

Clinical Paper
Orthognathic Surgery

Pharyngeal airway space changes after maxillomandibular advancement: a five-year retrospective study

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Abstract. The aim of this study was to compare the alterations in three regions of the airway—nasopharynx, oropharynx, and hypopharynx—in relation to the area of the midsagittal plane, volume, and minimal axial area after maxillomandibular advancement (MMA) surgery. Thirty patients who had undergone MMA surgery were evaluated at four time points: preoperative (T0), immediately postoperative (T1), 1 year postoperative (T2), and ≥ 5 years postoperative (T3). All measurements were performed using computed tomography, analyzed in Dolphin Imaging 11.0 Premium 3D software. The area in the midsagittal plane presented a mean increase of 22.0% between T0 and T3 ($P < 0.001$), with the highest increase in the oropharynx (24.1%, $P < 0.001$). The total volumetric increase at T3 was 16.7% ($P < 0.001$), with the highest increase in the nasopharynx (15.7%; $P < 0.001$). The lowest minimal axial area was found for the oropharynx at all time points, and the highest increase in minimal axial area was found for the nasopharynx (114.9%; $P < 0.001$). MMA surgery showed the highest increase in upper posterior airway between T0 and T1, and this was followed by a progressive reduction until T3, but with a statistically significant increase at T3 compared with T0 in all cases.

Key words: orthognathic surgery; upper posterior airway; computed tomography.

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Orthognathic surgery has been a successful option for the correction of severe dentofacial deformities, providing alterations in the upper posterior airways and gaining the attention of the scientific com-

munity^{1,2}. The aim of orthognathic surgery is to establish harmonious facial aesthetics, optimal functional occlusion, and stability. Improvements in upper posterior airway (UPAW) conditions may

also be an important goal of orthodontic-surgical treatment. Maxillomandibular advancement (MMA) surgery promotes anteroposterior, vertical, and lateral–lateral movement due to the displacement of

the bony bases to a new position, generating tensions in the soft tissues of the region and usually resulting in a volumetric increase in UPAW³. MMA appears to increase UPAW volume through the advancement of the maxilla and subsequent forward movement of the soft palate. Furthermore, when a counterclockwise direction is used, the soft palate is also moved more downward. Also, with the advancement of the mandible, the genioglossus and geniohyoid muscles and the base of the tongue are repositioned more forward⁴. Moreover, genioplasty promotes an additional increase in UPAW by repositioning the hyoid bone anteriorly and superiorly, with the greatest effect in the hypopharynx region^{5,6}.

Although several studies have already shown that MMA surgery increases the UPAW space, some of these studies performed airway evaluations on two-dimensional radiographs, included a heterogeneous population or a small sample, or covered a short follow-up period^{3,4,7–12}.

The aim of this study was to evaluate changes in three specific regions of the UPAW—nasopharynx, oropharynx, and hypopharynx—in relation to the area of the midsagittal plane, volume, and minimal axial area after MMA surgery, over a follow-up period of at least 5 years, using cone beam computed tomography (CBCT).

Materials and methods

The study was submitted to and approved by the Ethics Committee for Research Involving Humans of the Federal University of Ceará – UFC. The medical records of 428 patients attending a private clinic were evaluated. From the total sample, the first 30 patients who met the inclusion/exclusion criteria for the study were selected.

The inclusion criteria were as follows: the patient had to be American Society of Anesthesiologists (ASA) status 1, with a class II facial pattern and maxillary and mandibular deficiency, and to have undergone orthognathic surgery with MMA, associated with an advancement genioplasty or anti-clockwise rotation of the occlusal plane; the patient's age had to fall within the range of 21–35 years; CBCT documentation had to be available for all time points evaluated in the study (T0, preoperative; T1, immediately postoperative ≤30 days; T2, 1 year postoperative; T3, a minimum of 5 years postoperative); and the bone bases treated

had to be stable at T3. To evaluate bone stability at T3, computed tomography (CT) scans were superimposed on T1 scans using cranial base segments and the Dolphin Imaging 11.9 superimpose tool (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA) and compared. Linear measurements were performed to evaluate the anteroposterior, vertical, and axial stability. The criterion of a maximum 2 mm of difference was established as showing stability of the movement at points in the maxilla (anterior nasal spine and the canine eminences) and the mandible (pogonion and mental foramen).

