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Long-term quality of life outcomes of maxillomandibular advancement osteotomy in patients with obstructive sleep apnoea syndrome

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Abstract. This study was performed to evaluate the long-term impact of maxillomandibular advancement (MMA) surgery on the apnoea–hypopnoea index (AHI) and quality of life (QoL) in patients with obstructive sleep apnoea syndrome (OSAS). The medical files of 12 OSAS patients who underwent MMA by one surgeon between 1995 and 1999 were reviewed retrospectively. Patients received a clinical assessment, polysomnography, and QoL questionnaires as part of routine care preoperatively ($n = 12$), within 2 years postoperative ($n = 12$), and again in 2016 ($n = 9$). A successful surgical outcome was defined as an AHI decrease of >50% with <20 events/h. Of the 66.7% (8/12) of patients who were initially cured, 66.7% (4/6) remained stable at a median follow-up of 19 years. Only the two patients with the highest AHI showed abnormal Epworth Sleepiness Scale scores. After convalescence, most patients reported stable symptomatic improvement. Aesthetic changes were found acceptable and all but one patient stated that they would undergo the surgery again. It is concluded that MMA is a safe and effective procedure. Ageing and weight gain might counterbalance the positive effects of surgery in the long term. It is therefore suggested that re-evaluation every 5 years should be scheduled, since a spontaneous AHI increase over time does not seem to be reflected by symptomatic changes.

Key words: obstructive sleep apnoea syndrome; long-term; maxillomandibular advancement osteotomy; quality of life; apnoea–hypopnoea index.

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Obstructive sleep apnoea syndrome (OSAS) is highly prevalent in the general population[1–3]. It is characterized by chronic sleep deprivation due to recurrent respiratory cessation for 10 seconds or more during sleep. Patients complain of snoring, headaches, daytime sleepiness, and reduced concentration. OSAS patients are typically middle-aged, obese patients who often present with cardiometabolic comorbidities[1,4].

Non-invasive treatment consists of weight control, adopting a supine sleep position, and the use of sedatives, alcohol, or cigarettes. Mechanical measures include sleeping with a continuous positive airway pressure (CPAP) device, which is currently considered the gold standard, or oral appliances that pull the tongue forward by moving the mandible anteriorly, and in that way dilating the airway. However, these devices might be tolerated poorly by patients in the long term. Moreover, relapse occurs immediately after treatment withdrawal[5–7].

Surgical interventions such as tracheostomy, uvulopalatopharyngoplasty (UPPP), or upper airway correction have also been suggested, although results are variable. The efficacy of surgical maxillofacial osteotomies, on the other hand, has been widely reported. Bimaxillary advancement surgery increases the skeletal volume of the face, enlarging the airway space[1,8,9]. Despite its documented success, surgery is not yet considered to be standard treatment because of the lack of long-term studies examining the impact of the jaw correction at ≥5 years post-surgery[5].

The aim of this study was to describe the quality of life (QoL) outcome over a period of almost 20 years after maxillomandibular advancement (MMA) surgery. The change in apnoea–hypopnoea index (AHI) and other relevant parameters associated with OSAS are also reported.

Material and methods

Patient population

This study was a retrospective review of patient medical files. Twelve OSAS patients who were consecutively treated with MMA by a single surgeon (CDC) at the Ghent University Hospital or AZ Sint-Jan Brugge-Oostende AV between November 1995 and December 1999 for clinically diagnosed OSAS were included. For inclusion, the patients had to have received clinical assessments, polysomnography (PSG), and QoL questionnaires as part of routine care preoperatively ($n = 12$), within 2 years postoperative ($n = 12$), and again in 2016 ($n = 9$) as part of the routine long-term follow-up program organized by the department. The study was approved by the local ethics committees. All patients provided written informed consent.

At the time, MMA surgery was performed under general anaesthesia and included a bilateral sagittal split osteotomy (BSSO) of the mandible alone, or bimaxillary surgery with or without a genioplasty, as judged by the treating physician. A BSSO of the mandible was performed and fixed with three bicortical screws (Titamed, Antwerp, Belgium) on both sides. In the case of bimaxillary surgery, the mandible-first principle was employed. First the mandible was advanced by at least 10 mm. The maxilla was then fixed in its new position with four L-shaped miniplates (Titamed, Antwerp, Belgium) after a standard Le Fort I osteotomy with linear advancement or counterclockwise rotation in a new correct class I occlusion. An additional chin osteotomy was performed in only two patients.

