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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

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ABSTRACT

Introduction: The aim of this retrospective study was to evaluate changes in pharyngeal airway space (PAS), soft palate, and hyoid bone position after bimaxillary orthognathic surgery in skeletal Class II and Class III patients.
Methods: Patients were divided into Group 1: Class III patients who underwent maxillary osteotomies and mandibular setback surgery (N = 43); and Group 2: Class II patients who underwent maxillomandibular advancement surgery (N = 36). Cone beam computed tomography (CBCT) images were acquired one month before and six to eight months after orthognathic surgery. PAS area, volume and minimum axial area (MAA), soft-palate morphology, and hyoid bone position measurements obtained before and after orthognathic surgery were compared using the Gamma family test ($p \leq 0.10$).
Results: In Class II group the maxillomandibular advancement surgery significantly increased the PAS area, volume, and MAA and significantly affected hyoid bone position and soft-palate morphology. In Class III group, maxillary osteotomies and mandibular setback also showed increase in PAS area, however without statistically significant values for most of the evaluated measurements.
Conclusion: The results of the present study indicate that PAS and related structures are expected to be improved in Class II patients submitted to bimaxillary surgery, and they are not negatively affected by bimaxillary surgery in Class III patients.

1. Introduction

In recent years, several studies have focused their attention on pharyngeal airway space (PAS) changes after orthognathic surgery (Shin et al., 2015; Hasebe et al., 2011). The main reason for concern is the fact that the PAS may become narrower after orthognathic surgery, decreasing or even obstructing the airflow during breathing (Shin et al., 2015).

In general, the combination of orthodontics and orthognathic surgery is a valid option for the treatment of skeletal Class II and

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Class III to restore maxillary function and esthetics (Dantas et al., 2015). A specific surgical treatment is indicated for each of these deformities (Park and Baik, 2001). One of the most commonly used methods to correct dental deformities is the Le Fort I osteotomy (Shin et al., 2015), generally followed by bilateral sagittal osteotomy (Iwai et al., 2017).

When a patient is diagnosed with skeletal Class III and undergoes mandibular setback surgery alone, the PAS is expected to shrink, decreasing air passage (Gokce et al., 2014; Hsieh et al., 2015) and predisposing the patient to obstructive sleep apnea syndrome (OSAS) and hypopnea (Gonçales et al., 2014; Canellas et al., 2016). On the other hand, maxillomandibular advancement surgery performed in patients with skeletal Class II may result in a larger PAS (Jakobsone et al., 2011). In addition to the PAS, recent studies have also addressed alterations in soft-palate morphology and hyoid bone and tongue position after orthognathic surgery (Gonçales et al., 2014; Degerliyurt et al., 2009).

Patients who undergo orthognathic surgery present spatial changes in the bony bases of the maxilla and the mandible, which result in morphological alterations of the PAS (Kim et al., 2016). Hyoid bone movement after orthognathic surgery may occur due to changes that take place in the surrounding muscles to compensate for the reduction of the PAS (Shin et al., 2015). This compensation may occur due to the relaxation of the tension of the muscles that support the hyoid bone while adapting to this new muscular condition (Shin et al., 2015). Such changes can cause pressure on the tongue, which in turn will cause morphological changes in the soft palate (Li et al., 2014). The effect of orthognathic surgery on the soft palate is, however, poorly understood, and further studies are required (Li et al., 2014; Burkhard et al., 2014). Furthermore, detailed explanations regarding the three-dimensional alterations of the PAS, hyoid bone position, and soft palate of patients who undergo sagittal bimaxillary orthognathic surgery by means of standardized samples are still scarce in the literature. Therefore, the objective of this study was to evaluate changes in the PAS, soft palate, and hyoid bone position in a sample of patients with Angle class II and class III, who underwent bimaxillary orthognathic surgery. The null hypothesis tested was that there is no PAS and related structures changes after sagital bimaxillary surgery.

2. Material and methods

The Ethics Committee for Research Involving Human Beings approved the present study. This study was conducted according to the recommendations of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines (Von Elm et al., 2008). Due to the retrospective nature of this study, the Committee did not require a signed informed consent.

2.1. Sample

Records of patients of both genders comprised the sample; other criteria required the participants to be > 18 years old, be diagnosed with skeletal Class II or Class III, and have undergone orthognathic surgery. Skeletal discrepancy was determined by an orthodontist with long experience and by lateral cephalometric radiographs derived from CBCT images taken with Dolphin® software. Intermaxilar sagittal relationship was defined by ANB angle (Steiner, 1953). Patients in Class II group presented ANB >4, and in Class III group they had ANB <0.

Patients showing craniofacial anomalies, such as cleft lip and palate, lesions involving the head and neck region; syndromes and paranasal surgery prior to orthognathic surgery (Dantas et al., 2015; Nocini et al., 2016); and patients younger than 18 years of age, due to their incomplete development of the craniofacial structures, were excluded from the study. Sample size calculation was performed using repeated analysis of variance (ANOVA) measures with a significance level of 5% and power of analysis of 95%, which resulted in a minimum number of 36 patients per group. A total of 79 records were selected and divided into two groups: Group 1, patients with Class III deformities who underwent maxillary osteotomies and mandibular setback surgery (N = 43); and Group 2, patients with Class II deformities who underwent maxillomandibular advancement (N = 36). In both groups the occlusal plane was planed to be corrected by its counterclockwise rotation (in Class III group: n = 16, in Class II group: n = 23) or its clockwise rotation (in Class III group: n = 28, in Class II group: n = 13), however those rotations should be 5° maximum. Also both groups include some patients who underwent maxillary impaction (in Class III group: n = 18, in Class II group: n = 29). All patients in both groups underwent additional genioplasty.

Different orthodontists performed the pre- and postoperative orthodontic treatment, but a single experienced oral and maxillofacial surgeon performed all the virtual surgical planning and supervised all the surgeries, which were conducted by the same team of surgeons between 2014 and 2017. Mandibular advancement and setback were performed through bilateral mandibular sagittal osteotomy (Kim et al., 2011; Raffaini and Pisani, 2013); maxillary osteotomies were performed through Le Fort I osteotomy (Kim et al., 2011). In all cases, functionally stable internal fixation was used (Kim et al., 2011; Raffaini and Pisani, 2013).

2.2. Data collection method

CBCT image acquisitions were performed with the same equipment and by the same dental radiologist and imaging specialist. CBCT images were acquired up to one month before surgery (T_0) and again between six to eight months after the surgery (T_1) (Shin et al., 2015; Dantas et al., 2015; Kim et al., 2011), according to the surgical protocol established by the Oral and Maxillofacial Surgery Program.

CBCT images were acquired with i-CAT Next Generation equipment (Imaging Sciences International, Hatfield, PA, USA). The volumes used were reconstructed with an isometric voxel size of 0.300 mm, field of view (FOV) of 17 × 23 cm (comprising the frontal region, 2 cm above the glabella, to just below the hyoid bone, 2 cm below the mandible), tube tension of 120 kVp, and tube current of 3–8 mA.

