Prediction of 3-dimensional pharyngeal airway changes after orthognathic surgery: A preliminary study

Daniel Paludo Brunetto,[a] Leandro Velasco,[b] Leonardo Koerich,[a] and Mônica Tirre de Souza Araújo[c]
Rio de Janeiro and São Paulo, Brazil

Introduction: Recent studies have shown some contradictory results when evaluating the consequences of orthodontic-surgical treatments on the pharyngeal airway. Therefore, the purpose of this study was to correlate the amount of jaw displacement with the volume variation and the minimal cross-sectional area of the pharyngeal airway. A comparison was made between the correlations with the percentage and the absolute values of the measurement variations. **Methods:** Forty-two patients were divided into 2 groups according to the kind of orthognathic surgery that they had undergone. Group 1 had 22 subjects who had undergone maxillary advancement associated with mandibular setback, and group 2 had 20 patients who had undergone maxillomandibular advancement. The pharyngeal airway was divided into the upper segment and the lower segment, and the sum of these volumetric measures resulted in the total volume. The maxillary and mandibular displacements were assessed using closest point iteration after a voxel-wise cone-beam computed tomography superimposition. Hence, jaw displacements were correlated, using Pearson's correlation and linear regression analysis, to the volume variations of the pharyngeal airway (first time separately and then both groups together) and to the minimal cross-sectional area variation. **Results:** The strongest correlation found was between maxillary displacement and the upper segment in group 2 (r = 0.898, R^2 = 0.888; $P \leq 0.001$). With the groups' data combined, the variables mandibular displacement and the lower segment showed a linear correlation (r = 0.921, R^2 = 0.914; $P \leq 0.001$). Maxillary displacement showed a strong positive correlation with the minimal cross-sectional area variation in group 2 (r = 0.710, R^2 = 0.604; $P \leq 0.01$). **Conclusions:** Correlations with the percentage values were substantially stronger than the correlations with the absolute values. Stronger positive correlations were found between the jaw's displacement and the volume variation of the volume segment that was closer to it in both kinds of surgeries. Only the maxillary displacement is a reliable predictor of the minimal cross-sectional area variation after maxillomandibular advancement. (Am J Orthod Dentofacial Orthop 2014;146:299-309)

Alterations of the dimensions of the pharyngeal airway (PA) after surgical-orthodontic treatment have been the subject of numerous studies confirming the importance of the dimensions of the PA to a good quality of life. A recent systematic review elucidated the importance of craniofacial and PA morphologies on the etiology of obstructive sleep apnea.[1] Nevertheless, there is still sparse evidence of the type and severity of these alterations, especially regarding the 3-dimensional (3D) measurements.[2,3] This is true primarily because most of the studies assessing these changes had used cephalometric radiographs[2,4,5] that provided only 2-dimensional (2D) measurements in a lateral view, worsened by structure superimpositions.[6] In addition, those that actually had used 3D images adopted different methodologies, compromising comparisons between them and weakening the evidence.[2,7]

Cone-beam computed tomography (CBCT) has given a greater power of analysis to orthodontists and oral surgeons, providing accurate 2D and 3D measurements of the PA—for example, cross-sectional area and volume, respectively.[8] Although with the current technology the patient might be exposed to a higher level of

radiation than customary orthodontic digital records,[9] the benefits for surgical-orthodontic patients are evident: a more comprehensive sagittal and lateral analysis; the possibility of multiple 2D or 3D virtual planning simulations of the surgical movements; and prototyping of a surgical guide—in association with digital models—for more predictable surgical results.[10] Moreover, current imaging technology allows a voxel-wise computed cranial base superimposition of the preoperative and postoperative CBCT scans,[11] permitting a reliable assessment of jaw displacement after the orthognathic surgery.[12]

Few studies have tried to correlate the surgical displacement of the jaws with the PA's dimension alterations, and most used 2D cephalometric radiographs in their evaluations.[13,14] The studies that used 3D assessment had correlated the jaw displacements with the absolute values of the volume variation[15]; this seems not to be a reliable correlation concerning the wide variation of the PA volume according to face morphology and other factors.[16]

Therefore, the purpose of this study was to correlate the degrees of maxillary and mandibular displacement arising from surgical-orthodontic treatment with the volume and the minimal cross-sectional area variation of the PA and compare the strength of these correlations between absolute and percentage assessments of the measurement variations.

MATERIAL AND METHODS

The project was approved by the research ethics committee of the Institute of Collective Health Studies from the Federal University of Rio de Janeiro. A sample calculation, based on previous studies, showed that at least 17 subjects would be necessary in each group to detect differences of 65 mm^2 in the minimal cross-sectional area and 2500 mm^3 in the PA volume, with a power of 0.8 and a significance level of 0.05.[17,18]

All the patients were selected from the archives of Hospital da Face (São Paulo, SP, Brazil) from a pool of 338 operated patients. None had a documented diagnosis of obstructive sleep apnea. The selection process was carried out in 2 phases. In the first phase, these inclusion criteria were applied: (1) patients from 18 to 30 years of age, (2) preoperative and postoperative CBCT scans taken with the same machine, (3) the postoperative scan taken from 5 to 8 months after surgery (immediately after bracket debonding), and (4) craniocervical inclination between 90° and 110°.[19] Exclusion criteria applied were (1) important maxillary and mandibular transverse asymmetry,[20] (2) chin augmentation,[21] (3) syndromic patients, and (4) evident airway pathology. The second phase comprised 2 specific steps: preoperative (T1) and postoperative (T2) scans of the

eligible patients were loaded into Dolphin Imaging software (version 11.5; Dolphin Imaging & Management Solutions, Chatsworth, Calif). The head orientation was performed by an experienced operator (D.P.B.): the horizontal reference was the Frankfort horizontal plane (FHP), defined bilaterally by porion and right orbitale landmarks, parallel to the floor; the midsagittal plane (MSP), vertically oriented and defined by nasion, anterior nasal spine, and basion; and the transporionic plane, defined by bilateral porion landmarks and oriented perpendicular to the FHP and the MSP.[22]

On step 1 of the second phase, 5 points were used on the MSP: S point, posterior nasal spine (PNS), A-point, B-point, and menton. S point served as a reference for the delineation of the horizontal reference line (parallel to the FHP) and the vertical reference line (perpendicular to the FHP). A vertical analysis (Fig 1, A) and a horizontal analysis (Fig 1, B) were performed on the T1 and T2 scans. The purpose of the vertical analysis was to exclude patients with substantial vertical variations (greater than 2 mm for any point between T1 and T2) from the sample. The horizontal analysis excluded patients with anteroposterior variations of less than 3 mm for either A-point or B-point, to ensure that only patients with significant anteroposterior jaw displacement would be selected.

