Original Investigation

Maxillomandibular Advancement for Treatment of Obstructive Sleep Apnea
A Meta-analysis

Soroush Zaghi, MD; Jon-Erik C. Holty, MD, MS; Victor Certal, MD; Jose Abdullatif, MD; Christian Guilleminault, DM, MD, DBiol; Nelson B. Powell, MD, DDS; Robert W. Riley, MD, MS, DDS; Macario Camacho, MD

IMPORTANCE Maxillomandibular advancement (MMA) is an invasive yet effective surgical option for obstructive sleep apnea (OSA) that achieves enlargement of the upper airway by physically expanding the facial skeletal framework.

OBJECTIVE To identify criteria associated with surgical outcomes of MMA using aggregated individual patient data from multiple studies.

DATA SOURCES The Cochrane Library, Scopus, Web of Science, and MEDLINE from June 1, 2014, to March 16, 2015, using the Medical Subject Heading keywords *maxillomandibular advancement*, *orthognathic surgery*, *maxillary osteotomy*, *mandibular advancement*, *sleep apnea*, *surgical*, *surgery*, *sleep apnea syndrome*, and *obstructive sleep apnea.*

STUDY SELECTION Inclusion criteria consisted of studies in all languages of (1) adult patients who underwent MMA as treatment for OSA; (2) report of preoperative and postoperative quantitative outcomes for the apnea-hypopnea index (AHI) and/or respiratory disturbance index (RDI); and (3) report of individual patient data. Studies of patients who underwent adjunctive procedures at the time of MMA (including tonsillectomy, uvulopalatopharyngoplasty, and partial glossectomy) were excluded.

DATA EXTRACTION Three coauthors systematically reviewed the articles and updated the review through March 16, 2015. The PRISMA statement was followed. Data were pooled using a random-effects model and analyzed from July 1, 2014, to September 23, 2015.

MAIN OUTCOMES AND MEASURES The primary outcomes were changes in the AHI and RDI after MMA for each patient. Secondary outcomes included surgical success, defined as the percentage of patients with more than 50% reduction of the AHI to fewer than 20 events/h, and OSA cure, defined as a post-MMA AHI of fewer than 5 events/h.

RESULTS Forty-five studies with individual data from 518 unique patients/interventions were included. Among patients for whom data were available, 197 of 268 (73.5%) had undergone prior surgery for OSA. Mean (SD) postoperative changes in the AHI and RDI after MMA were −47.8 (25.0) and −44.4 (33.0), respectively; mean (SE) reductions of AHI and RDI outcomes were 80.1% (1.8%) and 64.6% (4.0%), respectively; and 512 of 518 patients (98.8%) showed improvement. Significant improvements were also seen in the mean (SD) postoperative oxygen saturation nadir (70.1% [15.6%] to 87.0% [5.2%]; $P < .001$) and Epworth Sleepiness Scale score (13.5 [5.2] to 3.2 [3.2]; $P < .001$). Rates of surgical success and cure were 389 (85.5%) and 175 (38.5%), respectively, among 455 patients with AHI data and 44 (64.7%) and 13 (19.1%), respectively, among 68 patients with RDI data. Preoperative AHI of fewer than 60 events/h was the factor most strongly associated with the highest incidence of surgical cure. Nevertheless, patients with a preoperative AHI of more than 60 events/h experienced large and substantial net improvements despite modest surgical cure rates.

CONCLUSIONS AND RELEVANCE Maxillomandibular advancement is an effective treatment for OSA. Most patients with high residual AHI and RDI after other unsuccessful surgical procedures for OSA are likely to benefit from MMA.

JAMA Otolaryngol Head Neck Surg. doi:10.1001/jamaoto.2015.2678
Published online November 25, 2015.

Supplemental content at jamaotolaryngology.com

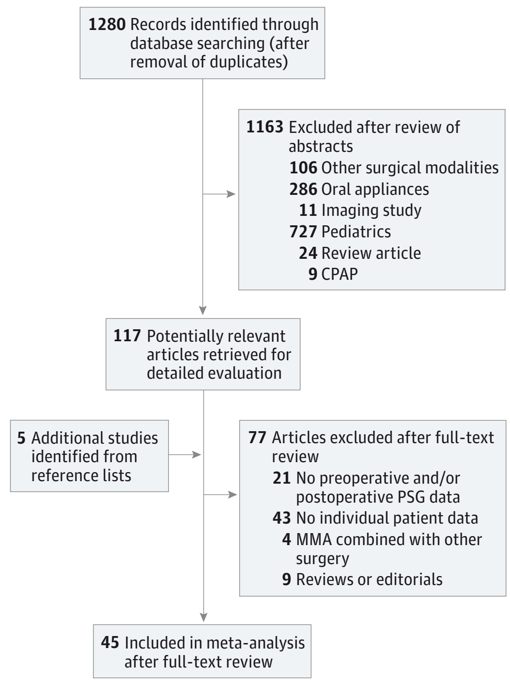
Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Soroush Zaghi, MD, Department of Head and Neck Surgery, David Geffen School of Medicine at UCLA, 10833 LeConte Ave, Room 62-132, Center for Health Sciences, Los Angeles, CA 90095 (soroush.zaghi@gmail.com).