To avoid measurement errors, the scanning technique was modified so that all patients sat upright during the exam. Chin and head support was used for initial positioning but were removed during the acquisition to prevent interferences with virtual surgical planning (Sutthiprapaporn et al., 2008). Patients were instructed to adopt a natural head position, looking at their own eyes in a mirror on the opposite wall (Shin et al., 2015; Chang et al., 2015). The preoperative scan was maintained in centric relation and, in the postoperative scan, was maintained in maximum habitual intercuspation (Shin et al., 2015; Kochar et al., 2016); tongue and lips were at rest (Shin et al., 2015), and the patient was breathing lightly and avoiding swallowing (Chang et al., 2015; Kochar et al., 2016). As part of the Charlotte protocol (Bobek et al., 2015), patients were positioned with a preoperative wax bite registration. This protocol opens the occlusion slightly so that at the moment the overlap of the study model is scanned with CBCT, there is no overlap of the lower teeth with the superiors in the creation of the cranial composite.

2.3. Measurements

Two calibrated evaluators analyzed the preoperative and postoperative images. Calibration was conducted with 18 randomly chosen CBCT scans, which were measured twice within an interval of 15 days. Both examiners measured all images obtained at T_0 and T_1 and repeated the analysis 15 days later. No more than 10 CBCT scans were analyzed per day to avoid fatigue. All the measurements were made directly on the three-dimensional (3D) CBCT images.

The CBCT images were exported using the Digital Imaging and Communications in Medicine (DICOM) extension and were imported into the Dolphin 3D Imaging software (Dolphin Imaging & Management Solutions®, Chatsworth, CA, USA), version 11.9. According to Cevidanes et al., 2009 and Brunetto et al., 2014 to transfer images to the virtual environment, spatial orientation was performed so that the axial plane was repositioned coincidently with the Frankfurt horizontal plane (FHP), and the median sagittal plane was set based on the natural head position recorded by photographs (frontal and profile pictures) as well as medline deviation were transferred to the CBCT. It was an adaptation of the Charlotte protocol, where the presence of the bite wax was minimal (1 mm), with the only purpose of separating the teeth and facilitating the superimposition of CBCTs, and this minor mandible rotation caused minimal change for the mensuration. However, to offset the space generated between the registrations of wax used in the preoperative CBCT, it was held in the Dolphin software by a maneuver that positioned the mandible in centric relation.

Perpendicular to the FHP, a line was drawn passing through the nasion. In cases of asymmetry, orientation was conducted so that these planes were as close as possible to the original orientation planes. This virtual orientation allowed the attainment of the head's correct rotation in such a way that bilateral structures coincided (Uesugi et al., 2014). After the image was standardized in the software, point S (the sella turcica) on the sagittal reconstruction was used as a landmark to trace the horizontal reference line (HRL) parallel to the FHP, and the vertical reference line (VRL) perpendicular to the FHP.

The post-op CBCTs were oriented from superimposed pre-op CBCTs (the T_0 CBCTs were already oriented by the natural head position). The base of the skull, the sella turcica, frontonasal suture, frontozygomatic suture and others structures that did not suffer surgical movement were used for the superimposition (Shafi et al., 2013; Kim et al., 2017). The tool "superimposition" in Dolphin software was used and a refined adjustment was applied checking in the three reconstructions (coronal, axial and sagittal) (Fig. 1). The same point (S) was used to reproduce the reference lines in T_1. The occlusal plane was determined through cephalometric measurements in T_1 and T_2. If the occlusal plane had a rotation greater than 5°, clockwise or counterclockwise, the exam was excluded from the study (Brunetto et al., 2014).

2.4. Maxillary and mandibular movement

Four craniometric points were used in the sagittal reconstruction to verify the extent of mandibular and maxillary movement: (1) Point PNS (posterior nasal spine), (2) Point A (maxilla), (3) Point B (mandible), and (4) Point Me (menton). With the reference lines defined, four horizontal and four vertical measurements were performed. Vertical measurements were conducted from the HRL to points PNS, A, B, and Me and were identified as V-PNS, V-A, V—B, and V—Me. Horizontal measurements to these same points were conducted from the VRL and identified as H-PNS, H-A, H—B, and H—Me (Fig. 2). (Yamashita et al., 2017)

2.5. Hyoid bone displacement

For the hyoid bone (HYB), one vertical (HYB-Vert) and one horizontal (HYB-Horiz) line, beginning at the most anterosuperior point of the hyoid bone, were drawn to HRL and VRL to assess hyoid bone displacement (Fig. 3A). (Yamashita et al., 2017) In addition, the linear distances from the hyoid bone body to the anterosuperior region of the third cervical vertebra (HYB—C3) to measure the displacement diagonal of the hyoid bone was made, and to analyze the relation to the mandible, the shortest distance was drawn between the hyoid bone body and the base of the mandible (HYB-BM) and was also measured (Fig. 3B).

