Three-dimensional pharyngeal airway space changes after bimaxillary advancement

Thaís Lima ROCHA
https://orcid.org/0000-0003-3382-0868

Ludmila LIMA
https://orcid.org/0000-0002-7758-0870

Arnaldo PINZAN
https://orcid.org/0000-0002-7195-5299

Eduardo SANT’ANA
https://orcid.org/0000-0001-5994-5453

Renato Luiz Maia NOGUEIRA
https://orcid.org/0000-0003-1940-0402

Caroline Nemetz BRONFMAN
https://orcid.org/0000-0001-5143-2178

Guilherme JANSON
https://orcid.org/0000-0001-5969-5175

Submitted: December 06, 2019 • Revised and accepted: August 19, 2020

arnaldopinzan@gmail.com

How to cite: Rocha TL, Lima L, Pinzan A, Sant’Ana E, Nogueira RLM, Bronfman CN, Janson G. Three-dimensional pharyngeal airway space changes after bimaxillary advancement. Dental Press J Orthod. 2021;26(5):e2119364.

(1) Universidade de São Paulo, Faculdade de Odontologia de Bauru, Departamento de Ortodontia (Bauru/SP, Brazil).
(2) Universidade de São Paulo, Faculdade de Odontologia de Bauru, Departamento de Estomatologia (Bauru/SP, Brazil).
(3) Universidade Federal do Ceará, Faculdade de Odontologia, Departamento de Cirurgia Oral (Fortaleza/CE, Brazil).
(4) † Deceased during the preparation of the manuscript.
ABSTRACT

Introduction: The probability of improvement in the upper airway space (UAS) with orthognathic surgery should be considered during the surgical-orthodontic treatment decision, providing not only an esthetic, but also a functional benefit for the patient.

Objective: The purpose of this study was to evaluate the 3D changes in the upper airway space after maxillomandibular advancement surgery (MMA).

Methods: A retrospective analysis of 56 patients, 21 male and 35 female, with a mean age of 35.8 ± 10.7 years, who underwent MMA was performed. Pre- and postoperative cone-beam computed tomography scans (CBCT) were obtained for each patient, and the changes in the UAS were compared using Dolphin Imaging 11.7 software. Two parameters of the pharyngeal airway space (PAS) were measured: airway volume (AV) and minimum axial area (MAA). Paired t-test was used to compare the data between T₀ and T₁, at 5% significance level.

Results: There was a statistically significant increase in the UAS. Bimaxillary advancement surgery increased the AV and the MAA, on average, by 73.6 ± 74.75% and 113.5 ± 123.87%, respectively.

Conclusion: MMA surgery tends to cause significant increase in the UAS; however, this increase is largely variable.

Keywords: Bimaxillary advancement. Orthognathic surgery. Upper airway space. Cone-beam computed tomography. Obstructive sleep apnea.
RESUMO

Introdução: A probabilidade de melhoria do espaço aéreo superior (EAS) com cirurgia ortognática deve ser considerada durante a decisão do tratamento ortodôntico-cirúrgico, proporcionando não somente um benefício estético, mas também funcional, para o paciente.

Objetivo: O objetivo do presente estudo foi avaliar as alterações 3D no espaço das vias aéreas superiores após a cirurgia de avanço maxilomandibular (AMM).

Métodos: Foi realizada uma análise retrospectiva de 56 pacientes, 21 homens e 35 mulheres, com média de idade de 35,8 ± 10,7 anos, submetidos a AMM. Foram obtidas tomografias computadorizadas de feixe cônico (TCFC) pré- e pós-operatórias para cada paciente, e as alterações no EAS foram comparadas usando o software Dolphin Imaging v. 11.7. Foram medidas dois parâmetros do espaço aéreo faríngeo (EAF): volume das vias aéreas (VVA) e área axial mínima (AAM). Foi utilizado o teste t pareado para comparar os dados entre T₀ e T₁, com nível de significância de 5%.

Resultados: Houve um aumento estatisticamente significativo no EAS. A cirurgia de avanço bimaxilar aumentou o volume das vias aéreas (VVA) e a área axial mínima (AAM) em média 73,6 ± 74,75% e 113,5 ± 123,87%, respectivamente.

Conclusão: A cirurgia de AMM tende a causar o aumento significativo do EAS; no entanto, esse aumento é altamente variável.

Palavras-chave: Avanço bimaxilar. Cirurgia ortognática. Vias aéreas superiores. Tomografia computadorizada de feixe cônico. Apneia obstrutiva do sono.
INTRODUCTION

Harmonious facial esthetics and great functional occlusion have been recognized as the two most important goals of orthodontic treatment. For the correct indication of treatment, an accurate malocclusion and skeletal discrepancy diagnosis is needed. This care leads to adequate planning and multidisciplinary treatment with the objective of an esthetic and functional correction.¹

Dissatisfaction with facial esthetics is considered the most common motivating factor in the search for orthognathic surgery, since this is the procedure indicated in cases of severe dental and skeletal discrepancies in adult patients.²

Airways effects caused by skeletal movements of the basal bones after orthognathic surgery are essential because they produce a change in the position of the hyoid bone and tongue.³