Maxillomandibular advancement (MMA) is an invasive yet potentially effective surgical option in the treatment of obstructive sleep apnea (OSA) for patients who have difficulty tolerating continuous positive airway pressure and whose OSA has been refractory to other surgical modalities.[1] Maxillomandibular advancement achieves enlargement of the nasopharyngeal, retropalatal, and hypopharyngeal airway by physically expanding the facial skeletal framework via Le Fort I maxillary and sagittal split mandibular osteotomies. Advancements of the maxilla and mandible increase tension on the pharyngeal soft tissue, thereby enlarging the medial-lateral and anteroposterior dimensions of the upper airway.[2] A previous meta-analysis[3] demonstrated a mean decrease in the apnea-hypopnea index (AHI) from 63.9 to 9.5 events/h with a pooled surgical success rate of 86.0% and OSA cure rate of 43.2% using study-level data. Despite a large number of studies reporting excellent outcomes on the cohort level, baseline individual variables that might be associated with a highly effective outcome remain to be elucidated. Indeed, assessment of whether any preoperative factors could be consistently associated with postoperative outcomes could help to shape patient selection criteria and to counsel patients regarding their chances to achieve a significant improvement with MMA.

We performed a systematic review of the literature and meta-analysis of studies reporting individual patient data among adults who underwent MMA for the treatment of OSA. The purpose of our meta-analysis was to use aggregated individual patient-level data from a large number of studies to assess whether any baseline preoperative factors might be predictive of postoperative AHI and respiratory disturbance index (RDI) outcomes, surgical success, and/or OSA cure. Our specific aim was to elucidate factors associated with outcome effect size and the likelihood of surgical success and cure.

Figure 1. PRISMA Flow Diagram



The meta-analysis included 518 unique patients undergoing 518 unique procedures. CPAP indicates continuous positive airway pressure; MMA, maxillomandibular advancement; and PSG, polysomnography.

Methods

Three of us (V.C., J.A., and M.C.) independently performed a literature search to identify potentially relevant studies via search of the Cochrane Library, Scopus, Web of Science, and MEDLINE. These same three of us came to a consensus as to which studies met the inclusion criteria and submitted these to another one of us (S.Z.), who independently reviewed each article to ensure that they met the inclusion and exclusion criteria.

Search Strategy

The 4 databases were searched from June 1, 2014, through March 16, 2015. The Medical Subject Heading keywords and phrases searched included *maxillomandibular advancement*, *orthognathic surgery*, *maxillary osteotomy*, *mandibular advancement*, *sleep apnea*, *surgical*, *surgery*, *sleep apnea syndrome*, and *obstructive sleep apnea*.

Study Inclusion Criteria

We included studies in all languages of (1) adult patients (aged >18 years) who underwent MMA (with or without genial tubercle advancement) as a treatment for OSA; (2) reports of preoperative and postoperative quantitative outcomes for the AHI and/or RDI; and (3) reports of individual patient data. We excluded studies of patients who underwent adjunctive procedures at the time of MMA (including tonsillectomy, uvulopalatopharyngoplasty, and partial glossectomy).

Methodologic Quality of Included Studies

We screened 1280 MMA studies for potential relevance, and 117 nonduplicated articles were downloaded for detailed evaluation (**Figure 1**). An effort was made to include all available studies in all languages, including library requests and direct contact with the authors. Five more articles were added based on a review of references. After reviewing the full-text versions of 122 articles, a total of 45 studies were included. One of these was a randomized clinical trial.[4] The other 77 articles were excluded because preoperative and/or postoperative polysomnographic data were missing (n = 21), individual patient data were not available (n = 43), MMA was combined with other surgeries (n = 4), or the articles were reviews or editorials (n = 9). The 45 included studies were written in English (n = 40), French (n = 2), German (n = 1), Dutch (n = 1), and Chinese (n = 1). A quality control questionnaire was developed to evaluate the methodologic quality of each study (eAppendix in the Supplement). Results of the questionnaire are given in eTable 1 in the Supplement.

Data Abstraction

Individual patient data from each article were abstracted into a spreadsheet (Excel 2013; Microsoft Corporation). Abstracted data included age, sex, prior OSA surgery, body mass index (BMI; calculated as weight in kilograms divided by height in meters squared), AHI, nadir of the pulse oximeter oxygen saturation level (Spo_2), RDI, Epworth Sleepiness Scale score, posterior airway space, length of maxilla advancement, length of mandible advancement, and sella-nasion points A and B angles. All articles were reviewed at least 3 times to ensure accurate transposition of the data. Email correspondence was used to contact authors of included studies to acquire individual patient data for pertinent missing variables (ie, age, sex, and BMI).

Outcome Measures

The main outcome measure was the change in AHI (ΔAHI, calculated as preoperative AHI – postoperative AHI) or the change in RDI (ΔRDI, calculated as preoperative RDI – postoperative RDI) after surgery for each patient. The secondary outcome measures were rates of surgical success and OSA cure. Surgical success was defined as the percentage of patients with greater than 50% reduction of the AHI to fewer than 20 events/h after MMA; surgical cure was defined as a post-MMA AHI of fewer than 5 events/h. We selected variables agreed on by consensus[5] to grade RDI severity on the same scale as AHI severity. On this scale, 0 to fewer than 5 events/h indicates normal; 5 to fewer than 15, mild sleep apnea; 15 to fewer than 30, moderate sleep apnea; and 30 or more, severe sleep apnea. If the RDI was reported, the same criteria were used for surgical success and OSA cure, respectively. Seventeen studies[6-22] reported RDI data (without AHI), and, among these, 8 studies[6,8-12,14,20] provided an explicit definition or reference for RDI that is consistent with AHI according to present guidelines[5]; these data points were corrected as AHI data.

