 to 0.30 ± 0.07 for the premolar region and from 0.48 ± 0.08 to 0.37 ± 0.07 in the molar region. This reduction means that SARME promoted an increase in palate width and a decrease in palate depth and suggests that the transverse space increase, facilitating the accommodation of the tongue in the oral cavity in parallel to the reduction of palate height, theoretically facilitated the coupling of the tongue and its stabilization during sleep.

A moderate correlation was detected between initial AHI and initial palate width in the region of the first premolars ($r = 0.624$) and between the first molars ($r = 0.661$), suggesting that the narrowing of the maxilla plays an important role in the determination of OSA. A moderate correlation was also observed between initial AHI and palate height/width ratio in the premolar region ($r = 0.539$ for AHI). This means that, the narrower and the higher the palate, especially in the premolar region, the higher the probability of developing apnea, supporting the hypothesis of a lack of space for coupling and of the occurrence of tongue fall during sleep (Jordan et al., 2009). This hypothesis is further supported when the reduction of AHI is correlated with palate dimensions, showing that the reduction of palate height in the first premolar region was moderately correlated ($r = 0.628$) with an improvement of OSA. A moderate correlation of AHI reduction with increased palate width was observed in the premolar region but not in the molar region. Thus, a transverse reduction in the anterior region appears to play a more important role in OSA than a reduction of the molar region.

However, in these patients with severe OSA, the reduction of palate depth seems to play an even more determinant role, since we detected a very strong correlation with the improvement of OSA both regarding the premolar and molar regions ($r = 0.940$ and $r = 0.994$, respectively). In this same group, the correlation of height/width ratio with OSA improvement was strong in the molar region ($r = 0.880$) and extremely strong in the premolar region ($r = 0.922$). This means that, in the treatment of OSA, the greater the width of the maxilla and the lower the depth of the palate, especially in the premolar region, the better will be the results. This correlation appeared to be even stronger in moderate OSA. The improvement of palate dimension in all measurements and in the two regions was correlated with the improvement of AHI. A correlation was also detected between palate dimensions and volumetric gain of the pharynx.

The transverse dimensions of the maxilla in the premolar region also appear to have a greater influence than those of the molar region. A moderate correlation was observed between LP increase and total LP due to the increase of palate width in this region ($r = 0562$ and $r = 0.617$). It seems that palate depth in this region

Table 10
Correlation between the difference in palate width, height and height/width ratio and the increase in airway in patients with OSA according to the severity of the condition.

Group		% P width	% P Height	% M Width	% M Height	% P Ratio	% M Ratio
Mild OSA	% UP	0.550	0.662	0.003	0.241	0.695	0.231
	% LP	0.515	0.085	0.295	0.512	0.064	0.520
	% TP	0.677	0.207	0.264	0.228	0.758	0.024
Moderate OSA	% UP	0.472	0.232	0.745	0.929	0.308	0.920
	% LP	0.749	0.894	0.478	0.571	0.855	0.171
	% TP	0.120	0.369	0.226	0.972	0.295	0.527
Severe OSA	% UP	0.486	0.100	0.919	0.193	0.278	0.551
	% LP	0.879	0.745	0.345	0.629	0.916	0.266
	% TP	0.860	0.634	0.518	0.476	0.826	0.087

% UP – Percent increase in the upper pharynx; % LP – Percent increase in the lower pharynx; %TP – percent increase in the total pharynx; %P Width – Percent increase in palate width in the premolar region; %P Height – Percent reduction of palate depth in the premolar region; %M Width – Percent increase in palate width in the molar region; %M Height – Percent reduction of palate depth in the molar region; %P Ratio – Percent variation in the palate height/width ratio in the premolar region.

only had a direct effect on UP in both the premolar and molar regions (r = 0520 and r = 0.569).

Various correlations between LP and palate measurements were observed in patients with severe OSA. All the correlations between LP and transverse palate measurements in the premolar region were extremely strong or strong (r = 0.879 and r = 0.745). The reduction of palate height in the molar region showed a moderate correlation with the LP increase. Among patients with moderate apnea, the factors measured in the premolar region support the idea that this region has a stronger correlation with the increase in LP. These TP correlations show similarity to LP correlations. Curiously, UP measurements showed a correlation only with palate width in the molar region (r = 0.919).

Thus, evidence indicates that the increase in UP volume in patients with severe OSA is strongly related to the reduction of palate height in the molar region and that the LP is more related to the increase in palate width in the premolar region and to the depth of the premolar and molar region.

The advancement of the tongue toward the interior of the buccal cavity seems to be the main factor explaining this gain in LP and consequently in TP. With the increase in the dental and bone perimeter promoted by surgical maxillary expansion, the tongue can find enough space within the dentoalveolar framework. This explains why the increase in pharyngeal space occurs in the lower levels of the organ, in contrast to what would be expected if there were a direct effect on the bone dimensions, where the greater increase in space should occur in the nasal cavity and in the upper portion of the pharynx (Iwasaki et al., 2013; Ozbek et al., 2009; Phoenix et al., 2011).

Another hypothesis regarding the physiopathology of OSA is that palate enlargement and lowering promote a better support for the tongue during sleep, especially during its moment of relaxation. This possibility is supported by the results of the correction of palate measurements (width and height) and the behaviors of OSA and of the airway.

5. Conclusion

The narrowing of the palate, especially in the region of the premolars, and its greater depth are related to the severity of OSA. SARME promoted transverse maxillary enlargement and lowering of palate depth, reducing OSA in adult patients and also increasing the airway, especially in its lower half.

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Declaration of Competing Interest

The authors declare that there are no conflicts of interest and that the study received no support from the industry or other similar sources.

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