Journal of Cranio-Maxillo-Facial Surgery 47 (2019) 1331–1337

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

# Use of CAD-CAM technology to improve orthognathic surgery outcomes in patients with severe obstructive sleep apnoea syndrome

Diego Sergio Rossi [a], Michele Romano [a, b], Ahmed Hassan Sweed [a, c, *], Alessandro Baj [a, b], Aldo bruno Gianni [a, b], Giada Anna Beltramini [a]

[a] Dental and Maxillo-Facial Surgery Unit, IRCCS Ca Granda Ospedale Maggiore Policlinico di Milano, Via Francesco Sforza 35, Milan, Italy
[b] Department of Biomedical, Surgical and Dental Sciences, University of Milan, Italy
[c] ORL-HNS, Zagazig University, Faculty of Medicine, Egypt

ARTICLE INFO

*Article history:*
Paper received 19 January 2019
Accepted 19 June 2019
Available online 25 June 2019

*Keywords:*
CAD-CAM
Orthognathic surgery
OSAS
Bi-maxillary surgery
MMA

ABSTRACT

*Introduction:* Although multilevel surgery is the mainstay treatment for severe obstructive sleep apnoea syndrome (OSAS), bi-maxillary surgery (maxillomandibular advancement [MMA]) is the most efficacious single procedure for the expansion of the whole pharyngeal airway. MMA is an alternative to the gold standard of continuous positive airway pressure and is equivalent to tracheotomy.
*Patients and method:* Computer-aided design/computer-aided manufacturing (CAD-CAM) technology was used to virtually assess the degree of mandibular and/or maxillary advancement and rotation required to obtain adequate posterior airway space (PAS) in eight patients (seven males, one female). The mean age of the patients was 45.5 years (range, 27–51 years), and the average body mass index was 28.9 kg/m$^2$ (range, 21.9–31.8 kg/m$^2$).
*Results:* The study group showed significant mandibular advancement, widening of the PAS, and reduction of the apnoea hypopnea index ($p < 0.0001$, $p < 0.0001$, and $p < 0.0002$, respectively). Moreover, patient satisfaction scores regarding postoperative facial profile changes showed excellent compliance.
*Conclusion:* This study demonstrated that bi-maxillary surgery is an efficient single surgical procedure in patients with multilevel OSAS. CAD-CAM technology aided surgeons in performing this operation precisely and enabled patients to expect specific facial profiles.


## 1. Introduction

Obstructive sleep apnoea syndrome (OSAS) is a common condition due to upper airway collapsibility (i.e. retropalatal–retrolingual pharyngeal) during sleep. It has been associated with significant cardiovascular morbidity and mortality (Levy et al., 2011). Multilevel surgery is the mainstay treatment for severe OSAS (Tantawy et al., 2018) via modification of the pharyngeal airway by extirpation of obstructed soft tissue, or by expansion/modification of the craniofacial skeleton (Barrera, 2016). Maxillomandibular advancement (MMA) is the most efficacious single procedure for the expansion of the whole pharyngeal airway; this approach serves as an alternative to the gold standard of continuous positive airway pressure and is equivalent to tracheotomy. MMA indications range from a backup operation after the failure of other protocols to use as a primary procedure in patients with severe hypopharyngeal collapse and/or retrognathia (Laganà et al., 2013).

Computer-aided design/computer-aided manufacturing (CAD-CAM) technology has been utilised in orthognathic surgery, where it has facilitated great advancement in outcomes (Naran et al., 2018). Using this technology, cutting guides, occlusal splints, and custom-made plates can be manufactured to ensure exact bony repositioning (Farrell et al., 2014). Few studies have examined the role of CAD-CAM technology in skeletal surgery in patients with OSAS. In this study, we assessed the outcomes of CAD-CAM orthognathic procedures performed in patients with OSAS.

* Corresponding author. Otorhinolaryngology, Head and Neck Surgery Department, Faculty of Medicine, Zagazig University, Egypt.
*E-mail address:* dr.orl.sweed@gmail.com (A.H. Sweed).

https://doi.org/10.1016/j.jcms.2019.06.010
1010-5182/

## 2. Materials and Method

### 2.1. Study Design

This retrospective study was conducted at the Maxillofacial and Dental Unit of the Fondazione Ca' Granda IRCCS Ospedale Maggiore Policlinico Milan and covered the period of January 2017–June 2018. The study was performed in accordance with the principles of the Declaration of Helsinki, and all enrolled subjects provided written informed consent after the purpose of the research had been explained to them. This study was approved by the ethics committee of the Fondazione Ca' Granda IRCCS Ospedale Maggiore Policlinico Milan.