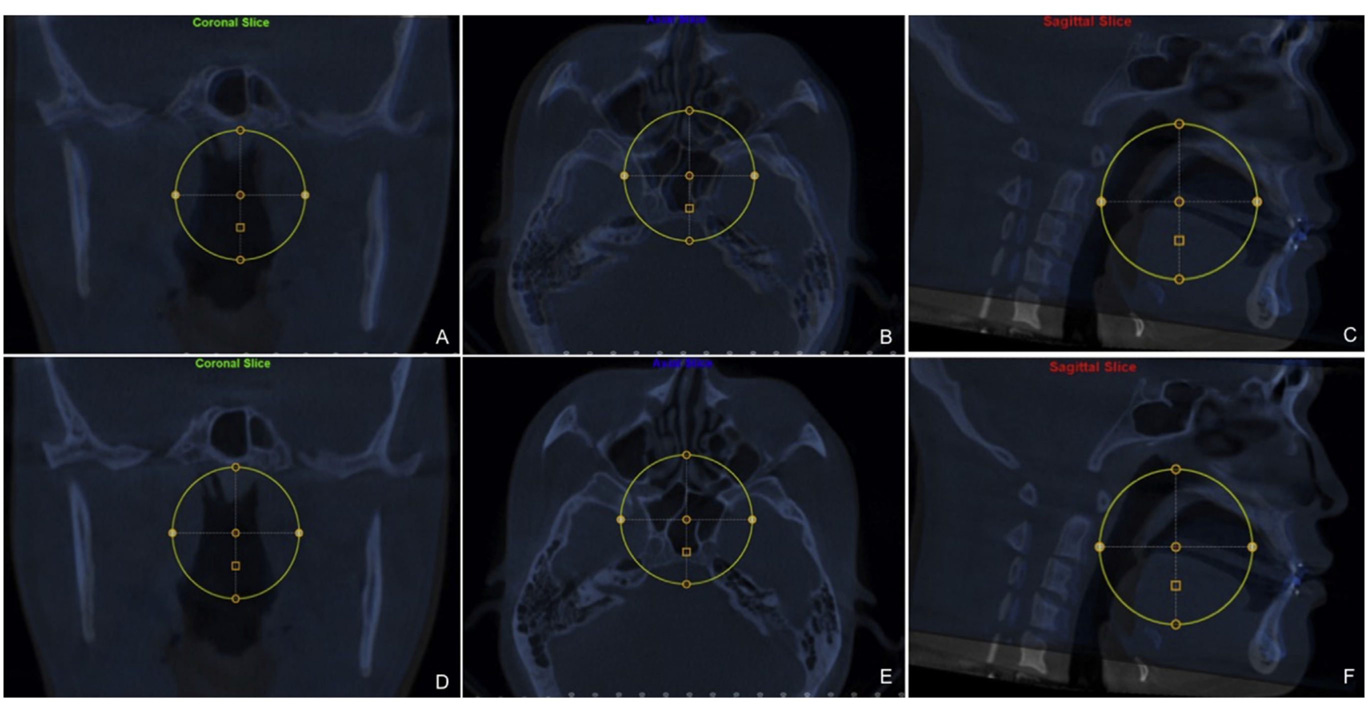

Fig. 1. Superimposed of pre-operative (in gray) and post-operative (in blue) CBCTs before the fine adjustments. (A): Coronal slice, (B): Axial slice, (C): Sagittal slice and after the fine adjustments, (D): Coronal slice, (E): Axial slice and (F): Sagittal slice.

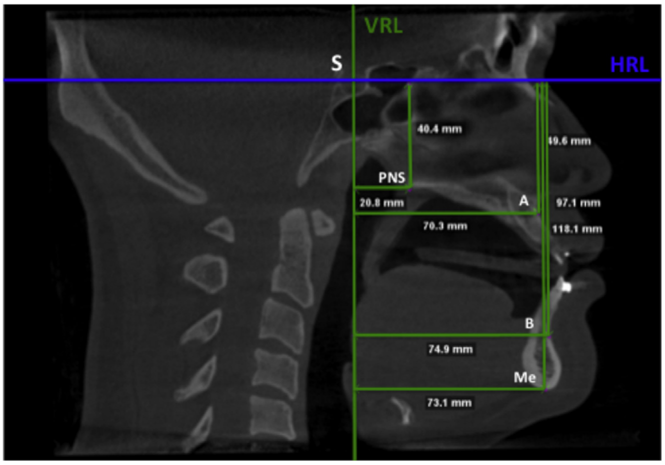

Fig. 2. Sagittal reconstruction of the horizontal and vertical linear measurements of points PNS, A, B, and Me.

2.6. Soft palate

Three measurements were conducted to analyze soft palate morphology: (1) soft-palate length (SPL), the distance between the PNS and the lower soft palate (LSP) (Fig. 3C); (2) soft-palate thickness (SPT), measured at the thickest point along the PNS-LSP line (Fig. 3C); (3) soft-palate angle (SPang), formed by the LSP–PNS to the PNS–ANS (Fig. 3D). (Li et al., 2014)

2.7. The sagittal and transverse dimensions of PAS

Four axial tomographic reconstructions parallel to the FHP, at the level of points PNS, A, B, and Me, were employed. To measure the sagittal and transverse dimensions of PAS, two lines were performed in each reconstruction: the anteroposterior (AP) and laterolateral (LL) (Fig. 4).

2.8. PAS area, volume, and MAA

The sinus/airway tool of the Dolphin 3D Imaging software was used to isolate the anatomic PAS. The seed-points tool was employed to place the seeds in the region of interest, and all areas of the PAS with similar grayscale intensity were selected. This similarity depended on an adjustment of the sensitivity threshold. Although the PAS virtual filling sensitivity threshold is automatically determined by the software (Chang et al., 2013), and the appropriate value of threshold is calculated to define the PAS boundaries for each patient, in the present study the average value was from 41 with low standard deviation (± 2), the threshold value was set for each patient and the entire filling was confirmed in the three reconstructions (sagittal, coronal and axial) (Yamashita et al., 2017). This threshold is a tool of the 3D image software that controls PAS volume filling (Yamashita et al., 2017).

Total PAS volume was measured within the following craniometric limits (Fairburn et al., 2007): upper limit, horizontal line connecting the PNS and the basion; lower limit, horizontal line passing through the most inferoanterior point of the fourth cervical vertebra (C4); posterior limit, vertical line outlining the posterior pharyngeal wall; and anterior limit, vertical line outlining the soft palate, tongue, and anterior pharyngeal wall (Fig. 5).

So that the evaluation would be more accurate than the total, the PAS volume was then subdivided into four segments, with their limits described in Table 1, all of which had the same anteroposterior limits of total PAS volume (Fig. 6).

Limits were also verified in the coronal and axial reconstructions. After the anatomical delimitation, all PAS was outlined and filled with seed points. All viewing planes were verified to ensure that the area had been fully filled with the seed points. The software then automatically calculated the PAS sagittal area (mm^2),

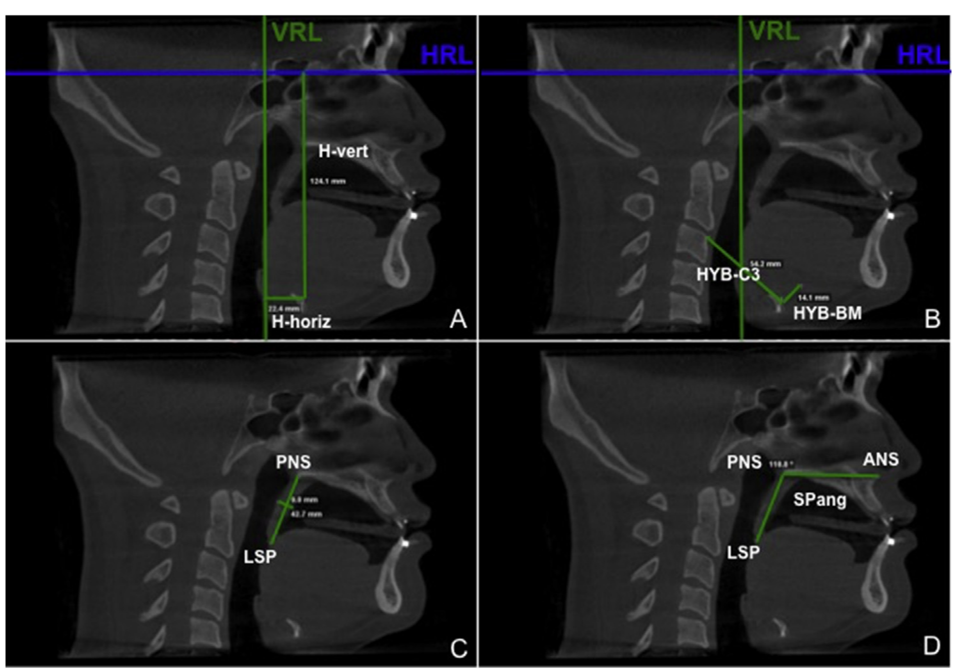

Fig. 3. Sagittal reconstruction showing the linear measurements of the hyoid bone (HYB) and the soft palate. Point S, used as reference for the intersection between the horizontal (HRL) and vertical (VRL) reference lines. **(A)** Horizontal and vertical measurements of the hyoid bone to the reference lines. **(B)** Measurements from the hyoid bone to the anteroposterior region of the third cervical vertebra and from the hyoid bone to the base of the mandible. **(C)** Linear measurements of the soft-palate length and thickness. **(D)** Soft-palate angular measurement. Point S: sella turcica, HRL: horizontal reference line, VRL: vertical reference line.