The following exclusion criteria were applied: patients with a transverse maxillary deficiency; patients with severe facial asymmetry or the presence of a syndrome; those who experienced some intercurrent during the orthodontic-surgical treatment, such as undesirable fracture, or loss of rigid internal fixation; patients with symptoms of a disorder or degeneration of the temporomandibular joint; and those who had undergone surgical procedures prior to the MMA.

All MMA surgeries were performed by the same surgical team and consisted of bilateral sagittal osteotomy of the mandible and Le Fort I osteotomy, fixed by means of functionally stable internal fixation.

Three-dimensional (3D) CT scans were obtained at T0, T1, T2, and T3 using an i-CAT machine (Imaging Sciences International, Hatfield, PA, USA) and then loaded into Dolphin Imaging 11.0 Premium 3D software (Dolphin Imaging & Management Solutions, Chatsworth, CA, USA). The following variables were evaluated: (1) area of the midsagittal plane of the UPAW and of the nasopharynx, oropharynx, and hypopharynx regions; (2) total volume of the UPAW and the nasopharynx, oropharynx, and hypopharynx; and (3) the minimal axial area in the nasopharynx, oropharynx, and hypopharynx.

For the delimitation of UPAW, points similar to those used by Raffaini and Pisani (2013)¹² and Schendel et al. (2014)¹³ were used as a reference. The superior limit of the UPAW was the line passing through the root of the soft palate parallel to the Frankfort plane. The inferior limit of the UPAW was a line between the hyoid bone and the third cervical vertebra. The nasopharynx was delimited superiorly by the upper limit of UPAW and inferiorly by a line parallel to the superior one passing through the upper airway space, touching the lower part of

the first vertebra. The oropharynx was delimited superiorly by the inferior border of the nasopharynx and inferiorly by a line that crossed the posterior superior airway space above the base of the epiglottis, parallel to the upper limit. The hypopharynx was delimited superiorly by the lower border of the oropharynx and inferiorly by the lower limit of the UPAW.

Statistical analysis

For intra-examiner calibration, the measurements of five patients were performed by a single examiner in duplicate (16.7% of the sample), with a 30-day interval between measurements ($\kappa = 0.900$). Reproducibility was estimated by intra-class correlation coefficient. Data were submitted to the Kolmogorov–Smirnov normality test, expressed as the mean \pm standard deviation value, and analyzed using the analysis of variance (ANOVA) test followed by the Bonferroni post-test (parametric data). In addition, Pearson correlation was performed. Data were analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA), adopting a 95% confidence level for all analyses. In the descriptive analyses, the mean and standard deviation of the initial and final measurements of the total area, the total volume, and the minimal axial area of the airway in the nasopharynx, oropharynx, and hypopharynx regions were presented. The paired-samples *t*-test was performed to verify whether there was a significant change between the preoperative values and those obtained postoperative.

Results

Thirty patients were selected for inclusion in the study. The male to female ratio was 1:2 and the mean age of the patients was 26.5 years (range 21–35 years). The mean follow-up time was 76.3 months (range 61–97 months). Maxillary advancement ranged from 3.4 mm to 8.1 mm (mean 5.9 mm); mandibular advancement ranged from 7.3 mm to 13.9 mm (mean 10.4 mm). The average body mass index (BMI) at T0 was 24.8 ± 3.36 kg/m², and at T3 was 25.9 ± 3.56 kg/m², with a statistically significant difference ($P = 0.0024$).

