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Maxillomandibular advancement as the initial treatment of obstructive sleep apnoea: Is the mandibular occlusal plane the key?

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P. Rubio-Bueno, P. Landete, B. Ardanza, L. Vázquez, J.B. Soriano, R. Wix, A. Capote, E. Zamora, J. Ancochea, L. Naval-Gías: Maxillomandibular advancement as the initial treatment of obstructive sleep apnoea: Is the mandibular occlusal plane the key?. Int. J. Oral Maxillofac. Surg. 2017; xxx: xxx–xxx.

Abstract. Maxillomandibular advancement (MMA) can be effective for managing obstructive sleep apnoea (OSA); however, limited information is available on the predictor surgical variables. This study investigated whether normalization of the mandibular occlusal plane (MOP) was a determinant factor in curing OSA. Patients with moderate or severe OSA who underwent MMA were evaluated by preoperative and postoperative three-dimensional (3D) scans and polysomnograms. The postoperative value of MOP and the magnitude of skeletal advancement were the predictor variables; change in the apnoea–hypopnoea index (AHI) was the main outcome variable. Thirty-four subjects with a mean age of 41 $\pm$ 14 years and 58,8% female were analysed. The Epworth Sleepiness Scale (ESS) was 17.4 $\pm$ 5.4 and AHI was 38.3 $\pm$ 10.7 per hour before surgery. Postoperative AHI was 6.5 $\pm$ 4.3 per hour ($P < 0.001$) with 52.94% of the patients considered as cured, and 47.06% suffering from a mild residual OSA with ESS 0.8 $\pm$ 1.4 ($P < 0.001$). 3D changes revealed a volume increase of 106.3 $\pm$ 38.8%. The mandible was advanced 10.4 $\pm$ 3.9 mm and maxilla 4.9 $\pm$ 3.2 mm. MOP postoperative value was concluded to be the best predictor variable. Treatment planning should include MOP normalization and a mandibular advancement between 6 and 10 mm. The maxillary advancement would depend on the desired aesthetic changes and final occlusion.

Key words: maxillofacial surgery; maxillomandibular advancement; obstructive sleep apnoea syndrome; orthognathic surgery; sleep-disordered breathing; counterclockwise rotation occlusal plane; mandibular occlusal plane; mandibular distraction osteogenesis.

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Obstructive sleep apnoea syndrome (OSA) is a medical condition with an estimated prevalence of 4–6% in the adult population as defined by an apnoea and hypopnoea index (AHI) of ≥5 events per hour[1]. OSA is related to cardiovascular and metabolic diseases, among others, and is potentially life threatening. Campos-Rodríguez et al.[2] identified a 10% absolute increase in mortality rate for OSA patients who did not use continuous positive airway pressure (CPAP).

The standard management of OSA is CPAP therapy[1], but empirical studies have suggested that CPAP compliance is low, ranging from 30% to 60%[3–5]. Most patients report that they are uncomfortable using the device and the majority of patients would prefer alternative treatment options.

Maxillomandibular advancement (MMA) is the most effective surgical therapy for adult patients with OSA[6–11] outside the tracheostomy treatment option. The treatment consists of osteotomies of the mandible and the maxilla, producing simultaneous advancement of the maxillomandibular complex. This procedure enlarges the pharyngeal space by expanding the skeletal framework, and thus reducing the risk of pharyngeal collapse during negative pressure inspiration[12,13].

It is currently used for patients with dentofacial deformities requiring orthognathic surgery. Patients with a severe obstructive disease, in whom all applicable conservative therapies have failed or proved intolerable[14] can also benefit from MMA surgery. However, the procedures are difficult to perform, requiring very specific surgical experience. In addition, careful surgical planning and postoperative follow-up are two important elements to consider and ensure long-term stability.

MMA is a revolutionary alternative to conventional treatments for OSA, but there are no well-defined studies about the surgical variables that predict AHI normalization and/or the minimum amount of skeletal advancement that can lead to OSA resolution. This study reports on the surgical treatment outcomes of the 34 subjects with moderate to severe OSA after MMA, with special attention to treatment planning and 3D pharyngeal changes. The study's primary objective was to determine the type and amount of skeletal movements as predictors to correct the AHI and pharyngeal airway space volume (PAS-VOL) changes.

In this study, the hypothesis was that normalization of the mandibular occlusal plane is mandatory to effectively enlarge the upper airway when MMA is performed and should thus be included in the treatment planning to cure the disease. In the cases where the amount of skeletal advancement is better defined, a more rational surgical planning regime will be possible enabling the scope of the technique that is not limited to treating retrognathic patients.

Material and methods

The study population comprised all the patients presenting for the evaluation and management of OSA. Data were collected between December 2007 and January 2015 at the Nisa Pardo de Aravaca Hospital's Department of Oral and Maxillofacial Surgery in Madrid, Spain.

It was designed as a prospective cohort study that aimed to follow up the selected patients over 12 months after intervention. No patient received any concomitant surgical adjunctive procedure, before or after MMA. All patients signed an informed consent for surgery, and specific consent for 3D scan examination, photographs, and 3D virtual planning. Permission from Institutional Review Board Human Studies Committee was obtained.

Diagnosis of OSA was according to current guidelines, and severity was defined as the following: mild (AHI 5–14 per hour), Moderate (15–29 per hour), and severe (>30 per hour)[1].

The following criteria were used to select the study participants: patients had to be adults with moderate to severe OSA (AHI ≥ 15 per hour); refusal to begin or continue treatment with CPAP; health conditions compatible with this surgery; normal anatomy of the mandibular ascending ramus and the temporomandibular joint (TMJ).