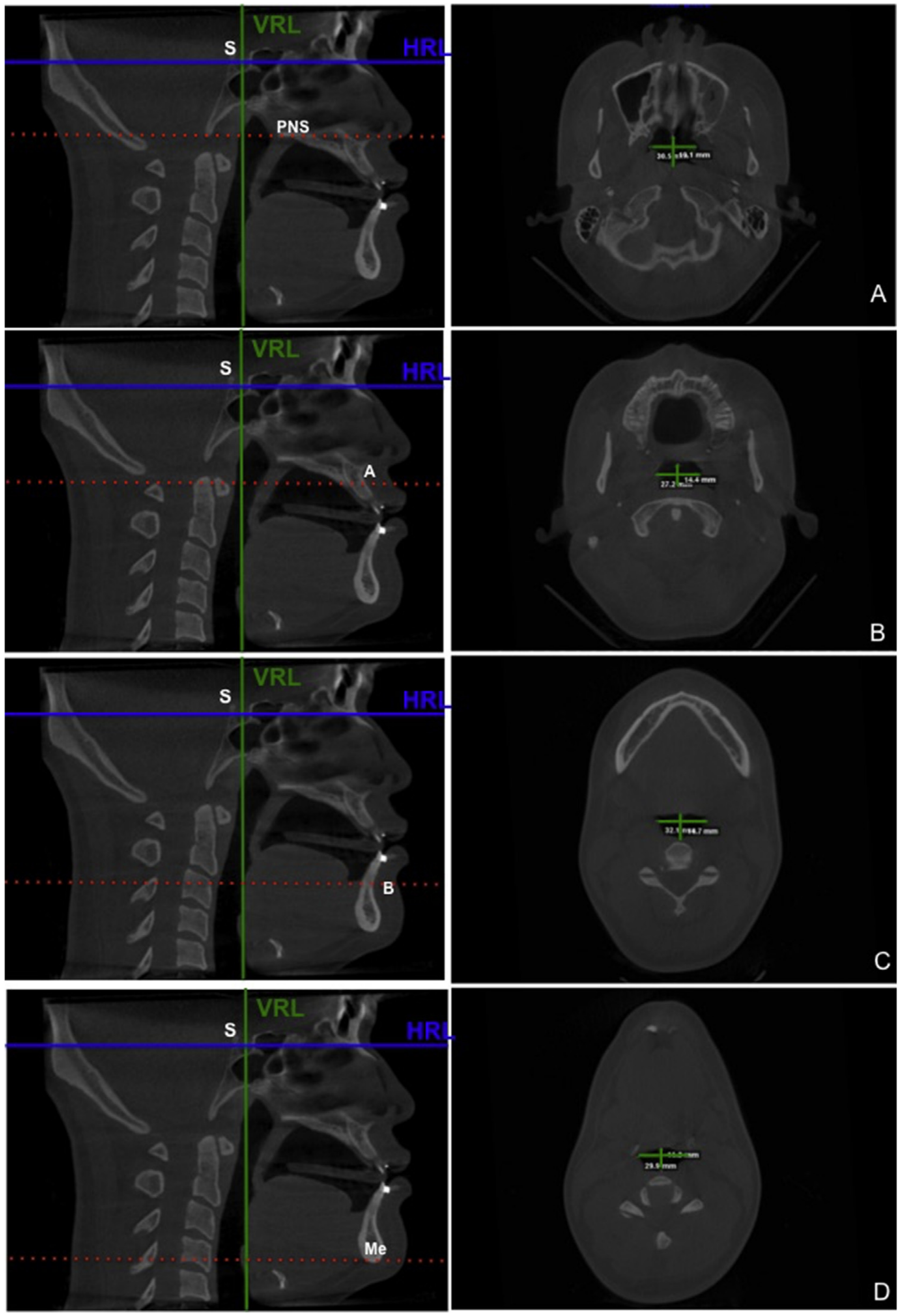

Fig. 4. CBCT axial images illustrating the anteroposterior (AP) and laterolateral (LL) measurements at: level of point PNS; level of point A; level of point B; level of point Me. PNS: posterior nasal spine; A: maxilla; B: mandible; Me: menton.

volume (mm^3), and the Minimum Axial Area (MAA) (mm^2), which is the region of greater constriction of the PAS in the total volume and in each volumetric segment. The linear distance between a point at MAA level and point S (MAA-S) was also recorded (Fig. 7).

2.9. Statistical analysis

The Kappa test was performed to establish intra- and inter-examiner agreement. To determine the effect size, the Cohen test was used, the values were defined among three scores: small (0.20–0.50), medium (0.50–0.80) and high (>0.80); for this study only scores higher than 0.50 were used. Because of the positive, asymmetric and correlated responses, the Generalized Linear Models (Gamma Model) were used to compare the data obtained from the studied variables before T_0 and after T_1 orthognathic surgery, with p-values $\leq$0.10 considered significant. The data was analyzed with R software, version 3.2.1 for Windows (2013) and with SAS, version 9.03.

3. Results

The female/male ratio was 4:3 in Group 1, and 3:1 in Group 2. Mean age (at the time of surgery) of participants was 30.41 ± 11.12 and 32.55 ± 10.19 years old, for Groups 1 and 2, respectively.

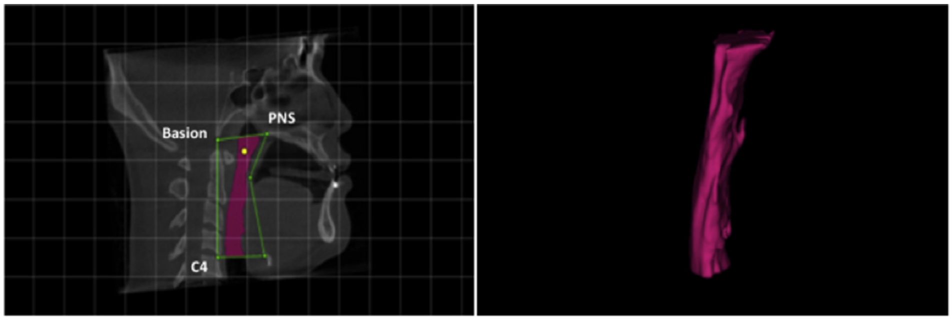

Fig. 5. Outlining and measurement of the total PAS volume (mm^3) on the Sinus- Airway screen of Dolphin Imaging & Management® 3D software, version 11.9.

Table 1
Craniometric limits of segmented PAS.

