Journal of Cranio-Maxillo-Facial Surgery 45 (2017) 1408–1414

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Three-dimensional analysis of the pharyngeal airway space and hyoid bone position after orthognathic surgery

Amanda Lury Yamashita, Liogi Iwaki Filho, Pablo Cornélius Comelli Leite, Ricardo de Lima Navarro, Adilson Luiz Ramos, Isolde Terezinha Santos Previdelli, Matheus Henrique Dal Molin Ribeiro, Lilian Cristina Vessoni Iwaki*

Dentistry Department (Head: Prof. Carlos Alberto Herrero de Morais, DDS, PhD), State University of Maringá, Avenida Mandacaru, nº 1550, 87080-000, Maringá, Paraná, Brazil

ARTICLE INFO

Article history:
Paper received 11 March 2017
Accepted 27 June 2017
Available online 4 July 2017

Keywords:
Orthognathic surgery
Hyoid bone
Cone-beam computed tomography

ABSTRACT

Purpose: The aim of this study was to evaluate changes in the pharyngeal airway space (PAS) and hyoid bone position after orthognathic surgery with cone-beam computed tomography (CBCT).

Material and methods: This study was conducted with the tomographic records of 30 patients with skeletal class II or III deformities submitted to two different types of orthognathic surgery: Group 1 ($n = 15$), maxillary advancement, and mandibular setback; and Group 2 ($n = 15$), maxillomandibular advancement. CBCT scans were acquired preoperatively (T_0); and at around 1.5 months (T_1) and 6.7 months (T_2) postoperatively. PAS volume, minimum cross-sectional area (min CSA), and hyoid bone position changes were assessed with Dolphin Imaging 3D software, and results analyzed with ANOVA and a Tukey–Kramer test ($p < 0.05$).

Results: The hyoid bone was significantly displaced in the horizontal dimension, moving posteriorly in Group 1, and anteriorly in Group 2. Although PAS volume and min CSA increased after both surgeries, these measurements were significantly larger only in Group 2. The significant differences that existed between groups preoperatively no longer existed after the surgeries.

Conclusions: Both orthognathic surgeries assessed resulted in changes in hyoid bone position and increased PAS volume and min CSA, particularly after maxillomandibular advancement surgery.

1. Introduction

Dentomaxillofacial deformities may not only compromise the masticatory function and the facial profile of patients (Li et al., 2014), but it may also lead to the narrowing of the pharyngeal airway space (PAS) and respiratory sleep disorders (Grauer et al., 2009; Claudino et al., 2013; Castro-Silva et al., 2015). When orthodontic treatment alone cannot reach satisfactory results in patients with severe bone deformities, orthognathic surgery may be required not only to enhance facial harmony and occlusion, but also to improve breathing (Hong et al., 2011; Raffaini and Pisani, 2013; Li et al., 2014; Al-Moraissi et al., 2015; Hatab et al., 2015). As a result, much attention has been paid to alterations of the PAS structures after orthognathic surgery in recent years (De Souza Carvalho et al., 2012; Gokce et al., 2014; Li et al., 2014).

Orthognathic surgery procedures (maxillomandibular advancement and setback) can modify the relationships between bone structures and soft tissues, such as the soft palate, uvula, palate, base of the tongue and suprahyoid muscles, epiglottis, and hyoid bone (De Souza Carvalho et al., 2012; Panou et al., 2013; Raffaini and Pisani, 2013; Gokce et al., 2014; Christovam et al., 2016). These structures are anatomically and functionally associated with the PAS and, depending on the magnitude and direction of skeletal correction, their movement may lead to alterations in the area (Hong et al., 2011; De Souza Carvalho et al., 2012). When surgery is considered, it is advisable that potential changes in the hyoid bone position and PAS be studied for each patient in order to evaluate treatment changes and to predict postoperative stability (Kim et al., 2013; Christovam et al., 2016).

* Corresponding author. Dentistry Department, State University of Maringa, Avenida Mandacaru nº 1550, CEP: 87080-000, Maringa, Parana, Brazil. Fax: +55 44 3011 9052.

E-mail address: lilianiwaki@gmail.com (L.C.V. Iwaki).

http://dx.doi.org/10.1016/j.jcms.2017.06.016
1010-5182/

Technological advances in computer graphics as well as in imaging diagnosis are becoming a common reality in dental care routines. In contrast to two-dimensional lateral cephalograms, which do not permit the precise evaluation of the PAS (Hatab et al., 2015), cone beam computed tomography (CBCT) can reproduce different sections of the body in multiplanar images (axial, sagittal, and coronal), and assess all the structures in layers with adequate definition (Kim et al., 2014). The evaluation of CBCT images with the use of software allows specific anatomic features to be three-dimensionally delimited in real size (1:1) (Hong et al., 2011), permitting the accurate and reliable analysis and measurement of the PAS morphology and hyoid bone position (Claudino et al., 2013; Schendel et al., 2014; Castro-Silva et al., 2015). However, the evidence available on alterations of hyoid bone position and airway volume after maxillomandibular advancement, and maxillary advancement and mandibular setback surgery, based on 3D images, is still scarce (Christovam et al., 2016).