Statistical Analysis

Data were analyzed from July 1, 2014, to September 23, 2015. Meta-analysis was performed to assess for heterogeneity of the studies included and to assess the overall effect size of the MMA intervention. Heterogeneity was assessed by the following 3 methods: (1) graphic inspection of forest plots; (2) review of the I^2 statistic with cutoffs of 25% (low), 50% (moderate), and 75% (high)[23]; and (3) review of the Cochran Q statistic[23] with a heterogeneity cutoff of $P \le .10$. Data were pooled using a random-effects model.

Univariate and multivariate analyses of the individual patient data were performed to assess for preoperative factors that could predict differences in patient outcomes. Multivariate analysis was performed with a standard least squares–effect leverage model using backward elimination to select the variables for the model. The Hosmer-Lemeshow test for goodness of fit was performed to assess for adequacy of the models analyzed. Results are reported according to the PRISMA statement guidelines.[24] Unless otherwise indicated, data are expressed as mean (SD).

Results

Individual data from 518 unique patients undergoing 518 unique procedures were extracted from 45 studies, including 9 studies[7,13,15-19,21,22] with RDI data alone (63 patients), 34 studies[4,6,8-12,14,20,25-51] with AHI data alone (450 patients), and 2 studies[52,53] with RDI and AHI data (5 patients). Of 339 patients with sex data available, 282 (83.2%) were male; the mean patient age was 45.3 (10.0) years with a mean preoperative BMI of 33.8 (9.7). The median minimum follow-up time reported by the studies was 6 months, with a range of 2 to 6 months. **Table 1** summarizes pre-MMA and post-MMA characteristics.

Mean post-MMA ΔAHI was −47.8 (25.0); mean post-MMA ΔRDI, −44.4 (33.0). A negative ΔAHI or ΔRDI value represents a net decrease in the postoperative AHI or RDI outcome and characterizes improvement of OSA after surgery. Forest plots for AHI and RDI outcomes (**Figure 2**) show symmetric inverted funnel shapes and are consistent with minimal publication bias. We found statistically significant heterogeneity and a low to moderate level of inconsistency among the studies included in the meta-analysis for the ΔAHI (Cochran $Q_{35} = 90.42$; $P < .001$; $I^2 = 61.3\%$ [moderate]) and the ΔRDI (Cochran $Q_{10} = 17.04$; $P < .001$; $I^2 = 41.3\%$ [low]). A random-effects model was assumed to control for heterogeneity, and appropriateness was confirmed by analysis of variance. Graphs of study reference vs each baseline factor were inspected visually, and we found no significant outliers in the data series.

In this series, 512 of 518 patients (98.8%) experienced an improvement with respect to the primary outcome measures of ΔAHI and ΔRDI. Among patients with AHI data (n = 455), 90% experienced improvements in the AHI of at least −19 events/h; 75%, at least −30 events/h; 50%, at least −46 events/h; 25%, at least −62 events/h; and 10%, exceeding −78 events/h. Three hundred eighty-nine of the 455 patients with AHI data (85.5%) had greater than 50% reduction and AHIs of fewer than 20 events/h after MMA (surgical success); 366 of 455 (80.4%), fewer than 15 events/h; 290 of 455 (63.7%), fewer than 10 events/h; and 175 of 455 (38.5%), fewer than 5 events/h (OSA surgical cure). Similarly, among the 68 patients with RDI data, 90% experienced improvements in the RDI of at least −10 events/h; 75%, at least −18 events/h; 50%, at least −39 events/h; 25%, at least −71 events/h; and 10%, exceeding −86 events/h. Forty-four of 68 patients with RDI data (64.7%) had a greater than 50% reduction and an RDI of fewer than 20 events/h after MMA (surgical success); 41 of 68 (60.3%), fewer than 15 events/h; 27 of 68 (39.7%), fewer than 10 events/h; and 13 of 68 (19.1%), fewer than 5 events/h (OSA surgical cure).

On multivariate analysis using a standard least squares–effect leverage model with backward elimination, the following baseline preoperative factors were found to be statistically significantly associated with OSA surgical cure by AHI: age ($P = .03$), preoperative AHI ($P < .001$), and preoperative Spo_2 nadir ($P = .04$). Patients with surgical cure were characterized as younger with a lower preoperative AHI and higher Spo_2 nadir compared with patients without a surgical cure (eTable 2 in the Supplement). The factor associated with OSA surgical success by AHI was preoperative AHI ($P = .02$); patients who achieved surgical success were characterized by lower preoperative AHI compared with patients who did not achieve surgical success (eTable 3 in the Supplement). Preoperative AHI was the single factor consistently associated with outcome and correlated with other measures of OSA disease severity (RDI, Spo_2 nadir,