In the second step, 2 customary cephalometric measurements were performed on the T1 and T2 scans as well. If the palatal plane or the occlusal plane had a variation greater than 5° (either clockwise or counterclockwise), the patient was eliminated from the study. This criterion was applied to better visualize the PA modifications after isolated anteroposterior jaw movements.

At the end of the selection, 42 subjects were selected, of which 22 (10 male, 12 female) had undergone maxillary advancement associated with mandibular setback and were allocated to group 1. The other 20 (8 male, 12 female) had undergone maxillomandibular advancement and constituted group 2 (Table I).

All CBCT scans were taken with an i-CAT machine (Imaging Sciences International, Hatfield, Pa) by the same radiology technician. The scanning protocol was 120 kV, 5 mA, 13 × 17 cm field of view, 0.4 mm voxel, and scanning time of 20 seconds. The patients had been told to maintain natural head position, to keep the teeth in occlusion, to not swallow, and to breathe smoothly during the examination. All scans were requested as a part of the initial or final records of the orthodontic treatment. The same oral surgeon (L.V.) was responsible for all the surgical procedures, performing a LeFort 1 osteotomy for the maxilla and a bilateral sagittal split osteotomy for the mandible. Titanium plates were used for rigid fixation of the jaws.
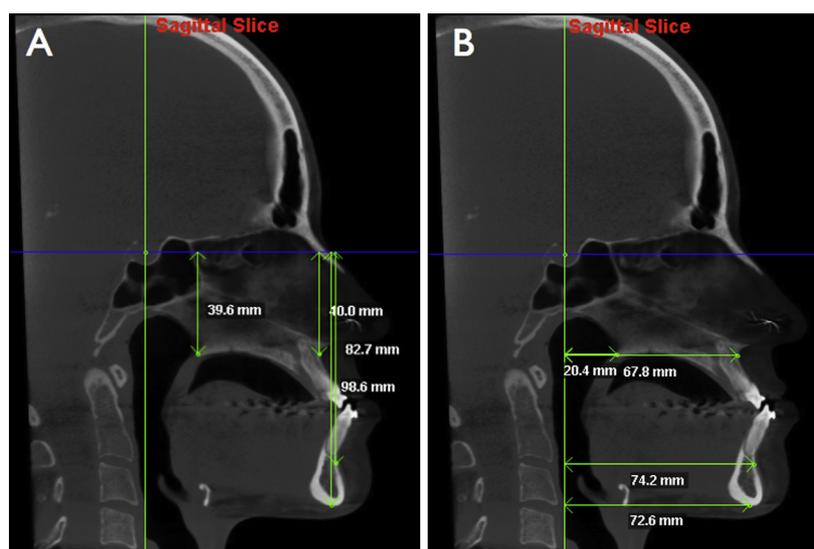
Fig 1. Images showing the measurements used in step 1 of the second phase of the sample selection process: **A,** the 4 vertical measurements (perpendicular distance of PNS, and A, B, and Me points to the horizontal reference line); **B,** the 4 horizontal measurements (perpendicular distance of PNS, and A, B, and Me points to the vertical reference line).

Table I. Sample distribution			
Group	*n*	*Age (y, mean ± SD)*	*P*
1	22	23.02 ± 2.98	0.029
2	20	24.77 ± 2.79	

For the volume assessment, the PA was divided into 2 segments using the "sinus/airway" tool of the Dolphin3D software. The superior segment (VolA) had the following limits (on the MSP): superior limit, line parallel to the FHP through the most superior point of the PA[16]; anterior limit, line perpendicular to the FHP through the most anterior and inferior point of the sphenoidal sinus; inferior limit, line parallel to the FHP through the most concave point of the anterior and inferior wall of the second cervical vertebra; posterior limit, line perpendicular to the FHP through the most posterior point of the pharynx (posterior wall) (Fig 2, *A*).[16] The lower segment (VolB) had the same anterior and posterior limits as VolA. Its superior limit was the same as VolA's inferior limit, and its inferior limit was a line parallel to the FHP through the most inferior and anterior point of the fourth cervical vertebra (Fig 2, *B*). The total volume (VolTo) was obtained by the sum of both segments' volumes. The division limit of the 2 segments was measured (perpendicular distance from the limit line to S point) at T1 and reproduced on the T2 scan, with the aid of the reference line. The minimal cross-sectional area (min CSA) was assessed by the "sinus/airway" tool as

well. The upper and lower limits and the threshold (sensitivity) used were the same as the ones determined for the volumetric measurements; once they were set, the software indicated the most constricted point of the PA. All measurements were performed on the T1 and T2 scans, and their variations were assessed through percentage (T2/T1−1) and absolute (T2−T1) values.