Upper Airway Space (UAS) is formed by soft tissue structures: tonsils, soft palate, uvula, tongue and lateral pharyngeal wall. The mandible and the hyoid bone are the main craniofacial bone structures that determine the airway size. Thus, the UAS anatomical conformation allows factors such as obesity, muscle hypotonicity and mandibular deficiency to favor the obstruction, generating Obstructive Sleep Apnea (OSA), which has been the subject of numerous studies.⁴⁻⁷
OSA is characterized by recurrent episodes of partial or complete upper airway (UA) obstruction during sleep. The airflow is reduced in hypopnea or completely interrupted in apnea. These respiratory events are normally interrupted by micro-arousals. According to the American Academy of Sleep Medicine (AASM) criteria, to diagnose OSA it is necessary that the patient presents the following symptoms: excessive daytime sleepiness not explained by other factors, choking during sleep, recurrent awakenings, non-repairing sleep, daytime fatigue or difficulty in concentrating, and polysomnographic monitoring overnight showing five or more obstructive respiratory events per hour of sleep.8

Several factors can aggravate or predispose to sleep disorders. Changes in the upper airway space caused by orthognathic surgery have been a concern, because the quality of sleep can be increased or aggravated by these changes. The main concern involving these dimensional changes caused by orthognathic surgery is the sleep quality.3,9-11

Thus, the orthodontist should be aware of changes that may occur in the upper airway before proposing orthognathic surgery for patients. It is important to assess whether the patient with mandibular retrusion has associated symptoms of obstructive sleep apnea, such as obesity, excessive daytime sleepiness and snoring. The reason for this is that the
possibility of improvement or not with orthognathic surgery should be considered during the decision for surgical orthodontic treatment, providing not only esthetic but also functional benefits for the patient.\textsuperscript{3,9,12,13}

Although there is clear evidence that bimaxillary advancement surgery can effectively increase the upper airway,\textsuperscript{14,15} most studies have a limited number of patients.\textsuperscript{16-20} Besides, they have not individually quantified the amount and percentages of upper air volume and minimum axial area increase. Therefore, the purpose of this study is to evaluate, in 3D images, the changes in the pharyngeal airway space (PAS) in skeletal Class I or Class II malocclusion patients, submitted to bimaxillary advancement surgery using bilateral sagittal split osteotomy for mandibular advancement, associated with maxillary advancement with Le Fort I maxillary osteotomy.

**MATERIAL AND METHODS**

This study was approved by the Ethics in Research Committee at *Faculdade de Odontologia de Bauru* (FOB-USP, Brazil), under protocol number 48092215.0.0000.5417.

Using an alpha error of 5% and a beta error of 20%, considering a standard deviation of 37%, to detect a minimum difference of 10% for the volumetric pharyngeal space variable, the results indicated that a minimum of 55 patients was necessary.\textsuperscript{13}
A retrospective analysis of 56 patients (35 female, 21 male), with a mean age of 35.8 ± 10.7 years, who underwent bimaxillary advancement orthognathic surgery due to functional and esthetic complaints, was performed. The sample was selected to be as homogeneous as possible. Inclusion criteria consisted of adult patients of both sexes diagnosed primarily with skeletal Class II and some with skeletal Class I malocclusion, submitted to bimaxillary advancement surgery. These patients did not have a documented OSA diagnosis and had no respiratory indications for surgery. Patients with severe facial asymmetry, transverse discrepancy of the maxilla, presence of syndromes, temporomandibular joint disorder or degeneration, and incomplete records were excluded. Sample characteristics regarding sex and age are presented in Table 1.

Table 1: Sample distribution by sex and age.

|                | Skeletal Class I |          | Skeletal Class II |          | Total sample |          |
|----------------|-----------------|----------|-------------------|----------|--------------|----------|
|                | n   | %    | n   | %    | n   | %    |
| Sex            |     |      |     |      |     |      |
| Female         | 18  | 32.1 | 38  | 67.9 | 56  | 100  |
| Male           | 13  | 23.2 | 8   | 14.3 | 21  | 37.5 |
| Age            |     |      |     |      |     |      |
| Mean           | 38.43| 10.40| 38.72| 10.76| 38.63| 10.55|
| SD             |     |      |     |      |     |      |

*p < 0.001*<sup>†</sup>

<sup>†</sup>Chi-square test; <sup>‡</sup>t-test; *Statistically significant at *p* < 0.05.
All procedures were performed by the same surgeon, who performed the maxillary advancement using a Le Fort I maxillary osteotomy, and the mandibular advancement using bilateral sagittal split osteotomy technique, with rigid fixation of the bone segments. The amount of advancement was planned using Arnett’s soft tissue cephalometric analysis.\textsuperscript{21} The patients had a mean maxillary advancement of $3.27 \pm 3.24$ mm, and a mean mandibular advancement of $9.41 \pm 4.26$ mm. There was also a mean maxillary intrusion of $-1.3 \pm 4.3$ mm and a mean mandibular downward movement of $0.53 \pm 5.19$ mm. Horizontal displacements were measured from A and B points to a line parallel to the true vertical, through Sella; and vertical displacements were measured from A and B points to a perpendicular line to the true vertical, through Nasion. All patients received routine postoperative orthodontic treatment.