Table 1. Pre-MMA and Post-MMA Characteristics

Characteristic	No. of Patients[a]	Pre-MMA	Post-MMA	*P* Value
Age, mean (SD), y	345	45.3 (10.0)	NA	NA
Male, %	282/339	83.2	NA	NA
Prior OSA surgery, %[b]	197/268	73.5	NA	NA
BMI, mean (SD)[c]	82	33.8 (9.7)	32.8 (9.4)	.52
Polysomnography				
AHI, mean (SD), events/h	455	57.2 (25.4)	9.5 (10.4)	<.001
AHI ≥30 events/h, %	394/455	86.6	5.7	<.001
AHI ≥20 events/h, %	439/455	96.5	13.2	<.001
RDI, mean (SD), desaturations/h	68	65.8 (31.9)	21.4 (21.7)	<.001
RDI ≥30 desaturations/h, %	62/68	91.2	26.5	<.001
RDI ≥20 desaturations/h, %	66/68	97.1	32.4	<.001
SpO_2, mean (SD), nadir, %[c]	186	70.1 (15.6)	87.0 (5.2)	<.001
Cephalometrics, mean (SD)				
SNA, degrees	107	79.9 (3.9)	84.7 (3.9)	<.001
SNB, degrees	107	75.1 (4.9)	80.9 (4.4)	<.001
PAS, mm	124	5.5 (2.8)	11.5 (3.4)	<.001
Epworth Sleepiness Scale score, mean (SD)[d]	113	13.5 (5.2)	3.2 (3.2)	<.001
Maxillary advancement, mean (SD), mm	215	NA	9.0 (1.6)	NA
Mandibular advancement, mean (SD), mm	234	NA	10.2 (2.3)	NA
Surgical cure, %[e]				
AHI surgical cure	175/455	NA	38.5	NA
RDI surgical cure	13/68	NA	19.1	NA
Surgical success, %[f]				
AHI surgical success	389/455	NA	85.5	NA
RDI surgical success	46/68	NA	67.6	NA

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); MMA, maxillomandibular advancement; NA, not applicable; OSA, obstructive sleep apnea; PAS, posterior airway space; RDI, respiratory disturbance index; SpO_2, pulse oximeter oxygen saturation level; SNA, sella-nasion point A; SNB, sella-nasion point B.

[a] Indicates the total number of patients for whom each variable was reported. For characteristics reported as percentage of patients, numbers indicate number of patients/number with data available.

[b] Includes tonsillectomy, uvulopalatopharyngoplasty, septoplasty, turbinate reduction, and partial glossectomy.

[c] Only patients with pre-MMA and post-MMA measurements are included.

[d] Scores range from 0 to 24, with higher scores indicating increased mean sleep propensity.

[e] Defined as a post-MMA AHI or RDI of fewer than 5 events/h.

[f] Defined as the percentage of patients with a post-MMA AHI or RDI of fewer than 20 events/h and a post-MMA reduction in the AHI or RDI of at least 50%.

Epworth Sleepiness Scale score, and BMI). Other preoperative factors (including female sex, higher preoperative BMI and Epworth Sleepiness Scale score, and lower preoperative SpO_2 nadir) were shown to have an association with outcome effect size only on univariate analyses.

The individual patient data were divided into the following 4 cohorts with respect to preoperative AHI: fewer than 30 events/h, 30 to fewer than 60 events/h, 60 to fewer than 90 events/h, and 90 or more events/h. Pearson χ^2 analysis showed a greater likelihood of surgical success ($P = .009$) and surgical cure ($P < .001$) for patients in the lower preoperative AHI cohorts (**Table 2**). Patients with a higher preoperative AHI are less likely to achieve the constructs of surgical success and cure. Preoperative mean BMI was significantly higher among patients in the higher preoperative AHI cohorts at 27.2 (1.5) for fewer than 30 events/h, 29.9 (7.0) for 30 to fewer than 60 events/h; 32.8 (7.1) for 60 to fewer than 90 events/h; and 38.8 (8.2) for 90 or more events/h ($P < .001$, Pearson χ^2 test). Preoperative SpO_2 nadir was lower among patients in the higher preoperative AHI cohorts ($P < .001$, Pearson χ^2 test). Cohorts with a higher preoperative AHI experienced a greater degree of improvement to the SpO_2 nadir outcome ($P = .005$, Pearson χ^2 test). We otherwise found no significant differences in any of the other factors among the preoperative AHI cohorts.

We found a direct linear correlation between preoperative AHI and ΔAHI ($R^2 = 0.84$; $P < .001$). Patients with more severe preoperative AHI values experienced the greatest magnitude of reduction in the postoperative AHI values compared with patients with lower preoperative AHI values (**Figure 3**). Similar results were obtained for RDI data ($R^2 = 0.60$; $P < .001$).

Genial tubercle advancement was performed in 174 of 518 patients (33.6%) at the time of MMA surgery; on multivariate analysis using the standard least squares–effect leverage model, the percentage of change of the sella-nasion point A angle was the only factor that had a statistically significant difference between the groups (mean [SD] MMA + genial tubercle advancement, 7.1% [0.4%]; MMA, 4.1% [0.5%]; $P = .02$). An increase in the sella-nasion point A angle is known to be a direct surgical consequence of genial tubercle advancement; no other apparent differences in outcomes existed between the MMA–genial tubercle advancement vs MMA groups.