To obtain the jaw displacement, a method of CBCT scan superimposition that has already been described and tested in the literature was used.[11] In summary, the cranial base and both jaws were segmented from the T1 and T2 scans using the ITK-SNAP open-source software.[23] With the software IMAGINE (developed by the National Institutes of Health, Bethesda, Md, and modified at the University of North Carolina, Chapel Hill), a voxelwise method for cranial base superimposition was performed using T1 as the reference and moving T2 with 6 degrees of freedom.[11] Then, 3D surface models were imported to CMF software (Maurice Muller Institute, Bern, Switzerland) that allows quantifying the distance between 2 surfaces at any location.[24] Details of this methodology of superimposition can be found in the study of Carvalho et al.[12] Two tools of the CMF–color map and isoline–were used to assess the distance of A-point and B-point between the T1 and T2 scans (Fig 3). The A-point distance represented maxillary 3D displacement and B-point the mandibular 3D displacement.

The volume variation of each segment and the min CSA area were correlated (Pearson correlation) with the
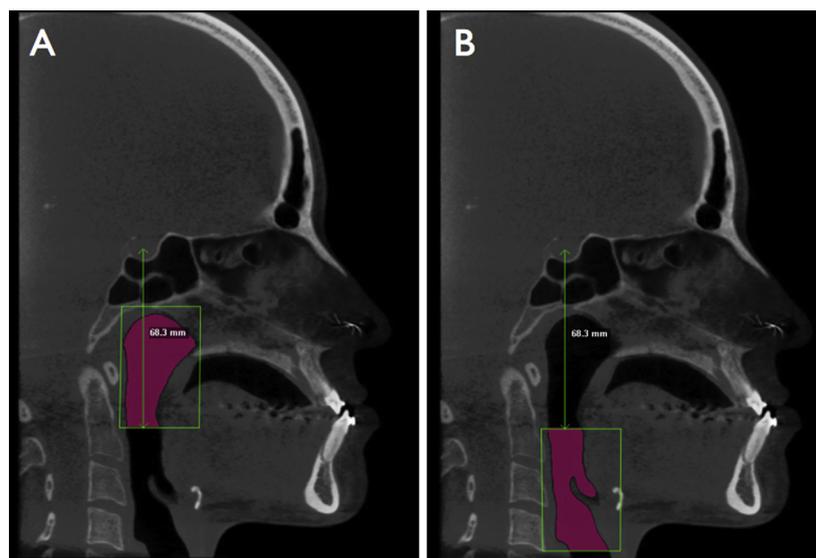
Fig 2. Demonstrative images of the boundaries used to measure the 2 volume segments that constituted the PA (on the midsagittal plane). The reference line (perpendicular distance to S point) depicted was built on the T1 scan and reproduced on the T2 scan to increase the reliability of the volumetric measurements. **A,** Boundaries used to measure the upper segment volume (VolA); **B,** boundaries on the lower segment (VolB).
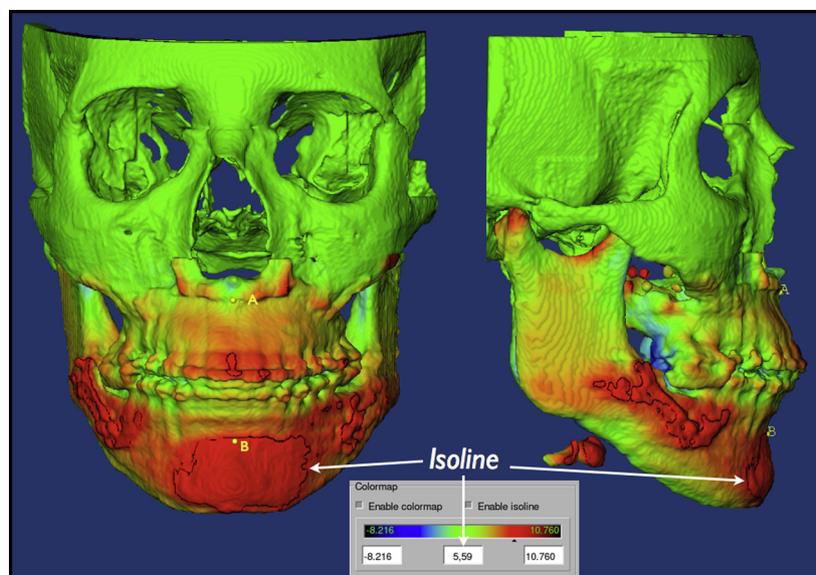

Fig 3. Lateral and frontal views (CMF software) of the superimposed preoperative and postoperative models of a patient who had undergone maxillomandibular advancement. The color map tool depicts in different colors what occurred to the respective structures after the surgery: *green*, no movement; *red*, forward movement; and *blue*, backward movement. The *isoline* shows Point B displacement after surgery.

jaw displacement, and a linear regression model was proposed. At first, the groups were analyzed separately, and then the data were combined and the tests redone just for the volume variations. All measurements of the 20 patients were repeated after a 2-week interval for the calibration test. A *t* test for independent samples was performed to detect differences between the groups concerning baseline volumetric measurements and the

Table II. Intraclass correlation coefficients (ICCs)	
Measurement	*ICC*
VolA	0.941
VolB	0.934
VolTo	0.948
min CSA	0.902
Maxillary displacement	0.964
Mandibular displacement	0.939

Table III. Anteroposterior jaw displacements (mm)					
Group	*Mean*	*SD*	*Median*	*Minimum*	*Maximum*
1					
Mx (A-point)	5.06	0.86	4.95	3.87	6.98
Md (B-point)	−5.25	0.95	−5.02	−7.27	−4.18
2					
Mx (A point)	4.74	1.09	4.71	3.09	7.36
Md (B point)	6.34	1.58	6.00	4.16	9.14

Mx, Maxillary; *Md*, mandibular.

amount of displacement of the jaws. All statistical tests were performed using SPSS software (version 17.0; SPSS, Chicago, Ill).

RESULTS

All the measurements showed excellent intraclass correlation coefficients, higher than 0.9 (Table II). The baseline measurements had no statistical differences between sexes or groups.

VolA variation percentages for groups 1 and 2 were 14.90% ± 6.51% and 31.11% ± 12.48%, respectively, and VolB's were −2.05% ± 2.57% and 26.49% ± 9.34%, respectively. The maxilla had similar displacements in the 2 groups (*P* = 0.098), whereas the mandible had evident differences (Table III).

