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Computed tomography visualizing alterations in the upper airway after orthognathic surgery

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ABSTRACT

Three-dimensional (3D) software has revolutionized planning in orthognathic surgery. This technology allows the simulation of surgical movements and evaluation of the volume and area of the pharyngeal airway space (PAS), which are not possible with two-dimensional (2D) software. Many patients undergo orthognathic surgery to improve occlusion and facial profile. The PAS may increase or decrease depending on the surgical movements. This study aimed to evaluate the changes in the area and volume of the PAS in patients having bimaxillary movement in orthognathic surgery. The minimum axial area and volume of the PAS (preoperative (T0) and postoperative (T1) air volumes) of 68 patients (26 male and 42 female, mean age 36.6 ± 12.1 years) were analyzed. Evaluations were conducted using cone-beam computed tomography in the Nemoceph 3D-OS program. A paired t-test was used to compare pre- and postoperative volume data, and the Wilcoxon test was used to compare pre- and postoperative data of the minimal axial area. All the tests were performed with Statistica software (StatSoft Inc., Tulsa, OK, USA), and a significance level of 5% was adopted. In the study of the method error, no casual or systematic error was found between the first and second measurements of the variables ($p > 0.05$ in all measurements). Bimaxillary surgery presented a mean of 70.46% in volume and a median increase of 61.27% in the minimum axial area, which varied from −22.50% to 659.06%. The results demonstrated that bimaxillary advancement significantly increased the volume and minimum axial area of the upper airway; however, the increase was not homogeneous in all the patients.

1. Introduction

Malocclusion and facial esthetics are the main factors that lead a patient to opt for orthognathic surgery, which is conducted for dentoskeletal discrepancies in adult patients. Orthognathic surgery aims to provide an adequate maxillomandibular relationship with normal dental occlusion to promote a balance in the stomatognathic system. Orthognathic surgery results in changes in soft tissues, and these alterations can lead to an increase or decrease in the air space (Foranda and Elias, 2011; Mattos et al., 2011).

Planning is becoming increasingly accurate in orthognathic surgery because of technological advancements. The main advantage is the prediction of surgical treatment results in terms of correction of dentoskeletal deformities, function, and aesthetics. Recent studies have analyzed the precision of software for surgical planning and changes in hard and soft tissues (Foranda and Elias, 2011; Raffaini and Pisani, 2013; Brunetto et al., 2014; Burkhard et al., 2014; Butterfield et al., 2015; Hart et al., 2015).

Patients with class I or II malocclusion usually have maxillomandibular advancement surgery, which is associated with increased air space. However, the morphological and volumetric changes are still not well known. Similarly, patients who have class III malocclusion can be treated only with a mandibular retreat or

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combined bimaxillary surgery with maxillary advancement and mandibular setback. The mandibular retreat has a higher risk of decreasing the upper airway space than the bimaxillary surgery (Mattos et al., 2011).

Most of the research related to airspace evaluation has been performed through cephalometric analyses of profile cephalograms, with specific cephalometric points and soft tissue landmarks. Some studies showed that the position and posture of a patient interfere in air space, making 2D analysis imprecise. A 3D image allows the evaluation of the area and volume more precisely than 2D images, where the position of the patient's head interferes with the measurement (Aboudara et al., 2003).

According to Mattos et al. (2011), further research is necessary to evaluate the alterations in the volume of the airways caused by orthognathic surgery using cone-beam computed tomography (CBCT). CBCT offers significant advantages compared to linear measurements by cephalometrics. In addition, previous work with CBCT scanning involved a small sample and/or lack of standardization in the way the measurements were performed (Mattos et al., 2011; Raffaini and Pisani, 2013; Mehra et al., 2001; Park et al., 2012; De Souza Carvalho et al., 2012).

Therefore, the present study aimed to evaluate the variation in the axial area and volume of the pharyngeal air space (PAS) in patients with classes I, II, and III skeletal malocclusions. CBCT (Nemoceph 3D-OS software, Nemotec, SL, Madrid, Spain) was used to plan bimaxillary orthognathic surgery for these patients.