PAS segmentation	Limit	Anatomical limits
Segment 1 – (Upper oropharynx)	Upper	Horizontal line connecting the PNS and the basion
	Lower	Line crossing the midpoint of the length of the soft palate
Segment 2 – (Mid-oropharynx)	Upper	Line crossing the midpoint of the length of the soft palate
	Lower	The most inferoposterior point of the soft palate
Segment 3 – (Lower oropharynx)	Upper	The most inferoposterior point of the soft palate
	Lower	The most upper-anterior point of C4
Segment 4 – (Hypopharynx)	Upper	Line crossing the most upper-anterior point of C4
	Lower	Line crossing the most inferoanterior point of C4

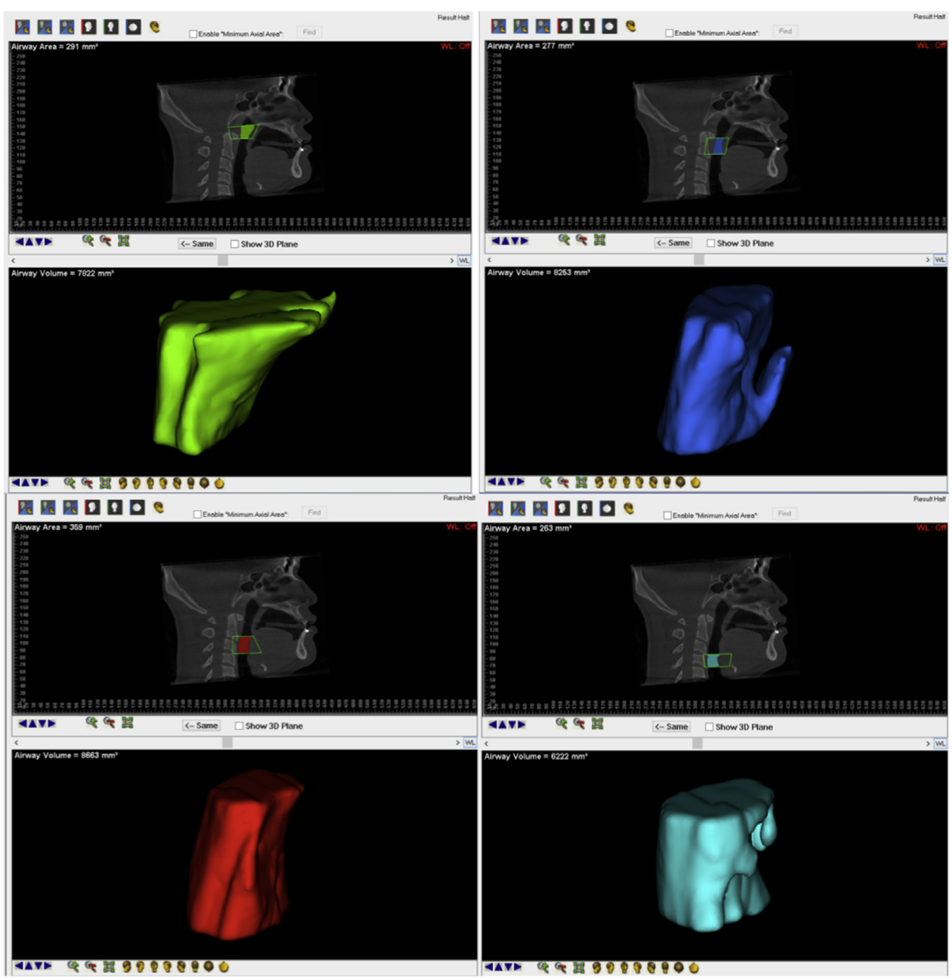

Fig. 6. Delimitation and volume measurement (mm^3) with 3D image software (Dolphin Imaging & Management®, version 11.9) of each individualized segment. **(A)** Segment 1 (upper oropharynx). **(B)** Segment 2 (mid-oropharynx). **(C)** Segment 3 (lower oropharynx). **(D)** Segment 4 (hypopharynx).

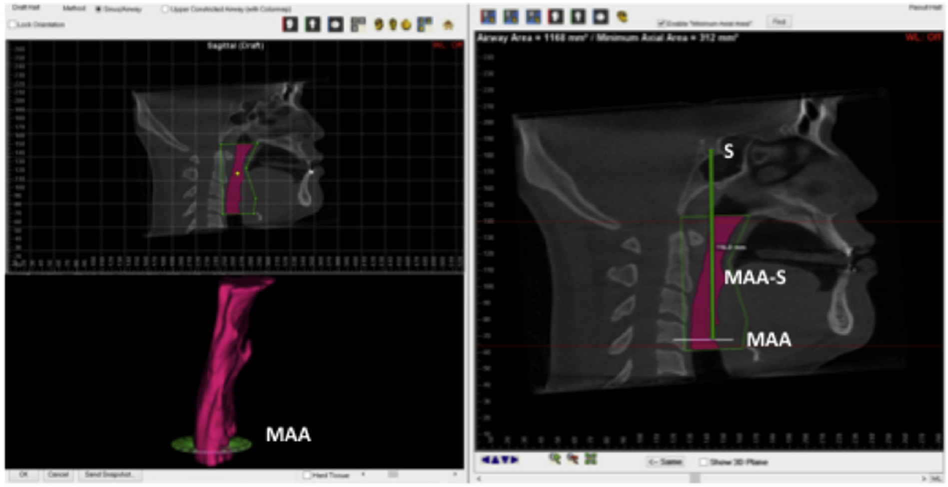

Fig. 7. Outlining and measurement of the MAA and its distance perpendicular to point S (MAA-S).

The Kappa test demonstrated excellent intra and inter-examiner agreements (0.95) for all measured variables. CBCT was performed with a mean of 23.08 ± 20.16 days preoperatively (T_0) and 190.20 ± 77.7 days postoperatively (T_1). The accurate p-values for each variable are shown in Table 2 and the data obtained from all studied variables is presented in Table 3 (Group 1) and Table 4 (Group 2).

Concerning the surgical intervention, in Group 1, horizontal changes confirmed the maxillary advancement (H-PNS, H-A) and the mandible setback (H–B, H–Me) (Table 2). Vertical points did not present statistically significant changes, although they tended to show a reduction of facial vertical dimension (Table 3).

In Group II, mean maxillary sagittal changes were small, showing H-A slightly setback and H-PNS advanced. Sagittal mandibular advancement was clearly demonstrated by H–B and H–Me (Table 4). Vertical points in Group II did not show significant changes (Table 4).

Hyoid bone measurements demonstrated that in Group 1, only HYB-Horiz was not significantly different, whereas all the other variables decreased in T_1, indicating that the hyoid bone moved up and backward after orthognathic surgery (Table 3). In Group 2, HYB-Vert, HYB-C3, and HYB-BM demonstrated statistically significant differences. Although H-Horiz increased, all the other measurements decreased at T_1, demonstrating that the hyoid bone moved up and back after the surgery (Table 4).

Soft-palate measurements in Group 1 demonstrated that only SPang underwent a statistically significant increase after surgery, suggesting that there was a slight opening in the angle formed by the soft palate-PNS-anterior nasal spine (Table 3). In contrast, Group 2 demonstrated statistically significant changes in all variables, with increased soft-palate thickness and decreased SPang and SPL (Table 4).