Therefore, the aim of this study was to analyze the changes in hyoid bone position and in the PAS volume in a group of patients with angle class II and class III deformities submitted to orthognathic surgery, using CBCT scans and Dolphin Imaging 3D software.

2. Material and methods

2.1. Ethical approval

This study was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki), and was approved by the Permanent Ethics Committee for Experiments Involving Humans at the State University of Maringá (UEM), Brazil (CAAE 13862413.7.0000.0104). The study was a cross-sectional observational study performed in conformity with the recommendations of the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines (von Elm et al., 2008). Due to the retrospective nature of this study, a signed informed consent was not required by the Committee.

2.2. Patients

The criteria for the selection of the tomographic images to be included in our study were patients >18 years, diagnosed with Class II and Class III skeletal deformities, who were submitted either to maxillary advancement and mandibular setback, or to maxillomandibular advancement orthognathic surgery. Patients with craniofacial syndromes (lip and palate clefts), or a history of previous surgeries in the head and neck region, were excluded from the study (Uesugi et al., 2014; Shin et al., 2015; Kochar et al., 2016).

Selected records were divided into two groups according to the type of orthognathic surgery: Group 1 – maxillary advancement and mandibular setback ($n = 15$); and Group 2 – maxillomandibular advancement ($n = 15$) (Brunetto et al., 2014; Gonçales et al., 2014). Mandibular setback and advancement were achieved with bilateral sagittal split osteotomy and the use of functionally stable fixation; while Le Fort I osteotomy was used for maxillary advancement (Brunetto et al., 2014; Li et al., 2014; Schendel et al., 2014; Butterfield et al., 2015; Hatab et al., 2015). All surgical procedures were performed by the same team of experienced buccal-maxillofacial surgeons at the Orthognathic Surgery Outpatient Unit (UEM), between 2013 and 2014. During the course of treatment, all patients also received multidisciplinary care by a speech therapist, a nutritionist, and a social worker.

2.3. Acquisition of tomographic images

All CBCT scans were conducted by the same dental radiology and imaging specialist at the Clinical Research Imaging Laboratory (UEM) using the i-CAT® Next Generation (Imaging Sciences International, Hatfield, PA, EUA). Volumes were reconstructed with isometric voxel size of acquisition of 0.30 mm, FOV (field of view) of 17 × 23 cm, tube tension of 120 kVp, and tube current of 3–8 mA. CBCT scans were obtained at three intervals as part of the surgical protocol: preoperatively – 1–2 months before the surgery (T_0), to assist diagnostics and surgery planning; early postoperatively – 1–2 months after the surgery (T_1); and late postoperatively – 5–8 months after the surgery (T_2), to ascertain surgery outcome (Jakobsone et al., 2011; De Souza Carvalho et al., 2012; Kim et al., 2013; Burkhard et al., 2014; Shin et al., 2015).

During acquisition, patients were instructed to remain seated on a chair and adopt a natural head position by looking at their own eyes in a mirror on the opposite wall (Kim et al., 2014; Dalmau et al., 2015; Shin et al., 2015; Canellas et al., 2016). Patients were also instructed to maintain maximum intercuspation with their tongues and lips at rest, to breathe lightly, and avoid swallowing during image acquisition (Kim et al., 2014; Kochar et al., 2016; Canellas et al., 2016). No support for the chin and head were used during image acquisition, as these could be confused with the soft tissues in the region, and negatively affect orthognathic surgery virtual planning.

2.4. Tomographic scan analysis

Measurements on all CBCT images acquired at T_0, T_1, and T_2 were conducted by the same examiner, who was trained and calibrated by a Dolphin Imaging Company representative. Calibration was performed with the use of 10 randomly chosen images. The CBCT images were exported using the DICOM (Digital Imaging and Communications in Medicine) extension and were imported into Dolphin Imaging software (version 11.9) (Dolphin Imaging & Management Solutions®, Chatsworth, CA, USA). To transfer the acquired images to the virtual environment, spatial orientation was performed in order to reposition the axial plane coincidently with the FHP, and the midsagittal plane coincidently with the midline perpendicular to the FHP, passing through the cephalometric point of the nasion (foremost point of the frontonasal suture). In case of asymmetry, orientation was conducted so that these planes were as close as possible to the original orientation planes (Fig. 1). This virtual orientation achieved the correct rotation of the head, in which the bilateral structures were coincident (Brunetto et al., 2014; Uesugi et al., 2014; Canellas et al., 2016).