2. Materials and methods

This research involved a retrospective sample composed of 68 adult patients with occlusal pattern and facial profile of classes I, II, and III skeletal occlusions. The ANB (A point-nasion-B point) angle was used to classify the skeletal relationship between the maxilla and mandible relative to the cranial base (Frankfurt plane) as follows: Class I, between 1 and 4 ANB; class II, > 4 ANB; and class III, < 1 ANB. Patients underwent bimaxillary advancement or mandible setback orthognathic surgery, which was associated with advancement genioplasty or counter-clockwise rotation of the occlusal plane, respectively. This research was approved by the Research Ethics Committee of the Bauru Dental School, University of Sao Paulo (protocol 1.595.857).

The selected CBCT examination findings belonged to the collection of a private practice clinic and were part of the documentation required for planning, preoperative, and postoperative follow up of the patients. The same team of maxillofacial surgeons performed the surgical procedures of the patients involved in the sample. These surgeons used the same surgical technique of bilateral sagittal osteotomy for mandibular advancement and total Le Fort I osteotomy for maxillary advancement with the use of a rigid internal fixation with titanium miniplates and trans-operative maxillomandibular fixation. All patients received pre- and post-operative orthodontic treatment.

To standardize the sample selection, the study included adult patients of both sexes, and patients with classes I, II, and III skeletal malocclusions with bimaxillary surgical correction. The following characteristics were adopted as exclusion criteria: dental loss or agenesis of a large number of teeth (six or more); extraction of teeth before the orthognathic surgery in orthodontic preparation; severe facial asymmetry; presence of syndromes; respiratory diseases; obstructive sleep apnea; and disorder or degeneration of the temporomandibular joint.

The evaluations were made from CBCT images (I-Cat Cone-Beam, Imaging Science, Hatfield, PA, USA) with field-of-view protocol 23 × 17 cm (120 kVp, 36.90 mAs, 40 s, voxel of 0.40 mm). CBCT data were converted to Digital Imaging and Communications in Medicine (DICOM) format, and 3D measurements of the airway area and volume were conducted (Nemoceph 3D-OS).

The patients in this study underwent CBCT examination in the preoperative period, after orthodontic (T0) preparation, and for a minimum interval of 6 months postoperative preparation after orthognathic surgery (T1) under the same conditions. These conditions were as follows: patient sitting down, head in a natural position; oriented to breathe quietly and told not to swallow during the examination; and instructed to remain in maximum usual intercuspidation. The initial and final CBCT scans were performed on the same CBCT scanner.

To evaluate the superior air space, points (Raffaini and Pisani, 2013; Schendel et al., 2014) were used as a reference. Posterior nasal spine was the point located at the tip of the posterior nasal spine; cervical vertebra 2 (VC_2) was the point at the upper body of the second cervical vertebra; cervical vertebra 3 (VC_3) was the point at the posterior-inferior aspect of the body of the third cervical vertebra; and hyoid bone (H) was the posterior-superior point of the hyoid bone.

Thus, the PAS in the retropalatal area was the upper border (line between the posterior and second nasal spine cervical vertebrae), and the retroglossal area was the lower border (line between the hyoid bone and the third cervical vertebra). Fig. 1 shows the demarcation of the reference points.

To evaluate the method error and to determine the reliability of the results, 20 CBCT scans were randomly selected to perform the same measurement twice within a 30-day interval.

To test the hypothesis of the normal distribution of cephalometric variables, the Kolmogorov–Smirnov test was applied. The paired t-test was used to compare pre- and postoperative volume-related data, whereas the Pearson test was used to correlate the volume and PAS area data into the skeletal classes I to III. All the tests were performed using the statistical software Statistica Version 7.0 (StatSoft Inc., Tulsa, OK, USA) with a significance level of 5%.

3. Results

A total of 68 patients were evaluated: 18 class I, 32 class II, and 18 class III, including 26 men and 42 women, between 24 and 65 years of age (mean 36.56 years). Table 1 shows data from the selected sample. No patient was treated for obstructive sleep apnea. A total of 42 patients (61.7%) underwent postoperative genioplasty, with 11 class I, 21 class II, and 10 class III. Their mean movement