A thorough review of the patients' mandibular anatomy was completed prior to surgery. An ascending ramus length >50 mm (distance measured from the condylion to the gonion in a 3D scan) was required to perform a bilateral sagittal split osteotomy of the mandible. Patients with severe ramus hypoplasia and/or condylar resorption were considered as inadequate candidates for receiving conventional MMA. Intraoral mandibular distraction osteogenesis was indicated and performed in this group of patients as it has been suggested in previous studies[15] and were excluded of this series.

Additional criteria in the cohort selection included acceptance of customized morphing software simulation; the patient's acceptance of corrective orthodontic treatment pre- and postoperatively and complete retention after removing the braces during a minimum of a 2-year follow-up with a good dental hygiene track record.

Patients were excluded from the study if they had central sleep apnoea diagnosed by a neurophysiologist, were active smokers, had previous uvulopalatopharyngoplasty (UPPP), or complete edentulism (toothless or had extremely bad remaining teeth) and/or severe TMJ disease in stages IV–V of Wilkes classification.

Other demographic variables collected included age, sex, body mass index (BMI), treatment with CPAP, and using a mandibular advancement device (MAD) as additional parameters for describing all patients selected for the study.

In terms of the OSA, AHI, mean blood oxygen saturation (SaO_2), oxygen desaturation index (ODI), and the value of the Epworth Sleepiness Scale (ESS) were recorded for all patients before 6 six months after MMA. The ODI was observed to be 3% or more oxygen desaturation lasting 10 seconds or more per hour. Each patient underwent hospital-based nocturnal polysomnography (PSG) preoperative and 6 months postoperatively.

OSA assessments

The PSG results from the standard PSG locations from electroencephalogram (F3, F4, C3, C4, O1, O2, A1, and A2), electrooculogram, and electromyogram recordings were obtained with standard procedures by means of Cadwell Easy 2 (Cadwell, Kennewick, WA, USA) digital data acquisition system using a sampling frequency of 512 Hz. Airflow and thoracoabdominal effort were recorded quantitatively by nasal pressure cannula, thermistor, and respiratory inductance plethysmography. The studies were done following the American Academy of Sleep Medicine standard diagnostic guidelines by an experienced doctor in sleep medicine[1].

Surgical planning

Each selected patient underwent a preoperative anaesthesia evaluation. Hypertension, obesity, and diabetes were not considered as absolute contraindications for this surgery.

Standardized preoperative aesthetic evaluation based on clinical facial analysis (CFA) was performed for all patients using Arnett principles[16].

A 3D computed tomography scan was captured with an i-CAT machine (Imaging Sciences International, Hatfield, PA) be-

Fig. 1. Three-dimensional scan image before maxillomandibular advancement. The upper airway is outlined in translucent white.

fore surgery to evaluate both the superior airway and the skeletal components of this anatomical region. A waxbite registration (Delar, Lake Oswego, USA) was used to verify that the TMJs were seated in the glenoid fossa during the procedure. Precise indications were also given to place the tongue against the incisor teeth and to hold the breath during exhalation. Head orientation was checked as often as necessary to maintain a natural head position[16]. All explorations were supervised personally by the same investigator (P.R.-B.).

The scan images were loaded into Dolphin Imaging 11.0 Premium 3D software (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA) for the initial anatomical analysis and surgical planning. The superior upper airway boundary was defined at midsagittal plane, at the level of the basion (Ba, median point of the anterior margin of the foramen magnum), and the inferior boundary at the anteroinferior vertex of the fourth cervical vertebra (C4). The posterior nasal spine was discarded as the superior boundary because its position changes after the maxillary osteotomy. The lateral and posterior boundaries of the model consisted of the pharyngeal walls and the anterior boundary, the anterior wall of the pharynx, the base of the tongue, and the soft palate. All this defined volume was called the pharyngeal airway space volume (PAS-VOL), and was measured in mm^3. The minimum axial area (MAA) is the minimum cross-sectional area (axial area) of the entire PAS, and it was measured in mm^2.

A 3D surgical virtual planning with specific Software (CD Ortosan, Madrid, Spain) was performed to elaborate the intermediate surgical splint. The angle between the mandibular occlusal plane (MOP) and the true vertical line (TVL), the MOP–TVL angle, was especially considered to allow maxillomandibular counterclockwise (CCW) advancement (normal values between 92° and 96°).

The 3D superimposition of both pre- and postoperative scans were analysed with this software to measure the real skeletal spatial changes of pogonion (Pg), A point (A), and MOP–TVL angle after surgery, and all the airway changes (Figs. 1 and 2).

The airway and skeletal variables considered for the study were both the preoperative and postoperative PAS-VOL and the MAA including the MOP–TVL angle, pogonion changes (Pg), and A point changes (A).

Surgery was performed under general anaesthesia with endotracheal intubation and controlled hypotension. No patient required blood transfusion. All procedures were performed intraorally with local bone grafts from the sinus walls and osseous nasal septum as well as plasma-rich growth factors[17] as needed. Stabilization was achieved with titanium plates and screws and intermaxillary fixation was not needed. A continuous water-circulating external cooling device (Hilotherm (R) GmbH, Argenbuhl-Eisenharz, Germany) was used for all patients. Maximum hospitalization was 48 hours.

Postoperative follow-up

All patients were evaluated weekly during the first 8 weeks and monthly for the first year postoperatively.

The post-surgical assessment was performed 6 months after surgery. Consisting of the following clinical reviews: a radiological evaluation with panoramic and lateral cephalometric radiographs, a nocturnal PSG, and a new 3D computed tomography scan, with the same preoperative protocol.