After image standardization, the landmark S (sella turcica) on the sagittal plane was used as a reference point for outlining the horizontal reference line (parallel to the FHP) and the vertical reference line (perpendicular to the FHP). Hyoid bone position was then determined in relation to these two lines (Fig. 2). Vertical (HBV) and horizontal (HBH) measurements were taken by drawing a line from the most anterosuperior point of the hyoid bone to the reference lines (Kim et al., 2013; Shin et al., 2015).

To analyze PAS volume, the 'sinus/airway' tool was used on the sagittal reconstruction (Fig. 3). Total PAS volume (Fig. 3A) had the following cephalometric limits: i) upper limit – horizontal line connecting posterior nasal spine to the basion (PNS–Ba); ii) lower limit – horizontal line passing through the uppermost point of the epiglottis to the most anteroinferior point of the third cervical vertebra (epiglottis–C3); iii) posterior limit – vertical line delimiting the posterior pharyngeal wall (C3–Ba); and iv) anterior limit – a line delineating the soft palate, tongue, and the anterior wall of the pharynx (epiglottis – soft palate – PNS) (Valladares-Neto et al.,

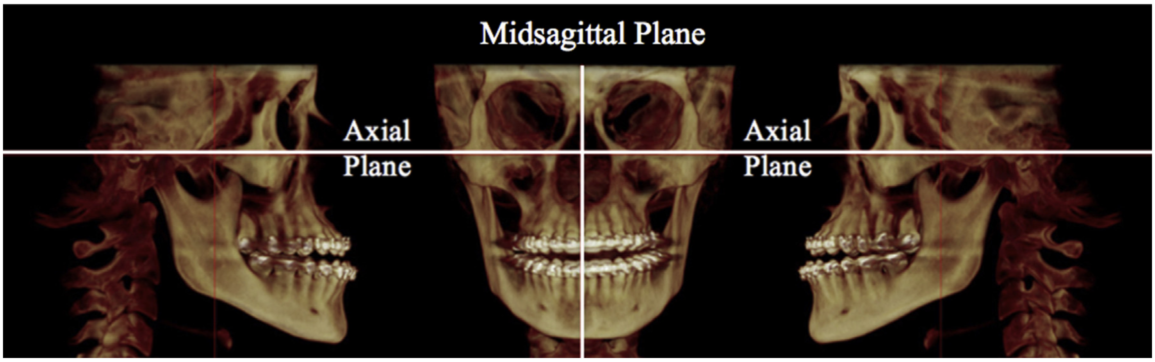

Fig. 1. Standardization of the head position. Axial plane: horizontal plane coinciding with FHP. Midsagittal plane: vertical plane coinciding with the midline, perpendicular to FHP through the nasion.

2013; Gonçales et al., 2014; Butterfield et al., 2015; Shin et al., 2015). To provide a more detailed analysis, PAS was subdivided into the upper (Fig. 3B) and lower (Fig. 3C) segments by drawing a line traversing from the most inferoposterior point of the soft palate to the most inferoanterior point of the second cervical vertebra (C2) (Valladares-Neto et al., 2013; Brunetto et al., 2014; Gonçales et al., 2014; Shin et al., 2015).

The sensitivity threshold used in all image acquisitions was adjusted and standardized at 41 ± 5. This threshold is a Dolphin tool that controls PAS volume filling (Alves et al., 2012). After all lines delimiting the PAS had been drawn, the limit value was chosen and then the software automatically filled with seed points and exhibited the PAS within the selected area. All visualization planes were verified to ensure that the delimited area had been completely filled with the seed points. After that, the software calculated PAS volume (mm^3) and the minimum cross-sectional area (min CSA – mm^2) (Fig. 3D).

2.5. Statistical analysis

Sample size calculation performed with ANOVA, at a level of significance set at 5%, and power at 80%, determined a minimum number of 12 patients for each group.

To avoid operator fatigue, image measurements were conducted over a period of 10 days. Images of six randomly selected patients were separated and measured again 15 days after the first assessments to verify intra-examiner agreement using the Wilcoxon signed rank test. As the intra-examiner agreement for the evaluations conducted was >0.80, the results obtained in the first assessment were used in the analyses.

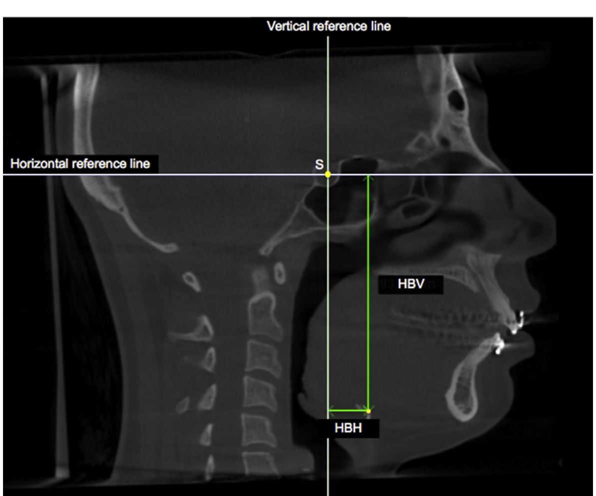

Fig. 2. Sagittal plane showing the measurement of hyoid bone position. S: sella turcica; HBV: hyoid bone vertical measurement; HBH: hyoid bone horizontal measurement.