### 2.2. Study Subjects

All patients with severe OSAS (apnea hypopnea index AHI>30/h) who agreed to pay for CAD-CAM procedures (planning and manufacture of mandibular cutting guides, custom-made mandibular advancement plates, and final occlusal splits) were included in this study. Patients with failed primary OSAS surgery, mild OSAS (AHI = 5–14/h) –moderate OSAS (AHI = 15–30/h), only retropalatal collapse, and body mass index (BMI) > 35 kg/m$^2$ were excluded.

### 2.3. Preoperative Preparation

The histories of all included patients, including information provided by their sleeping partners, were examined in detail. Additional assessments included the administration of the Epworth Sleepiness Score questionnaire; clinical evaluation, including palate, tongue, dental occlusion, and facial profile assessment; and polysomnography (PSG) at the sleep laboratory. With the assistance of a computer engineer, a maxillofacial surgeon performed computed tomography examinations and virtual planning with Proplan CMF (Materialise) software to obtain patient-specific measurements (mandibular advancement, maxillary rotation and advancement, and SNA-SNB-ANB angles modifications) for the planning of MMA to overcome pharyngeal collapse and achieve satisfactory posterior airway space (PAS) (Fig. 1).

Preoperative and postoperative virtual facial soft-tissue designs were obtained, and all patients were counselled about their new facial profiles (Fig. 2). One month postoperatively, patients rated their satisfaction with facial profile changes using a visual analogue scale (0–10; 0 = not satisfied at all, 10 = completely satisfied).

### 2.4. Surgical Procedure

Before the surgical intervention, drug-induced sleep endoscopy (DISE) was performed in the operating room with an anaesthesiologist, attended by an otorhinolaryngologist and a maxillofacial surgeon, to clearly identify the site of obstruction.

MMA was performed under general anaesthesia with nasotracheal intubation. A mandible-first approach was preferred; bilateral sagittal-splint osteotomies were performed with the aid of a mandibular cutting guide using a piezoelectric instrument. Subsequently, pre-planned mandibular advancement was achieved and maintained with patient-specific CAD-CAM custom-made plates (Fig. 3). Le Fort I osteotomy was performed with excision of any overlapping bone, as determined by CAD-CAM pre-planning. The maxilla was moved to its new position (after anticlockwise rotation and advancement), which was established accurately by a CAD-CAM final occlusal splint attached to the mandible. Finally, the maxilla was fixed on each side with two L-shaped miniplates and monocortical screws (Fig. 3).

When additional genioplasty was needed (i.e. for patient no. 8), standard sliding genioglossus advancement was performed. The patient's occlusion was maintained by a final CAD-CAM occlusal splint and elastic maxillomandibular fixation.

A senior anaesthesiologist performed awake extubation; patients were admitted overnight into intermediate care, and then were followed in the general ward for 3–5 days.

### 2.5. Postoperative Follow Up

The standard follow-up regimen was as follows: weekly visits in the first month, then every 2 weeks in the second and third months, then monthly until the end of the first year (minimum follow-up period in this study: 6 months). Patients wore the elastic maxillomandibular fixation apparatus for 24 h/day for 2 weeks, then overnight only for 2 weeks; they then underwent removal of the elastics and were allowed fluids and a soft diet for the following 2 weeks.

Potential complications, including facial pain and oedema, issues with surgical wound healing and bony union, occlusal problems, nerve injury and paraesthesia, and tooth loss, were addressed when present.