Surgical success was defined as a postoperative AHI <20 and a 50% reduction in AHI after MMA procedure, and the ''cure rate'' was defined as a postoperative AHI <5, as described by Holt yang Guilleminault[6].

Statistical analysis

Data quality was checked through the assessment of all the variable ranges, outliers, and errors. First, the patient data formed the basis of a descriptive analysis, computed to provide an overview of the

Fig. 2. Three-dimensional scan image after maxillomandibular advancement. The upper airway is outlined in translucent white. Note the enlargement of the pharyngeal airway space.

study population. Continuous variables were tested for normality applying the Shapiro test, allowing the researchers to proceed with further analysis with the usual parametric tests if normality was met, otherwise with non-parametric tests.

In the case of the quantitative variables, differences by sex were performed with the *t*-test for the variables in which normality could be assumed, and the Wilcoxon–Mann–Whitney test in cases where normality could not be assumed. Pre- and post surgery pair-wise comparisons were calculated with the Wilcoxon signed rank sum test. The quantitative variables were expressed as mean ± standard deviation, while the qualitative ones as counts and percentage of the total. Comparisons between the qualitative variables were done with χ^2 test. In order to assess association in a bivariate analysis, Pearson's correlation was calculated. Given the observational, standard practice approach, no formal a priori sample size calculation was estimated. However, a posteriori power calculation indicated plenty of significance in all comparisons. For all analyses, $P < 0.05$ was considered statistically significant. Statistical software R version 3.2.3 was used[18].

Results

Thirty-four OSA patients, 20 female and 14 male, were studied (Table 1, Fig. 3). The mean age of these patients was 41 ± 14 years (ranging 21–66 years). Eighteen patients (16 women) consulted initially for mandibular retrognathism but

Table 1. Demographic, clinical, polisomnographic characteristics and definition of skeletal and pharyngeal airway parameters preoperatively.

Variable	Overall (n = 34)	Female (n = 20)	Male (n = 14)	P-value
Age in years, M ± SD	40.8 ± 13.9	36.0 ± 13.4	47.8 ± 11.9	0.01
CPAP, n (%)	16 (47.1)	4 (20.0)	12 (85.7)	<0.001
MAD, n (%)	9 (26.5)	5 (25.0)	4 (28.6)	1.00
BMI in kg/m^2, M ± SD	27.6 ± 4.5	27.1 ± 4.8	28.4 ± 4.2	0.41
AHI, M ± SD	38.3 ± 10.7	36.7 ± 10.3	40.5 ± 11.2	0.294
ODI, M (SD)	34.7 ± 12.5	33.1 ± 12.3	37.0 ± 12.8	0.37
ESS, M ± SD	17.4 ± 5.4	17.4 ± 5.9	17.6 ± 5.0	0.96
FUT in months, M ± SD	50.0 ± 29.4	54.0 ± 30.2	44.1 ± 28.1	0.33
Angle's classification				
I	3 (8.8)	0 (0.0)	3 (21.4)	0.08
II	27 (79.4)	18 (90.0)	9 (64.3)	
III	4 (11.8)	2 (10.0)	2 (14.3)	
PAS-VOL, M ± SD	13824 ± 3080	13074 ± 2788	14897 ± 3258	0.10
MAA, M (SD)	108.8 ± 40.2	106.4 ± 41.3	112.2 ± 39.7	0.68
MOP–TVL angle, M (SD)	100.9 ± 4.1	102.2 ± 3.9	99.0 ± 3.7	0.02

Note. MAD, mandibular advancement device; ESS, Epworth Sleepiness Scale; FUT, follow-up time in months.
MOP–TVL angle. Normal range: 92–96° for both men and women.
Angle's classification: class I, the normal anteroposterior relationship of the mandible to the maxilla. The mesiobuccal cusp of the permanent maxillary first molar occludes in the buccal groove of the permanent mandibular first molar; class II, the posterior relationship of the mandible to the maxilla. The mesiobuccal cusp of the permanent maxillary first molar occludes mesial to the buccal groove of the permanent mandibular first molar; class III, the anterior relationship of the mandible to the maxilla, may have a subdivision. The mesiobuccal cusp of the permanent maxillary first molar occludes distal to the buccal groove of the permanent mandibular first molar.
PAS-VOL, pharyngeal airway space volume, mm^3, 3D. Volume of airway from Basion (Ba) to C4 (anteroinferior vertex).
MAA, minimum axial area, mm^2, 2D. Minimum cross sectional area (axial area) of the entire airway.
MOP–TVL angle, mandibular occlusal plane–true vertical line angle. Degrees.

were unaware that they were suffering from OSA. Only 16 patients (47%) in this series had been previously diagnosed with OSA and referred by the pneumologist to the department. Nine patients of the series (26.4%) had MAD as a non-invasive alternative therapy, which was also unsuccessful at controlling the disease. Once these patients were programmed for surgery, the use of a MAD was immediately interrupted to avoid problems caused bycondylar position. Sixteen patients in the series (47%) were using CPAP at the time of being evaluated for MMA surgery as an alternative treatment option.