In Group 1, the sagittal and transverse dimensions measurements of the PAS demonstrated, in general, a small decrease in mean values. However, only AP and LL measurements at point Me demonstrated a statistically significant increase (Table 3). In Group 2 the AP and LL measurements were found to be statistically

Table 2
The accurate p-values of the measurements.

Variable		Group 1 p-value	Group 2 p-value
Linear measurements (mm)	H-PNS	0.0658	<0.0001
	H-A	0.0033	0.0704
	H–B	<0.0001	0.0023
	H–Me	<0.0001	0.2468
	V-PNS	0.17	0.0299
	V-A	0.9708	0.3428
	V–B	0.8932	0.0334
	V–Me	0.1631	<0.0001
Hyoid bone displacement (mm)	HYB-Vert	<0.0001	<0.0001
	HYB-Horiz	0.0428	0.1041
	HYB-C3	<0.0001	<0.0001
	HYB-BM	0.3285	<0.0001
Soft-palate measurements (mm)	SPT (mm)	<0.0001	0.1575
	SPL (mm)	0.8042	0.4696
	SPang (°)	<0.0001	0.3293
	PNS-AP	0.036	0.3105
	PNS-LL	0.2745	0.7358
	A-AP	0.7813	0.5159
	A-LL	0.0527	0.9140
	B-AP	<0.0001	0.2160
	B-LL	0.0034	0.6171
	Me-AP	<0.0001	0.0790
	Me-LL	0.1061	0.0073
PAS area (mm^2)	Total PAS	<0.0001	0.2972
PAS volume (mm^3)	Total PAS	0.0147	0.1659
MAA (mm^2)	Total PAS	<0.0001	0.4376
MAA-S (mm)		0.0048	0.473

Table 3
Mean and standard deviation (SD) of the measurements taken from class III patients (Group I) before (T_0) and after (T_1) orthognathic surgery.

Variable		T_0	T_1	p-value
Linear measurements (mm)	H-PNS	20.81 (3.37)	24.35 (3.32)	≤0.01
	H-A	66.90 (5.27)	68.10 (4.66)	NS
	H–B	71.55 (6.90)	68.39 (6.44)	≤0.01
	H–Me	68.55 (6.96)	67.20 (6.89)	≤0.01
	V-PNS	39.26 (3.75)	38.15 (5.06)	NS
	V-A	43.78 (5.78)	43.01 (5.22)	NS
	V–B	87.06 (6.98)	84.93 (6.09)	NS
	V–Me	107.41 (7.81)	103.95 (8.38)	NS
Hyoid bone displacement (mm)	HYB-Vert	106.15 (11.76)	97.44 (9.62)	≤0.01
	HYB-Horiz	23.37 (7.26)	21.26 (8.04)	NS
	HYB-C3	42.00 (7.33)	36.24 (5.57)	≤0.01
	HYB-BM	8.28 (6.12)	5.31 (2.79)	≤0.01
Soft-palate measurements (mm)	SPT (mm)	8.36 (1.72)	8.13 (2.29)	NS
	SPL (mm)	37.08 (5.17)	36.00 (5.58)	NS
	SPang (°)	116.99 (18.32)	119.93 (8.44)	≤0.05
Sagittal and transverse dimensions of PAS (mm)	PNS-AP	18.93 (3.93)	18.36 (3.78)	NS
	PNS-LL	24.90 (4.66)	24.68 (5.18)	NS
	A-AP	16.90 (3.87)	16.55 (4.11)	NS
	A-LL	25.13 (3.63)	25.06 (4.95)	NS
	B-AP	8.98 (3.71)	9.74 (4.35)	NS
	B-LL	24.89 (5.00)	24.44 (5.55)	NS
	Me-AP	12.27 (3.90)	13.37 (3.43)	≤0.10
	Me-LL	27.44 (8.14)	23.59 (9.56)	≤0.05
PAS area (mm^2)	Total PAS	803.93 (180.62)	832.35 (233.75)	NS
	Segment 1	257.73 (56.64)	250.92 (73.08)	NS
	Segment 2	177.05 (64.34)	186.33 (87.16)	NS
	Segment 3	231.30 (103.07)	279.74 (116.10)	≤0.01
	Segment 4	158.05 (44.90)	170.57 (69.57)	NS
PAS volume (mm^3)	Total PAS	19364.82 (6306.55)	20452.85 (6632.41)	NS
	Segment 1	6605.68 (2078.93)	6203.80 (2186.99)	NS
	Segment 2	4554.93 (2103.62)	4346.43 (2208.99)	NS
	Segment 3	5231.83 (2773.27)	6001.97 (3206.76)	≤0.01
	Segment 4	3643.22 (1313.79)	3998.90 (2129.16)	NS
MAA (mm^2)	Total PAS	154.40 (74.65)	163.65 (91.53)	NS
	Segment 1	325.27 (114.35)	321.62 (106.41)	NS
	Segment 2	216.69 (114.34)	219.67 (115.52)	NS
	Segment 3	176.62 (86.34)	200.72 (116.42)	<0.10
	Segment 4	207.32 (99.90)	211.30 (84.47)	NS
MAA-S (mm)		82.91 (14.06)	80.87 (14.34)	NS

different in almost all the measured points. In general, an increase in the measurements was observed, indicating that there was a real linear increase of the PAS after maxillomandibular advancement surgery (Table 4).

PAS area and volume in Group 1 demonstrated a statistically significant increase only in segment 3 (lower oropharynx). However, in Group 2, PAS area and volume increased significantly not only in the total PAS but also in all volumetric segments. All results and values for both groups are described with as much detail as in Tables 3 and 4

MAA measurements in Group 1 demonstrated that a statistically significant increase was observed only in segment 3. In Group 2, however, MAA measured in the total volume and in all volumetric segments demonstrated a statistically significant increase. Concerning the MAA-S distance, although no significant changes were observed in Group 1, indicating that MAA generally remained in the same place after maxillary osteotomies and mandibular setback surgery, in Group 2, MAA-S increased significantly, indicating an MAA shift downward after maxillomandibular advancement surgery (Table 4).

4. Discussion

According to some studies, CBCT images allow an accurate evaluation of linear and three-dimensional changes that occur in the oral cavity after orthognathic surgery (Jakobsone et al., 2011; Degerliyurt et al., 2009; Gurani et al., 2016). Larson in 2012 (Larson, 2012) listed several advantages of CBCT as well the accuracy, absence of distortions, 1:1 scale, ease of diagnosis and treatment planning for surgeons and orthodontists. The CBCT carried out within six to eight months after surgery is important, because the soft and hard tissues, as well as the muscles, are already adapted to the new position, featuring a post-operative stability (Kochar et al., 2016; Brunetto et al., 2014; Larson, 2012). Our study agrees with this author; the average difference between surgery and post-operative CBCT was 7.3 months.