In the quantitative analysis of the total UPAW area in the midsagittal plane (Table 1, Fig. 1), a mean increase of 6.42 cm² was observed between T0 and T1, which is an increase of 84.2% ($P < 0.001$). At T2, the mean increase compared to T0 was 3.04 cm², which is an increase of 39.9% ($P < 0.001$). When compared to T0 there

Table 1. Descriptive analysis of the upper posterior airway (UPAW) area in the midsagittal plane in the preoperative (T0), immediate postoperative (T1), 1-year postoperative (T2), and ≥ 5 -year postoperative (T3) periods.

	T0	T1	T2	T3
Total UPAW				
Average (cm ²)	7.62	14.04 (84.2%; $P < 0.001$)	10.66 (39.9%; $P < 0.001$)	9.30 (22.0%; $P < 0.001$)
Minimum (cm ²)	3.79	7.65	6.43	5.26
Maximum (cm ²)	12.26	22.04	16.79	15.22
Nasopharynx				
Average (cm ²)	3.87	7.18 (85.5%; $P < 0.001$)	5.17 (33.5%; $P < 0.001$)	4.50 (16.3%; $P < 0.001$)
Minimum (cm ²)	1.59	3.85	2.68	2.16
Maximum (cm ²)	7.08	16.40	8.18	7.74
Oropharynx				
Average (cm ²)	2.20	3.59 (63.2%; $P < 0.001$)	2.80 (27.2%; $P < 0.001$)	2.73 (24.1%; $P < 0.001$)
Minimum (cm ²)	1.14	2.68	1.79	1.42
Maximum (cm ²)	3.58	4.67	4.18	3.95
Hypopharynx				
Average (cm ²)	1.51	2.89 (91.3%; $P < 0.001$)	2.22 (47.0%; $P < 0.001$)	1.86 (23.1%; $P < 0.001$)
Minimum (cm ²)	0.71	1.87	1.32	0.97
Maximum (cm ²)	3.43	4.58	3.93	3.78

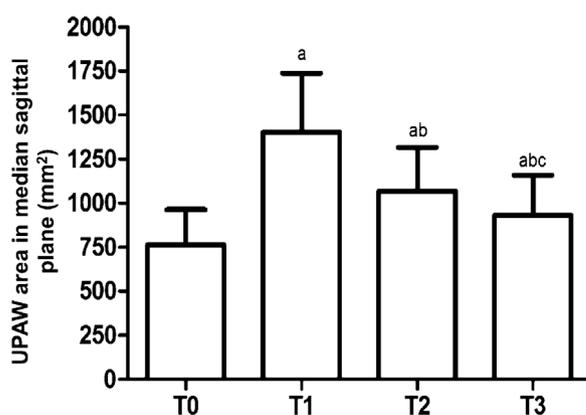


Fig. 1. Quantitative analysis of the total upper posterior airway area in the midsagittal plane at T0 (preoperative), T1 (immediately postoperative), T2 (1 year postoperative), and T3 (≥ 5 years postoperative).

was an average increase of 1.68 cm² at T3, which is an increase of 22.0% ($P < 0.001$).

On separate evaluation of the nasopharynx, oropharynx, and hypopharynx

regions, they presented behaviour similar to that of the total area in the midsagittal plane of the UPAW. There was a mean increase in the area of the nasopharynx in

the midsagittal plane of 3.31 cm² between the T0 and T1 ($P < 0.001$). At T2, there was mean increase of 1.30 cm² ($P < 0.001$) in relation to T0. An average increase of 0.63 cm² was observed at T3 in comparison to T0 ($P < 0.001$). In the oropharynx, there was a mean increase in the area in the midsagittal plane between T0 and T1 of 1.39 cm² ($P < 0.001$). At T2, the mean increase was 0.60 cm² in relation to T0. A statistically significant increase was also observed at T3 in relation to T0, with an average increase of 0.53 cm² ($P < 0.001$). The area of the hypopharynx in the midsagittal plane presented a mean increase of 1.38 cm² between T0 and T1 ($P < 0.001$). At T2, the mean increase was 0.71 cm² ($P < 0.001$) in relation to T0. At T3, a statistically significant increase was observed in relation to T0, with an average increase of 0.35 cm² ($P < 0.001$).