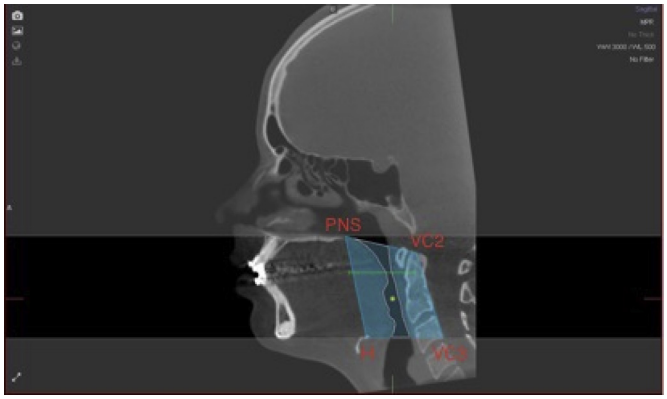

Fig. 1. Computed tomography image in a sagittal section showing the area of pharyngeal airspace marked on the trapezoid in green. The region of interest was demarcated by the red line that circumvented the anterior and posterior portion of the pharynx. Posterior nasal spine (PNS); cervical vertebra 2 (VC_2); cervical vertebra 3 (VC_3); and hyoid bone (H).

Table 1
Age (Average ± Standard Deviation), Genre and Total of patients divided by Skeletal Class.

	Skeletal Class I	Skeletal Class II	Skeletal Class III
Age (years)	35,67 ± 10,78	36,56 ± 12,96	38,94 ± 15,31
Male	8	9	9
Female	10	23	9
Total	18	32	18

was 0.85 mm in class I, 3.52 mm in class II, and 0.98 mm in class III, presenting a statistically significant difference ($p < 0.05$) in patients with class II malocclusion compared to the other two groups of patients. Table 2 gives the mean values of the movement by genioplasty.

The movements performed in the surgical procedures of patients with class I malocclusions ranged from 7.15 mm to 16 mm for mandibular advancement, averaging 12.39 mm. Patients with class II malocclusion showed variations ranging from 7.1 mm to 19.65 mm, with a mean of 13.38 mm of mandibular advancement. In patients with class III malocclusions, setback was performed from 0.38 mm to 11.01 mm, with a mean of 4.35 mm. The jaw advances ranged from 1.78 mm to 9.48 mm, with an average of 4.37 mm. The mean movement of patients with class III malocclusions was 0.98 mm, with a statistically significant difference ($p < 0.05$) when compared to classes I and II facial patterns. Table 3 gives the mean values.

3.1. PAS volume

In patients with class I malocclusions undergoing mandibular advancement, an increase in mean PAS volume of 7.89 mm^3 was observed, while patients with class II and III malocclusions had an average increase of 9.73 mm^3 and 5.49 mm^3, respectively. The highest PAS volume was found in patients with class I malocclusions with 23.63 mm^3, followed by patients with class II malocclusions with 21.14 mm^3 and class III malocclusions with 20.85 mm^3. In all the classes, an average increase in PAS volume was observed when comparing preoperative and postoperative results ($p \leq 0.05$). Table 4 lists the pre-, and postoperative means and standard deviations of PAS volume and their differences. Fig. 2 shows the preoperative SBP volume, and Fig. 3 shows the postoperative change.

3.2. PAS area

When the measurements of the PAS area were performed, the highest mean was obtained in the patients with class I malocclusions with 292.65 mm^2, followed by the patients with class III malocclusions with 285.85 mm^2, and class II malocclusions with 244.14 mm^2. The largest increase in PAS area was found in class II patients with a difference of 131.28 mm^2. In all the classes, there was an average increase of the PAS area when comparing the preoperative and postoperative period ($p \leq 0.05$). Table 5 lists the pre- and postoperative means and standard deviation of the PAS area and their differences.

Table 2
Mentoplasty movimentation in Class I, Class II and Class III (Average ± Standard Deviation).

	Skeletal Class I	Skeletal Class II	Skeletal Class III
Mentoplasty (mm)	0,89 ± 5,03	3,52 ± 4,34*	0,98 ± 5,33
Patients	11	21	10

*Statistical Difference $p < 0.05$.

Table 3
Mandible movimentation in Class I, Class II and Class III (Average ± Standard Deviation).

	Skeletal Class I	Skeletal Class II	Skeletal Class III
Advancement (mm)	12,39 ± 2,59	13,38 ± 2,82	4,37 ± 2,73
Setback (mm)	-	-	−4,35 ± 3,71
Average ± SD (mm)	12,39 ± 2,59	13,38 ± 2,82	0,98 ± 5,33*

*Statistical Difference $p < 0.05$.
SD Standard Deviation.

Table 4
Pre, post-operative and difference of PAS volume (Average ± Standard deviation).