Alterations in hyoid bone position, PAS volume and min CSA were statistically analyzed with repeated measures using ANOVA, followed by Tukey–Kramer post-hoc test. All statistical tests were performed with the R 3.2 software for Windows (R-project for statistical computing) at a 5% level of significance ($p < 0.05$).

3. Results

The records of eight male and 22 female patients were selected. The mean age of patients in Group 1 was 24.8 ± 8.49 years, while in Group 2 it was 27.6 ± 7.26 years. CBCT scan acquisitions in Group 1 occurred at a mean of 1.2 months preoperatively (T_0), and 1.6 (T_1) and 7.2 months (T_2) postoperatively. In Group 2, acquisitions took place at a mean of 1.8 months before surgery (T_0), and 1.4 (T_1) and 6.2 months (T_2) after surgery.

ANOVA showed no statistically significant differences either between groups or between the acquisition times in the hyoid bone vertical dimension (HBV). In the horizontal dimension (HBH), however, significant differences were observed. Although HBH in Group 2 was significantly smaller than in Group 1 before surgery (T_0), after the surgery (T_1 and T_2) this difference no longer existed. In Group 1, HBH decreased significantly (−HBH) at T_2 in relation to T_0, indicating a posterior displacement of the hyoid bone over time after maxillary advancement and mandibular setback surgery. In contrast, in Group 2, HBH increased significantly (+HBH) both at T_1 and T_2 when compared with T_0, indicating an anterior displacement of the hyoid bone after maxillomandibular advancement surgery (Table 1).

Overall, after the orthognathic surgery, PAS volume increased in both groups. Before the surgery (T_0), total and upper PAS volume in Group 2 were significantly smaller than those in Group 1. However, after the surgeries, no significant differences between groups were observed. In Group 1, despite the small increases observed, no significant differences in the upper, lower, and total PAS volume were observed at any moment after the surgery relative to T_0. In Group 2, however, upper, lower, and total PAS volume were significantly greater at T_1 when compared with T_0; a difference that remained stable at T_2 (Table 2).

Min CSA, in general, increased after the surgeries. Before surgery (T_0), min CSA in Group 2 was significantly smaller than that in Group 1; a difference that no longer existed after the surgeries. Although min CSA did no show significant differences in Group 1, min CSA was significantly larger at both T_1 and T_2 in Group 2 (Table 3).