In relation to the total UPAW volume (Table 2, Fig. 2), there was a mean in-

Table 2. Descriptive analysis of the upper posterior airway (UPAW) volume in the preoperative (T0), immediate postoperative (T1), 1-year postoperative (T2), and ≥ 5 -year postoperative (T3) periods.

	T0	T1	T2	T3
Total UPAW				
Average (cm ³)	184.30	321.98 (74.7%; $P < 0.001$)	250.89 (36.1%; $P < 0.001$)	215.23 (16.7%; $P < 0.001$)
Minimum (cm ³)	78.37	184.34	122.93	101.19
Maximum (cm ³)	260.21	512.12	437.69	428.77
Nasopharynx				
Average (cm ³)	102.04	184.20 (80.5%; $P < 0.001$)	143.03 (40.2%; $P < 0.001$)	118.03 (15.7%; $P < 0.001$)
Minimum (cm ³)	37.90	90.18	67.78	48.90
Maximum (cm ³)	201.27	252.54	241.80	220.08
Oropharynx				
Average (cm ³)	50.28	87.66 (74.3%; $P < 0.001$)	71.29 (41.8%; $P < 0.001$)	55.73 (10.8%; $P < 0.001$)
Minimum (cm ³)	20.44	44.84	34.14	24.37
Maximum (cm ³)	95.72	140.12	123.19	100.01
Hypopharynx				
Average (cm ³)	26.99	82.78 (206.7%; $P < 0.001$)	49.81 (84.5%; $P < 0.001$)	30.68 (13.7%; $P < 0.001$)
Minimum (cm ³)	11.76	64.59	29.97	16.49
Maximum (cm ³)	41.26	98.89	68.93	45.43

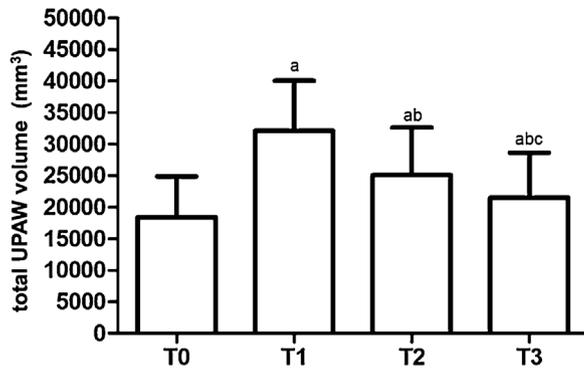


Fig. 2. Quantitative analysis of the total upper posterior airway volume at T0 (preoperative), T1 (immediately postoperative), T2 (1 year postoperative), and T3 (≥ 5 years postoperative).

crease of 137.68 cm³ between T0 and T1, representing an increase of 74.4% ($P < 0.001$). At T2, the mean increase was 66.59 cm³, equivalent to an increase of 36.1% in relation to T0 ($P < 0.001$). A statistically significant increase was observed at T3 in relation to T0, with a mean increase of 30.93 cm³, representing an increase of 16.7% ($P < 0.001$).

In the separate analysis of the UPAW segments, the same pattern of modifications in volume occurred in the segments as in the total UPAW. The nasopharynx presented a mean increase in volume of 82.16 cm³ between T0 and T1 ($P < 0.001$). At T2, the mean increase was 40.99 cm³ ($P < 0.001$) compared with T0. A statistically significant increase was observed at T3 in relation to T0, with an average increase of 15.99 cm³ ($P < 0.001$). In the oropharynx, there was an average increase in volume between T0 and T1 of 37.38 cm³ ($P < 0.001$). At T2, the mean increase was 21.01 cm³ ($P < 0.001$) in relation to T0. At T3, there was a statistically significant increase in relation to T0, with an average increase of 5.45 cm³ ($P < 0.001$). The hypopharynx presented a mean increase of 55.79 cm³ between T0 and T1

($P < 0.001$). At T2, the mean increase in relation to T0 was 22.82 cm³ ($P < 0.001$). A statistically significant increase was observed at T3 in relation to T0, with an average increase of 3.69 cm³ ($P < 0.001$).