### 2.6. Statistical Analysis

Statistical analyses were performed using SPSS 14.0 statistical software for Windows (SPSS Inc, Chicago, IL, USA). Differences

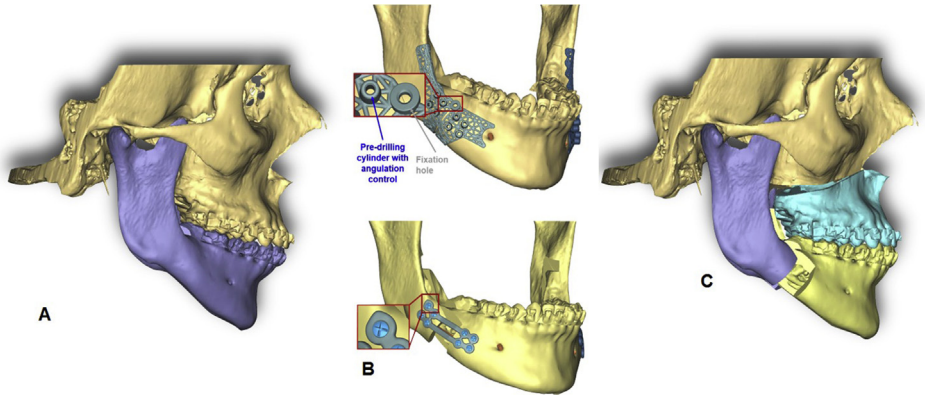


**Fig. 1.** Skeletal virtual preoperative planning. A: Initial bony skeleton. B: Mandible with cutting guide and pre-drilling cylinder for the custom-made advancement plate. C: Final bony skeleton after mandibular advancement, as well as maxillary advancement and rotation.

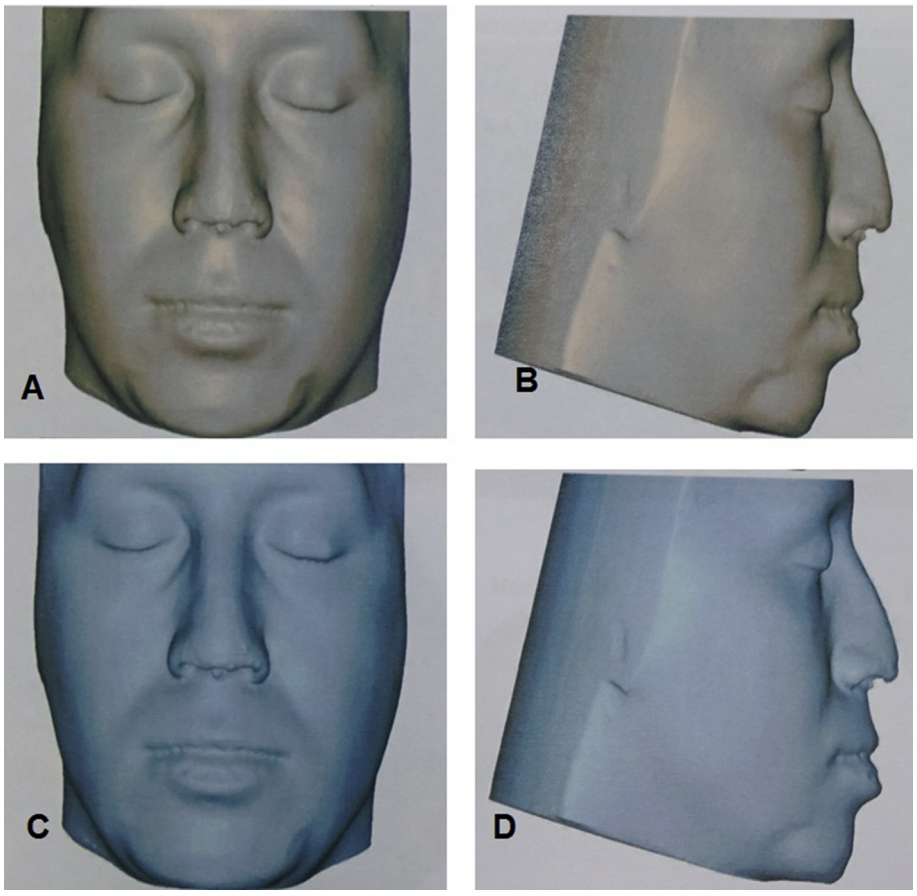


**Fig. 2.** Soft-tissue preoperative planning (images used for patient counselling). A, B: Preoperative frontal and lateral views. C, D: Postoperative expected frontal and lateral views.