PSG, as the gold standard to clinically diagnose OSAS patients, was performed overnight shortly after the clinical work-up, at the hospital where prior PSGs had also been performed, eliminating intercentre variability for individual patients. The participating centres were the Department of Respiratory Medicine, Ghent University Hospital ($n = 8$), the Department of Pneumology, AZ Groeninge Kortrijk ($n = 1$), and the Department of Pneumology, AZ Sint-Jan Brugge-Oostende AV ($n = 1$).

OSAS severity was graded as 'absent' (AHI 0–4), 'mild' (AHI 5–14), 'moderate' (AHI 15–30), or 'severe' (AHI >30)[10]. Moreover, in accordance with the definition most often used in the literature[11–14], a successful surgical outcome was defined as a decrease in AHI of >50% with <20 events/h[11]. Treatment failure was defined as a persistent AHI of ≥30/h after MMA surgery[15].

A cone beam computed tomography (CBCT) scan was taken of all patients as part of the long-term follow-up consultation, using a standardized scanning protocol (i-CAT; Imaging Sciences International, Inc., Hatfield, PA, USA), as described in detail by Guijarro-Martinez and Swennen[16,17].

All DICOM data were viewed using the picture archiving and communication system (PACS) at default settings. Airway length (i.e., from posterior nasal spine to the base of the epiglottis), and the anteroposterior (AP) and lateral (LAT) width of the smallest airway area were measured by a single investigator using the freehand tool incorporated in the PACS software, and according to cephalometric landmarks described by Abramson et al.[18]. Volumetric measurements of the total upper airway and its sub-regions were obtained using Brainlab iPlan software (Brainlab, Munich, Germany), according to the validated cephalometric landmarks as published by Guijarro-Martinez and Swennen[17].

Patient QoL was rated with the OSAS questionnaire at all time points. This registers the impact of OSAS treatment(s) on the most common complaints (i.e., headache, blood pressure, daytime sleepiness, night-time awakening, concentration, frequent nocturnal diuresis, snoring, sexual activity, facial aesthetics, and self-confidence), based on a numerical scale from −5 to +5, with negative and positive values indicating worsening and improvement of symptoms, respectively.

The Epworth Sleepiness Scale (ESS) is a standardized validated questionnaire measuring the level of daytime sleepiness. The patient is asked to rate the chance of falling asleep in eight different daily life situations. A higher score corresponds to a higher level of daytime sleepiness, with a cut-off of ≥10/24 considered to be abnormal[19,20].

Statistical analysis

A descriptive analysis was performed, with presentation of the data as the median and interquartile range (IQR) or minimum-maximum range (range). Spearman correlation was used to examine potential correlations between AHI, ESS, body mass index (BMI), and other relevant parameters. The Mann–Whitney *U*-test was applied to examine potential differences between successful and unsuccessful postoperative outcomes. The Wilcoxon signed rank test was used to examine the change in oxygen values at the different time points. All analyses were performed using IBM SPSS Statistics version 21.0 (IBM Corp., Armonk, NY, USA).

Results

Study population

Twelve patients had MMA surgery in the 1990s, of whom nine completed the long-term re-evaluation at the department. Two patients died before the long-term re-evaluation. One patient was unable to attend the department for objective re-evaluation, but stated that she had no subjective complaints and was not receiving any type of OSAS treatment at the time.

The demographic and clinical characteristics of the study patients are shown in Table 1. Ten of the 12 patients were male. The median age at the time of MMA surgery was 43.5 years, ranging from 34 to 63 years. Ten patients presented with a class II, retrognathic profile, and two patients had a class I occlusion, without further skeletal malpositioning. All 12 patients had tried CPAP treatment prior to MMA surgery, and one had also tried an oral appliance. Two patients had undergone surgical interventions – genioglossus–tuberculum advancement in one and UPPP, tracheostomy, and septoplasty in the other – which proved unsuccessful. All patients requested a long-term, permanent solution, most often because of CPAP intolerance.

Two patients had a BSSO, six had a BSSO in combination with Le Fort I (LFI) surgery, and two had a LFI, BSSO and genioplasty. One patient also had a septum correction at the time of bimaxillary surgery. The surgical plan could not be retrieved for two patients.