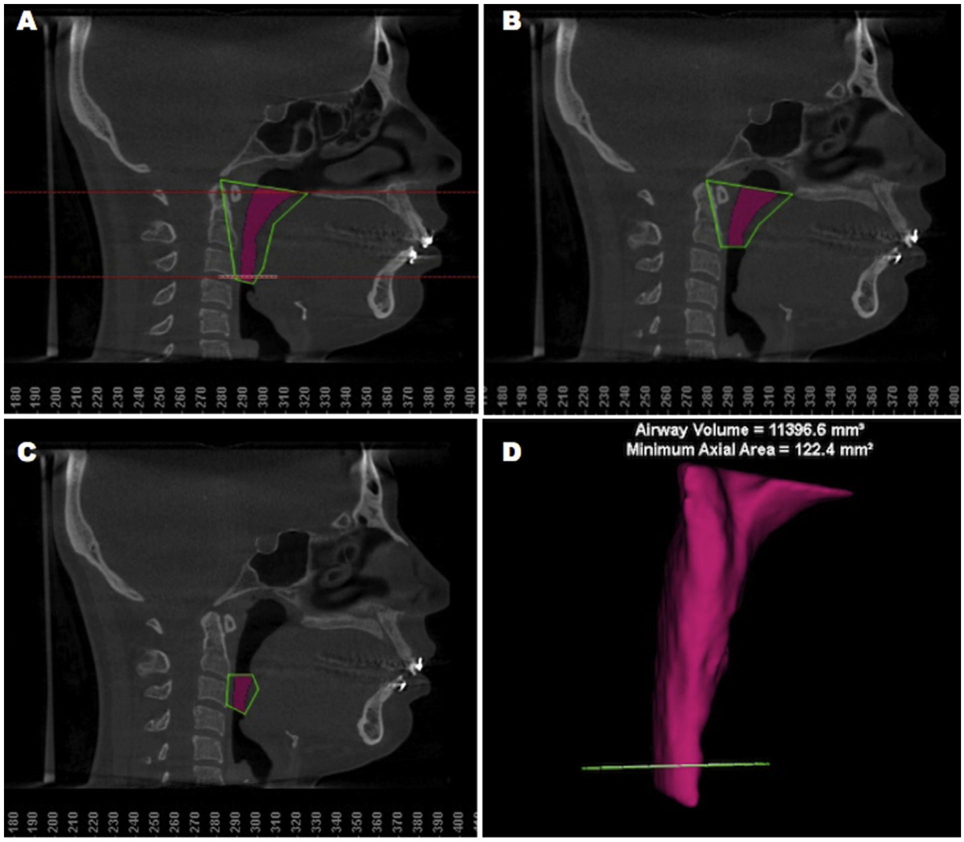

Fig. 3. Delimitation and measurement of PAS. (A) PAS total segment; (B) PAS upper segment; (C) PAS lower segment; (D) 3D visualization of the PAS total volume and the determination of the minimum cross-sectional area (min CSA).

4. Discussion

The aim of this study was to evaluate the postoperative changes in hyoid bone position, PAS volume, and min CSA by analyzing the tomographic scans of patients submitted to two different types of orthognathic surgery. The results of the study demonstrated that the hyoid bone was significantly displaced in the horizontal dimension, moving posteriorly in Group 1, and anteriorly in Group 2 (Table 1). Although PAS volume and min CSA increased after both surgeries, these measurements were significantly larger only in Group 2, so that the significant differences that existed between groups preoperatively no longer existed after the surgeries (Tables 2 and 3).

PAS volume is influenced by the different patterns of malocclusion (Grauer et al., 2009; Castro-Silva et al., 2015). Class III subjects (Group 1) presented significantly larger upper and total PAS volume than Class II individuals (Group 2) preoperatively, indicating that Class II patients were more susceptible to the development of obstructive sleep apnea syndrome (OSAS) (Claudino et al., 2013; Castro-Silva et al., 2015). This perception was

Table 1
Position of the hyoid bone (mm).

Acquisition time	HBH (mean ± SD)		HBV (mean ± SD)	
	Group 1	Group 2	Group 1	Group 2
T_0	23.84 ± 9.11aA	17.49 ± 6.20aB	98.07 ± 7.85	98.21 ± 7.23
T_1	24.27 ± 7.21a	20.00 ± 8.25b	96.83 ± 7.37	96.07 ± 5.97
T_2	21.34 ± 7.69b	20.22 ± 6.98b	98.03 ± 8.42	98.04 ± 8.51
% change	−11.71%	15.60%	−0.004%	−0.017%

Different lower-case letters indicate statistical differences between times. Different upper-case letters indicate statistical differences between groups (Tukey–Kramer test).

Table 2
Upper, lower, and total PAS volume (mm^3).

Acquisition time	Upper volume (mean ± SD)		Lower volume (mean ± SD)		Total volume (mean ± SD)	
	Group 1	Group 2	Group 1	Group 2	Group 1	Group 2
T_0	10367.71 ± 3466.59A	7185.71 ± 1771.44aB	4615.51 ± 1756.70	4029.29 ± 2278.06a	14518.91 ± 4397.45A	11020.71 ± 3520.30aB
T_1	10609.58 ± 2385.95	9378.84 ± 1871.38b	5042.54 ± 2920.35	4871.81 ± 2065.73b	15219.05 ± 4674.44	13850.71 ± 2877.11b
T_2	11401.21 ± 3635.83	9731.85 ± 2165.74b	4906.25 ± 2586.72	4829.60 ± 2639.53b	15690.83 ± 5155.45	14354.43 ± 4565.93b
% change	9.97%	35.43%	6.3%	19.86%	8.07%	30.25%

Different lower-case letters indicate statistical differences between times. Different upper-case letters indicate statistical differences between groups (Tukey–Kramer test).

Table 3
Minimum cross-sectional area (min CSA − mm^2).

Acquisition time	Min CSA (mean ± SD)	
	Group 1	Group 2
T_0	202.39 ± 76.30A	131.45 ± 75.84aB
T_1	207.42 ± 100.62	180.36 ± 56.30b
T_2	223.46 ± 113.26	194.69 ± 84.90b
% change	10.41%	48.04%

Different lower-case letters indicate statistical differences between times. Different upper-case letters indicate statistical differences between groups (Tukey–Kramer test).

reinforced by the fact that preoperative min CSA measurements in Group 2 were also significantly smaller in comparison with those in Group 1. The measurement of min CSA is an important factor in PAS evaluation of patients who are candidates for orthodontic-surgical treatment because of its role as a risk factor for OSAS (Degerliyurt et al., 2009; Brunetto et al., 2014; Gokce et al., 2014; Canellas et al., 2016). According to Schendel et al. (2014), the smaller the min CSA, the greater the predisposition to OSAS.