Every patient underwent a preoperative CBCT at the end of the presurgical orthodontic treatment, and a postoperative CBCT at the follow-up visit, after a mean of 8.43 months after surgery. In each case, CBCT was performed with the i-CAT (Imaging Science, Hatfield, PA, USA). The scanning speed was 40 s, and high-resolution images were obtained. The radiologic parameters were 120 KpV, 36.90 μSv, and a voxel size of 0.4 mm. During the CBCT, each patient was carefully instructed to be seated, with the Frankfurt horizontal plane parallel to the floor, the head in natural position, to breathe quietly and not to swallow during the scan. The images were then stored as Digital Imaging and Communications in Medicine (DICOM) data files.
Each CBCT scan was processed using Dolphin Imaging software version 11.7 (Dolphin Imaging and Management Solutions, Patterson Dental Supply, Inc., Chatsworth, CA). The area of interest for the upper airway evaluation was defined as the velopharynx, oropharynx and hypopharynx. The limits of the UAS used in this study were two lines: the upper line, passing through the post-palatal area; and the lower line, passing through the post-glossal area. The landmarks used were Posterior Nasal Spine (PNS) – point at posterior edge of the nasal spine; CV₂ – point of the top of the body of the second cervical vertebra; CV₃ – lower posterior point of the body of the third cervical vertebra; Hyoid bone (H) – posterior superior point of the hyoid bone. The area of interest was defined by a clipping box and seeds in the airway space.

Once the portion of the airway of interest was defined, the Dolphin 3D airway analysis tool was used to define and measure two parameters of the pharyngeal airway space (PAS): airway volume (AV) and minimum axial area (MAA). Each patient’s UAS measurements, before and after surgery, were then compared (Fig 1).
Three-dimensional pharyngeal airway space changes after bimaxillary advancement

Figure 1: Upper airway volumetric measurement. A) Limits of retropalatal and retroglossal areas, in sagittal view. B, C) The corresponding limits in the axial and coronal views, respectively. Pink areas denote defined airway portion of interest.

**ERROR STUDY**

Twenty CBCT were randomly selected and remeasured by the same examiner after a 15-day interval. The random errors were calculated according to Dahlberg’s formula, \( S^2 = \frac{\Sigma d^2}{2n} \), where \( S^2 \) is the error variance and \( d \) is the difference between two determinations of the same variable; and the systematic errors were estimated with dependent \( t \)-tests, at \( p < 0.05 \).

**STATISTICAL ANALYSES**

Kolmogorov-Smirnov tests were used to test the normal distribution of the variables.

Pre- and postoperative data comparisons of airway volume and minimum cross-sectional area of the upper airways were performed with paired \( t \)-tests. The influence of maxillary and
mandibular advancement in the changes of airway volume and minimum axial area were evaluated with multiple linear regression analyses. Airway changes comparisons considering the skeletal sagittal relationship (Class I vs. Class II) and sex (Female vs. Male) as subgroups were performed with Mann-Whitney U tests.

The statistical analyses were performed with Statistica software (Statistica 7, StatSoft Inc., Tulsa, OK). Results were considered significant at $p < 0.05$.

**RESULTS**

The random errors were within acceptable limits\(^{24,25}\) (AV = 686.48mm\(^3\); MAA = 0.21mm\(^2\)), and there was no significant systematic error for both variables ($p$-values were 0.155 and 0.468 for AV and MAA, respectively).

There were significant increases in volume and minimum axial area in the airways after surgery (Table 2). The mean percentage of changes in the AV and MAA were 73.6% (SD = 74.75; Min. = 10.6; Max. = 447.0) and 113.5% (SD = 123.87; Min. = -42.7; Max. = 555.3), respectively.

The amount of maxillary and mandibular advancement did not show significant influence on the airway volume and minimum axial area (Table 3).
**Table 2:** Intrigroug airway volume and minimum axial area changes with the surgical procedure (paired t-tests, n = 56).

|                  | Preoperative (T₀) | Postoperative (T₁) | Mean difference (T₁ - T₀) | p     | 95% CI         |
|------------------|-------------------|-------------------|--------------------------|-------|----------------|
| AV (mm³)         | Mean              | SD                | Mean                     | SD    |               |
|                  | 13392.07          | 6235.74           | 21133.29                 | 7922.92 | 7741.22       | 0.000*       | 6024.82 - 9457.63 |
| MAA (mm²)        | 142.33            | 86.35             | 251.30                   | 126.25 | 108.97        | 0.000*       | 79.67 - 138.27    |

* Statistically significant at p < 0.05. AV: airway volume. MAA: minimum axial area.

**Table 3:** Multiple linear regression analyses considering maxillary and mandibular advancements as predictors, and airway volume (AV) and minimum axial area (MAA) changes as outcome variables.

| Variables                    | AV (mm³) change | MAA (mm²) change |
|------------------------------|-----------------|------------------|
|                              | B               | P                | 95% CI           | B               | P                | 95% CI           |
|                              | Lower limit     | Upper limit      |                  | Lower limit     | Upper limit      |                  |
| Constant                     | 6866.72         | 0.003            | 2428.28 - 11305.16 | 135.05          | 0.001            | 59.53 - 210.58   |
| Maxillary advancement        | 66.84           | 0.825            | -537.96 - 671.66  | -0.03           | 0.995            | -10.32 - 10.26   |
| Mandibular advancement       | 68.71           | 0.773            | -407.59 - 545.01  | -2.72           | 0.503            | -10.82 - 5.38    |

AV (mm³) change, $r^2 = 0.004$, $P = 0.890$; MAA (mm²) change, $r^2 = 0.011$, $p = 0.754$.