The median follow-up of the nine patients who attended long-term re-evaluation was 19 years (range 14–20 years), and their median age was 62 years (range 49–82 years). At long-term follow-up, no patient complained of neurosensory sequelae. One patient had suffered dentoalveolar relapse towards the initial malocclusion. No patient expressed subjective complaints of temporomandibular joint problems.

Seven patients smoked at the time of MMA, two of whom had continued this habit. At the latest follow-up, the patients reported consuming a median of 14 units (range 0–25 units) of alcoholic beverages and 42 units (range 14–49 units) of caffeinated drinks per week. Five of the nine patients suffered from diabetes and seven took medications for cardiovascular morbidities.

Apnoea–hypopnoea index (AHI) and oxygen saturation (SaO_2)

The change in AHI over time is presented in Table 2. Of the 12 patients, eight (66.7%) had a successful outcome (i.e., a decrease in AHI of >50% and <20 events/h), three had an unsuccessful outcome, and MMA surgery failed in one patient (i.e., a persistent AHI of $\geq$30/h after MMA surgery). Immediately postoperative, 25% of these 12 patients were categorized as normal, 41.7% as having mild OSAS, and 25% as having moderate OSAS. One patient worsened postoperatively and was still categorized as having severe OSAS.

At a median follow-up of 19 years, four of the nine patients evaluated (44.4%), or four of the six initially successful patients (66.7%), maintained a successful outcome. Of these four successful patients, one had a normal AHI and three patients showed mild OSAS. The remaining two initially successful patients relapsed to preoperative AHI values; one had moderate OSAS and the other had severe OSAS. With regard to the other three re-evaluated patients, two had a complete relapse to preoperative values after an unsuccessful surgical outcome. The patient for whom treatment failed completely restarted CPAP treatment approximately 6 months postoperative. At present, he continues to suffer from severe OSAS and attends biannual close follow-up.

MMA surgery resulted in a significant increase in minimal oxygen saturation ($P = 0.010$) and significantly reduced oxygen levels below 88% immediately postoperative ($P = 0.021$). Only a trend towards significance of the latter result was seen at long-term postoperative ($P = 0.091$) (data not shown). Moreover, no significant difference in preoperative oxygen saturation values was observed between patients with successful and unsuccessful outcomes (Table 3).

The patients presented a median preoperative BMI of 28.1 kg/m^2 (range 24.5–35.0 kg/m^2). After approximately 19 years of follow-up, median BMI was 29.9 kg/m^2 (range 25.2–36.1 kg/m^2).

As presented in Table 3, no significant difference ($P > 0.05$) in age, AHI, BMI, oxygen saturation, sleep efficiency, or smoking or alcohol habits could be found between patients with a successful treatment outcome and those with an unsuccessful treatment outcome immediately postoperative. In patients whose treatment remained successful at long-term evaluation, a trend towards significantly older age, higher average SaO_2, and lower AHI was observed in comparison to preoperative values. However, they did not significantly differ in preoperative parameters in comparison to those who relapsed. A trend towards significantly higher AHI, higher BMI, and lower sleep efficiency was found in the unsuccessful group in comparison to the successful group at long-term assessment.

Spearman correlation indicated a significant positive correlation between AHI and BMI ($R_s = 0.733$, $P = 0.025$). However, no significant correlation was found between the changes in BMI versus in AHI between T2 and T0, indicating that weight gain was not the only factor that contributed to the AHI relapse. A significant inverse correlation was found between AHI and alcohol use ($R_s = -0.778$, $P = 0.039$); however, this effect disappeared when combined with BMI in a general linear model with AHI as the dependent variable. No significant correlation was found between AHI and age, sex, social status, presence of diabetes or cardiovascular comorbidities, smoking, and stress ($P > 0.05$).

Upper airway dimensions

Airway dimensions of the nine patients re-evaluated at long-term post MMA surgery are presented in Table 4. Spearman correlation did not indicate an association between upper airway dimensions and AHI, except for a significant negative correlation between lateral width at the smallest airway area and AHI ($R_s = 0.707$, $P = 0.018$). Comparison of upper airway volume between successful and unsuccessful patients (i.e., failure, relapse) showed a trend towards a larger oropharyngeal volume in successful patients ($P = 0.050$). No significant difference was found in airway length or AP/LAT width at the smallest area between the two groups.