There is no consensus in the literature for an established standard of airway segmentation (Gokce et al., 2014). The objective was to analyze the changes caused by the displacement of each jaw, so the PAS was subdivided into two similar-size segments (upper and lower), taking as reference the most inferior point of the soft palate. This is an easily determinable point that coincides with the most concave point at the anterior-inferior wall of the second cervical vertebra (Brunetto et al., 2014; Dalmau et al., 2015). By doing so, the upper segment was mainly under the influence of the uvula and the soft palate (attached to the maxilla), while the lower segment was under the influence of the tongue muscles (attached to the mandible) (Brunetto et al., 2014; Kochar et al., 2016).

The hyoid bone plays an important role in keeping the airways open – being essential for sleep – and in sleep disorders (Hasebe et al., 2011; Schendel et al., 2014). Because the base of the tongue, the hyoid bone, and the walls of the pharynx are interconnected by muscles and tendons, PAS is usually altered when movements in the bony base of the maxilla and mandible occur (De Souza Carvalho et al., 2012; Li et al., 2014; Shin et al., 2015; Kochar et al., 2016). In patients diagnosed with Class III deformities, mandibular setback surgery has been shown to result in the hyoid bone moving posteriorly (Hasebe et al., 2011; Kim et al., 2013; Li et al., 2014; Shin et al., 2015), predisposing these patients to OSAS (Uesugi et al., 2014). In a study conducted by Kim et al. (2013), the posterior displacement of the hyoid bone was positively correlated to posterior movement of the menton and the amount of mandibular setback. Thus, mandibular setback surgery alone has been increasingly replaced by maxillary advancement and mandibular setback surgery, with the intent to interfere less with hyoid bone position and the PAS (Gokce et al., 2014; Uesugi et al., 2014; Al-Moraissi et al., 2015; Christovam et al., 2016; Canellas et al., 2016).

The scans of patients submitted to maxillary advancement and mandibular setback surgery in our study (Group 1) demonstrated that the hyoid bone moved posteriorly, following the backwards movement caused by mandibular setback, in agreement with previous studies (Hasebe et al., 2011; Kim et al., 2013; Li et al., 2014; Shin et al., 2015). Nonetheless, the amount of hyoid bone movement did not significantly affect the lower PAS volume in these patients. This may be explained by the fact that the combined movements of the maxilla and the mandible in opposite directions seem to have minimized their effect on PAS structures. The maxillary advancement provided by Le Fort I osteotomy pulls the soft tissue of the palate forward, which in turn affects the palatoglossal muscles, increasing tongue support, and reducing the constricting effect of mandibular setback (Gooday, 2009; Jakobsone et al., 2011; Burkhard et al., 2014). Similarly to the results in our study, some increase in the total PAS has been observed previously after maxillary advancement and mandibular setback surgery (Brunetto et al., 2014; Gokce et al., 2014). However, the opposite has also been reported, suggesting that maxillary advancement and mandibular setback surgery may lead to a reduction rather than an increase in PAS volume (Hong et al., 2011; Li et al., 2014; Al-Moraissi et al., 2015; Hatab et al., 2015; Christovam et al., 2016). The reason for the different results found among studies is probably related to the amount of movement, both maxillary and mandibular, required to achieve the desired surgical result. Future studies should take into consideration the amount of movement involved in this type of surgery to determine how much advancement/setback of the jaw is required to significantly change the PAS.

In contrast to Group 1, patients submitted to maxillomandibular advancement surgery (Group 2) demonstrated a significant anterior movement of the hyoid bone, following the forward movement of the mandible, confirming the findings of previous studies (Eggensperger et al., 2005; Gonçales et al., 2014). In these patients, the forward movement of the hyoid bone seemed to be correlated with the significant increase in lower PAS volume and min CSA. Maxillomandibular advancement surgery enlarges the entire PAS by elevating the tissues attached to the maxilla, mandible, and hyoid bone, resulting in increased tension in the suprahyoid and velopharyngeal musculature (Fairburn et al., 2007). As a result, patients in Group 2 demonstrated statistically significant increases in both upper and lower PAS volume, and min CSA postoperatively. In addition to correcting dentofacial and esthetic deformities, these results confirm that real volumetric gain in the PAS can also be achieved with maxillomandibular advancement surgery, increasing patients' airway passage and improving breathing (Fairburn et al., 2007; De Souza Carvalho et al., 2012; Raffaini and Pisani, 2013; Valladares-Neto et al., 2013; Schendel et al., 2014; Butterfield et al., 2015; Christovam et al., 2016).

Some criticism may be aimed at the decision to submit patients to three CBCT scans in a short period of time (8–10 months), which seems excessive. However, the CBCT scans used in our study were part of patients' surgical records, taken for surgical planning and follow-up, and not specifically for this study. In particular, the early follow-up examination, performed at 1–2 months postoperatively (T_1), might be considered too soon for evaluating long-term PAS changes. Although this examination was originally conducted for surgical reasons to observe postoperative soft tissue edema, it provided an opportunity to analyze its effects on the measurements (De Souza Carvalho et al., 2012). Compared with T_2, when postoperative edema had subsided completely, only small increases in PAS volume and min CSA were observed relative to T_1, demonstrating that initial edema did not significantly affect the measurements.