	Pre (mm^3)	Pos (mm^3)	Dif (mm^3)
Class I	15,74 ± 7,28	23,63 ± 10,21	7,89 ± 6,93*
Class II	11,41 ± 4,11	21,14 ± 6,47	9,73 ± 5,00*
Class III	15,35 ± 5,38	20,85 ± 9,58	5,49 ± 7,53*

*PAS Volume $p < 0,05$.

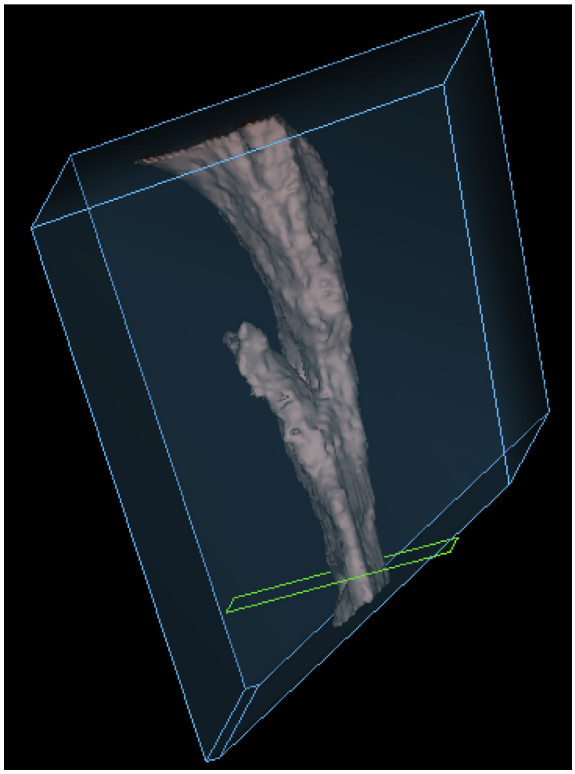

Fig. 2. Computed tomography in a sagittal section showing the volume of pharyngeal airway space (PAS) in preoperative period.

When correlated, volume results show class I and class II values different from class III values ($p = 0.016$). There was also a difference when correlating the area between classes, with class III being different in relation to the other two groups ($p = 0.011$). Table 6 gives the values of the volume and area correlations. Fig. 4 shows the preoperative area of the SBP, and Fig. 5 shows the change that occurred in the postoperative period.

4. Discussion

The variables of PAS volume and area were chosen because they are extremely important in the understanding of the respiratory process. The volume dictates the storage capacity of the PAS, and

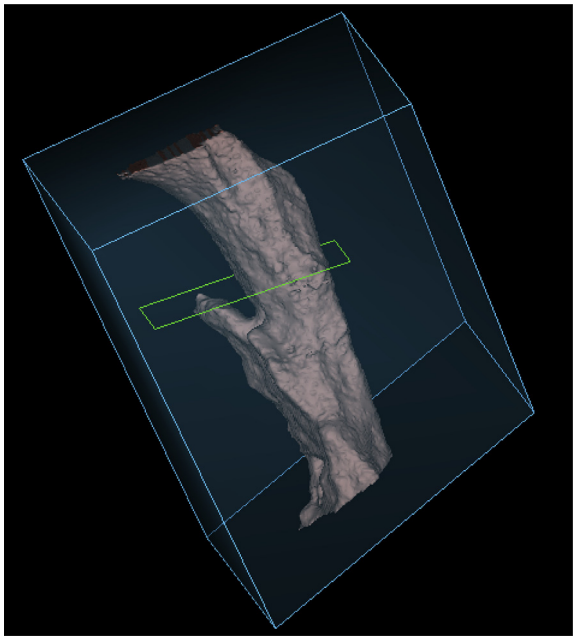

Fig. 3. Computed tomography in a sagittal section showing the volume of pharyngeal airway space (PAS) in postoperative period.

Table 5
Pre, post-operative and difference of PAS area (Average ± Standard deviation).

	Pre (mm^2)	Pos (mm^2)	Dif (mm^2)
Class I	178,53 ± 91,40	292,65 ± 138,64	114,12 ± 87,09*
Class II	112,86 ± 57,50	244,14 ± 94,12	131,28 ± 80,96*
Class III	181,18 ± 78,98	285,85 ± 123,73	104,68 ± 131,08*

*PAS Area $p < 0,05$.

Table 6
Pearson correlation between PAS volume, area and advancement in Skeletal Class I to III.