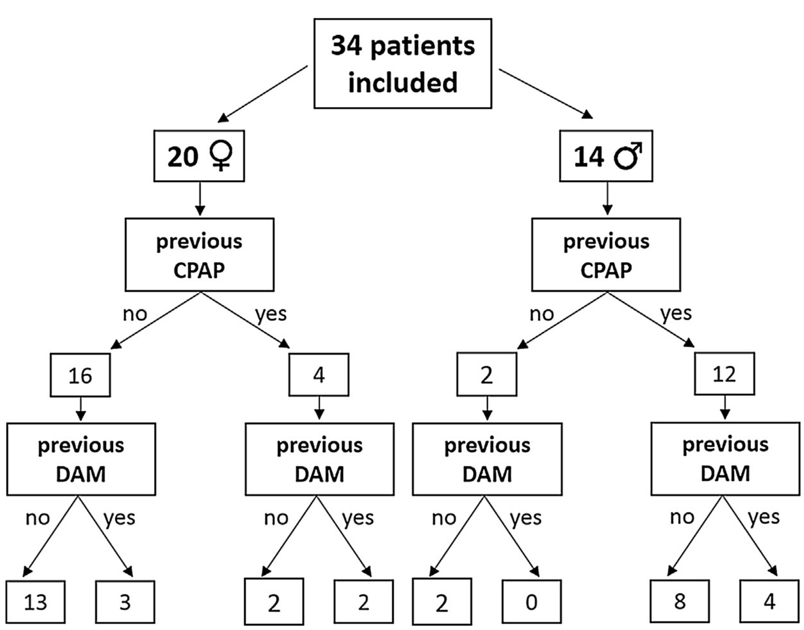

Fig. 3. STROBE. MAD, mandibular advancement device.

On the basis of Angle's Classification of Dental Occlusion, 27 patients showed class II malocclusion, four patients had class III malocclusion, and only three patients had a normal class I occlusion. The patient profiles confirmed mandibular retrognathism in varying degrees (Table 1).

The data also showed that there were differences in age and CPAP use between men and women ($P < 0.05$) which was considered to be most likely because of physical appearance. Significant statistical differences between the men and women in their MOP–TVL angle were observed (Table 1).

All the patients in this series were medically stable enough to undergo MMA. Postoperatively, the AHI was between 0.9 and 14.9, with a cure rate of 52.94% and residual mild OSA in 47.06%. The patients' ODI ranged between 0.5 and 17. The Epworth index ranged from 0 to 5, and the BMI was between 20.7 and 36.7 kg/m^2. The characteristics of postoperative variables are presented in Table 2.

Considering the skeletal anatomy as analysed in the 3D scans, all the patients showed different degrees of maxillary deficiency and mandibular retrognathia. The MOP–TVL angle was reduced in 32 (94.1%) cases, unchanged in one case (95°), and increased in another case (from 92° to 94°). The postoperative values of the MOP–TVL ranged from 92 to 99.3° (mean and SD 95.7 ± 2), which means a decrease in the occlusal plane between 2 and 11.8° (mean and SD 5.2 ± 3.7). The real skeletal surgical movements and the airway parameters are summarized in Table 2 (3D superimposition data). Pharyngeal airway space volume (PAS-VOL) increased from 46.4% to 238% (106.3 ± 37.8%). MAA increased from 143.4 ± 89.9%, with a range between 18% and 396% of the initial area ($P < 0.05$). The advancement of the maxilla ranged from 0.5 to 12.4 mm (mean and SD 4.9 ± 3.2) and the mandibular advancement ranged from 2.6 to 18.5 mm (mean and SD 10.4 ± 3.9).

Table 2 presents the results of the differences by sex. Only vertical movement of pogonion is found to be statistically significantly different between men and women. The female patients showed greater movement than the male patients.

Having shown differences between men and women, the pre- and postoperative variances in their clinical anatomical characteristics were also analysed. Table 3

Table 2. Variables after surgery.

Variable	Overall ($n = 34$)	F ($n = 20$)	M ($n = 14$)	-value
BMI, M (SD)	25.5 (4.3)	25.2 (5.0)	25.8 (3.1)	0.64
ODI, M (SD)	5.36 (4.05)	5.47 (3.79)	5.20 (4.54)	0.85
AHI, M (SD)	6.45 (4.33)	6.66 (4.91)	6.16 (3.49)	0.73
ESS, M (SD)	0.79 (1.41)	0.7 (1.6)	0.93 (1.14)	0.16
PAS-VOL, M (SD)	28142 (6686)	26464 (5349)	30538 (7819)	0.11
MAA, M (SD)	251.2 (75.5)	253.1 (83.3)	248.6 (65.7)	0.86
MOP–TVL, M (SD)	95.7 (2.0)	95.7 (2.0)	95.8 (2.0)	0.92
AP-Pg, M (SD)	10.4 (3.9)	10.9 (4.2)	9.7 (3.4)	0.37
V-Pg, M (SD)	−4.08 (3.94)	−5.33 (3.32)	−2.28 (4.16)	0.03
AP-A, M (SD)	4.92 (3.25)	4.11 (3.42)	6.09 (2.69)	0.07
V-A, M (SD)	−0.93 (2.60)	−0.92 (2.59)	-0.95 (2.71)	0.97

Note. PAS-VOL, pharyngeal airway space volume, mm^3, 3D. Volume of airway from Basion (Ba) to C4 (anteroinferior vertex).
MAA, minimum axial area, mm^2, 2D. Minimum cross sectional area (axial area) of the entire airway.
MOP–TVL angle, mandibular occlusal plane–true vertical line angle. Degrees.
MOP–TVL angle. Normal range, 92–96° for both men and women.
MAA, minimum axial area, mm^2, 2D. Minimum cross-sectional area (axial area) of the entire airway.
AP-Pg, anteroposterior movement of pogonion. Pogonion (Pg) is defined as the most anterior point of the mandibular symphysis.
V-Pg, superoinferior or vertical movement of pogonion. Negative, superior movement (impaction); positive, inferior movement (descent); zero, no variation.
AP-A, anteroposterior Movement at A. A point (A) is defined as the deepest point of the curve of the maxilla between the anterior nasal spine and the dental alveolus. Positive, advancement.
V-A, superoinferior or vertical movement at A. Negative, superior movement (impaction); positive, inferior movement (descent); zero, no variation.