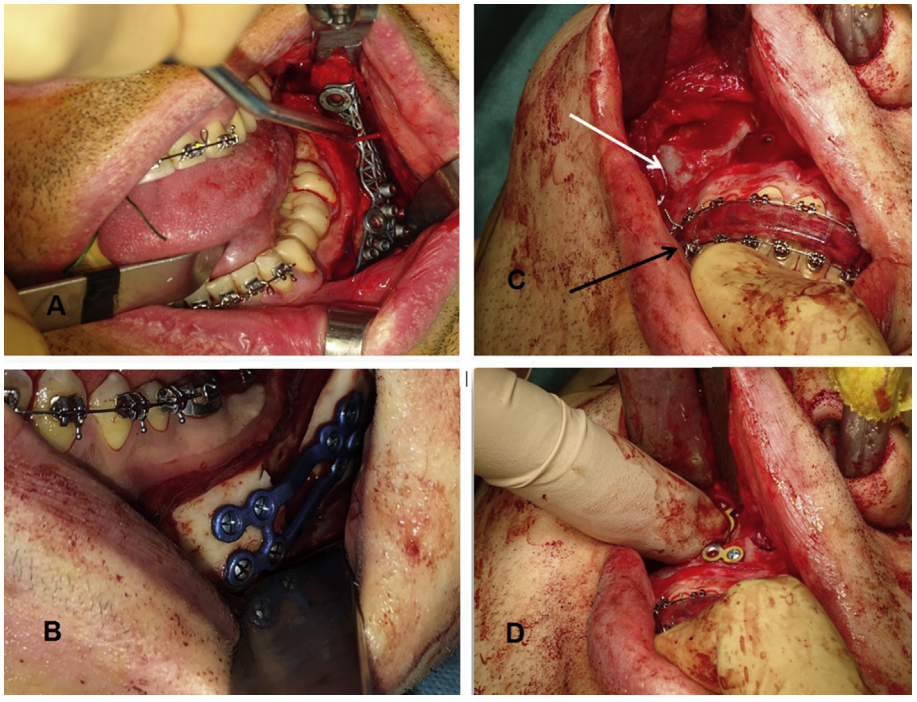


**Fig. 3.** Intraoperative steps of CAD-CAM maxillomandibular advancement. A: Cutting guide fitted at the mandibular osteotomy site. B: Mandibular advancement plates. C: Occlusal splint (black arrow) with Le Fort I osteotomy (white arrow). D: Intraoperative bending of the L-shaped plate for fixation of the maxilla in its new position.

between preoperative and postoperative data were assessed by Student's paired t-test. P values < 0.05 were considered to be significant.

## 3. Results

The study group comprised eight patients (seven males, one female), with a mean age of 45.5 years (range, 27–51 years) and an average BMI of 28.9 kg/m$^2$ (range, 21.9–31.8 kg/m$^2$). They exhibited a range of facial profiles (five retrognathic, two normal, and one prognathic; Table 1).

Orthognathic measurements were taken preoperatively and postoperatively for the assessment of outcomes. The average change in the SNA angle was 2.34° ($p = 0.0535$), whereas the average change in the SNB angle was 6.3° ($p < 0.0001$). The average change in the PAS diameter was 7.41 mm ($p < 0.0001$). The average extent of MMA achieved was 14.3 mm, and the average occlusal (maxillary counter-clockwise) rotation achieved was 5.63° (Table 2).

All surgeries were successful (defined as postoperative apnoea hypopnea index [AHI] <50% preoperative AHI), as indicated by postoperative PSG data (average change in AHI from preoperative 55 ± 17.3 events/h to postoperative 8.9 ± 4.2 events/h; $p = 0.0002$; Table 3).

The role of virtual planning in the cases included in this study was to preoperatively plan the surgical interventions and provide CAD-CAM mandibular cutting guides, custom-made advancement plates, and occlusal splints. Collapse was retropalatal and retrolingual in six (75%) patients, and retrolingual only in two (15%) patients; the average total operation time (including DISE, anaesthesia, surgery, and recovery) was 267.5 min (Table 4).

Tracheotomy was not required in the operating room or during early postoperative intermediate care. No major complication (e.g. nerve injury, tooth loss, osteomyelitis, or open-bite malocclusion) occurred. Facial oedema peaked on the second postoperative day and lasted for 5 days. The average VAS score for patients' satisfaction with their facial profiles was 8.12 (i.e. excellent) (Fig. 4a, b; Table 4).