	Skeletal Class I	Skeletal Class II	Skeletal Class III
PAS volume	p = 0,189	p = 0,379	p = 0,016*
PAS area	p = 0,122	p = 0,246	p = 0,011*

*Statistically significant.

the minimum axial area is the narrowest site of the PAS. Schendel et al. (2012) evaluated the development of the upper airway in 1300 patients who underwent orthodontic treatment. Their study aimed to establish normative data for the size and shape of the airway at different ages, and considered the volume and minimum axial area as the main variables (Schendel et al., 2012).

Regarding the use of diverse programs with the same applicability, Nemotech is barely mentioned in the literature. Articles that refer to it analyze only cephalometry and/or facial soft tissue profile, not upper airways. In contrast to the Dolphin 3D program, which is already well established, Nemotech demonstrates high accuracy and reliability for the evaluation of volumetric measurements of airspace (Brunetto et al., 2014; De Souza Carvalho et al., 2012; El and Palomo, 2010; Weissheimer et al., 2012). The patient sample was chosen according to the inclusion and exclusion criteria already mentioned, and the patients were selected consecutively. The inclusion of female patients and those with class II malocclusion addressed a predominant characteristic of the group that sought this type of corrective surgery in our surgery department.

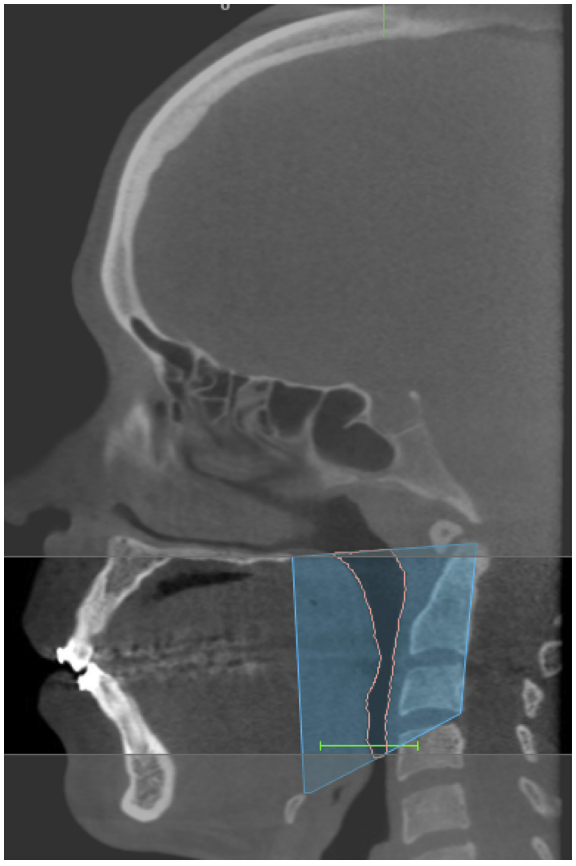

Fig. 4. Computed tomography in a sagittal section showing the area of pharyngeal airway space (PAS) in preoperative period.

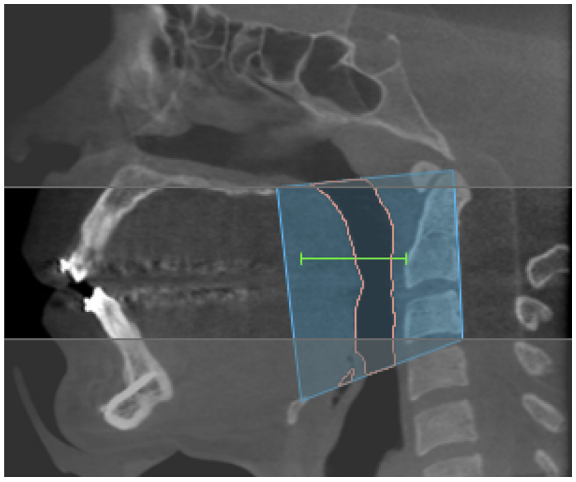

Fig. 5. Computed tomography in a sagittal section showing the area of pharyngeal airway space (PAS) in postoperative period.