Table 3. Comparison of characteristics before and after surgery, with the Wilcoxon signed rank sum test.

	Before (median)	After (median)	*P*-value
BMI	27.1	24.7	<0.001
ODI	33	4.9	<0.001
AHI	35	4.7	<0.001
ESS	20	0	<0.001
PAS-VOL	13894.3	26973.85	<0.001
MAA	104	247.85	<0.001
MOP–TVL angle	100,9	95,7	<0.001

Note. Differences in location are statistically significant for all cases.

presents the results of the comparison of the continuous variables before and after the surgery using the Wilcoxon sign rank test. All six characteristics measured before and after surgery were found statistically different (all $P < 0.05$) (Figs. 4–9).

Some patterns were found when comparing AHI after surgery with the main anatomical change variables: AP-Pg, AP-A, MOP–TVL, and volume increase. The minimal mandibular advancement (AP-Pg) for an individual considered cured (AHI <5 per hour) was 6.3 mm; over an advancement of 7 mm, 50% of the patients were healed and over 13.7 mm, the 100% (Fig. 10). The minimum volume increase in a patient with AHI less than 5 per hour was 80.26%. For amounts exceeding this, eight patients remained after surgery with a mild OSA, and if the volume exceeded 104.6% all patients achieved an AHI <5. Considering maxillary advancement (AP-A) a gain above 7.5 mm implies that all patients overcame their obstructive sleep apnoea syndrome (Fig. 11). Combining a maxillary and mandibular advancement of more than 6 mm each, all the patients in our sample showed a MOP–TVL below 96° and an AHI less than 5 per hour, meaning they were all cured.

This study showed evidence of a strong association of 0.65 in terms of Pearson's correlation between AHI and MOP–TVL ($P < 0.001$). But it also provided insight that AHI and BMI were not related (correlation = 0.08, $P = 0.65$). The Pearson correlation between MOP–TVL and BMI was also calculated, suspecting that BMI could be a confounding variable. This correlation was 0.37 ($P = 0.03$), which implied an association, but as the two conditions were not satisfied the BMI was not deemed a confounding variable.

Considering the amount of skeletal sagittal movements, the AHI correlation with mandibular and maxillary advancements were respectively −0.44 ($P = 0.009$) and −0.26 ($P = 0.137$).

Postoperative healing was uneventful. Epithelialization of the incisions was complete after 4 weeks. Minimal wound dehiscence was observed in two patients, but was self-limited, keeping up with a good oral hygiene routine using 0.12% chlorhexidinegluconate mouth rinse as the unique treatment. The most frequent complication was temporary impairment of the inferior alveolar nerve (75%). No major complications were encountered.

The new facial profile was considered subjectively good to excellent in all cases by the patients and their relatives. Occlusion was excellent in every case immediately after surgery (canine and molar class I occlusion, overjet 2–3 mm, anterior overbite 1–4 mm, posterior overbite 1–2 mm, aligned upper and lower dental midlines to the facial midline, and no posterior crossbite) and remained stable during the whole follow-up period in all patients, clinically and after 3D superimposition analysis. Orthodontic retainers were used in every case for at least 1 year after removal of the orthodontic appliances.

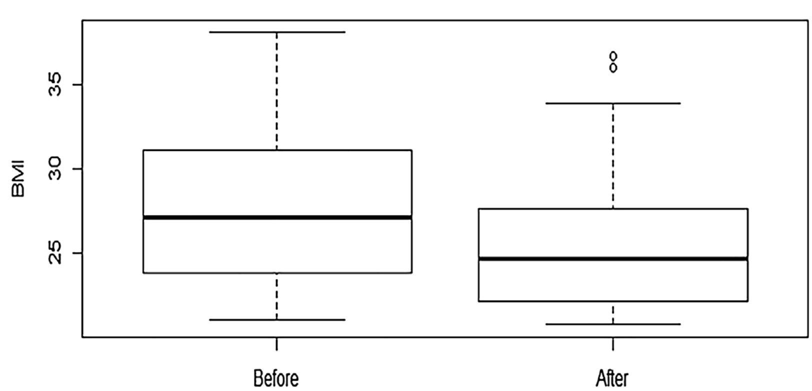

Fig. 4. BMI (body mass index) before and after surgery.

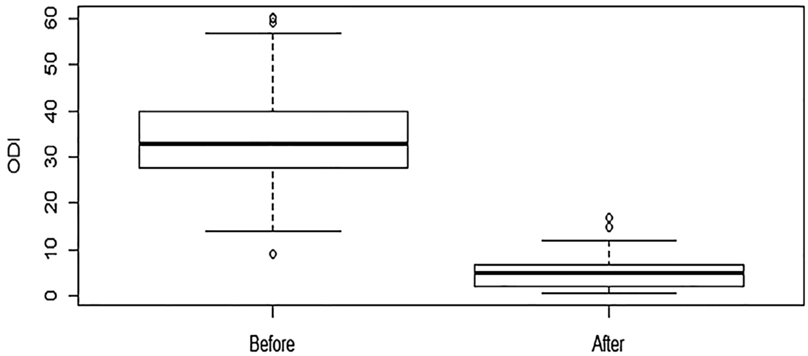

Fig. 5. ODI (oxygen desaturation index) before and after surgery.