Similar airway volume and minimum axial area changes were observed between skeletal Class I and Class II, and between female and male patients (Tables 4 and 5).

Table 6 displays the number of patients according to the percentage of changes in the airway volume and minimum axial area.
Table 4: Airway volume (AV) and minimum axial area (MAA) changes comparison regarding skeletal sagittal relationship (Mann-Whitney U test).

|                      | Skeletal Class I (n=18) | Skeletal Class II (n=38) | Mean difference | P      | 95% CI          |
|----------------------|-------------------------|--------------------------|-----------------|--------|-----------------|
| AV (mm$^3$) change   | 8050.70                 | 7594.62                  | 456.07          | 0.362  | -3252.43 - 4164.59 |
| MAA (mm$^2$) change  | 121.92                  | 102.82                   | 19.09           | 0.425  | -44.03 - 82.21   |

Table 5: Airway volume (AV) and minimum axial area (MAA) changes comparison regarding sex (Mann-Whitney U test).

|                      | Female (n=35) | Male (n=21) | Mean difference | P      | 95% CI          |
|----------------------|---------------|-------------|-----------------|--------|-----------------|
| AV (mm$^3$) change   | 8261.78       | 6873.62     | 1388.15         | 0.630  | -2171.30 - 4947.61 |
| MAA (mm$^2$) change  | 114.02        | 100.52      | 13.50           | 0.986  | -47.49 - 74.49  |

Table 6: Number of patients according to the percentage of changes in the minimum axial area and airway volume.

| MAA and AV | Range of % of change between $T_0$ and $T_1$ (difference value/initial value x 100) | n (AV) | % AV in relation to the total sample (n = 56) | n (MAA) | % MAA in relation to the total sample (n = 56) |
|------------|-----------------------------------------------------------------|--------|---------------------------------------------|--------|---------------------------------------------|
|            | -40 < X ≤ 0                                                     | 1      | 1.8%                                        | 4      | 7.1%                                        |
|            | 0 < X ≤ 25                                                      | 11     | 19.6%                                       | 6      | 10.7%                                       |
|            | 25 < X ≤ 50                                                     | 16     | 28.6%                                       | 5      | 8.9%                                        |
|            | 50 < X ≤ 75                                                     | 9      | 16.1%                                       | 12     | 21.4%                                       |
|            | 75 < X ≤ 100                                                    | 7      | 12.5%                                       | 9      | 16.1%                                       |
|            | 100 < X ≤ 200                                                   | 9      | 16.1%                                       | 10     | 17.9%                                       |
|            | X > 200                                                         | 3      | 5.3%                                        | 10     | 17.9%                                       |
|            | **TOTAL**                                                       | **56** | **100%**                                    | **56** | **100%**                                    |
DISCUSSION

The present study only verified CT scans taken at the postoperative stage at a mean of 8.43 months. The reduction in airway space in the immediate postoperative period may occur as a consequence of edema, masking the actual gain in airway space. Edema is an important factor in the evaluation of airway space, particularly in the immediate postoperative period of maxillomandibular advancement surgery.\textsuperscript{9,26,27} It was observed that the difference in time of follow up between the studies was quite variable, from 6 weeks to 12 years, constituting a bias in possible comparisons between studies. This type of assessment is not performed due to the ethical issues involved in exposing patients to unnecessary radiation.\textsuperscript{14} The most common period of follow-up was 6 months.\textsuperscript{3,9}

Patients in the present sample had a mean mandibular advancement of 9.41 ± 4.26 mm. Bimaxillary advancement surgery performed an important role in the OSA correction when medical treatment is not tolerated and in patients who wish a definitive correction, whereas this surgery with an advancement greater than 10 mm is considered effective to improve OSAS.\textsuperscript{26} Based on the common perception and the literature, older adult patients usually require advancement of 10 mm.\textsuperscript{16,28-30}