Cephalometric images have been commonly used to evaluate the anatomy of the facial skeleton and upper airway; however, they are limited in their representation of 3D structures. CBCT is a highly reliable diagnostic tool that provides 3D representation of the structures of the head and neck (Butterfield et al., 2015). Some studies have used CBCT to provide accurate 3D images of upper airway alterations in the different surgical movements of the maxillomandibular complex (Alves et al., 2012; Araújo, 2013). In this study, there is a large difference in air concentration gradient

comparing soft or hard tissues that allows greater accuracy for airway identification and quantification using a systematic method of varying gray-scales, thereby making CBCT an ideal technology for evaluating PAS (De Souza Carvalho et al., 2012).

De Sousa Miranda et al. (2015) performed a study with 23 patients who underwent a maxillomandibular and counter-clockwise advancement surgical procedure of the occlusal plane. In their study, PAS volume had a mean growth of 10.118 mm^3. (De Sousa Miranda et al., 2015). Similarly, the PAS variable increased in the current study, demonstrating a significant difference of 58.08. These values are close to or better than those in the referenced literature.

In an analysis with patients arranged at highly specific intervals, 34 in a sample of 50 had a change in PAS from −50% to 100%. Of these 34 patients, three displayed a negative percentage, that is, a reduction in PAS. Schendel et al. (2014) evaluated 10 patients in the pre- and postoperative period who underwent maxillomandibular advancement using CBCT with 3D software. They obtained a gain of 74.1 cm^3 in the preoperative period and 176.9 cm^3 in the postoperative period. However, two patients in their sample exhibited a reduction in airway volume: one in the retropalatal region and the other in the retroglossal region (Schendel et al., 2014). These results demonstrate the great variability in the area of the greatest contusion of the oropharynx, where orthognathic surgery alters the pharyngeal anatomy, and this narrow region may increase or decrease.

De Sousa Miranda et al. (2015) investigated 23 patients who underwent surgical maxillomandibular advancement and counter-clockwise rotation of the occlusal plane. They reported an average of 20.476 cm^3 in the preoperative period and 30.595 cm^3 in the postoperative period (De Sousa Miranda et al., 2015). In our study, a mean of 15.834 cm^3 was obtained preoperatively compared to 25.368 cm^3 in the postoperative period of at least 6 months. These findings were reaffirmed in the revised literature, and the variation between the means in T0 and T1 was practically identical.

Analyses on the patients at specific intervals of percentage changes in PAS volume revealed that 34 patients (68%) had a gain of up to 100% of air volume, 12 patients (24%) had a gain of more than 100%, and only four patients (8%) had a reduction in air volume. In a study of 23 patients, two patients who had a reduction in air volume were reported by De Sousa Miranda et al., 2015. Butterfield et al. (2015) believed that maxillomandibular advancement, despite producing an increase in airway width, decreased constriction and resistance of air passages, leading to a decrease in the height of this region. This phenomenon possibly justified the reduction found in the volume (Butterfield et al., 2015).

Mehra et al. (2001) reported an increase in volume of the upper airway with bimaxillary advancement. Discrepancies in these changes were noted between the referred studies. Butterfield et al. (2015) reported that these differences in volumetric gains between studies could be a result of the different parameters used to delineate the limits of PAS, and variation in maxillomandibular motion, magnitude, and occlusal plane rotation.

Therefore, the interrelationship between the skeletal position of the maxilla and mandible is critical. The soft tissues of attachment and the muscles that anchor and stabilize the airway explain how skeletal movements can influence the position, shape, and size of the air tube (Saitoh, 2004). Through advancement of the bone insertion sites of the pharyngeal airway musculature, maxillomandibular advancement increases total air volume, compresses the lateral walls, and changes the airway shape from circular to oblong, resulting in an airway that is less prone to collapse (Butterfield et al., 2015).

5. Conclusion

This study quantifies the mean values of changes in the air volume and minimal axial area after bimaxillary advancement surgery in patients with classes I, II, and III skeletal malocclusions. The results reveal that maxillomandibular advancement surgery provides a significant volumetric increase in the upper air space and minimal axial area, despite the class III setback surgery. However, this gain does not always occur at the same magnitude for all patients.

Therefore, further work with longer follow-up of PAS is necessary to evaluate the effectiveness of this type of surgical treatment for soft tissue alterations that occur with orthognathic surgery.