## 4. Discussion

MMA, as a primary intervention or secondary procedure, has been proven to be the most efficacious surgery for the management of moderate to severe OSAS. MMA counteracts the pathophysiology of OSAS by widening the collapsible upper airway (retropalatal and retrolingual spaces) (Barrera, 2016).

The degree of advancement required for effective MMA remains under debate; some authors have considered advancement similar to that of an effective oral appliance to be sufficient (Hoekema et al., 2006), whereas others have argued that maximum advancement should be obtained during the operation. After reviewing the

**Table 1**
Patient data: Age-sex-BMI and facial profile.

| | SEX | Age | BMI | Facial profile \ occlusion |
|---|---|---|---|---|
| 1 | M | 46 | 29.4 | Class II - Retrognathic |
| 2 | M | 49 | 31.8 | Class II - Retrognathic |
| 3 | M | 49 | 31.3 | Class I - normal profile |
| 4 | M | 51 | 30 | Class I - normal profile |
| 5 | F | 47 | 28.6 | Class II - Retrognathic |
| 6 | M | 47 | 30 | Class III - prognathic |
| 7 | M | 48 | 28 | Class II - Retrognathic |
| 8 | M | 27 | 21.9 | Class II - Retrognathic |
| | 7 M + 1 F | 45.5 years old | Average 28.9 kg/m2 | 5 class II<br>2 class I<br>1 class III |

**Table 2**
Orthognathic data; changes in cephalometric angles, mandibular position - maxillary position - posterior airway space.

| | Pre-operative cephalometric angles | | | Post operative cephalometric angles | | | Mandibular advancement in angle($^0$) Post op SNB-preop SNB | Mandibular advancement in mm | Maxillary advancement in angle ($^0$) Post op SNA- pre op SNA | Anticlockwise maxillary rotation(occlusion plane rotation) in degree ($^0$) | Posterior airway space PAS in mm | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SNA | SNB | ANB | SNA | SNB | ANB | | | | | Pre-operative PAS | Postoperative PAS |
| 1 | 79.06 | 72.7 | 6.36 | 80.3 | 78.6 | 1.7 | 5.9 | 14 | 1.24 | 5.1 | 7.83 | 15.55 |
| 2 | 77.94 | 75.08 | 2.86 | 81.65 | 82.41 | −0.76 | 7.33 | 15.2 | 3.71 | 7.3 | 5.81 | 13.2 |
| 3 | 83.72 | 79.38 | 4.34 | 88.85 | 86.77 | 2.08 | 7.39 | 15.7 | 5.13 | 5 | 10.2 | 18.87 |
| 4 | 79.06 | 73.62 | 5.44 | 81.9 | 80.02 | 1.88 | 6.4 | 13.8 | 2.84 | 6 | 5.27 | 9.9 |
| 5 | 86.64 | 79 | 7.64 | 84.32 | 85.21 | −0.89 | 6.21 | 13.7 | −2.32 | 6.2 | 7.27 | 14.84 |
| 6 | 75.9 | 79.3 | −3.4 | 81.6 | 84.9 | −3.3 | 5.6 | 13.2 | 5.7 | 1.2 | 9.21 | 16.5 |
| 7 | 78.77 | 74.1 | 4.67 | 77.7 | 79.5 | −1.8 | 5.4 | 14.4 | −1.07 | 4.8 | 7.36 | 15.32 |
| 8 | 79 | 75.5 | 3.5 | 82.5 | 81.7 | 0.8 | 6.2 | 14.5 | 3.5 | 9.4 | 6.53 | 14.54 |
| | 80 | 76.08 | 3.93 | 82.4 | 82.39 | −0.03 | 6.3 | 14.3 mm | 2.34 | 5.63 | 7.43 mm | 14.84 mm |
| | | SNB variation | | | | | | | | | PAS variation | |
| | | P value is less than 0.0001 HS | | | | | | | | | p value is less than 0.0001 HS | |
| | SNA variation | | | | | | | | | | | |
| | P value 0.0535 NS | | | | | | | | | | | |