Even with the increasing number of 3D studies evaluating the airways, the great variability in the choice of airway delimitation
landmarks makes it difficult to compare them. Posterior nasal spine (PNS) was used as the anterior limit of the airway space for volumetric measurements, as performed in other studies.\textsuperscript{31-33} Hyoid bone and PNS were used because they are hard tissues, which consist of more precise and consistent form of identification, compared to soft tissue palate and epiglottis, which could vary after surgery.\textsuperscript{25,30,34} The different measurements adopted by the authors to evaluate the oropharyngeal airway changes make it impossible to compare all studies among themselves, regardless of the type of surgery adopted.\textsuperscript{3,14} PNS was used as the airway limit for volumetric measurements, as in most studies.\textsuperscript{25,32,33,35} Small variations in the anatomical limits and calibration and training of examiners did not seem to have great influence on the results.\textsuperscript{14,26} The present study evaluated only the changes in the oropharyngeal region, due to the difficulty of evaluating the nasopharyngeal region. In a study evaluating the reliability and accuracy of airway measurement in three dimensions of three different software, the authors observed a precision discrepancy in the volume quantification between the different evaluated software. According to them, the nasopharyngeal volume evaluation was more challenging and showed lower reliability, due to the presence of some anatomical structures (turbinate and the concha region) that create intricate anatomy.\textsuperscript{35} For the oropharyngeal evaluation, there was a smaller difference in the results found in different software.\textsuperscript{9}
Dolphin 3D software was used because it showed high accuracy and reliability for the volumetric assessment of airspace in previous studies, and was therefore used in this study.\textsuperscript{9,26,35,36} This software provides greater accuracy because it is a tool for inclusion of reference points in the images, which allows quantification control of volume limits, with few errors (1\%).\textsuperscript{35,36} Variations in the soft palate and tongue positions between pre- and post-surgical exams may significantly influence the outcome of this variable.\textsuperscript{26} Thus, patients who presented visible differences in the position of these structures in T\textsubscript{0} and T\textsubscript{1} periods were excluded from the sample.

The literature shows that there is no difference in the upper airway when comparing patients with Class I and Class II malocclusion, unlike the patient with Class III malocclusion.\textsuperscript{37} In the present study, there was significant increase in the airway volume and minimum axial area in almost all patients, regardless of sex and sagittal relationship (Tables 2, 3 and 4). These variables were analyzed to indirectly contribute to the surgical treatment of patients with OSA. Many surgical treatments used for patients with OSA, such as turbinectomies, uvulopalatopharyngoplasty, and reduction glossectomies, are associated with low success rates, between 17\% and 40\%, when performed alone, because they act only on the airway obstruction.\textsuperscript{38-42} Bimaxillary advancement has the benefit of optimizing airway gain, increasing success rate in OSA treatment, and correcting the patients’ dentofacial and esthetic deformities.\textsuperscript{43,44}
Although a retrusive craniofacial profile is predictive of OSA, there is still controversy among authors.\textsuperscript{45,46} Comparisons performed at the preoperative stage between OSA patients and control patients without OSA showed significant less volume in the OSA group, as expected. Nevertheless, the control group without OSA had relatively (but not statistically significant) more bimaxillary retrusion, when compared with the OSA group, indicating that the craniofacial profile may not reliably predict the presence of OSA.\textsuperscript{19}

In this research, bimaxillary advancement surgery provided significant volumetric increases in the upper airways, as well as in the minimal axial area, corroborating with the literature.\textsuperscript{13,18} After assessing the airway morphological changes, the bimaxillary advancement leads to airway increase in all dimensions, anteroposterior or latero-medial.\textsuperscript{25,26,47,48} Another study observed statistically significant increases in all airway dimensions in the analysis of minimal axial area and volume,\textsuperscript{9} and in the oropharyngeal airway at the soft palate level.\textsuperscript{3} Some studies have evaluated the effects of single-jaw orthognathic procedures on the upper airways, and have also found significant increases in upper airway volume.\textsuperscript{17,49,50}

There was no volumetric gain in the oropharyngeal region in only one patient of the sample (Table 5). This can occur because bimaxillary advancement causes an increase in airway width,
decreasing its constriction and air passage resistance, and may lead to a decrease in height in this area. In the current study, nine patients had MAA values below 67mm², and presented a postoperative mean gain of 143.26% (Table 5). There is a statistically significant relationship between the narrower cross section of the upper airway and the OSA probability. Small airway area of about 40 to 67mm² is associated with OSA, so the patients in this sample left the range of predisposition to OSA.

In this research, the minimum axial area and volume presented considerable gains. One study concluded that the airway resistance decrease after this type of surgery was secondary to a shorter and wider area. Poiseuille’s law demonstrates that as the radius of a tube (or an airway) increases and height decreases, there is a resulting significant decrease in airway resistance. Based on this evidence, it could be thought that increasing the surface area due to increases in anteroposterior and transverse dimensions could lead to a decrease in airway resistance. Despite this outcome, four patients presented a decrease in MAA (Table 6); yet, still maintaining normal values. Individual anatomical changes and soft tissue adaptations (hyoid bone position, pharyngeal airway space narrowing and tongue position) may justify this decrease.
Due to a representative number of patients, it was possible to ascertain that bimaxillary advancement actually produces significant increase in the UAS regardless of sex and skeletal sagittal relationship, and to individually quantify the amount and percentages of AV and MAA increases.

Adequate surgical planning considers the airways, masticatory function, occlusion and esthetics. Proper management of all four variables leads to success.\textsuperscript{25,54} CBCT generalized use and the recent development of automated airway analysis systems that have been validated allow a more refined surgical planning by the surgeon, since exact locations and extent of obstruction can best be visualized. Thus, the surgery can be individualized for each patient.\textsuperscript{30,55}

In addition, OSA has a multifactorial etiology; thus, static airway morphology is not the only factor that contributes to its manifestation. The airway is a dynamic biological structure subjected to various hormonal, neuromuscular and biomechanical influences, which are also factors that may play a role in the OSA pathophysiology.\textsuperscript{56,57} However, bimaxillary advancement surgery provides anatomical and/or structural improvement of the pharyngeal airway in patients with OSA, but other contributing factors should also be considered to influence the OSA presence and severity.\textsuperscript{41} It is necessary to consider the possibility of gain in the upper airway volume and MAA, in the
treatment of patients with different malocclusions, especially those with mandibular retrusion likely to have a minor oropharyngeal region. For this reason, a detailed analysis of the volume and airways shape, with cephalometric evaluations, may prove to be a valuable diagnostic addition to Orthodontics. As a result, balance between function restoration and esthetic optimization is extremely important in the treatment of these types of patients.