The majority of the correlations—13 of 16—showed greater strengths when made with the percentage value and so were used to describe the results (Table IV). Stronger correlations were found between the jaw and the volume segment that was closer to it in both groups (Fig 4). In contrast, jaws seem to have little influence on the more distant segments. The strongest correlation and best goodness of fit to the linear regression model (expressed by R^2) were observed between the maxillary displacement and VolA percentage variation (VolA%) in group 2 (r = 0.898, R^2 = 0.888; *P* ≤0.001). "R^2 = 0.888" means that 88.80% of the variation in VolA% could be explained by the respective maxillary displacement, showing that the latter is a good predictor of VolA's percentage variation. When total volume correlations were analyzed (Max-VolTo% and Mand-VolTo%), the maxilla showed a higher influence than did the mandible. When the volumetric data of both groups were analyzed together (n = 42), the variables Max-VolA% showed a bad adjustment to the regression model (r = 0.587, R^2 = 0.345; *P* ≤0.01). There was a statistical difference on the VolA% variation in the groups (*P* ≤0.001), despite their similar maxillary displacements (*P* ≤0.001) (Fig 5). Regarding the correlation Mand-VolB% with the combined data, the strongest correlation and the best adjustment to the regression model (r = 0.921, R^2 = 0.914; *P* ≤0.001) of the entire study were found (Fig 5).

Table IV. Percentage of measurement variation between T1 and T2 (%)				
Group	*Mean ± SD*	*Median*	*Minimum*	*Maximum*
1				
VolA	14.90 ± 6.51	13.62	4.36	30.71
VolB	−2.05 ± 2.57	−1.64	−7.01	2.46
VolTo	6.04 ± 3.63	6.04	1.30	13.97
min CSA	−9.73 ± 27.42	−5.5	−50.53	27.42
2				
VolA	31.11 ± 12.48	29.81	16.52	71.73
VolB	26.49 ± 9.34	21.89	16.21	45.98
VolTo	28.50 ± 8.74	25.37	16.44	52.30
min CSA	56.91 ± 25.10	54.61	12.9	108.43

The min CSA percentage variation presented a linear variation just when correlated with the maxillary displacement (r = 0.710, R^2 = 0.604; *P* ≤0.01) on the maxillomandibular advancement surgery (Fig 6). In group 1, neither the maxillary nor the mandibular displacement could be considered a good predictor for the min CSA% variation (Table V).

DISCUSSION

The T2 scans of the eligible patients had been taken 5 to 8 months after the surgery, ensuring that postoperative swelling would not interfere with the measurements of the PA.[25,26] Data of both sexes could be analyzed together because they had no significance differences, as in other studies.[4,5,27]

The 2 kinds of surgical-orthodontic treatments were selected because of their differences and similarities. The main difference is that in 1 type, the mandible goes forward; in the other one, it goes backward. The maxilla is advanced in both types, and so more information about the mandibular displacement consequences in the PA could be evaluated. The fact that these surgeries are indicated to correct different malocclusions did not have relevance, since the purpose of this study was to evaluate the effects of the jaw displacement separately in different regions of the PA—upper and lower segments. One-jaw surgery would probably have more
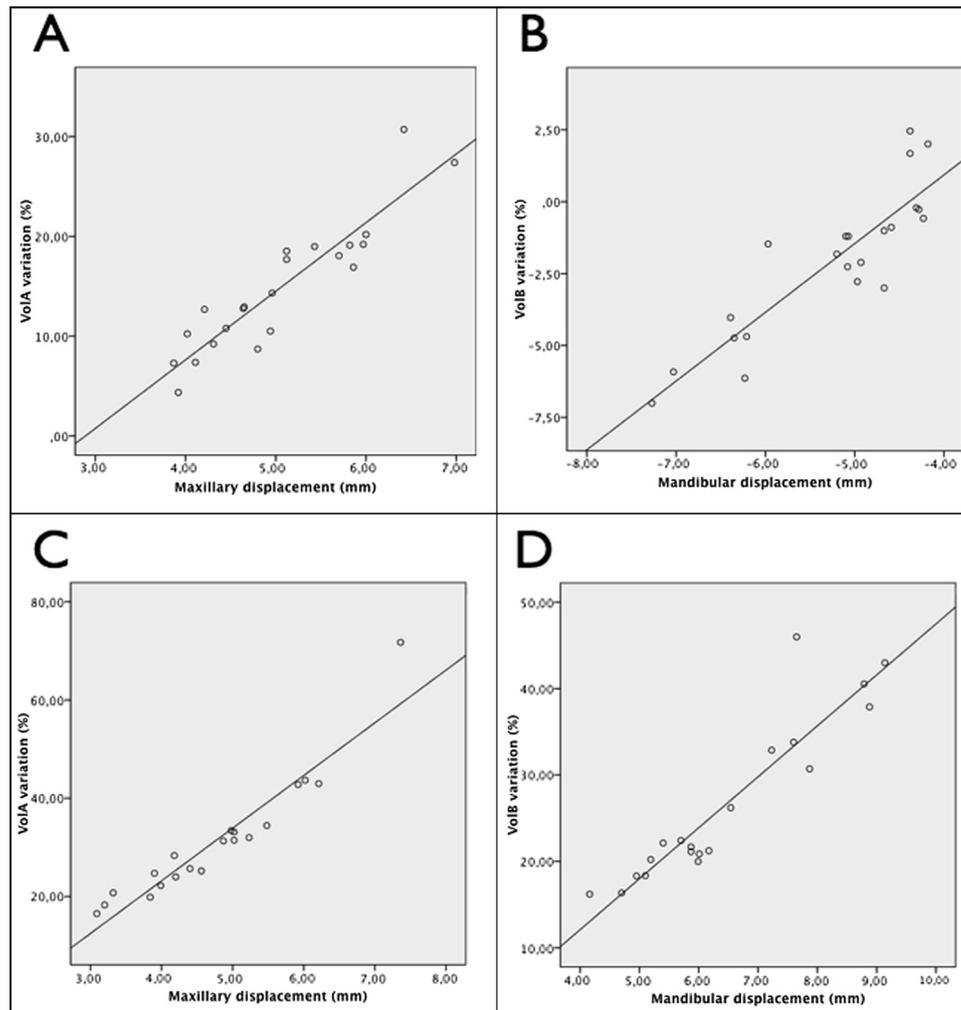
Fig 4. Linear regression models of the variables "jaw displacement" and "percentage of volume variation" of their closer volume segment: **A,** variables maxillary displacement and percentage variation of the upper segment volume—Max-VolA(%)—in group 1 (r = 0.841, R^2 = 0.812; $P \leq$0.001); **B,** variables Mand-VolB(%) in group 1 (r = 0.879, R^2 = 0.769; $P \leq$0.001); **C,** variables Max-VolA(%) in group 2 (r = 0.898, R^2 = 0.888; $P \leq$0.001); **D,** variables Mand-VolB(%) in group 2 (r = 0.861, R^2 = 0.846; $P \leq$0.001).