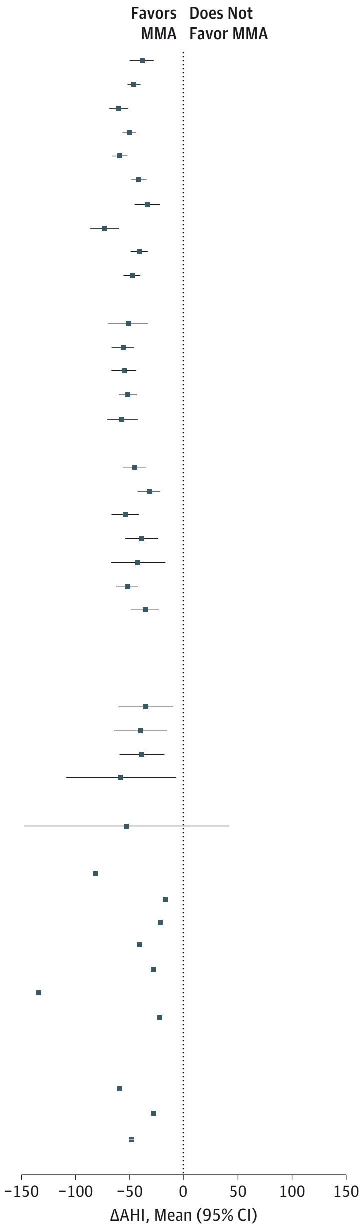
Discussion

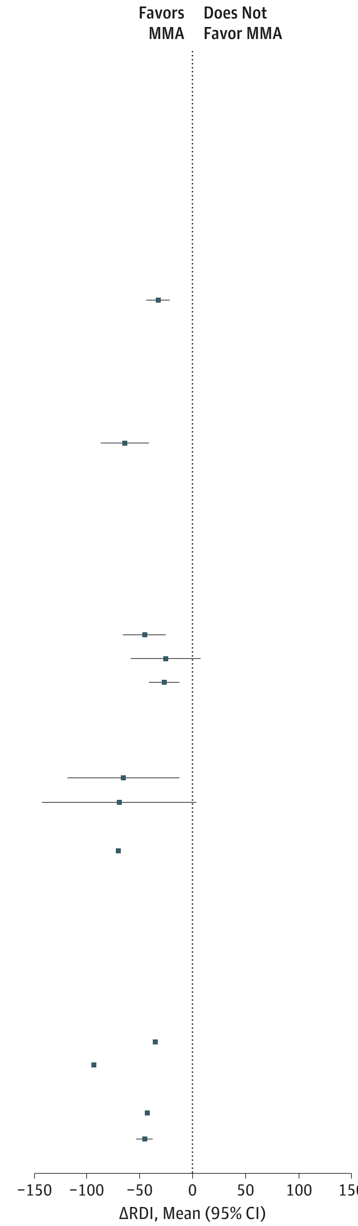
Maxillomandibular advancement is a highly effective OSA surgical treatment that is associated with substantial improvements to AHI and RDI. Among 518 patients, 512 (98.8%) experienced improvement in outcomes (2 patients had no reported change from preoperative to postoperative AHI and RDI, and 4 patients had worse postoperative polysomnographic outcomes).[6,7,25-27] The mean AHI improved from a mean (SD) preoperative value of 57.2 (25.4) to a postoperative value of 9.5 (10.4). Similarly, the mean (SD) RDI improved from a preop-

Figure 2. Forest Plot of the Meta-analysis of Maxillomandibular Advancement (MMA) Studies With Individual Patient Data

Source (No. of Patients)	ΔAHI, Mean (95% CI)	ΔRDI, Mean (95% CI)
Serra et al,[26] 2012 (n = 35)	−37.9 (22.1)	
Brevi et al,[31] 2011 (n = 33)	−45.1 (11.7)	
Riley et al,[10] 1990 (n = 30)	−59.2 (17.1)	
Vicini et al,[4] 2010 (n = 25)	−49.6 (12.1)	
Riley et al,[11] 1989 (n = 25)	−58.3 (13.6)	
Jalbert et al,[32] 2012 (n = 25)	−40.8 (13.3)	
Varghese et al,[33] 2012 (n = 24)	−33.1 (22.4)	
Li et al,[9] 2000 (n = 23)	−72.4 (26.1)	
Hochban et al,[28,35] 1994; 1997 (n = 23)	−40.3 (15.0)	
Ronchi et al,[36] 2010 (n = 22)	−47.0 (14.5)	
Jones et al,[7] 2010 (n = 20)		−32.0 (10.6)
Fairburn et al,[25] 2007 (n = 20)	−50.7 (36.3)	
Li et al,[37] 2000 (n = 19)	−55.5 (19.5)	
Wagner et al,[38] 2000 (n = 17)	−54.4 (21.4)	
Ronchi et al,[39] 2013 (n = 15)	−50.6 (14.9)	
Riley et al,[12] 1990 (n = 15)	−55.9 (26.9)	
Dattilo and Drooger,[13] 2004 (n = 15)		−63.6 (21.3)
Hochban et al,[28] 1997 (n = 14)	−44.2 (19.6)	
Lin et al,[30] 2011 (n = 12)	−31.2 (18.8)	
Goh and Lim,[27] 2003 (n = 11)	−53.2 (22.1)	
Schnedel et al,[40] 2014 (n = 10)	−37.7 (27.1)	
Waite et al,[6] 1989 (n = 9)	−41.4 (44.1)	
Riley et al,[14] 1986 (n = 9)	−51.1 (17.6)	
Li et al,[29] 2010 (n = 8)	−34.8 (21.5)	
Arcuri et al,[15] 2011 (n = 8)		−45.0 (17.3)
Hendler et al,[16] 2001 (n = 7)		−25.2 (27.0)
Abramson et al,[17] 2011 (n = 7)		−26.3 (12.0)
Jaspers et al,[41] 2013 (n = 6)	−34.2 (39.2)	
de Lange et al,[42] 2004 (n = 6)	−39.0 (38.3)	
Hoekema et al,[43] 2006 (n = 4)	−37.8 (25.9)	
Barrera,[52] 2013 (n = 4)	−57.3 (64.1)	−65.0 (33.2)
Lee et al,[18] 1999 (n = 3)		−69.0 (34.0)
Yu et al,[44] 2009 (n = 2)	−52.1 (29.8)	
VanSickels and Wallender,[19] 2012 (n = 1)		−70.0
Sencimen et al,[45] 2012 (n = 1)	−80.6	
Schendel et al,[46] 2011 (n = 1)	−16.0	
Matsuo et al,[47] 2009 (n = 1)	−20.6	
Johnson and Boyd,[20] 2002 (n = 1)	−40.1	
El et al,[48] 2011 (n = 1)	−27.1	
Doff et al,[49] 2013 (n = 1)	−133.0	
Corcoran et al,[50] 2009 (n = 1)	−21.0	
Conley and Legan,[21] 2006 (n = 1)		−34.8
Colin,[22] 2004 (n = 1)		−93.0
Barrera et al,[51] 2007 (n = 1)	−57.9	
Banhiran et al,[53] 2007 (n = 1)	−26.9	−42.4
Overall	**−47.8 (4.7)**	**−44.4 (8.0)**