References

Aboudara CA, Hatcher D, Nielsen IL, Miller A: A three-dimensional evaluation of the upper airway in adolescents. Orthod Craniofac Res 6: 173, 2003

Alves M, Baratieri C, Mattos CT, Brunetto D, Fontes RC, Santos JRL, Ruellas ACO: Is the airway volume being correctly analyzed? Am J Orthod Dentofac Orthop 141(5), 2012

Araújo MM: Estudo comparativo de dois programas de computador (DOLPHIN IMAGING® E NEMOTEC®) versus o método manualutilizados para análises cefalométricas de pacientes com deformidade dento-facial padrão II. In: São José dos Campos. Tese (Livre-Docência) - Instituto de Ciência e Tecnologia de São José dos Campos. UNESP - Univ Estadual Paulista, 2013

Brunetto DP, Velasco L, Koerich L, Araújo MT: Prediction of 3-dimensional pharyngeal airway changes after orthognathic surgery: a preliminary study. Am J Orthod Dentofacial Orthop 146: 299, 2014

Burkhard JP, Dietrich AD, Jacobsen C, Roos M, Lübbers HT, Obwegeser JA: Cephalometric and three-dimensional assessment of the posterior airway space and imaging software reliability analysis before and after orthognathic surgery. J Craniomaxillofac Surg 42: 1428, 2014

Butterfield KJ, Marks PL, McLean L, Newton J: Linear and volumetric airway changes after maxillomandibular advancement for obstructive sleep apnea. J Oral Maxillofac Surg 73: 1133, 2015

De Sousa Miranda W, Álvares de Castro Rocha V, Lara Dos Santos Marques K, Trindade Neto AI, do Prado CJ, Zanetta-Barbosa D: Three-dimensional evaluation of superior airway space after orthognathic surgery with counter clockwise rotation and advancement of the maxillomandibular complex in class II patients. Oral Surg Oral Med Oral Pathol Oral Radiol 120: 453, 2015

De Souza Carvalho AC, Magro Filho O, Garcia Jr IR, Araujo PM, Nogueira RL: Cephalometric and three-dimensional assessment of superior posterior airway space after maxillomandibular advancement. Int J Oral Maxillofac Surg 41: 1102, 2012

El H, Palomo JM: Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofac Orthop 137: 50, 2010

Foranda R, Elias FM: Avaliação de dois programas de computador na previsão do perfil facial de pacientes submetidos à cirurgia ortognática. RPG Rev Pós Grad 18: 229, 2011

Hart PS, McIntyre BP, Kadioglu O, Currier GF, Sullivan SM, Li J, Shay C: Postsurgical volumetric airway changes in 2-jaw orthognathic surgery patients. Am J Orthod Dentofacial Orthop 147: 536, 2015

Mattos CT, Vilani GN, Sant'Anna EF, Ruellas AC, Maia LC: Effects of orthognathic surgery on oropharyngeal airway: a meta-analysis. Int J Oral Maxillofac Surg 40: 1347, 2011

Mehra P, Downie M, Pita MC, Wolford LM: Pharyngeal airway space changes after counterclockwise rotation of the maxillomandibular complex. Am J Orthod Dentofacial Orthop 120: 154, 2001

Park SB, Kim YI, Son WS, Hwang DS, Cho BH: Cone-beam computed tomography evaluation of short- and long-term airway change and stability after orthognathic surgery in patients with class III skeletal deformities: bimaxillary surgery and mandibular setback surgery. Int J Oral Maxillofac Surg 41: 87, 2012

Raffaini M, Pisani C: Clinical and cone-beam computed tomography evaluation of the three-dimensional increase in pharyngeal airway space following maxillomandibular rotation-advancement for Class II-correction in patients without sleep apnoea (OSA). J Craniomaxillofac Surg 41: 552, 2013

Saitoh K: Long-term changes in pharyngeal airway morphology after mandibular setback surgery. Am J Orthod Dentofacial Orthop 125: 556, 2004

Schendel SA, Jacobson R, Khalessi S: Airway growth and development: a computerized 3-dimensional analysis. J Oral Maxillofac Surg 70: 2174, 2012

Schendel SA, Broujerdi JA, Jacobson RL: Three-dimensional upper-airway changes with maxillomandibular advancement for obstructive sleep apnea treatment. Am J Orthod Dentofac Orthop 146: 385, 2014

Weissheimer A, de Menezes LM, Sameshima GT, Enciso R, Pham J, Grauer D: Imaging software accuracy for 3-dimensional analysis of the upper airway. Am J Orthod Dentofac Orthop 142: 801, 2012