reliable correlations; however, bimaxillary jaw surgery is preferred when considering the PA issue.[4,28]

The sample selection process was designed and applied to eliminate patients with large vertical variations after the surgery. Maxillary impaction and counterclockwise rotation of the maxillomandibular complex lead to mandibular counterclockwise rotation and anterior displacement.[29] Because we intended to evaluate just the effects of the anteroposterior displacement of the jaws on the airway, these events could cause misinterpretation of the data.

Dolphin3D software was chosen because it had previously shown high reliability for volumetric measurements of the PA.[8,30] In this study, the PNS was not used as the anterior limit of the PA for volumetric measurements, as in most studies,[31-33] because it undergoes anterior displacement with the surgery.[20] As its substitute, the most inferior and anterior point on the sphenoidal sinus was used because it was considered a stable and easily recognizable point. Hong et al[31] used the epiglottis, and Grauer et al[16] used the most inferior point of the third cervical vertebra as the lower limit. In our study, the lower limit of VolB was extended to the fourth cervical vertebra so that the effects of mandibular displacement would be better depicted. The superior and posterior limits used were already described in the literature.[16] To better assess the changes, the PA was divided into 2 segments.
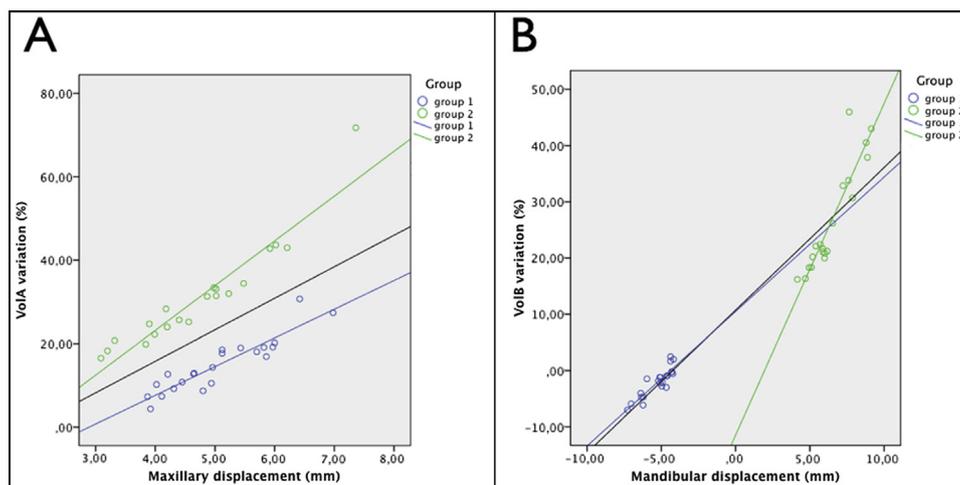
Fig 5. Linear regression models, controlled for kind of surgery, of the combined data of both groups: **A,** the variables Max-VolA(%) showed a bad adjustment to the regression model (r = 0.587, R^2 = 0.345; $P \leq 0.01$), represented as the *black line*; **B,** variables Mand-VolB(%) showed the strongest correlation and the best adjustment of the entire study (r = 0.921, R^2 = 0.914; $P \leq 0.001$).
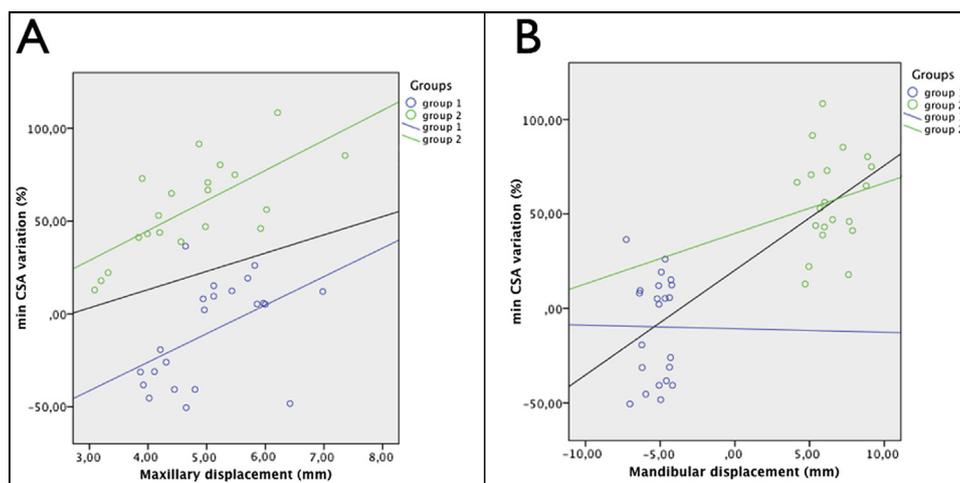

Fig 6. Linear regression models, controlled for kind of surgery, correlating the degree of jaw displacement with the percentage variation of the minimal cross-sectional area of the PA: **A,** variables Max-min CSA(%) in group 1 (r = 0.486, R^2 = 0.312; $P \geq 0.05$) and group 2 (r = 0.710, R^2 = 0.604; $P \leq 0.01$); **B,** variables Mand-min CSA(%) in group 1 (r = 0.084, R^2 = 0.051; $P \geq 0.05$) and group 2 (r = 0.215, R^2 = 0.088; $P \geq 0.05$).