In the analysis of the minimal axial area (Table 3), the nasopharynx presented an average increase of 1.86 cm², representing an increase of 213.7% ($P < 0.001$) between T0 and T1. At T2, the mean increase in relation to T0 was 1.32 cm², an increase of 151.7% ($P < 0.001$). An average increase of 1.00 cm² occurred at T3, equivalent to an increase of 114.9% ($P < 0.001$). For oropharynx, there was a mean increase of 1.01 cm² between T0 and T1, an increase of 138.3% ($P < 0.001$). At T2, the mean increase was 0.62 cm², representing an increase of 84.9%. A statistically significant increase was observed at T3 in relation to T0, with a mean increase of 0.35 cm², 47.9% ($P < 0.001$). For the hypopharynx, comparison between T0 and T1 showed a mean increase of 1.32 cm², equivalent to an increase of 163.8%, ($P < 0.001$). At T2, the mean increase in relation to T0 was 0.69 cm², 85.6% ($P < 0.001$). There was a statistically significant increase at T3 compared to T0, with an average increase

of 0.36 cm², which is an increase of 44.6% ($P < 0.001$).

On analysis of the data obtained, a positive correlation was found between the increase in minimal axial area and the total volume increase of the airway, but without statistical significance (Fig. 3; $P = 0.325$). The correlation between the total volume increase at T1 and the amount of volume loss at T3 showed statistical significance (Fig. 4; $P = 0.007$).

Discussion

CBCT has become a very important tool for studying the UPAW, allowing 3D reconstruction of the mineralized tissues and air spaces of the maxillofacial region with minimal distortion when compared with traditional CT. This allows the precise quantification of the airway morphology before and after orthodontic-surgical treatment for patients with a dentofacial deformity^{7,14}. The airways are surrounded by soft tissues (muscles and adipose tissue) as well as hard tissues (cartilage and bone). All these tissues play a role in the anatomy and function of the UPAW; thus, it is normal for the airways to respond to changes in these tissues. Volumetric analysis of the airway can be a challenge due to variability in head position and phase breathing¹⁵. However, the whole craniofacial region is acquired in about 40 seconds using CBCT and this may reduce the variability due to changes in position of the head, which are more frequent with slower techniques, such as magnetic resonance imaging and conventional CT. Nevertheless, standardized head posture instructions should be given to the patients.

Previous studies have shown that MMA leads directly to an increase in the UPAW in all dimensions, both anteroposterior and lateral-lateral^{7-9,12,16,17}. However, these studies are subject to certain limitations,

Table 3. Descriptive analysis of the minimal axial area measurements of the upper posterior airway (UPAW) segments in the preoperative (T0), immediate postoperative (T1), 1-year postoperative (T2), and ≥ 5 -year postoperative (T3) periods.

	T0	T1	T2	T3
Nasopharynx				
Average (cm ²)	0.87	2.73 (213.7%; $P < 0.001$)	2.19 (151.7%; $P < 0.001$)	1.87 (114.9%; $P < 0.001$)
Minimum (cm ²)	0.20	1.71	1.31	0.57
Maximum (cm ²)	2.40	3.89	3.42	3.19
Oropharynx				
Average (cm ²)	0.73	1.74 (138.3%; $P < 0.001$)	1.35 (84.9%; $P < 0.001$)	1.08 (47.9%; $P < 0.001$)
Minimum (cm ²)	0.26	0.94	0.58	0.45
Maximum (cm ²)	2.54	2.63	3.01	2.71
Hypopharynx				
Average (cm ²)	0.80	2.12 (163.8%; $P < 0.001$)	1.49 (85.6%; $P < 0.001$)	1.16 (44.6%; $P < 0.001$)
Minimum (cm ²)	0.45	1.42	0.86	0.66
Maximum (cm ²)	1.29	2.54	2.28	1.59