Quality of life

The median ESS score at long-term follow-up was 5 (range 1–13). As presented in Fig. 1, only the two patients with the highest AHI scores, indicating severe OSAS, showed abnormal ESS scores. The seven other patients evaluated showed no subjective complaints that could be related to OSAS.

Spearman correlation indicated no significant correlation between AHI and ESS ($P = 0.145$). Likewise, no significant correlation was found between BMI and ESS ($P = 0.203$).

On average, patients rated the impact of OSAS on their daily life prior to surgery as 8.4 on a scale of 1–10, with 10 being the worst possible negative impact. Immediately postoperative, they reported improvements in symptoms of headache (median 4, range 0 to 4), blood pressure (median 1, range 0 to 5), daytime sleepiness (median 4, range 1 to 5), concentration (median 2, range −1 to 5), insomnia (median 3, range 0 to 5), nycturia (median 5, range 4 to 5), snoring (median 4, range 3 to 5), and sexual relationship (median 0.5, range 0 to 3). Also, they did not report

Table 1. Demographic and clinical characteristics of the study patients.

Patient	Sex	Skeletal characteristics	Other interventions	Age at MMA (years)	Follow-up (years)	Reason for MMA	Age at follow-up (years)	Planned MMA procedure
1	M	Class II, retrognathic	CPAP	63	19	Patient initiative, request for long-term solution	82	BSSO (mm ND)
2	M	Class II, retrognathic maxilla, mandibular hypoplasia, narrow oropharyngeal PAS, large tongue, long soft palate	CPAP	47	19	CPAP intolerance, limitation for travelling abroad, request for more comfortable solution at older age	67	LFI (8 mm) BSSO (12 mm) genioplasty (5 mm)
3	M	Class II, retrognathic maxilla, mandibular hypoplasia, narrow naso-, oro-, and hypopharyngeal PAS	CPAP	43	19	CPAP intolerance towards the sound of the apparatus	62	BSSO (mm ND)
4	M	Retrognathic maxilla, retrognathic mandible, narrow PAS, low palate	CPAP	40	18	CPAP intolerance, difficult patient compliance	59	LFI (12 mm) BSSO (12 mm) Septum correction
5	M	Class II, retrognathic maxilla, retrognathic mandible, narrow PAS, low position of the hyoid	CPAP	41	20	CPAP intolerance, pulling off mask during sleep	61	LFI (12 mm) BSSO (12 mm) genioplasty (2 mm intrusion)
6	M	Class II, retrognathic	CPAP	51	16	CPAP intolerance, hinders falling asleep	68	LFI (12 mm) BSSO (11 mm)
7	M	Retrognathic maxilla, retrognathic mandible, narrow oro- and hypopharyngeal PAS, large uvula, short neck	CPAP, activator	44	20	CPAP and activator failed to provide efficient result; limitation for travelling with a motorcycle, intolerance from the partner towards the sound of the apparatus	64	LFI (mm ND) BSSO (mm ND)
8	M	Class I	CPAP	34	18	ND	52	LFI (10 mm) BSSO (9 mm)
9	M	Class II, retrognathic	CPAP	35	14	CPAP intolerance, persistent sinusitis, bronchitis	49	LFI (10 mm) BSSO (10 mm)
10	F	Class I, narrow PAS, hypopharyngeal obstruction, no skeletal malpositioning	CPAP, genioglossus–tuberculum advancement	40	NA	CPAP intolerance, sinus-related problems	NA	ND
11	M	Class II, retrognathic	CPAP	57	NA	ND	NA	ND
12	F	Moon face, retrognathic maxilla, retrognathic mandible, narrow PAS, thickened palate, normal occlusion	CPAP, UPPP, tracheostomy, septoplasty	47	NA	CPAP intolerance, acute sinusitis with clogging of the cannulae	NA	LFI (mm ND) BSSO (12 mm)

BSSO, bilateral sagittal split osteotomy; CPAP, continuous positive airway pressure; F, female; LFI, Le Fort I; M, male; MMA, maxillomandibular advancement; NA, not applicable; ND, not determined; PAS, pharyngeal airway space; UPPP, uvulopalatopharyngoplasty.

Table 2. Change in AHI following surgery for the 12 OSAS patients who underwent MMA[a]. T0: preoperative; T1: immediately postoperative, T2: long-term postoperative (median of 19 years).