The 3D software employed in the present study (Dolphin Imaging & Management Solutions®, version 11.9) has been shown to be both accurate and reliable in the measurement of PAS, with a low rate of error (1%) (El and Palomo, 2010; Guijarro-Martínez and Swennen, 2011). Among its advantages were rapid segmentation of the PAS, good segmentation sensitivity, the possibility of assessing reconstructions in three dimensions (axial, coronal, and sagittal), and MAA analysis. However, the high cost of the software, the lack of tools to correct or adjust PAS segmentation in two-dimensional reconstructions, and the incompatibility of its sensitivity threshold with other image software are some of its drawbacks (El and Palomo, 2010).

The results of the present study demonstrated that bimaxillary orthognathic surgery could significantly change the PAS, hyoid bone position, and soft-palate morphology, especially in patients with Class II deformities. Although Class III patients also presented some alterations after surgery, these alterations did not compromise any of the studied structures. Hart et al., in 2015 (Hart et al.,

Table 4
Mean and standard deviation (SD) of the measurements taken from class II patients (Group II) before (T_0) and after (T_1) orthognathic surgery.

Variable		T_0	T_1	p-value
Linear measurements (mm)	H-PNS	22.01 (3.28)	23.21 (3.69)	NS
	H-A	69.97 (4.71)	68.00 (5.06)	≤0.01
	H–B	61.37 (7.85)	65.99 (6.71)	≤0.05
	H–Me	57.28 (8.95)	65.26 (7.54)	≤0.01
	V-PNS	38.48 (3.60)	38.92 (3.37)	NS
	V-A	38.84 (5.70)	37.96 (4.81)	NS
	V–B	82.08 (5.99)	81.96 (6.50)	NS
	V–Me	100.58 (6.31)	99.47 (7.32)	NS
Hyoid bone displacement (mm)	HYB-Vert	105.61 (7.79)	95.58 (7.38)	≤0.01
	HYB-Horiz	19.12 (7.43)	21.93 (7.95)	NS
	HYB-C3	37.46 (4.88)	34.14 (5.53)	≤0.05
	HYB-BM	11.36 (6.32)	5.03 (2.45)	≤0.05
Soft-palate measurements (mm)	SPT (mm)	8.56 (4.48)	8.63 (4.44)	≤0.01
	SPL (mm)	37.48 (6.83)	33.92 (5.29)	≤0.01
	SPang (°)	128.68 (7.76)	123.7 (9.08)	≤0.01
Sagittal and transverse dimensions of PAS (mm)	PNS-AP	20.03 (3.40)	19.07 (2.92)	≤0.10
	PNS-LL	26.17 (5.05)	26.41 (4.05)	NS
	A-AP	17.30 (4.38)	17.46 (4.29)	NS
	A-LL	24.96 (5.40)	27.18 (5.09)	≤0.05
	B-AP	6.75 (2.88)	10.38 (2.88)	≤0.01
	B-LL	23.90 (6.24)	26.62 (4.40)	≤0.01
	Me-AP	9.43 (3.72)	12.89 (3.03)	≤0.01
	Me-LL	28.93 (5.72)	30.32 (5.12)	≤0.10
PAS area (mm^2)	Total PAS	644.96 (166.20)	841.78 (156.26)	≤0.01
	Segment 1	209.15 (55.70)	219.39 (40.59)	NS
	Segment 2	116.30 (52.04)	171.98 (64.21)	≤0.01
	Segment 3	193.88 (98.69)	288.68 (101.01)	≤0.01
	Segment 4	138.70 (55.02)	175.56 (40.47)	≤0.01
PAS volume (mm^3)	Total PAS	15984.97 (4999.03)	28031.69 (38080.01))	≤0.01
	Segment 1	5298.41 (1812.02)	5708.64 (1515.94)	NS
	Segment 2	3166.88 (1733.70)	5032.82 (2465.03)	≤0.01
	Segment 3	4083.51 (2422.74)	7144.97 (3115.55)	NS
	Segment 4	3384.63 (1434.13)	4139.85 (1181.20)	≤0.01
MAA (mm^2)	Total PAS	90.58 (58.24)	187.04 (73.45)	≤0.01
	Segment 1	251.76 (115.05)	325.26 (101.54)	≤0.01
	Segment 2	128.21 (74.36)	252.42 (114.06)	≤0.01
	Segment 3	109.81 (68.20)	202.94 (86.79)	≤0.01
	Segment 4	175.02 (91.52)	236.10 (75.56)	≤0.01
MAA-S (mm)		74.07 (10.85)	78.87 (14.24)	≤0.01

2015), also studied the influence of orthognathic surgery in patients with Class II and III characteristics and found significant changes in skeletal movements; on the other hand, in relation to the volume of the PAS, our study was statistically significant, different from the findings of Hart et al. (2015)

The linear measurements conducted in the present study confirmed that the maxilla moved forward while the mandible moved backward in patients in Group 1, whereas patients in Group 2 exhibited noticeable advancement of the mandible, but a very small displacement of the maxilla. The surgical advance of the maxilla occurred by the anteroposterior movement of the upper central incisor; nevertheless, when the advancement of the upper central incisor was associated with counterclockwise rotation of the oclusal plane, and anterior impaction, point A may move back. In Group II 23 Class II patients underwent counterclockwise rotation of the occlusal plane. The present study aimed to identify mainly sagittal corrections involved in Class II and Class III orthognathic surgeries. Further studies are being conducted in order to clarify the influence of vertical changes and PAS.

Our study was conducted based on a methodology proposed by Brunetto et al. (2014) However, the authors (Brunetto et al., 2014) have not specifically reported the results of each measurement, which prevents comparisons concerning the movement extent generated by each surgery. Only about 10% of the cases of Class III skeletal deformities underwent mandibular setback surgery alone, whereas 40% undergo bimaxillary surgery, and 50% maxillary advancement alone (Gokce et al., 2014; Kawamata et al., 2000). Proffit et al., 1996, 2012 suggested that the changes caused by combined maxillary advancement and mandibular setback were similar but not necessarily better than changes obtained with maxillary advancement and mandibular setback in isolation. Because the expected results are different, it is not possible to compare single with double-jaw surgeries (Larson et al., 2017). Nonetheless, double-jaw surgery is becoming more popular because of improved facial appearance and reduced likelihood of causing PAS obstruction (Hasebe et al., 2011; Proffit et al., 2012).

In both groups of studied patients, the hyoid bone demonstrated a statistically significant upward movement after bimaxillary orthognathic surgery, comprising both the third vertebra and the base of the mandible. These results corroborate with the findings of Jiang et al., 2017) (Jiang et al., 2017); In Group 1, the hyoid bone was moved significantly backward (0.87 mm). These results differ from some recent studies that demonstrated similar forward and backward movements for Groups 1 and 2 but observed no upward movements (Kim et al., 2017; Tepecik et al., 2018) Shin et al. (2015) assessed a patient group of both sexes with mandibular prognathism and found that six months after bimaxillary surgery, the hyoid bone had moved 2.61 mm backward. At the two-year follow-up, the authors observed that the hyoid bone had moved 1.23 mm forward but was still posteriorly located in relation to its initial position before the surgery. Jiang (2016) suggested that a strong correlation between the hyoid bone and the PAS exists, and that this correlation should be used as a reference for maxillofacial and orthodontic surgery planning to reduce the effects of hyoid bone movement in the PAS, however it seems that the upward movement of hyoid bone is advantageous to PAS.