The boundary chosen was the most concave point at the anterior-inferior wall of the second cervical vertebra, because in most patients it coincided with the most inferior point of the soft palate. Besides that, it was the most easily recognizable landmark that divided the PA into 2 similar-size segments. Thus, the upper segment was theoretically mainly under the influence of the uvula and the soft palate (attached to the maxilla), and the lower segment was under the influence of the tongue muscles (attached to the mandible). However, our results showed that the mandibular displacement actually had some influence in the upper segment volume, proved by the statistical difference on the VolA variation between the groups ($P \leq 0.001$) despite their similar mean maxillary displacements (Fig 5, *A*). El and Palomo[34] recently found a statistical difference on the oropharyngeal volume of subjects with mandibular retrusion

Table V. Measurement variations times jaw displacements				
	Absolute (T2−T1)		Percentage (T2/T1−1)	
Group	r	R²	r	R²
1				
Max-VolA	0.677†	0.612†	0.841‡	0.812‡
Max-VolB	0.056	0.003	0.106	0.011
Max-VolTo	0.656†	0.402†	0.783‡	0.611‡
Mand-VolA	0.053	0.003	0.159	0.025
Mand-VolB	0.702†	0.503†	0.879‡	0.769‡
Mand-VolTo	0.494*	0.244*	0.411*	0.169
Max-min CSA	0.212	0.045	0.486*	0.312
Mand-min CSA	0.81	0.038	0.084	0.051
2				
Max-VolA	0.810‡	0.668‡	0.898‡	0.888‡
Max-VolB	0.280	0.078	0.205	0.093
Max-VolTo	0.708†	0.573†	0.804‡	0.647‡
Mand-VolA	0.146	0.021	0.160	0.026
Mand-VolB	0.794†	0.679†	0.861‡	0.846‡
Mand-VolTo	0.559*	0.311*	0.644†	0.414*
Max-min CSA	0.485*	0.258*	0.710†	0.604†
Mand-min CSA	0.308	0.172	0.215	0.088

r, Pearson's correlation coefficient; R^2, coefficient of the linear regression.
*$P \leq 0.05$; †$P \leq 0.01$; ‡$P \leq 0.001$.

and mandibular protrusion, confirming the importance of the mandibular spatial position.

The importance of making such analyses and correlations with the percentage of the volume variation and not with the absolute value, as in most previous studies, is evidenced in Table IV.[35] The percentage evaluation eliminates the relevance of the baseline volume, which seems to have a high variation within the subjects and their facial morphology, among other factors.[16] Assuming variations of volume of 10,000 mm³ on a 16,478 mm³ airway and on a 54,255 mm³ airway (opposite ends of this study), one could realize that the clinical effects would not be the same in both patients. Now considering the percentage variation, the first one would have a 60% increase on its volume and the second just 18%, configuring a more credible analysis. This consideration becomes even more important because 3D measurement softwares proved to have high reliability yet poor accuracy.[8]

Jakobsone et al[27] reported an average forward movement of the maxilla of 3.7 mm (measured at Point A) and average backward movement of the mandible of 6.9 mm (measured at Point B) when analyzing maxillary advancement associated with mandibular setback. In our study, both jaws had similar degrees of movement in group 1, with mean of 5.06 ± 0.86 mm of forward movement of the maxilla and 5.25 ± 0.95 mm of backward movement of the mandible. In the maxillomandibular advancement group, the mean of jaw displacement was substantially

lower compared with previous studies, primarily because this surgery is used for the treatment of obstructive sleep apnea, requiring greater jaw advancement (10 mm, approximately).[36,37] The method to evaluate the jaw displacement described here was used because it is crucial to have a reliable 3D assessment of the surgical outcomes; 2D cephalometrics allow only sagittal and vertical evaluations of jaw displacements, even though patients with considerable transverse alterations had been excluded from this sample.[36]

Stronger correlations were found between the jaws and the volume segment that was closer to them. In the same way, when comparing patients subjected to isolated mandibular setback and maxillary setback associated with mandibular setback, Lee et al[20] found greater decreases of the nasopharynx and oropharynx volumes of the latter group. This probably occurs because the maxilla and soft palate have their correlated muscles and ligaments attached to the upper portion of the pharynx, and the mandible and tongue have their structures attached to the lower portion. However, our results showed that the mandibular displacement actually had an influence in the upper segment volume (despite the weak correlation between VolA and Mand), proved by the statistical difference on the degree of VolA variation between the groups ($P \leq 0.001$), despite their similar mean maxillary displacements (Fig 5, A). One likely explanation for this fact is the intimate relationship between the base of the tongue and the inferior portion of the soft palate. Therefore, when the first goes backward, it probably pushes the soft palate with it, decreasing VolA. Group 2 had stronger correlations and better adjustments to regression models compared with group 1, probably because both jaws moved in the same direction, leading to more predictable outcomes.

When the groups' volumetric data were combined, the adjustment of the variables Max-VolA to the regression model was weak. So, predicting the percentage of volume variation in the upper segment would be more reliable when using the regression model proposed for each kind of surgery separately. Regarding the lower volume segment, the combined data regression model Mand-VolB showed an excellent adjustment ($R^2 = 0.914$; $P \leq 0.001$) supported by greater statistical power (n = 42); because of that, it is suitable for use on both kinds of surgery studied. However, these data can be used only for patients with small surgical vertical variations and occlusal plane rotations. We believe that the strength of the correlations and goodness of fit to the linear regression models of this study are closely linked to the sample selection process. Panou et al[15] did not find important correlations between the amount of jaw displacement and the volumetric changes on the

PA when evaluating 17 subjects who had undergone bimaxillary surgery for Class III correction. However, a substantial part of their sample comprised vertical surgical movements of the jaws in association with anteroposterior displacements, such as maxillary impaction and maxillary down graft.