Patient	AHI			Δ T1 − T0 (%)	Outcome[b]	Δ T2−T0 (%)	Outcome[b]
	T0	T1	T2				
1	31.0	5.0	5.1	83.9	Successful	83.5	Successful
2	32.0	6.0	29.4	81.3	Successful	8.1	Unsuccessful
3	26.0	19.0	22.5	26.9	Unsuccessful	13.5	Unsuccessful
4	64.0	0.0	69.2	100.0	Successful	−8.1	Failure
5	50.0	86.0	49.0	−72.0	Failure	2.0	Failure
6	117.0	20.0	106.9	82.9	Unsuccessful	8.6	Failure
7	55.0	0.0	6.9	100.0	Successful	87.5	Successful
8	28.0	7.0	2.9	75.0	Successful	89.6	Successful
9	92.0	9.7	11.4	89.5	Successful	87.6	Successful
10	31.0	3.0	ND	90.3	Successful	ND	ND
11	84.0	21.0	ND	75.0	Unsuccessful	ND	ND
12	121.0	9.0	ND	92.6	Successful	ND	ND

AHI, apnoea–hypopnoea index; MMA, maxillomandibular advancement; ND, not determined; OSAS, obstructive sleep apnoea syndrome.

[a] Two patients died and one patient was lost to follow-up before quantitative evaluation at T2.

[b] According to the definition of Lye et al.[11], the surgical outcome is successful when the AHI reduction is at least 50% with <20 events/hour. "Unsuccessful" outcome was defined as fulfilling one of those two criteria. Treatment failure is defined as a persistent AHI of > = 30/h after MMA surgery[15].

noticeable facial changes, either in a positive or a negative sense. At approximately 19 years postoperative, the patients stated improvements in all previously reported symptoms, except for blood pressure (median −0.5, range −1 to 2), nycturia (median 0, range −3 to 4), and sexual activity (median 0, range −4 to 3) (Fig. 2). All but one patient stated that they would choose the surgery again, or recommend the procedure to friends and family with similar health problems.

Discussion

In this study, eight of 12 patients (66.7%) showed a successful postoperative outcome based on a reduction in AHI of 50% with <20 events/h, which remained stable in four out of six (66.7%) initially cured patients after a median of 19 years postoperative. The follow-up period was uneventful, except for one patient who suffered a relapse of the initial malocclusion. Daytime sleepiness, as measured with the ESS, was within normal limits for all but two patients, both suffering from severe OSAS. A significant correlation was found between AHI and BMI, although not between AHI and ESS. An improvement in symptoms of snoring, headache, blood pressure, daytime sleepiness, concentration, insomnia, nycturia, and sexual activity was reported by all patients immediately postoperative. Comparable results were found at long-term reevaluation, except for blood pressure, nycturia, and sexual activity. Patient satisfaction regarding aesthetic changes and improvements in QoL was high.

The results regarding the AHI, both short-term and long-term postoperative, are in agreement with those of a meta-analysis by Holty and Guilleminault, who reported a successful outcome after MMA surgery ranging between 65% and 100%, with a pooled surgical success rate of 86% based on 627 patients included in 53 separate publications[13]. Two recent publications, one by Vigneron et al. and the other by de Ruiter et al., described a successful outcome immediately postoperative in 85.7% of 34 patients and 71.0% of 62 patients, respectively, when applying the same definition[12,21]. Younger age, lower BMI, lower preoperative AHI, and a higher degree of maxillary advancement have been described as predictors of surgical success[13,22,23]. However, no significant difference in preoperative age, BMI, or AHI values was found between patients with successful versus unsuccessful outcomes in the present study.

In this study, two of the three patients with an unsuccessful outcome complied with one of the criteria defined, but not the two criteria combined (an AHI decrease of >50% with <20 events/h). One patient with severe OSAS unfortunately worsened postoperatively (AHI change from 50 to 86 events/h).

After a median of 19 years postoperative, a permanent normalization of the AHI was observed in four of the six patients who were initially cured. The two patients who relapsed had an AHI comparable to preoperative values. Both patients had a significant weight gain (+4.1 and +7.9 kg/m^2). Preoperatively, both had a retrognathic profile, with respectively a massive tongue and long soft palate, and a low palate. However, only one of these patients suffered from abnormal daytime sleepiness as indicated by a score of 12 on the ESS.