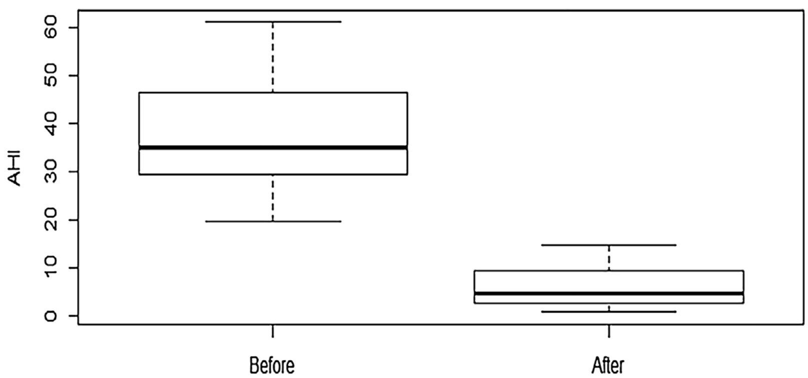

Fig. 6. AHI (apnoea–hypopnoea index) before and after surgery.

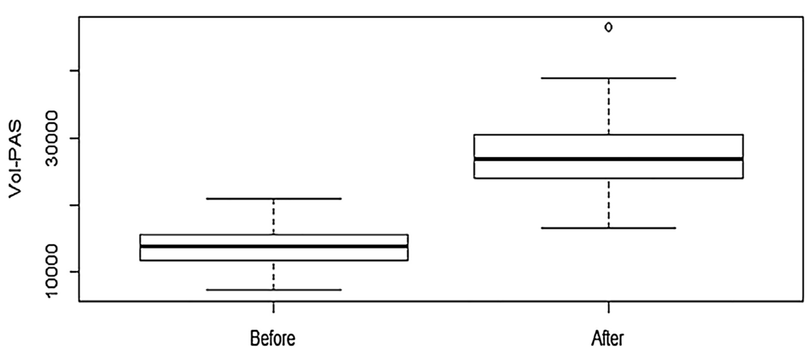

Fig. 7. PAS-VOL (pharyngeal airway space) before and after surgery.

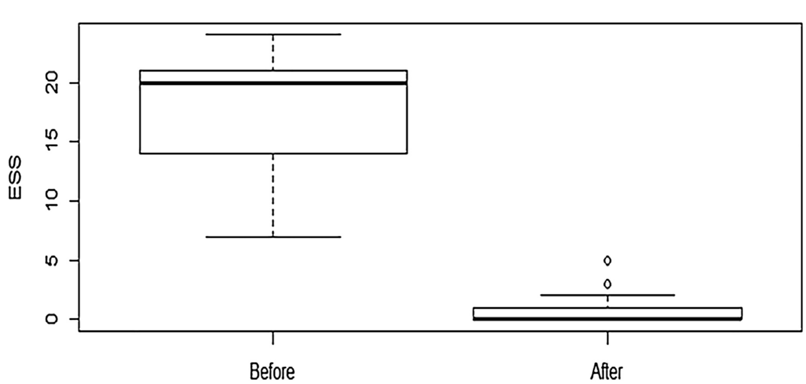

Fig. 8. ESS (Epworth Sleepiness Scale) before and after surgery.

No relapse of the OSA symptoms was described in any patient such as snoring or daytime sleepiness (median ESS after surgery was 0). This result is considered as an excellent outcome in terms of the facial and occlusal stability of the MMA procedure as observed during the 12 months of follow-up in all cases.

Discussion

This article aimed to determine if MMA is an effective way to treat OSA in adult patients and accurately define the most predictive surgical parameter to reach a cure level of the disease (AHI < 5). The hypothesis was that normalization of MOP is essential to produce an important increase in the PAS. Additionally, the statistical analysis tried to demonstrate that this correction of the MOP–TVL angle was more significant than the absolute value of the sagittal movement of the maxilla or even the mandibular bone.

This series contributes to the literature, with an important reduction of AHI after MMA in patients suffering from moderate to severe OSA and rejecting the chronic use of CPAP. AHI < 20 was achieved in 100% patients after MMA, with a residual AHI mean value of 6.45 (4.33) ($P < 0.001$).

However, some authors[19] have suggested using more rigorous criteria for judging surgical success for OSA beyond the generally accepted of at least a 50% reduction in AHI and residual AHI <20[6,10,11]. Considering this, 52,54% of the patients in our series were cured with an AHI <5, and 47.06% of the patients still showed a mild OSA (AHI between 5 and 14). A recent meta-analysis showed a cure rate of 38.5% after MMA[20]. There is strong scientific evidence that even a low AHI (5–14) can be related to a higher risk of cardiovascular disease[1,21]. Even though the objective can be considered extremely demanding, an AHI < 5 is pursued in every case (cure level) after any surgical procedure. It has been demonstrated that prevalence of OSA increases with age in both sexes[22]. This is an indicator that the natural history of the disease is that AHI can worsen with age, especially in young patients with obviously longer life expectancy.