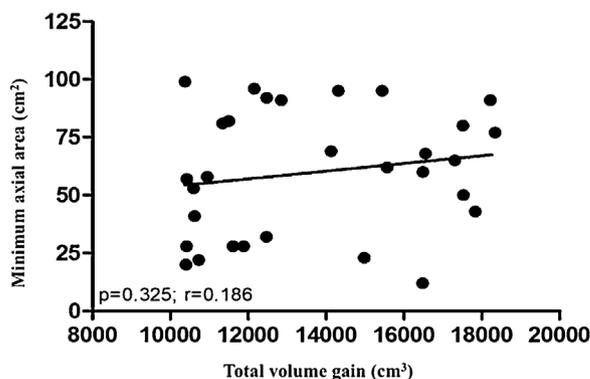


Fig. 3. Correlation between the increase in the minimal axial area and the total volume increase of the airway.

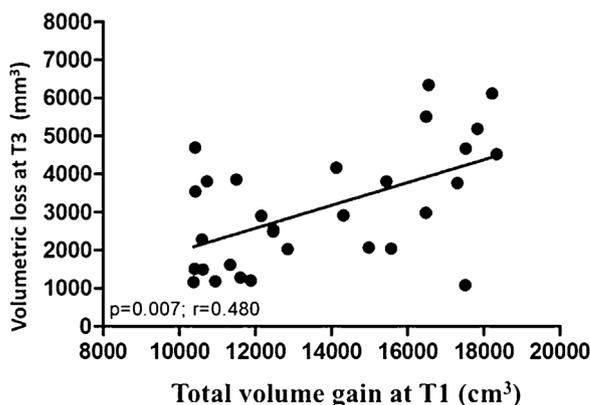


Fig. 4. Correlation between the total volume increase at T1 (immediately postoperative) and the amount of volume loss at T3 (≥ 5 years postoperative).

such as a limited follow-up time, which may lead to questions regarding the stability of the airway increase, and also a large age range, since there are indications that there is a systematic loss of UPAW size starting around 35 years of age¹⁸. For this reason, the present study was restricted to young adult patients (21–35 years) to avoid changes in muscle tone or loss of airway size due to age, and the minimum postoperative evaluation time at T3 was 5 years.

Controversy remains regarding the stability of the UPAW increase after MMA, with some studies claiming that the changes are stable and others reporting that the airways adapt to the changes and return to pre-surgery values^{7,8,19}. In the present study, the area of the midsagittal plane, volume, and minimal axial area presented a similar trend in all analyses, with a significant increase from T0 to T1 and a progressive reduction to T3 (Figs. 1 and 2), suggesting that adaptation of the UPAW occurs over a longer time than reported by other authors^{7,8}. However, it is important to note that even with the reduction that occurred over the periods evaluated, there remained a statistically

significant real increase at T3 when compared to T0 in the evaluation of the total UPAW and its segments separately.

Raffaini and Pisani (2013)¹² reported in their research that, after MMA, patients presented an improvement in UPAW parameters, with mean increases of 34% for the total area, 56% for the volume, and 112% for the axial area, as well as a positive improvement in respiratory function perceived by patients. Likewise, positive results were observed in the present study, since the average total increases obtained at T3 were 22.0% for area, 16.7% for volume, and 44.6% for the minimal axial area. The difference found between the results could be explained by the timing of postoperative follow-up, as it is not clear how long this was in the work by Raffaini and Pisani¹².

Regarding the volumetric analysis of the isolated segments, the oropharyngeal region had the lowest total long-term volume increase (T3). The hypopharynx had the highest average increase in the immediate postoperative period (T1) and was the region that presented the greatest recurrence in the present study. As shown in Fig. 4, with a higher volume

increase at T1 there was a higher loss of volume at T3.