ΔAHI: Cochran Q_{35} = 90.42; $P < .001$; I^2 = 61.3% (moderate)
ΔRDI: Cochran Q_{10} = 17.04; $P < .001$; I^2 = 41.3% (low)





Differences in the apnea-hypopnea index (ΔAHI) and respiratory disturbance index (ΔRDI) outcomes are shown as means (data markers) with 95% CIs (error bars) to include 2 SEs from the mean. The references are ranked in descending order of sample size. Results demonstrate a symmetric inverted funnel shape and reflect a data set for which publication bias has been minimized.

erative value of 65.8 (31.9) to a postoperative value of 21.4 (21.7). The mean (SE) reduction for AHI and RDI outcomes was 80.1% (1.8%) and 64.6% (4.0%), respectively. We also found significant improvements in the postoperative Spo_2 nadir and Epworth Sleepiness Scale score outcomes.

The overall surgical success and cure rates for MMA as a treatment for OSA were 85.5% and 38.5%, respectively, for AHI data and 64.7% and 19.1%, respectively, for RDI data. Patients with higher preoperative OSA severity were less likely to achieve the defined constructs of surgical success and OSA cure. For example, the cure rate was only 20% among patients with a preoperative AHI of 90 or more events/h but was as high as 56% for patients with preoperative AHI of fewer than 30 events/h. However, patients with higher preoperative OSA severity were most likely to experience the greatest magnitude of improvement. The mean ΔAHI of the cohort with a preoperative AHI of fewer than 30 events/h was −14.1 (11.6) events/h compared with a mean ΔAHI of −94.5 (23.5) events/h for the cohort with a preoperative AHI of greater than 90 events/h.

Our results show that patients with a high residual RDI and AHI after failure of other surgical procedures for sleep apnea

Table 2. Rates of Surgical Success or Cure by Preoperative AHI Severity

Surgical Success[a]	Preoperative AHI Cohort, Events/h <30 (n = 61)	30 to <60 (n = 192)	60 to <90 (n = 161)	≥90 (n = 41)
AHI cure, No. (%)	34 (55.7)[b]	88 (45.8)[b]	45 (28.0)	8 (19.5)
AHI Success-10, No. (%)	47 (77.0)[b]	140 (72.9)[b]	77 (47.8)	24 (58.5)
AHI Success-15, No. (%)	51 (83.6)[c]	169 (88.0)[c]	117 (72.7)	29 (70.7)
AHI Success-20, No. (%)	51 (83.6)[d]	176 (91.7)[d]	130 (80.7)[d]	31 (75.6)

Abbreviation: AHI, Apnea-Hypopnea Index.

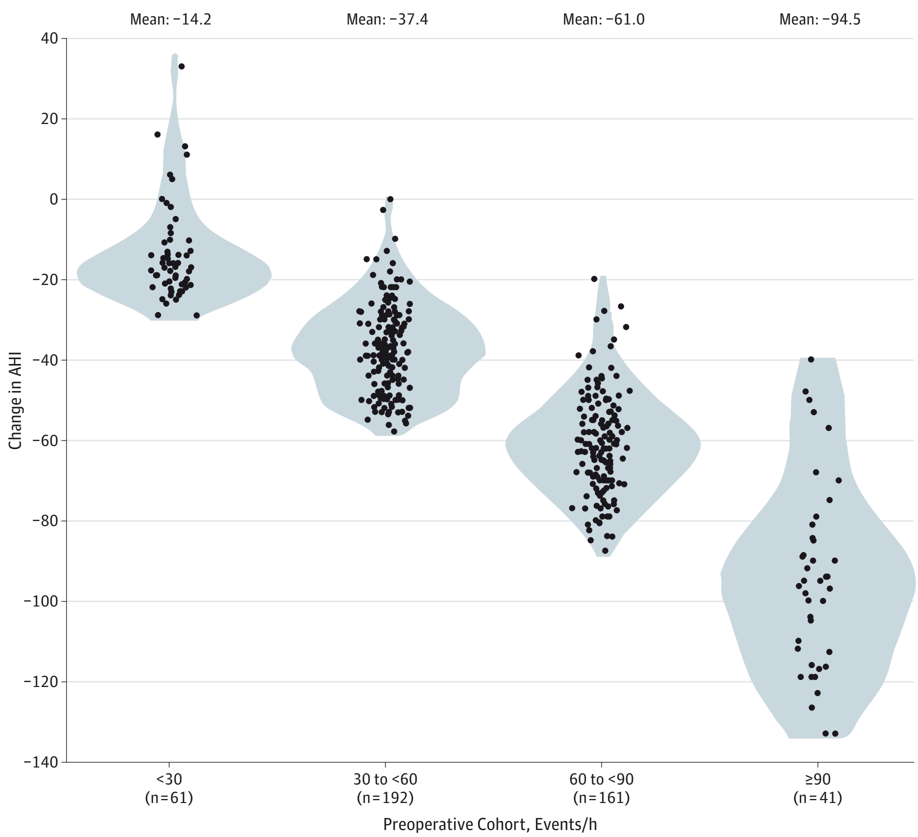
[a] Surgical success is defined as a greater than 50% reduction of AHI to fewer than 20 events/h after maxillomandibular advancement (MMA) (AHI Success-20); AHI Success-15, AHI levels of fewer than 15 events/h after MMA; AHI Success-10, AHI levels of fewer than 10 events/h after MMA; and AHI cure, AHI levels of fewer than 5 events/h after MMA.