The minimal cross-sectional area is important in the PA evaluation of patients who are candidates for orthodontic-surgical treatment because of its role as a risk factor for obstructive sleep apnea.[38] If this measurement is smaller, additional care regarding the surgical planning should be taken. CBCT and Dolphin3D showed high accuracy and reliability for the assessment of this measure and so were used in this study.[39] However, variations in the position of the soft palate and tongue between time points might significantly influence this measurement. Patients with visible differences of these structures' positions in the T1 and T2 CBCT scans must be excluded from the sample. Besides that, a comparison between the computer-generated value and the min CSA axial image is suggested on the selected patients to identify potential variance. Raffaini et al[40] found a mean of 112% increase in the min CSA of 10 patients who had undergone maxillomandibular advancement, in contrast to 56.91% in our study. However, the range of mandibular advancement in their sample was substantially higher (10-18 mm). No statistical correlation was found between maxillary displacement and the min CSA variation, or the mandibular displacement and min CSA variation on the maxillary advancement associated with mandibular setback. In the maxillomandibular advancement group, only the maxillary displacement had an important positive correlation with the measurement variation. Data of both groups were not analyzed together because there is only 1 min CSA for the whole PA, whereas there were 2 volumetric measurements (upper and lower segments) that allowed an integrated analysis.

The information of which jaw can provoke more substantial modifications on the PA volume and min CSA is crucial and can significantly modify the orthodontic-surgical treatment plan. Whether one is looking for a larger increase on the superior segment and on the min CSA of the PA, for example, it will be prudent to perform a greater maxillary advancement.

The main limitation of this retrospective study was the absence of information regarding the patients' quality of sleep before and after the surgical procedures. Although the craniofacial and PA morphologies are not the only etiologic factors of sleep-related breathing disorders, they are still considered important risk factors.[1,41] Another limitation was the difficulty to obtain T1 and T2 scans at the same breathing stage; this might have influenced the PA dimensions measurements. To reduce this problem, patients were instructed to breathe softly and not to swallow during the scanning.[4] A recent study reported the reliability of airway volumetric measurements, regardless of the operator's experience, increasing their external validity.[42] However, extreme caution should be taken when selecting and identifying the boundaries; otherwise, the results will be biased. Eventually, the threshold value selection, which is liable to be chosen when one is evaluating the pharyngeal airway on Dolphin3D, causes some subjectivity in the volumetric and area measurements. Alves et al[43] showed, in a prototype study, that the most accurate threshold values seemed to be much higher than the ones that have been used. The operator should be experienced and calibrated, and the same sensitivity value should be used on the T1 and T2 scans of the patient to minimize errors.

A sample of 17 (group 1) is not sufficient to offer conclusive results; the current casuistry is being expanded. However, aside from the quantity of the sample, its quality is important. That is why a thorough selection was applied; only 12.42% of the pooled sample was considered eligible. Studies with larger samples correlating jaw displacements and pharyngeal airway changes are encouraged to better understand the impact of these surgical-orthodontic treatments on this important structure.

CONCLUSIONS

1. Stronger correlations were found between the jaw displacements and the percentage of variation of the volume segment that was closer to them. Mandibular displacement proved to have an influence on the upper volume segment as well.
2. Pharyngeal airway dimension modifications should be assessed by comparison of the preoperative and postoperative percentage variation values (T2/T1−1) and not with the absolute values (T2−T1), for both volumetric and area measurements.
3. Prediction of the volume variation of the pharyngeal airway's upper segment should be made separately for each kind of orthognathic surgery. In contrast, the volume variation of the lower segment is predictable regardless of the kind of surgery (considering the filtering conditions).
4. Prediction of the minimal cross-sectional area percentage variation on the maxillary advancement associated with mandibular setback is not reliable when considering the maxillary and mandibular displacements. On the other hand, the maxillary displacement proved to be a reliable predictor of the min CSA (%) variation on maxillomandibular advancement surgery.

REFERENCES

1. Katyal V, Pamula Y, Martin AJ, Daynes CN, Kennedy JD, Sampson WJ. Craniofacial and upper airway morphology in pediatric sleep-disordered breathing: systematic review and meta-analysis. Am J Orthod Dentofacial Orthop 2013;143:20-30.e3.

2. 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;40:1347-56.

3. Kitahara T, Hoshino Y, Maruyama K, In E, Takahashi I. Changes in the pharyngeal airway space and hyoid bone position after mandibular setback surgery for skeletal Class III jaw deformity in Japanese women. Am J Orthod Dentofacial Orthop 2010;138:708.e1-10; discussion 708-9.

4. Degerliyurt K, Ueki K, Hashiba Y, Marukawa K, Nakagawa K, Yamamoto E. A comparative CT evaluation of pharyngeal airway changes in class III patients receiving bimaxillary surgery or mandibular setback surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:495-502.

5. Kim JS, Kim JK, Hong SC, Cho JH. Pharyngeal airway changes after sagittal split ramus osteotomy of the mandible: a comparison between genders. J Oral Maxillofac Surg 2010;68:1802-6.

6. Kawamata A, Fujishita M, Ariji Y, Ariji E. Three-dimensional computed tomographic evaluation of morphologic airway changes after mandibular setback osteotomy for prognathism. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:278-87.

7. Alsufyani NA, Al-Saleh MA, Major PW. CBCT assessment of upper airway changes and treatment outcomes of obstructive sleep apnoea: a systematic review. Sleep Breath 2013;17:911-23.