**LIMITATIONS**

The main limitation of this retrospective study was the great variability in the amount of maxillary and mandibular vertical and horizontal surgical displacements, due to including skeletal Class I and Class II malocclusions patients.

**CONCLUSIONS**

Bimaxillary advancement surgery to correct skeletal Class I and Class II malocclusions had a tendency to produce significant increase in the UAS (AV and MAA).

However, the amount of increase in the UAS, with bimaxillary advancement surgery in Class I and Class II malocclusions patients, widely varied.
Three-dimensional pharyngeal airway space changes after bimaxillary advancement

AUTHORS CONTRIBUTIONS

Thaís Lima Rocha (TLR)
Ludmila Lima (LL)
Arnaldo Pinzan (AP)
Eduardo Sant’Ana (ES)
Renato Luiz Maia Nogueira (RLMN)
Caroline Nemetz Bronfman (CNB)
Guilherme Janson (GJ)

Conception or design of the study:
AP, ES, RLMN.

Data acquisition, analysis or interpretation:
TLR, LL, AP, ES, RLMN, CNB, GJ.

Writing the article:
LL.

Critical revision of the article:
TLR, LL, AP, ES, RLMN, CNB, GJ.

Final approval of the article:
TLR, LL, AP, ES, RLMN, CNB, GJ.

Fundraising:
TLR.

Overall responsibility:
AP.

The authors report no commercial, proprietary or financial interest in the products or companies described in this article.
REFERENCES

1. Proffit WR. The soft tissue paradigm in orthodontic diagnosis and treatment planning: a new view for a new century. J Esthet Dent. 2000;12(1):46-49.

2. Pereira RMA, Souza GMM, Rocha VAC, Morimoto S, Tedesco TK, Mello-Moura ACV. Evaluation of the Post Orthognathic Surgery Satisfaction: a Comparative Cross-Sectional Study of Patients Class II and III. J Craniofac Surg. 2017;28(7):1833-1836.

3. 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. 2011;40(12):1347-1356.

4. Caples SM, Rowley JA, Prinsell JR, Pallanch JF, Elamin MB, Katz SG, et al. Surgical modifications of the upper airway for obstructive sleep apnea in adults: a systematic review and meta-analysis. Sleep. 2010;33(10):1396-1407.

5. Kyung SH, Park YC, Pae EK. Obstructive sleep apnea patients with the oral appliance experience pharyngeal size and shape changes in three dimensions. Angle Orthod. 2004;75(1):15-22.

6. Giralt-Hernando M, Valls-Ontañón A, Guijarro-Martínez R, Masià-Gridilla J, Hernández-Alfaro F. Impact of surgical maxillomandibular advancement upon pharyngeal airway volume and the apnoea–hypopnoea index in the treatment of obstructive sleep apnoea: systematic review and meta-analysis. BMJ Open Respir Res. 2019;6(1):e000402.
7. Rojo-Sanchis C, Almerich-Silla JM, Paredes-Gallardo V, Montiel-Company JM, Bellot-Arcís C. Impact of bimaxillary advancement surgery on the upper airway and on obstructive sleep apnea syndrome: A meta-analysis. Sci Rep. 2018;8:5756.

8. Behrents RG, Sheligkar AV, Conley RS, Flores-Mir C, Hans M, Levine M, et al. Obstructive sleep apnea and orthodontics: An American Association of Orthodontists White Paper. Am J Orthod Dentofacial Orthop. 2019;156(1):13-28.e11.

9. de Souza Carvalho ACG, Magro Filho O, Garcia Júnior IR, Araujo PM, Nogueira RL. Cephalometric and three-dimensional assessment of superior posterior airway space after maxillomandibular advancement. Int J Oral Maxillofac Surg. 2012;41(9):1102-11.

10. Li KK. Maxillomandibular advancement for obstructive sleep apnea. J Oral Maxillofac Surg. 2011;69(3):687-94.

11. Butterfield KJ, Marks PLg, McLean L, Newton J. Quality of life assessment after maxillomandibular advancement surgery for obstructive sleep apnea. J Oral Maxillofac Surg. 2016;74(6):1228-37.

12. Gokce SM, Gorgulu S, Gokce HS, Bengi AO, Karacayli U, Ors F. Evaluation of pharyngeal airway space changes after bimaxillary orthognathic surgery with a 3-dimensional simulation and modeling program. Am J Orthod Dentofacial Orthop. 2014;146(4):477-92.
13. Raffaini M, Pisani C. Clinical and cone-beam computed tomography evaluation of the three-dimensional increase in pharyngeal airway space following maxillo-mandibular rotation-advancement for Class II-correction in patients without sleep apnoea (OSA). J Craniomaxillofac Surg. 2013;41(7):552-7.