[b] $P < .001$, by Pearson χ^2 analysis.

[c] $P = .009$, by Pearson χ^2 analysis.

[d] $P = .003$, by Pearson χ^2 analysis.

Figure 3. Change in Apnea-Hypopnea Index (ΔAHI) by Preoperative AHI Severity



Four hundred fifty-five patients had AHI data. Mean differences are displayed for each preoperative AHI cohort. A direct linear correlation between preoperative AHI and ΔAHI is seen (R^2 = 0.84; $P < .001$) (ΔAHI = 3.76 − [0.90 × preoperative AHI]). Patients with more severe preoperative AHI values experienced the greatest magnitude of reduction in the postoperative AHI. The mean ΔAHI of the preoperative AHI cohort with fewer than 30 events/h was −14.1 (11.6) events/h compared with a mean ΔAHI of −94.5 (23.5) events/h for the preoperative AHI cohort with 60 to fewer than 90 events/h.

are highly likely to benefit from MMA. However, although these patients with the most severe and refractory OSA conditions experience a substantial improvement with respect to postoperative AHI and RDI, the current definitions of surgical success and OSA cure[54,55] may not sufficiently represent the benefit achieved from surgery. Indeed, some authors[56] have argued that surgical intervention for patients with sleep apnea is reserved only for those who cannot or will not accept continuous positive airway pressure therapy; as such, the goal of surgery is not to cure a condition that is obviously incurable but rather to offer a treatment that will help abate symptoms and minimize ongoing multisystem damage.

Surgical success is a vague and controversial entity that is not based on objective systematic data collection.[57] Neuropsychological OSA symptoms[58] and associated cardiovascular sequela[59] may still be present with an AHI of at least 5 events/h despite a 50% reduction in AHI with treatment. Patients may complain of persistent daytime fatigue, tiredness, difficulty concentrating, and memory deficits if the OSA is not completely treated.[58] Patients with residual OSA may be at risk for cardiovascular disease, heart failure, hypertension, and reduced insulin sensitivity.[57] The matrix of an AHI of 5 events/h is old but was suggested based on polysomnographic recording of 200 healthy individuals in 1976.[60] Many authors[5,54,56,57] agree that polysomnographic measures alone are insufficient to assess the severity of OSA and response to treatment and that better matrices based on objective validated testing should be developed. The area of reporting outcomes for OSA clearly requires further investigation as demonstrated by the inadequacies of these constructs in this article.

Holty and Guilleminault[3] performed a prior meta-analysis of 22 studies reporting AHI outcomes describing 627 adults undergoing MMA to treat OSA. They report a significant reduction in the mean (SD) AHI (63.9 [26.7] vs 9.5 [10.7] events/h; $P < .001$) at a mean follow-up of 5.3 months after MMA. The percentages of participants with a reduction greater than 50% and an AHI of fewer than 20, 15, 10, and 5 events/h after MMA were 86.0%, 77.6%, 63.4%, and 43.2%, respectively. Clinical factors associated with surgical success in the analysis by Holty and Guilleminault[3] included age, preoperative BMI, and preoperative AHI. The present meta-analysis differs in that it excludes studies that do not provide individual patient data and includes studies published since 2010. Our results are similar, with a few notable differences. In the prior study, patients with higher preoperative RDI and AHI were found to have a lower chance for surgical success and cure (which we corroborate herein) but with the implication that patients with high severity of disease are worse candidates for MMA surgery. The results of the present meta-analysis qualify the prior finding by demonstrating that patients with higher preoperative RDI and AHI experienced the greatest magnitude of improvement, although they did in fact have the lowest chance of achieving the end points of surgical success and cure.[3,61,62]

One important limitation of this meta-analysis is that we only included studies that reported individual patient data; as such, we may have introduced selection bias by systematically excluding studies with very large sample sizes. The following are some notable studies that did not meet the inclusion criteria owing to a lack of reported individual patient data: Riley et al[61] (n = 306), Prinsell[63] (n = 50), Li et al[8] (n = 175), and Bettega et al[64] (n = 51). Results of these studies (from centers with larger sample sizes and experience) reported higher levels of surgical success than reported in this meta-analysis. For example, Li et al[8] reported a 95% overall success rate with a mean change in RDI from 69.6 (27.9) to 7.7 (5.3) events/h. Prinsell[63] reported a 100% success rate with a mean change in AHI from 59.2 (28.4) to 4.7 (5.9) events/h. We show a moderate level of heterogeneity for studies included in the present meta-analysis, which reflects a broad range of experiences among different surgeons and populations with respect to use of the surgical technique. However, we were also limited by the heterogeneity in that the terms of the variables reported were inconsistent between the studies.