The soft-palate morphology of the patients in Group 1 was little affected by bimaxillary surgery, with only a small increase in soft-palate thickness and angulation and a small decrease in soft-palate length. On the other hand, the soft-palate morphology of patients in Group 2 presented significantly increased thickness and significantly decreased length and angulation. Li et al. (2014) studied the soft palate of 29 female patients with skeletal Class III who underwent bimaxillary surgery. Different from the present study, the authors found that soft-palate thickness had decreased while soft-palate length had increased. Nevertheless, the angulation formed between the soft and hard palate had also increased, in agreement with the findings in Group 1. The differences between the studies were the study design and sample size used. Although Li et al. (2014) investigated only 29 Class III female patients, the present study assessed 79 Class II and III patients of both sexes. Moreover, in their study, only Chinese patients were evaluated; our study was conducted in Brazilian patients. Nonetheless, these 2 studies are not sufficient to infer definitive conclusions about the soft palate in a more ethnically diverse population that could contribute to the generality of the findings.

Axial reconstructions at points PNS and A were selected for sagittal and transverse dimensions analysis because these regions tend to undergo changes after maxillary displacement, whereas axial reconstructions at points B and Me were chosen for AP/LL analysis because they are affected by mandibular displacement. Patients in both groups showed variations in AP and LL values, agreeing with the studies of Fairburn et al. (2007) and Hong et al. (2011), who also found AP/LL variations in both Class III and II patients. As expected, patients in Group 1 did not show significant differences in the AP and LL measurements, except for the axial reconstruction at point Me, probably as a result of mandibular setback. Interestingly, although AP increased, LL decreased significantly. This finding suggests that different structures, such as the mandible, tongue, and hyoid bone, which are intimately connected through muscles and ligaments (Chang et al., 2013; Hong et al., 2011), tend to adapt to the changes caused by orthognathic surgery. In the study by Hatab et al. (2015), the AP and LL distances were measured at three points after bimaxillary orthognathic surgery in 20 Class III patients (9 men and 11 women). At all points, the authors found decreased AP and LL measurements. Although a comparison between two of the points was not possible because they were at different levels, the results for point PNS indicate that they agree with the present study. Although a direct comparison is not possible because the measurements were performed at different reconstruction levels, the results for point PNS suggest an agreement between these study findings and ours. Nonetheless, the effect of bimaxillary orthognathic surgery on AP/LL measurements can be more clearly observed in the results of patients who underwent maxillomandibular advancement (Group 2), with most of the measurements presenting significant increase except for the reconstruction at point PNS, which demonstrated a slight decrease.

The effect of orthognathic surgery on the PAS is still controversial in the literature, with no standardized craniometric delimitation of the PAS (Gokce et al., 2014). In the present study, in an attempt to observe the impact of bimaxillary surgery on different regions of the stomatognathic system, the PAS was segmented into four parts: two upper segments, more closely related to structures such as the hard palate and uvula, and two lower segments, related to the mandible and tongue. Both Class III and II patients presented some increase in volume and area. Patients in Group 1 showed some increase in the PAS area and volume in all segments except for segment 1 (upper oropharynx), which showed a slight decrease. These results are important because they indicate that maxillary advancement in combination with mandibular setback does not negatively affect the PAS. In group 2, the results showed that considerable gains in the PAS area and volume can be achieved after maxillomandibular advancement surgery, with an overall PAS area and volume increase in all evaluated segments. These results agree with some previous studies that also showed increased PAS volume after bimaxillary surgery (Gokce et al., 2014; Jakobsone et al., 2011; Yamashita et al., 2017).

Similarly to the PAS, the MAA of each PAS segment was also recorded. These measurements showed that, in general, the MAA of patients who underwent bimaxillary surgery in the present study presented some increase. In Group 2, as expected, this increase was statistically significant, with MAA in all segments practically doubling in size. The MAA is an important variable to be considered in the assessment of the PAS of patients who are candidates for surgical orthodontic treatment. Because it may result in airflow congestion or even temporary interruption (pharyngeal collapse), MAA is a risk factor for OSAS (Burkhard et al., 2014), however the present study did not investigate the OSAS, because some clinical criteria are necessary to assess the OSAS according to Kapur et al., 2017) (Kapur et al., 2017). If the MAA measurement is small, additional care should be taken during surgical planning. Some previous authors did not find significant variations in MAA dimensions after bimaxillary surgery for the correction of Class III deformities (Jakobsone et al., 2011; Degerliyurt et al., 2008).

The distance between MAA and point S (MAA-S) was conducted to verify the existence of a displacement pattern. Although no changes were observed in Group 1, MAA-S significantly increased in Group 2, demonstrating that the MAA position moved downward with the movement of the mandible forward, which should result in improved airflow.

Ideally, randomized controlled trials would be more appropriate to assess whether changes in the PAS are definitive or recurrences may occur. However, when evaluating the effects of orthognathic surgery, there are ethical aspects that limit the performance of such studies. The surgical procedure cannot be randomized, because it would not be ethical to prevent patients from undergoing the best possible treatment (Christovam et al., 2016). Therefore, further research, with longer follow-up periods, are necessary to evaluate long-term changes in hyoid bone position, soft-palate morphology, and PAS volume. Other limitations of the present study were the non-evaluation of the PAS morphology and dimensions immediately after surgery and the non-assessment of its functionality. Another limitation is the use of wax bite registration only preoperatively, because this is a retrospective study, and CBCT could not ethically be performed again postoperatively with the wax bite registration; however, the Dolphin software has a tool that corrects this positioning while not impairing the study measurements.

Based on the results of the present study, it may be concluded that, in general, Class III patients who underwent maxillary advancement and mandibular setback surgery did not present reductions in the PAS area, volume, and MAA, whereas the hyoid bone's position moved up and back, and the soft palate presented only a slight opening in its angulation. In Group 2, however, the PAS area, volume, and MAA increased significantly, whereas the hyoid bone lifted up and forward, and more significant changes in the soft palate occurred, with decreased soft-palate angulation and length and increased soft-palate thickness.

To our knowledge there is no article in the literature that has performed bimaxillary orthognathic surgery in skeletal Class II and Class III patients in such a standardized way as ours. The same maxillofacial surgeon performed all virtual surgical planning in addition to having coordinated all the surgeries. Additionally, as the literature does not report articles that have studied the hyoid bone, soft palate and PAS in the same patient. Clinically, the results of the present study indicate that careful virtual surgical planning performed before bimaxillary surgery can ensure that PAS-related structures will not be negatively affected by bimaxillary surgery, regardless of the type of deformity.

Ethical approval

This retrospective observational cross-sectional analytical study was approved by the Ethics Committee for the Research Involving Human Beings of the State University of Maringá, Maringá, Brazil (CAAE: 1.245.436 of 09/25/2015).

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Conflicts of interest

None.

Patient consent

Not required.

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