**Table 3**
PSG data; preoperative and postoperative apnea hypopnea index.

| | Pre-operative AHI | Post-operative AHI | |
|---|---|---|---|
| 1 | 70 | 17.5 | Pre-op AHI |
| 2 | 52.6 | 9.4 | 55 ± 17.3 event/h |
| 3 | 75 | 7.6 | Post-op AHI |
| 4 | 50.2 | 6 | 8.9 ± 4.2 event/h |
| 5 | 41 | 9 | p-value 0.0002 (extremely significant) |
| 6 | 33.5 | 11.9 | |
| 7 | 78.3 | 5 | |
| 8 | 39.4 | 5 | |
| * | 61.28 | 8.93 | |

**Table 4**
Operative finding; orthognathic surgery, operation time, site of pharyngeal obstruction, patient satisfaction score.

| | Surgical intervention | Total operation time in min (presurgical sleep endoscopy DISE + induction anesthesia + orthognathic surgery + anesthesia recovery time) | Level of pharyngeal obstruction identified by sleep endoscopy DISE | VAS (visual analog score) |
|---|---|---|---|---|
| 1 | Bi-max surgery (MMA) | 300 | retropalatal and retrolingual | 8 |
| 2 | Bi-max surgery (MMA) | 280 | retropalatal and retrolingual | 9 |
| 3 | Bi-max surgery (MMA) | 300 | retropalatal and retrolingual | 6 |
| 4 | Bi-max surgery (MMA) | 270 | retropalatal and retrolingual | 8 |
| 5 | Bi-max surgery (MMA) | 250 | retrolingual | 8 |
| 6 | Bi-max surgery (MMA) | 290 | retropalatal and retrolingual | 9 |
| 7 | Bi-max surgery (MMA) | 230 | retropalatal and retrolingual | 7 |
| 8 | Bi-max surgery (MMA) + genioplasty | 220 | retrolingual | 10 |
| | | 267.5 min | | 8.12 |

results of MMA surgery for OSAS, surgeons came to a relative consensus that a minimum of 10 mm mandibular advancement should be achieved (Barrera, 2016; Hochban et al., 1997; Marc et al., 2012).

Advancements have been made in software technology and 3D bioprinting, as well as the utilisation of virtual surgical planning (VSP) for cranio-maxillofacial and orthognathic procedures; surgeons have made use of these technologies for the virtual assessment of airway obstruction to detect the level of obstruction and plan surgical protocols (e.g. excision of obstructing soft tissue [Mylavarapu et al., 2016] or skeletal expansion to widen the airway space [Resnick, 2018; Barrera, 2014; Liu et al., 2017]).

VSP plays vital roles in improving orthognathic surgeries for OSAS, enabling the accurate identification of the genial tubercles and the CAD-CAM production of cutting and positioning guides for precise genioglossus advancement (Liu et al., 2017), as well as accurate virtual airway planning and the CAD-CAM production of the cutting guides and plates required for optimal MMA (Resnick, 2018; Barrera, 2014). VSP helps surgeons to avoid possible complications (e.g. tooth root injury, inferior alveolar-mental nerve injury) during these surgeries.

Our success rate (postoperative AHI <50% preoperative AHI) in the present study was 100%, comparable to the results of conventional MMA (postoperative RDI [respiratory distress index] <50% preoperative RDI, 98% [Riley et al., 1993]; postoperative RDI <10/min, 65% [Waite et al., 1989] and 98% [Marc et al., 2012]) and virtually aided MMA (postoperative AHI <50% preoperative AHI, 100% [Barrera, 2014]).

Regarding orthognathic and PSG outcomes, significant differences were observed between the preoperative and postoperative SNB angle, PAS, and AHI ($p < 0.0001$, $p < 0.0001$, and $p < 0.0002$, respectively). We also successfully obtained and maintained the required mandibular advancement (average, 14.3 mm) and maxillary counter-clockwise rotation (average, 5.63°). Mandibular advancement in this study exceeded the minimal effective degree of advancement achieved with bi-maxillary surgery, for which a wide range (10–12 mm) has been reported in the literature (Barrera, 2016; Marc et al., 2012).

To our knowledge, only one publication describes the results of virtual MMA, in four patients (Barrera, 2014). The average BMIs of the patients included in that study and the present study were similar (31.09 and 28.9 kg/m$^2$, respectively). The average mandibular advancement achieved was 9 mm in the previous study and 14.3 mm in the present study; average postoperative PAS anteroposterior diameters were 13.99 mm and 14.54 mm, and average postoperative AHIs were 2.83 and 8.9 events/h, respectively. The differences in outcomes may be attributable to the performance of second-phase operations after palatal surgery in three of the four patients in the previous study, whereas all patients in the present study underwent primary OSAS surgery without palatal surgery.