Long-term failure of MMA surgery has been ascribed to weight gain, skeletal relapse, or aging[24].

There was a trend towards a significantly lower BMI in successfully operated patients who remained stable, in comparison to those who relapsed. Also, there was a positive Spearman correlation between BMI and AHI values. However, this was not the case for the change in the two parameters over time, indicating that BMI was not the sole cause of surgical failure. Indeed, according to the Cleveland Family study, the influence of body weight and sex on disease incidence diminishes with increasing age[25,26].

Surgical relapse after MMA surgery has been described to range between 7% and 20%[27,28]. In one study, advancements of >7 mm were found to be associated with an increased tendency towards relapse[28]. In the present study sample, an average advancement of 10.7 ± 1.6 mm for LFI and 11.0 ± 1.3 mm for BBSO was performed in seven of the 12 patients. Unfortunately, due to the lack of two-dimensional (2D) cephalometric imaging pre- and immediately postoperative, potential skeletal relapse could not be calculated. In the current study, OSAS relapse might also have been attributable to aging, possibly associated with a downward sag of the soft tissue profile[29]. In this study, two of three patients with severe OSAS who reached the age of ≥65 years at follow-up had relapsed.

Table 3. Comparison of clinical characteristics of patients with successful and unsuccessful outcomes after MMA surgery, immediately postoperative (T1) and long-term postoperative (T2); data are presented as the median (interquartile range), age is presented as the median (range).

	Immediately postoperative (T1)			Long-term postoperative (T2)							
	Successful ($n = 8$)	Unsuccessful ($n = 4$)[b]		Successful ($n = 4$)			Unsuccessful ($n = 2$)				
	Value prior to MMA surgery	Value prior to MMA surgery	*P*-value	Value prior to MMA surgery	Value at long-term follow-up	*P*-value	Value prior to MMA surgery	Value at long-term follow-up	*P*-value	*P*-value preop.[a]	*P*-value postop.[a]
Age (years)	40.0 (32.0–62.0)	46.5 (40.0–57.0)	0.231	37.0 (32.0–62.0)	58.0 (49.0–82.0)	0.068	42.0 (40.0–44.0)	63.0 (59.0–67.0)	0.180	0.481	0.643
AHI	52.5 (31.8, 71.0)	67.0 (44.0, 92.3)	0.933	52.5 (45.3, 64.3)	6.0 (4.6, 8.0)	0.068	48.0 (40.0, 56.0)	49.3 (39.4, 59.3)	0.655	1.000	0.064
BMI (kg/m^2)	27.6 (25.5, 29.5)	29.1 (25.1, 33.1)	0.794	29.0 (27.2, 31.2)	28.1 (27.1, 28.7)	0.465	26.0 (25.5, 26.5)	32.0 (31.1, 32.8)	0.180	0.355	0.064
Average SaO_2 (%)	91.0 (90.5, 92.5)	90.0 (85.4, 94.3)	0.776	91.0 (90.8, 91.5)	94.4 (94.1, 94.8)	0.068	ND	ND		0.147	0.147
Sleep efficiency (%)	87.0 (71.5, 91.0)	70.0 (63.0, 77.5)	0.304	87.0 (84.0, 89.0)	77.0 (72.4, 82.7)	0.109	76.5 (69.2, 83.7)	64.1 (63.0, 65.2)	0.655	0.767	0.064
ESS	ND	ND	ND	ND	4.0 (2.5, 5.5)	ND	ND	6.5 (10, 12.0)	ND	ND	0.814
Smoking (PY)	17.5 (0.0, 24.0)	13.0 (4.0, 34.0)	0.795	17.5 (12.8, 18.3)	35.5 (0.0, 48.0)	0.102	12.0 (6.0, 18.0)	20.0 (0.0, 40.0)	0.317	0.814	0.814
Alcohol (units/week)	11.2 (0.0, 42.0)	ND	ND	13.7 (9.1, 18.4)	14.0 (14.0, 25.2)	0.180	25.9 (17.9, 34.0)	8.1 (0.0, 16.1)	0.180	0.643	0.554

AHI, apnoea–hypopnoea index; BMI, body mass index; ESS, Epworth Sleepiness Scale; MMA, maxillomandibular advancement; PY, pack-years; SaO_2, oxygen saturation.