Computer software offers the possibility to measure distances, areas, and volumes of different cross-sections of the PAS precisely. The Dolphin Imaging 3D software (version 11.9) used in our study has been shown to be highly reliable in the measurement of hyoid bone position, PAS volume, and min CSA (El and Palomo, 2010; Weissheimer et al., 2012). This software is considerably more accurate than some of its predecessors used in PAS assessments (Alves et al., 2012; Weissheimer et al., 2012), with few errors (1%) (Weissheimer et al., 2012). Among its other advantages, the software is user friendly and provides fast PAS segmentation, good segmentation sensitivity, and the possibility of checking segmentation in two-dimensional slices, and to determine and measure the min CSA. Among the drawbacks are the cost, lack of tools to adjust or correct the PAS segmentation in two-dimensional reconstructions, and threshold interval units that are not compatible with other image softwares (Weissheimer et al., 2012).

An important limitation of our study is the absence of single-jaw surgery patients (maxillary advancement, mandibular advancement, or mandibular setback alone). Assessments performed in these patients could bring an important contribution to the understanding of the effects of different types of orthognathic surgery on PAS volume and hyoid bone movement (Brunetto et al., 2014). However, for some time, single-jaw surgery in our service has been replaced by bimaxillary surgery whenever possible, to minimize the effects of single-jaw surgery on the bone structures (Pereira-Filho et al., 2011) and on the PAS (Burkhard et al., 2014; Gokce et al., 2014; Hatab et al., 2015). Thus, the number of available CBCT records of single-jaw surgery patients was too small to be included in this study. Presently, these records are being expanded so that future studies with adequate samples may be conducted to assess the effect of single-jaw and bimaxillary surgery on PAS volume and hyoid bone movement.

5. Conclusion

Based on the results obtained in our study, it may be concluded that both the orthognathic surgeries assessed altered the position of the hyoid bone, and increased PAS volume and min CSA. Maxillomandibular advancement surgery, in particular, was capable of significantly increasing both PAS volume and min CSA, confirming its positive effect on breathing. Thus, care should always be exercised, during orthognathic surgery planning, to take into consideration not only the functional and esthetic needs of the patient, but also its effects on the PAS. Long-term follow-up studies are still necessary to ascertain if the changes in hyoid bone position, PAS volume, and min CSA observed after maxillomandibular advancement, and maxillary advancement combined with mandibular setback surgeries, will stabilize, or whether relapses may occur.

Sources of support

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflicts of interest

None.

Acknowledgements

The authors would like to thank Mr Antonio Carlos Correa for his assistance with the English version of this paper.

References

Al-Moraissi EA, Al-Magaleh SM, Iskandar RA, Al-Hendi EA: Impact on the pharyngeal airway space of different orthognathic procedures for the prognathic mandible. Int J Oral Maxillofac Surg 44: 1110–1118, 2015

Alves Jr M, Baratieri C, Mattos CT, Brunetto D, Fontes Rda C, Santos JR, et al: Is the airway volume being correctly analyzed? Am J Orthod Dentofac Orthop 141: 657–661, 2012

Brunetto DP, Velasco L, Koerich L, Araújo MT: Prediction of 3-dimensional pharyngeal airway changes after orthognathic surgery: a preliminary study. Am J Orthod Dentofac Orthop 146: 299–309, 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: 1428–1436, 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: 1133–1142, 2015

Canellas JV, Barros HL, Medeiros PJ, Ritto FG: Effects of surgical correction of class III malocclusion on the pharyngeal airway and its influence on sleep apnoea. Int J Oral Maxillofac Surg 45: 1508–1512, 2016

Castro-Silva L, Monnazzi MS, Spin-Neto R, Moraes M, Miranda S, Real Gabrielli MF, et al: Cone-beam evaluation of pharyngeal airway space in class I, II, and III patients. Oral Surg Oral Med Oral Pathol Oral Radiol 120: 679–683, 2015

Christovam IO, Lisboa CO, Ferreira DM, Cury-Saramago AA, Mattos CT: Upper airway dimensions in patients undergoing orthognathic surgery: a systematic review and meta-analysis. Int J Oral Maxillofac Surg 45: 460–471, 2016

Claudino LV, Mattos CT, Ruellas AC, Sant'Anna EF: Pharyngeal airway characterization in adolescents related to facial skeletal pattern: a preliminary study. Am J Orthod Dentofac Orthop 143: 799–809, 2013

Dalmau E, Zamora N, Tarazona B, Gandia JL, Paredes V: A comparative study of the pharyngeal airway space, measured with cone beam computed tomography, between patients with different craniofacial morphologies. J Craniomaxillofac Surg 43: 1438–1446, 2015