Studies have indicated that there is a significant relationship between a narrower cross-sectional area of the upper airway and the likelihood of obstructive sleep apnoea syndrome (OSAS)^{13,20}. Patients who present a minimal axial area of the airway smaller than 52 mm² present a high risk of developing OSAS, patients with a minimal axial area ranging from 52 mm² to 110 mm² present a moderate risk of developing OSAS, and patients with a minimal axial area greater than 110 mm² show a low risk of developing OSAS. In the present study, the oropharynx presented the smallest minimal axial area of the airways at all evaluation times (T0, T1, T2, and T3). At T0, 17 patients presented a minimal axial area of less than 52 mm² (eight in the nasopharynx, eight in the oropharynx, and one in the hypopharynx) and 13 patients presented a minimal axial area ranging from 52 mm² to 110 mm² (one in the nasopharynx, six in the oropharynx, and six in the hypopharynx). At T3, only one patient presented a minimal axial area of less than 52 mm², which was located in the oropharynx; 25 patients presented a minimal axial area ranging from 52 mm² to 110 mm² (four in the nasopharynx, 17 in the oropharynx, and four in the hypopharynx) and five patients presented a minimal axial area of more than 110 mm² in the three evaluated regions of the UPAW, placing them at low risk of developing of OSAS.

This study, as well as most studies that have evaluated the surgical effect of MMA in UPAW, provides quantitative information but does not address the qualitative effects of surgery experienced by the patients. In this regard, Poiseuille's flow rate law²¹ demonstrates that even a modest increase in the radius (the minimal axial area) of a tube (or airway) will result in a significant decrease in airway resistance, which will certainly produce improvements in the patient's airflow. However, the effect this has on the patient's quality of life needs to be better investigated. The increase in quality of life could be explained by the decrease in airway resistance, related to a shorter airway (in cases of maxillary impaction) and a wider airway²². Although airway height loss was not assessed, all cases showed a significant increase in minimal axial area at T3, probably leading to a reduction in airway resistance. In this study, if the height of the UPAW is considered stable, the estimated increase in airflow at T3 would be 2.9-fold in the nasopharyngeal region, 1.8-fold in the oropharynx, and 2.1-fold in the hypopharynx.

Limitations in previous 3D airway assessment studies in terms of differences in UPAW delimitation, variability in patient age in the population studied, and a short follow-up time, make comparisons between these previous studies and the present study difficult. A limitation of the present study is that the average BMI increased from $24.8 \pm 3.36 \text{ kg/m}^2$ at T0 to $25.9 \pm 3.56 \text{ kg/m}^2$ at T3 ($P = 0.0024$). Although not a large variation in BMI, this represents an average increase of 1.1-fold in BMI and this may have led to a reduction in the upper airway in some patients, generating a possible bias in the findings of this study. Finally, the study patients were not investigated with regard to OSAS, and the sleep apnoea index was not obtained either before or after MMA.

In conclusion, MMA surgery provided an increase in area of the airway in the midsagittal plane, airway volume, and minimal axial area of the UPAW and its segments. The pattern of modification was similar for each of the assessments, with a significant increase in the immediate post-operative period (T1) and a progressive reduction during the postoperative period up to ≥ 5 years (T3), but with a statistically significant increase remaining at T3 for all analyses performed. Through the increase in minimal axial area of the UPAW, MMA appears to reduce airflow resistance. New studies that also include patients diagnosed with OSAS, with assessment of the apnoea-hypopnoea index, are required. Furthermore, the studies should include an even longer follow-up time in order to clarify whether stability of the UPAW occurs after 5 years or whether there is still some degree of reduction.

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Competing interests

None.

Ethical approval

This study was submitted to and approved by the Ethics Committee for Research Involving Humans of the Federal University of Ceará – UFC (protocol 222/12).

Patient consent

Not required.

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