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

9. Grunheid T, Kolbeck Schieck JR, Pliska BT, Ahmad M, Larson BE. Dosimetry of a cone-beam computed tomography machine compared with a digital x-ray machine in orthodontic imaging. Am J Orthod Dentofacial Orthop 2012;141:436-43.

10. Hernandez-Alfaro F, Guijarro-Martinez R. New protocol for three-dimensional surgical planning and CAD/CAM splint generation in orthognathic surgery: an in vitro and in vivo study. Int J Oral Maxillofac Surg 2013;42:1547-56.

11. Cevidanes LH, Bailey LJ, Tucker GR Jr, Styner MA, Mol A, Phillips CL, et al. Superimposition of 3D cone-beam CT models of orthognathic surgery patients. Dentomaxillofac Radiol 2005;34:369-75.

12. Carvalho Fde A, Cevidanes LH, da Motta AT, Almeida MA, Phillips C. Three-dimensional assessment of mandibular advancement 1 year after surgery. Am J Orthod Dentofacial Orthop 2010;137(Suppl):S53.e1-12; discussion S53-5.

13. Tselnik M, Pogrel MA. Assessment of the pharyngeal airway space after mandibular setback surgery. J Oral Maxillofac Surg 2000;58:282-5.

14. Muto T, Yamazaki A, Takeda S, Sato Y. Accuracy of predicting the pharyngeal airway space on the cephalogram after mandibular setback surgery. J Oral Maxillofac Surg 2008;66:1099-103.

15. 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 2013;83:824-31.

16. 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 Dentofacial Orthop 2009;136:805-14.

17. 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 Dentofacial Orthop 2013;143:799-809.

18. El H, Palomo JM. Airway volume for different dentofacial skeletal patterns. Am J Orthod Dentofacial Orthop 2011;139:e511-21.

19. Muto T, Takeda S, Kanazawa M, Yamazaki A, Fujiwara Y, Mizoguchi I. The effect of head posture on the pharyngeal airway space (PAS). Int J Oral Maxillofac Surg 2002;31:579-83.

20. Lee JY, Kim YI, Hwang DS, Park SB. Effect of maxillary setback movement on upper airway in patients with class III skeletal deformities: cone beam computed tomographic evaluation. J Craniofac Surg 2013;24:387-91.

21. Lee Y, Chun YS, Kang N, Kim M. Volumetric changes in the upper airway after bimaxillary surgery for skeletal class III malocclusions: a case series study using 3-dimensional cone-beam computed tomography. J Oral Maxillofac Surg 2012;70:2867-75.

22. Cevidanes L, Oliveira AE, Motta A, Phillips C, Burke B, Tyndall D. Head orientation in CBCT-generated cephalograms. Angle Orthod 2009;79:971-7.

23. Yushkevich PA, Piven J, Hazlett HC, Smith RG, Ho S, Gee JC, et al. User-guided 3D active contour segmentation of anatomical structures: significantly improved efficiency and reliability. Neuroimage 2006;31:1116-28.

24. Chapuis J, Schramm A, Pappas I, Hallermann W, Schwenzer-Zimmerer K, Langlotz F, et al. A new system for computer-aided preoperative planning and intraoperative navigation during corrective jaw surgery. IEEE Trans Inf Technol Biomed 2007;11:274-87.

25. Chung C, Lee Y, Park KH, Park SH, Park YC, Kim KH. Nasal changes after surgical correction of skeletal Class III malocclusion in Koreans. Angle Orthod 2008;78:427-32.

26. Rosen HM. Lip-nasal aesthetics following Le Fort I osteotomy. Plast Reconstr Surg 1988;81:171-82.

27. Jakobsone G, Stenvik A, Sandvik L, Espeland L. Three-year follow-up of bimaxillary surgery to correct skeletal Class III malocclusion: stability and risk factors for relapse. Am J Orthod Dentofacial Orthop 2011;139:80-9.

28. Park SB, Kim YI, Son WS, Hwang DS, Cho BH. Cone-beam computed tomography evaluation of short- and long-term airway change and stability after orthognathic surgery in patients with Class III skeletal deformities: bimaxillary surgery and mandibular setback surgery. Int J Oral Maxillofac Surg 2012;41:87-93.

29. Wang YC, Ko EW, Huang CS, Chen YR. The inter-relationship between mandibular autorotation and maxillary LeFort I impaction osteotomies. J Craniofac Surg 2006;17:898-904.

30. 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;142:801-13.

31. 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:e401-8.

32. 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;69:2424-36.

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

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

35. 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 2013;13: S1010-5182.

36. Aboudara C, Nielsen I, Huang JC, Maki K, Miller AJ, Hatcher D. Comparison of airway space with conventional lateral headfilms and 3-dimensional reconstruction from cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2009;135:468-79.

37. 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;65:6-12.

38. Vos W, De Backer J, Devolder A, Vanderveken O, Verhulst S, Salgado R, et al. Correlation between severity of sleep apnea and upper airway morphology based on advanced anatomical and functional imaging. J Biomech 2007;40:2207-13.

39. Ghoneima A, Kula K. Accuracy and reliability of cone-beam computed tomography for airway volume analysis. Eur J Orthod 2013;35:256-61.

40. 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;41:552-7.

41. Miles PG, Vig PS, Weyant RJ, Forrest TD, Rockette HE Jr. Craniofacial structure and obstructive sleep apnea syndrome—a qualitative analysis and meta-analysis of the literature. Am J Orthod Dentofacial Orthop 1996;109:163-72.

42. Mattos CT, Cruz CV, da Matta TC, Pereira Lde A, Solon-de-Mello Pde A, Ruellas AC, et al. Reliability of upper airway linear, area, and volumetric measurements in cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2014;145:188-97.

43. Alves M Jr, Baratieri C, Mattos CT, Brunetto D, Fontes Rda C, Santos JR, et al. Is the airway volume being correctly analyzed? Am J Orthod Dentofacial Orthop 2012;141:657-61.