In spite of these results, the role of upper airway surgery for OSA still remains controversial. UPPP is considered to be the most common surgical procedure still used for adults with OSA; it has been evaluated extensively and the conclusion is that it is ineffective in the treatment of sleep apnoea[21]. However, the litera-

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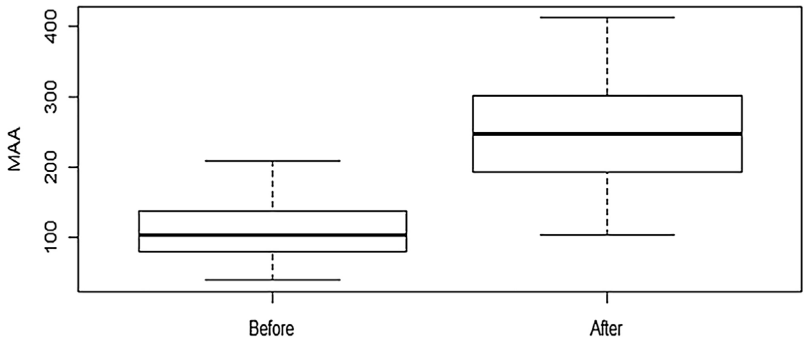

Fig. 9. MAA (minimum axial area) before and after surgery.

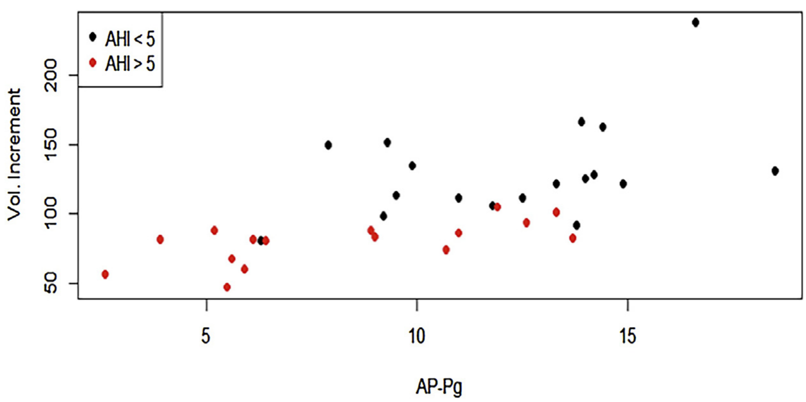

Fig. 10. Anteroposterior movement of the pogonion (AP-Pg) and pharyngeal airway space volume (PAS-VOL) increase (%). Pogonion is defined as the most anterior point of the mandibular symphysis. The minimum volume increase of a patient with postoperative AHI < 5 was 80.26%.

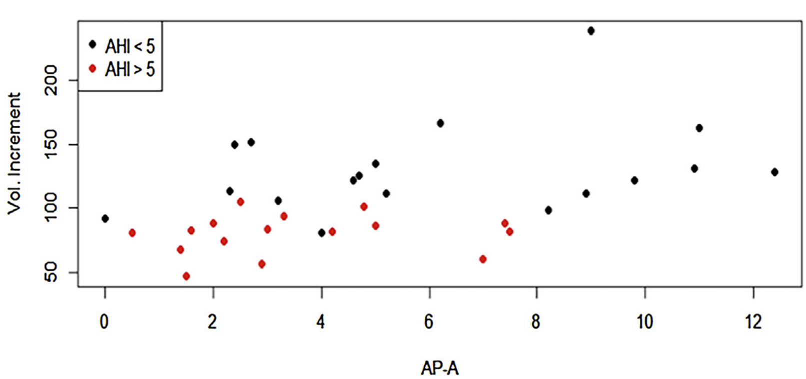

Fig. 11. Anteroposterior movement of point A (maxilla) and pharyngeal airway space volume (PAS-VOL) increase (%). Advancement over 7.5 mm implies that all patients overcame their obstructive sleep apnoea syndrome.

ture[7,11,20] indicates that MMA is increasingly reported as an alternative to CPAP.

MMA is the only surgical technique that dramatically increases the PAS[23] making it less prone to collapse. Increase in PAS parameters were also observed in this study, with a PAS-VOL mean increase of $106.3 \pm 37.8\%$ of the initial volume and MAA mean increase of $143.4 \pm 89.9\%$, that were found to be significantly meaningful. A minimum PAS increase of 104.6% was observed to be necessary to achieve a cure rate of 100%.

The amount of MMA and the change in mandibular occlusal plane were also tested for association with changes in AHI and PAS-VOL. In this study, horizontal mandibular advancement was statistically related to AHI after surgery ($r = 0.44$, $P = 0.008$), but not maxillary advancement. A MMA of 6.3 mm and a minimum maxillary advancement of 7.5 mm were necessary to reach a cure rate of 100% (AHI < 5). However, the postoperative MOP–TVL angle has shown to be the most important predictor variable for the decrease in AHI as there was a strong correlation between these two factors ($r = 0.65$, $P < 0.001$). All the cured patients had reached a postoperative MOP–TVL angle $\leq 96°$.

Even though some authors have demonstrated the long-term stability of MMA in OSA patients[24], large mandibular advancements over 10 mm, especially when associated with a CCW rotation of the occlusal plane, are more prone to progressive condylar resorption (PCR) and late relapse in non-OSA patients[25]. A few studies[26,27] have tried to find a mathematical correlation between maxillary and mandibular advancements and resulting changes in the dimensions of the upper airway. Souza et al.[26] found that for each millimetre of maxillary advancement together with 3 millimetres of mandibular advancement, there was a mean gain of 1.200 mm^3 in PAS-VOL 6 months after surgery.

Other studies have focused on finding out the amount of volumetric increase in the PAS-VOL and a decrease in AHI. Bianchi et al.[28] concluded that increases in the PAS-VOL of 70% or more achieved no further reduction in the AHI, which suggests that the clinical improvement in AHI reaches a plateau, and renders unnecessary further expansion.