Degerliyurt K, Ueki K, Hashiba Y, Marukawa K, Simsek B, Okabe K, et al: The effect of mandibular setback or two-jaws surgery on pharyngeal airway among different genders. Int J Oral Maxillofac Surg 38: 647–652, 2009

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: 1102–1111, 2012

Eggensperger N, Smolka W, Iizuka T: Long-term changes of hyoid bone position and pharyngeal airway size following mandibular setback by sagittal split ramus osteotomy. J Craniomaxillofac Surg 33: 111–117, 2005

El H, Palomo JM: Measuring the airway in 3 dimensions: a reliability and accuracy study. Am J Orthod Dentofac Orthop 137, 2010 S50.e1-S59.e1

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 65: 6–12, 2007

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 Dentofa Orthop 146: 477–492, 2014

Gonçales ES, Duarte MA, Palmieri Jr C, Zakhary GM, Ghali GE: Retrospective analysis of the effects of orthognathic surgery on the pharyngeal airway space. J Oral Maxillofac Surg 72: 2227–2240, 2014

Gooday R: Diagnosis, treatment planning and surgical correction of obstructive sleep apnea. J Oral Maxillofac Surg 67: 2183–2196, 2009

Grauer D, Cevidanes LS, Styner MA, Ackerman JL, Proffit WR: Pharyngeal airway volume and shape from cone-beam computed tomography: relationship to facial morphology. Am J Orthod Dentofac Orthop 136: 805–814, 2009

Hasebe D, Kobayashi T, Hasegawa M, Iwamoto T, Kato K, Izumi N, et al: Changes in oropharyngeal airway and respiratory function during sleep after orthognathic surgery in patients with mandibular prognathism. Int J Oral Maxillofac Surg 40: 584–592, 2011

Hatab NA, Konstantinović VS, Mudrak JK: Pharyngeal airway changes after mono- and bimaxillary surgery in skeletal class III patients: cone-beam computed tomography evaluation. J Craniomaxillofac Surg 43: 491–496, 2015

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 69: e401–e408, 2011

Jakobsone G, Stenvik A, Espeland L: The effect of maxillary advancement and impaction on the upper airway after bimaxillary surgery to correct class III malocclusion. Am J Orthod Dentofac Orthop 139: 369–376, 2011

Kim MA, Kim BR, Choi JY, Youn JK, Kim YJ, Park YH: Three-dimensional changes of the hyoid bone and airway volumes related to its relationship with horizontal anatomic planes after bimaxillary surgery in skeletal class III patients. Angle Orthod 83: 623–629, 2013

Kim MA, Kim BR, Youn JK, Kim YJ, Park YH: Head posture and pharyngeal airway volume changes after bimaxillary surgery for mandibular prognathism. J Craniomaxillofac Surg 42: 531–535, 2014

Kochar GD, Chakranarayan A, Kohli S, Kohli VS, Khanna V, Jayan B, et al: Effect of surgical mandibular advancement on pharyngeal airway dimensions: a three-dimensional computed tomography study. Int J Oral Maxillofac Surg 45: 553–559, 2016

Li YM, Liu JL, Zhao JL, Dai J, Wang L, Chen JW: Morphological changes in the pharyngeal airway of female skeletal class III patients following bimaxillary surgery: a cone beam computed tomography evaluation. Int J Oral Maxillofac Surg 43: 862–867, 2014

Panou E, Motro M, Ates M, Acar A, Erverdi N: Dimensional changes of maxillary sinuses and pharyngeal airway in class III patients undergoing bimaxillary orthognathic surgery. Angle Orthod 85: 1–8, 2013

Pereira-Filho VA, Castro-Silva LM, de Moraes M, Gabrielli MF, Campos JA, Juergens P: Cephalometric evaluation of pharyngeal airway space changes in class III patients undergoing orthognathic surgery. J Oral Maxillofac Surg 69: e409–e415, 2011

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 41: 552–557, 2013

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: 385–393, 2014

Shin JH, Kim MA, Park IY, Park YH: A 2-year follow-up of changes after bimaxillary surgery in patients with mandibular prognathism: 3-dimensional analysis of pharyngeal airway volume and hyoid bone position. J Oral Maxillofac Surg 73: 340.e1–340.e9, 2015

Uesugi T, Kobayashi T, Hasebe D, Tanaka R, Ike M, Saito C: Effects of orthognathic surgery on pharyngeal airway and respiratory function during sleep in patients with mandibular prognathism. Int J Oral Maxillofac Surg 43: 1082–1090, 2014

Valladares-Neto J, Silva MA, Bumann A, Paiva JB, 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 42: 1437–1445, 2013

von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, STROBE initiative: The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol 61: 344–349, 2008

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 Dentofac Orthop 142: 801–813, 2012