No complication (tooth root or nerve injury) occurred in our study subjects. Furthermore, the extents of facial pain and oedema were acceptable, possibly due to the utilisation of piezoelectric technology (Rossi et al., 2018). Our patients experienced no aesthetic complications and were satisfied with their postoperative facial profiles; the average satisfaction score was approximately 8, which indicates excellent satisfaction. Up to 5.2% of patients may report dissatisfaction with aesthetic outcomes (Blumen et al., 2009); preoperative counselling with the use of virtual postoperative profiles may eliminate this negative outcome.

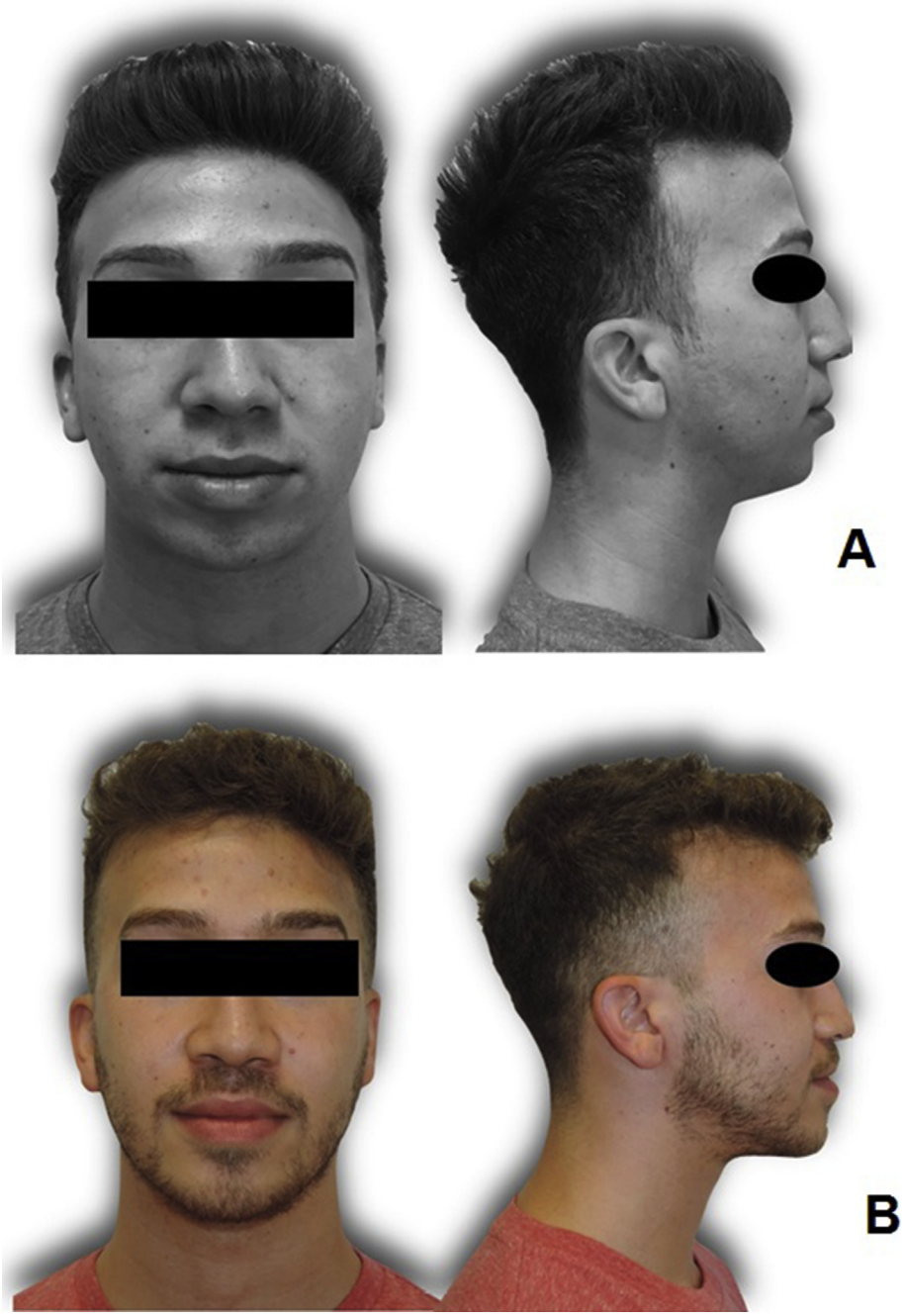


**Fig. 4.** A: Preoperative photographs, frontal and lateral views. B: Postoperative photographs, frontal and lateral views.