Previous studies highlighted the influence of the occlusal plane in facial aesthetics and PAS[29,30]. The majority of research results reported that MMA associated with CCW or CW rotation of the occlusal plane considered it to be a unique plane[8,31] measured with different cephalometric tracings (in general using the Frankfort horizontal plane or sella–nasion plane as the reference plane) or even not clearly specified. Conversely two different occlusal planes exist, the upper and the lower, also called the mandibular occlusal plane (MOP). In some particular cases, both planes can be almost parallel, but in many other situations MOP may be divergent, making it even more crucial to differentiate them.

The most critical site of upper airway obstruction is normally located at the hypopharynx[9] and therefore MOP is probably more determinant on volumetric upper airway changes. Moreover, MOP can be associated with a normal maxillary occlusal plane. If the studies only measure

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the upper plane, a mandibular occlusal plane alteration can be underdiagnosed. In contrast, when the upper occlusal plane is steep, the mandibular occlusal plane is also altered. This scenario makes it very difficult to compare our results with the studies as cited in the literature. A recent meta-analysis by Knudsen et al.[8] evaluated AHI and oxygen saturation after MMA, with or without CCW, and concluded that the data were insufficient to evaluate which technique is more effective to control OSA. In contrast, Brevi et al.[31] showed in a study of 33 patients with OSA that CCW rotation of the occlusal plane produced significant modifications in airway space that is consistent with our results.

The results of this study seem to indicate that ''normalization'' of the mandibular occlusal plane, by counterclockwise rotation, improves outcomes as measured by changes in the AHI. It can be argued that the authors may be overstating the significance of their results in regard to the importance of the MOP, as no comparator group was studied. In this study, 33 of the 34 patients received a CCW rotation of the MOP; however, the magnitude of the rotation was insufficient in several cases. Only those who reached a normal angle after surgery were cured. High-quality randomized controlled trial studies would be helpful to confirm our findings, but would not be ethical to conduct. Instead, well-designed observational studies have been shown to provide useful information similar to that obtained with randomized controlled trials. The shortcomings of this study could be the size and special characteristics of the study sample: 58.8% of the patients were relatively young women with class II malocclusion and steep MOP, in contrast to the vast majority of MMA studies that reported on middle-aged obese men. In the case of the patients included in this study, many of the women participating initially consulted for mandibular retrognathism and not for OSA. Therefore, there are significant limitations in generalizing the results of this study to the population of patients with OSA. Regarding malocclusion and facial profile, there is a high incidence of class II and steep MOP among OSA patients; however, MMA up to 10 mm can also be indicated in non-retrusive patients.

In this series, MMA was customized to the facial characteristics of each patient, with a wide range of movement of both jaws and also a wide range of PAS-VOL increase. In other words, the mandible and maxilla were not advanced as much as possible. Probably, a greater skeletal advancement and/or a greater CCW rotation of MOP would have been beneficial in those cases with postoperative residual mild OSA. If so, is it already possible to customize our surgical planning to the PAS-VOL?

These results are expected to represent a new perspective on the treatment, based on the prediction of PAS-VOL changes and PSG parameters. This study suggests that the amount of sagittal advancement can be tailored in each case, which replaces the current standard of 10 mm. If so, it's probably not necessary to advance the mandibular bone as much as possible, as it has been proposed until now. A mandibular advancement from 6 to 10 mm is associated with normalization of the MOP–TVL angle, with the maxillary advancement to correct the final occlusion being enough to cure the majority of patients with OSA.

Regarding the borderline cases with nonretrusive facial profile, using a preoperative 3D airway assessment with the mandible in maximum protrusion will provide a better definition of the exact amount of mandibular advancement to obtain a pharyngeal airway space volume increase of minimum 80% of the initial volume. This information may also be useful in order to avoid undercorrection and residual postoperative OSA.

In patients with mandibular hypoplasia and 3D scan measurements of the ascending ramus of the mandible Co-Go (condylion–gonion) equal or inferior to 50 mm, mandibular distraction osteogenesis has been indicated, instead of the conventional bilateral sagittal split osteotomy treatment, excluding those patients from this series. Intraoral mandibular distraction osteogenesis[15] has been considered aesthetically superior and more stable strategy to lengthen the ascending rami of the mandible, thus producing an effective CCW advancement of the mandibular body. Short ascending mandibular rami are associated with a steep mandibular occlusal plane, mild maxillary retrusion, severe mandibular retraction, and class II open bite, requiring greater CCW mandibular advancements. Long-term post-surgical skeletal stability is essential for successful correction of AHI in OSA patients. PCR is an irreversible and common complication, and an important factor in the development of late skeletal relapse after bimaxillary CCW advancement[25]; it can be underdiagnosed, and could be present in some patients with an increase of the AHI several years after surgery. PCR is related to greater advancements of the mandible, small condyles, TMJ disease, and higher mandibular occlusal plane[25].

Internal mandibular distraction osteogenesis of the ascending rami should also be considered as an alternative in patients with large CCW advancements, higher perioperative risks, very high AHI, and in those cases in which a final occlusal stability cannot be guaranteed by the use of preoperative orthodontics treatment.

In conclusion, both maxillary and mandibular advancement movements are correlated with an improvement in AHI, but the most important predictor variable seems to be normalization of the mandibular occlusal plane. These findings could help surgeons to plan surgeries with a different approach, defining more accurately the amount of mandibular advancement to avoid postoperative residual OSA. This will probably also lead to a decrease in the incidence of surgical relapse after unnecessary excessive skeletal advancements. Higher mandibular advancements (>10 mm) should be reserved to severe mandibular hypoplasias and/or very high AHI in which mandibular distraction osteogenesis could represent the best treatment option. Further research in a larger and more representative sample of OSA patients should confirm and extend the significance of these results.

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Competing interests

None.

Ethical approval

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