[a] Successful vs. unsuccessful.

[b] According to the definition of Lye et al.[11], the surgical outcome is successful when the AHI reduction is at least 50% with <20 events/hour. ''Unsuccessful'' outcome was defined as fulfilling one of those two criteria. Treatment failure is defined as a persistent AHI of
≥30/h after MMA surgery (Blumen et al.[15] Otolaryngol Head Neck Surgery).

Surgical success was only partly reflected in the reported QoL scores. Spearman correlation indicated no significant correlation between AHI and ESS. Only the two patients with the highest AHI values reported abnormal daytime sleepiness. This discrepancy is, however, in agreement with the literature[11,21,30]. Also, comparable to immediately postoperative, all but one patient reported improvements in OSAS-related symptoms. However, the effect on blood pressure, nycturia, and sexual activity had diminished by the latest follow-up, which could of course be attributed to older age. Only the patient with the highest AHI of 106.9/h reported a worsening of all of these symptoms in comparison to the immediate postoperative period. The discrepancy between OSAS severity and subjective feelings of QoL could indicate that patients adapt to their symptoms. Furthermore, most of these patients were not taking part in an active working life anymore, which could also have had an effect on subjective feelings of QoL.

Hudgel stated that although PSG is still the gold standard for diagnosing OSAS, the AHI should not be the sole indicator to determine the required patient care[31]. Symptoms of daytime sleepiness, sleep time and quality, BMI, (oro) pharyngeal anatomy, and certain health behaviours such as cigarette smoking or alcohol use should also be taken into account[25,31]. Moreover, since patients might ascribe their symptoms to the normal process of aging, thereby minimizing the severity, it is suggested that re-evaluation every 5 years postoperative should be integrated into the routine care in this patient population, in view of the severity of the diagnosis.

The study results should be interpreted with caution due to certain limitations. First, the sample size is relatively small, although the study included all consecutive patients who had MMA surgery in a 5-year period performed by a single surgeon at a time when MMA surgery was just being introduced as a treatment option for OSAS.

Second, the two female patients were both lost to follow-up. Although the male to female ratio for OSAS patients is 2:1, the study results may not be generalizable to the female population. Vigneron et al. suggested that women might perform better in the long-term; however, they suggested confirmation of this finding in a trial with a larger population of female OSAS patients[21]. Also, Silva et al. concluded that QoL, as mea-

Table 4. Presentation of airway dimensions and volume, based on the CBCT scan obtained at long-term postoperative (T2)[a].

Patient	Total airway volume (mm^3)	Nasopharyngeal volume (mm^3)	Oropharyngeal volume (mm^3)	Hypopharyngeal volume (mm^3)	Smallest LAT/AP width (mm)	Airway length (corrected for height[b]) (mm)
1	47,122	10,885	27,417	8820	6.80	71 (0.040)
2	30,413	9276	15,603	5534	3.80	68 (0.040)
3	34,061	8551	18,398	7112	5.75	65 (0.037)
4	32,907	7671	20,338	4898	23.00	76 (0.044)
5	50,041	8815	26,301	14,925	2.30	79 (0.045)
6	46,799	9761	26,229	10,809	2.00	77 (0.046)
7	42,580	11,515	23,228	7777	2.91	77 (0.046)
8	37,229	7284	26,490	3455	4.67	75 (0.041)
9	48,194	6405	35,822	5967	2.91	87 (0.051)

AP, anteroposterior, CBCT, cone beam computed tomography; LAT, lateral.
[a] Volume measurements were performed in Brainlab iPlan, and according to validated cephalometric landmarks as published by Guijarro-Martinez and Swennen[17]. Airway dimensions were measured in PACS, and according to cephalometric landmarks as published by Abramson et al.[18].
[b] Airway length corrected for height given in parenthesis.

sured with three different validated questionnaires, tends to be poorer only in female patients with severe OSA in a middle-aged to elderly cohort[32].

Third, objective quantification of skeletal stability was not included. Three-dimensional (3D) volume measurement of the airway through CBCT measurement should nowadays be an integral part of preoperative work-up and postoperative evaluation of surgical success[16,17,23]. However, at the time of surgery, the technology of CBCT was not yet available. Preoperative 2D cephalometric images could not be retrieved, making quantitative comparison impossible. Also, superimposition of 2D cephalometric images on a 2D virtually reconstructed 3D CBCT image might introduce an important source of analysis bias[33].