14. Rosário HD, Oliveira GMS, Freires IA, de Souza Matos F, Paranhos LR. Efficiency of bimaxillary advancement surgery in increasing the volume of the upper airways: a systematic review of observational studies and meta-analysis. Eur Arch Otorhinolaryngol. 2017;274(1):35-44.

15. de Souza Pinto GN, Iwaki Filho L, dos Santos Previdelli IT, Ramos AL, Yamashita AL, Stabile GAV, et al. Three-dimensional alterations in pharyngeal airspace, soft palate, and hyoid bone of class II and class III patients submitted to bimaxillary orthognathic surgery: A retrospective study. J Craniomaxillofac Surg. 2019;47(6):883-94.

16. Abramson Z, Susarla SM, Lawler M, Bouchard C, Troulis M, Kaban LB. Three-dimensional computed tomographic airway analysis of patients with obstructive sleep apnea treated by maxillomandibular advancement. J Oral Maxillofac Surg. 2011;69(3):677-86.

17. Hernandez-Alfaro F, Guijarro-Martinez R, Mareque-Bueno J. Effect of mono- and bimaxillary advancement on pharyngeal airway volume: cone-beam computed tomography evaluation. J Oral Maxillofac Surg. 2011;69(11):e395-400.
18. Valladares-Neto J, Silva MAG, Bumann A, Paiva J, Rino-Neto J. Effects of mandibular advancement surgery combined with minimal maxillary displacement on the volume and most restricted cross-sectional area of the pharyngeal airway. Int J Oral Maxillofac Surg. 2013;42(11):1437-45.

19. Butterfield KJ, Marks PLG, McLean L, Newton J. Pharyngeal airway morphology in healthy individuals and in obstructive sleep apnea patients treated with maxillomandibular advancement: a comparative study. Oral Surg Oral Med Oral Pathol Oral Radiol. 2015;119(3):285-92.

20. Parsi G, Alsulaiman AA, Kotak B, Mehra P, Will LA, Motro M. Volumetric changes of the upper airway following maxillary and mandibular advancement using cone beam computed tomography. Int J Oral Maxillofac Surg. 2019;48(2):203-210.

21. Arnett GW, Jelic JS, Kim J, Cummings DR, Beress A, Worley Jr CM, et al. Soft tissue cephalometric analysis: diagnosis and treatment planning of dentofacial deformity. Am J Orthod Dentofacial Orthop. 1999;116(3):239-253.

22. Houston WJ. The analysis of errors in orthodontic measurements. Am J Orthod. 1983;83(5):382-90.

23. Dahlberg G. Statistical methods for medical and biological students. George Allen and Unwin, Ltd.: London, 1940.

24. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop. 2011;139(6):e511-521.
25. Hart PS, McIntyre BP, Kadioglu O, Currier GF, Sullivan SM, Li J, et al. Postsurgical volumetric airway changes in 2-jaw orthognathic surgery patients. Am J Orthod Dentofacial Orthop. 2015;147(5):536-46.

26. Brunetto DP, Velasco L, Koerich L, Araujo MTS. Prediction of 3-dimensional pharyngeal airway changes after orthognathic surgery: a preliminary study. Am J Orthod Dentofacial Orthop. 2014;146(3):299-309.

27. Li KK, Powell NB, Riley RW, Troell Rj, Guilleminault C. Long-Term Results of Maxillomandibular Advancement Surgery. Sleep Breath. 2000;4(3):137-140.

28. Fairburn SC, Waite PD, Vilos G, Harding SM, Bernreuter W, Cure J, et al. Three-dimensional changes in upper airways of patients with obstructive sleep apnea following maxillomandibular advancement. J Oral Maxillofac Surg. 2007;65(1):6-12.

29. Riley RW, Powell NB, Li KK, Troell Rj, Guilleminault C. Surgery and obstructive sleep apnea: long-term clinical outcomes. Otolaryngol Head Neck Surg. 2000;122(3):415-21.

30. 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(3):385-93.

31. El AS, El H, Palomo JM, Baur DA. A 3-dimensional airway analysis of an obstructive sleep apnea surgical correction with cone beam computed tomography. J Oral Maxillofac Surg. 2011;69(9):2424-36.
32. Hong JS, Park YH, Kim Yj, Hong SM, Oh KM. Three-dimensional changes in pharyngeal airway in skeletal class III patients undergoing orthognathic surgery. J Oral Maxillofac Surg. 2011;69(11):e401-8.

33. Alves Jr. M, Franzotti ES, Baratieri C, Nunes LKF, Nojima LI, Ruellas ACO. Evaluation of pharyngeal airway space amongst different skeletal patterns. Int J Oral Maxillofac Surg. 2012;41(7):814-9.

34. Park JW, Kim NK, Kim JW, Kim Mj, Chang Yl. Volumetric, planar, and linear analyses of pharyngeal airway change on computed tomography and cephalometry after mandibular setback surgery. Am J Orthod Dentofacial Orthop. 2010;138(3):292-9.

35. El H, Palomo JM. Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofacial Orthop. 2010;137(4 Suppl):S50.e1-9; discussion S50-2.