## 5. Conclusion

VSP may improve the efficacy of MMA for the treatment of OSAS through the use of patient-specific regimens for surgical planning and to avoid possible complications; this approach may increase patient compliance following this skeletal surgery.

**Financial disclosure**

The authors declare no financial support or interest to this study.

**Conflicts of interest**

The authors declare no conflict of Interest.

## References

Barrera JE: Virtual surgical planning improves surgical outcome measures in obstructive sleep apneasurgery Laryngoscope 124(5): 1259–1266, 2014

Barrera JE: Skeletal surgery for obstructive sleep apnea. Otolaryngol Clin North Am 49(6): 1433–1447, 2016

Blumen MB, Buchet I, Meulien P, et al: Complications/adverse effects of maxillomandibular advancement for the treatment of OSA in regard to outcome. Otolaryngol Head Neck Surg 141: 591–597, 2009

Farrell BB, Franco PB, Tucker MR: Virtual surgical planning in orthognathic surgery. Oral Maxillofac Surg Clin North Am 26(4): 459–473, 2014

Hochban W, Conradt R, Brandenburg U, et al: Surgical maxillofacial treatment of obstructive sleep apnea. Plast Reconstr Surg 99: 619–626, 1997

Hoekema A, de Lange J, Stegenga B, et al: Oral appliances and maxillomandibular advancement surgery: an alternative treatment protocol for the obstructive sleep apnea-hypopnea syndrome. J Oral Maxillofac Surg 64: 886–891, 2006

Laganà F, Sacco R, Giannì AB: Maxillomandibular advancement in obstructive sleep apnea syndrome. Eur J Intern Med 24(8): e94–e95, 2013
Levy P, Tamisier R, Minville C, et al: Sleep apnoea syndrome in 2011: current concepts and future directions. Eur Respir Rev 20: 134–146, 2011
Liu SY, Huon LK, Zaghi S, et al: An accurate method of designing and performing Individual Specific Genioglossus Advancement. Otolaryngol Head Neck Surg 156(1): 194–197, 2017
Marc BB, Vezina JP, Pigot FJ, et al: Maxillomandibular advancement for obstructive sleep apnea syndrome. Oper Tech Otolaryngology-Head Neck Surg 23(Issue 1): 60–66, 2012
Mylavarapu G, Subramaniam D, Jonnagiri R, et al: Computational modeling of airway obstruction in sleep apnea in down syndrome: a Feasibility Study. Otolaryngol Head Neck Surg 155(1): 184–187, 2016
Naran S, Steinbacher DM, Taylor JA: Current concepts in orthognathic surgery. Plast Reconstr Surg 141(6): 925e–936e, 2018 Jun
Resnick CM: Precise osteotomies for mandibular distraction in infants with Robin sequence using virtual surgical planning. Int J Oral Maxillofac Surg 47(1): 35–43, 2018
Riley RW, Powell NB, Guilleminault C: Obstructive sleep apnea syndrome: a review of 306 consecutively treated surgical patients. Otolaryngol Head Neck Surg 108: 117–125, 1993
Rossi D, Romano M, Karanxha L, Baserga C, Russillo A, Taschieri S, Del Fabbro M, Giannì AB, Baj A: Bimaxillary orthognathic surgery with a conventional saw compared with the piezoelectric technique: a longitudinal clinical study. Br J Oral Maxillofac Surg 25, 2018
Tantawy AA, Askar SM, Amer HS, Awad A, El-Anwar MW: Hyoid bone suspension as a part of multilevel surgery for obstructive sleep apnea syndrome. Int Arch Otorhinolaryngol 22(3): 266–270, 2018
Waite PD, Wooten V, Lachner J, et al: Maxillomandibular advancement surgery in 23 patients with obstructive sleep apnea syndrome. J Oral Maxillofac Surg 47: 1256–1261, 1989