No association was found between a longer airway length or higher LAT/AP ratio and a higher AHI, as has been suggested previously in the literature, although the measurement landmarks have often been defined differently[18,34,35]. A non-significant trend towards larger oropharyngeal volumes was found in patients in whom the MMA surgery was still successful at long-term re-evaluation. However, the measured upper airway volumes in all study patients are comparable to normative data published by Schendel et al.[36]. Also, they are in agreement with airway volumes measured immediately post MMA surgery, as reported previously by our team[23]. This could indicate that skeletal relapse might not be the cause of OSAS relapse in the long-term.

Future longitudinal studies incorporating CBCT images prior to and at different time points postoperative could provide novel landmark evidence regarding the airway and orofacial adaptive changes that could impact the management of OSAS.

Fourth, neck circumference was not measured as a parameter. No such data were available preoperatively, hindering quantitative comparison. A neck circumference of 40 cm or more was considered an indication for surgery by Ferguson et al. in 1995, and a recent paper by de Ruiter et al. (2017) also suggests that neck girth might predict treatment failure in MMA. Therefore neck circumference will be incorporated in future anthropometric measurements in our department[12,37].

Fifth, patients were asked to complete the same questionnaire on current symptom severity that was applied 20 years ago, rating a comparison to the preoperative and immediate postoperative situation based on a numerical scale from −5 to +5. At present, there is no consensus on

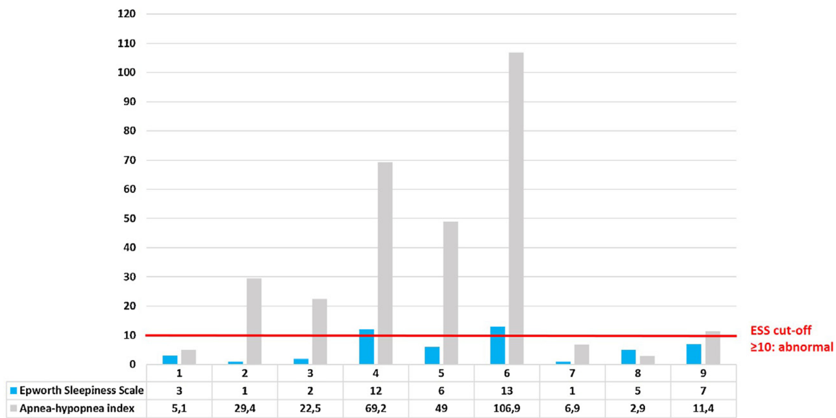

Fig. 1. Quality of life, as measured with the Epworth Sleepiness Scale and the apnoea–hypopnoea index, of the nine patients re-evaluated at long-term follow-up.

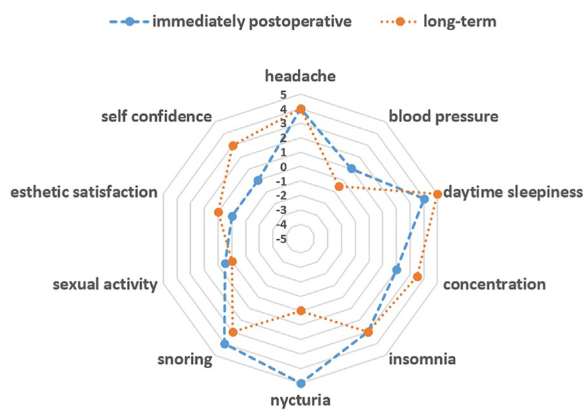

Fig. 2. Impact of maxillomandibular advancement surgery on quality of life, as measured with the OSAS questionnaire, immediately postoperative and at long-term follow-up.

the best QoL instrument to apply in OSAS patients[32,38]. Since re-evaluation was performed at a median follow-up of 19 years, they might have forgotten the impact of their condition prior to surgery, and thus recall bias may be present.

In conclusion, MMA surgery is a safe and effective alternative to CPAP in the long-term treatment of OSAS patients. Weight gain can negatively influence the treatment outcome and should be monitored. Consequently, systematic re-evaluation annually or every 5 years should be considered in view of the seriousness of the condition, which is more prevalent in an older population, and since subjective complaints are not always in relation to OSAS severity.

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