36. Weissheimer A, Menezes LM, Sameshima GT, Enciso R, Pham J, Grauer D. Imaging software accuracy for 3-dimensional analysis of the upper airway. Am J Orthod Dentofacial Orthop. 2012;142(6):801-13.

37. El H, Palomo JM. An airway study of different maxillary and mandibular sagittal positions. Eur J Orthod. 2013;35(2):262-70.

38. Wu J, Zhao G, Li Y, Zang H, Wang T, Wang D, et al. Apnea-hypopnea index decreased significantly after nasal surgery for obstructive sleep apnea: A meta-analysis. Medicine (Baltimore). 2017;96(5):e6008.
39. Li HY, Wang PC, Chen YP, Lee LA, Fang TJ, Lin HC. Critical appraisal and meta-analysis of nasal surgery for obstructive sleep apnea. Am J Rhinol Allergy. 2011;25(1):45-9.

40. Park CY, Hong JH, Lee JH, Lee KE, Cho HS, Lim SJ, et al. Clinical effect of surgical correction for nasal pathology on the treatment of obstructive sleep apnea syndrome. PLoS One. 2014;9(6):e98765.

41. Murphey AW, Kandl JA, Nguyen SA, Weber AC, Gillespie MB. The effect of glossectomy for obstructive sleep apnea: a systematic review and meta-analysis. J Otolaryngol Head Neck Surg. 2015;153(3):334-42.

42. Bachar G, Feinmesser R, Shpitzer T, Yaniv E, Nageris B, Eidelman L. Laryngeal and hypopharyngeal obstruction in sleep disordered breathing patients, evaluated by sleep endoscopy. Eur Arch Otorhinolaryngol. 2008;265(11):1397-402.

43. Holty JE, Guilleminault C. Maxillomandibular advancement for the treatment of obstructive sleep apnea: a systematic review and meta-analysis. Sleep Med Rev. 2010;14(5):287-97.

44. Mehra P, Downie M, Pita MC, Wolford LM. Pharyngeal airway space changes after counterclockwise rotation of the maxillomandibular complex. Am J Orthod Dentofacial Orthop. 2001;120(2):154-9.

45. Lowe AA, Fleetham JA, Adachi S, Ryan CF. Cephalometric and computed tomographic predictors of obstructive sleep apnea severity. Am J Orthod Dentofacial Orthop. 1995;107(6):589-95.
46. Riley R, Guilleminault C, Herran J, Powell N. Cephalometric analyses and flow-volume loops in obstructive sleep apnea patients. Sleep. 1983;6(4):303-11.

47. Butterfield KJ, Marks PL, McLean L, Newton J. Linear and volumetric airway changes after maxillomandibular advancement for obstructive sleep apnea. J Oral Maxillofac Surg. 2015;73(6):1133-42.

48. Zinser M, Zachow S, Sailer HF. Bimaxillary ‘rotation advancement’ procedures in patients with obstructive sleep apnea: a 3-dimensional airway analysis of morphological changes. Int J Oral Maxillofac Surg. 2013;42(5):569-78.

49. Chang MK, Sears C, Huang JC, Miller AJ, Kushner HW, Lee JS. Correlation of Airway Volume With Orthognathic Surgical Movement Using Cone-Beam Computed Tomography. J Oral Maxillofac Surg. 2015;73(12 Suppl):S67-76.

50. Tan SK, Leung WK, Tang ATH, Zwahlen RA. How does mandibular advancement with or without maxillary procedures affect pharyngeal airways? An overview of systematic reviews. PloS One. 2017;12(7):e0181146.

51. Bird RB, Stewart WE, Lightfoot EN. Transport phenomena. New York: John Wiley and Sons, Inc; 2002.
52. Gokce SM, Gorgulu S, Gokce HS, Bengi O, Sabuncuoglu F, Ozgen F, et al. Changes in posterior airway space, pulmonary function and sleep quality, following bimaxillary orthognathic surgery. Int J Oral Maxillofac Surg 2012;41(7):820-9.

53. Kawakami M, Yamamoto K, Fujimoto M, Ohgi K, Inoue M, Kirita T. Changes in tongue and hyoid positions, and posterior airway space following mandibular setback surgery. J Craniomaxillofac Surg. 2005;33(2):107-10.

54. Louro R, Calasans-Maia J, Mattos C, Masterson D, Calasans-Maia M, Maia L. Three-dimensional changes to the upper airway after maxillomandibular advancement with counterclockwise rotation: a systematic review and meta-analysis. Int J Oral Maxillofac Surg. 2018;47(5):622-629.

55. Maurer JE, Sullivan SM, Currier GF, Kadioglu O, Li J. The airway implications in treatment planning two-jaw orthognathic surgery: The impact on minimum cross-sectional area. Seminars in Orthodontics: Elsevier. 2016;22(1):18-26.

56. Eikermann M, Vogt FM, Herbstreit F, Vahid-Dastgerdi M, Zenge MO, Ochterbeck C, et al. The predisposition to inspiratory upper airway collapse during partial neuromuscular blockade. Am J Respir Crit Care Med. 2007;175(1):9-15.

57. Guilleminault C, Hill MW, Simmons FB, Dement WC. Obstructive sleep apnea: electromyographic and fiberoptic studies. Exp Neurol. 1978;62(1):48-67.