Maxillomandibular advancement is a highly invasive surgical procedure with risks that include pain, swelling, malocclusion, poor cosmetic result, facial numbness, tingling, jaw stiffness, and postsurgical relapse of advancement. Minor hemorrhage, local infection, and extrusion of hardware have also been reported.[1,3,28,62,65] Facial paresthesia due to stretching or injury to the inferior alveolar nerve is universally common (100% of patients) but has been reported to resolve in 85% to 90% of patients by 6 to 12 postoperative months.[8,66] Patient perception of facial aesthetics has been generally positive after MMA; modified MMA techniques, such as using counterclockwise rotation and presurgical or postsurgical orthodontics, have been developed to prevent maxillary protrusion and to improve facial aesthetics.[9] The mean (SD) duration of surgery (from tracheostomy and intermaxillary fixation to the final imaging in the operating room) according to 1 study was 6.0 (1.0) hours.[4] After undergoing MMA, patients require a mean of 3.5 days of hospitalization. Most patients are able to return to their regular functional status within 2 to 10 weeks after surgery.[63] Major complications are rare (approximately 1%) and are associated with being older and having a preoperative medical comorbidity.[3] Because many patients with OSA undergoing MMA are obese (mean BMI, 30.2) and have compromised airways, careful postoperative care is warranted, including postoperative evaluation by nasopharyngolaryngoscopy.[67] No deaths attributable to or related to MMA were identified in the literature search for this meta-analysis; however, the US surgical community is aware of 2 or 3 deaths that occurred during or immediately after MMA in the past 5 years (C.G., email communication, January 5, 2015).

Additional issues that are not addressed in this meta-analysis are the effect of ethnicity on the surgical approaches[27] and the amount of minimum advancement (particularly at the level of the maxilla) that is needed to achieve long-term improvement. Surgery performed on Far Eastern Asian patients (especially Asian women) requires aesthetic concerns that are different than those for white patients, and specific modifications of MMA have been developed.[29,30] Additional experience with the use of advancement measurements predefined by standardized imaging and virtual surgical planning may help to address some of these issues.[52] In addition, longer follow-up is needed because recurrences of OSA have been noted at 10 to 15 years after MMA surgery based on the experiences of one of us (C.G.). One of the limitations of MMA (observed clinically in many of the recurrences) is good long-term gain in anteroposterior direction but limited gain in the lateral dimension of the pharyngeal airway. Last, additional studies reporting outcomes in morbidly obese patients are necessary because currently only 33 morbidly obese patients have been identified in this and a recent meta-analysis[68] on the topic.

Conclusions

Maxillomandibular advancement is a highly effective treatment for OSA. Preoperative severity of OSA is the most reliable predictor of outcome effect size and the likelihood of surgical success and cure. Those patients with the most severe measures of OSA tend to benefit to the greatest degree. Patients with less severe measures of OSA experience a smaller magnitude of change in AHI or RDI postoperatively, but they have the highest chance of achieving surgical success and cure. Patients with high residual RDI and AHI scores (despite prior treatments by means of uvulopalatopharyngoplasty, partial glossectomy, and/or nasal surgery) are highly likely to benefit from management of OSA by means of MMA. Future studies will provide additional insights to help optimize patient selection for this treatment option.

ARTICLE INFORMATION

Submitted for Publication: June 6, 2015; final revision received August 21, 2015; accepted September 23, 2015.

Published Online: November 25, 2015. doi:10.1001/jamaoto.2015.2678.

Author Affiliations: Department of Head and Neck Surgery, David Geffen School of Medicine at UCLA (University of California, Los Angeles) (Zaghi); Pulmonary, Critical Care and Sleep Medicine Section, Pulmonary Division, Department of Medicine, Veterans Affairs Palo Health Care System, Stanford University, Palo Alto, California (Holty); Department of Otorhinolaryngology, Sleep Medicine Centre, Hospital CUF Porto, Porto, Portugal (Certal); Centre for Research in Health Technologies and Information Systems, University of Porto, Porto, Portugal (Certal); Department of Otorhinolaryngology, Hospital Bernardino Rivadavia, Buenos Aires, Argentina (Abdullatif); Sleep Medicine Division, Department of Psychiatry and Behavioral Sciences, Stanford Hospital and Clinics, Redwood City, California (Guilleminault, Camacho); Sleep Surgery Division, Department of Otolaryngology–Head and Neck Surgery, Stanford Hospital and Clinics, Redwood City, California (Powell, Riley); Division of Sleep Surgery and Medicine, Department of Otolaryngology–Head and Neck Surgery, Tripler Army Medical Center, Honolulu, Hawaii (Camacho).

Author Contributions: Dr Zaghi had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Study concept and design: Zaghi, Holty, Certal, Powell, Riley, Camacho.
Acquisition, analysis, or interpretation of data: Zaghi, Holty, Abdullatif, Guilleminault, Camacho.
Drafting of the manuscript: Zaghi, Abdullatif, Guilleminault, Camacho.
Critical revision of the manuscript for important intellectual content: Holty, Certal, Abdullatif, Guilleminault, Powell, Riley, Camacho.
Statistical analysis: Zaghi, Holty, Camacho.
Administrative, technical, or material support: Abdullatif, Powell.
Study supervision: Holty, Certal, Guilleminault, Powell, Riley, Camacho.

Conflict of Interest Disclosures: None reported.

Disclaimer: The views herein are the private views of the authors and do not reflect the official views of the US Department of the Army or the US Department of Defense.

Previous Presentation: This article was presented as a poster at the Sixth International Surgery, Sleep and Breathing Symposium of the International Sleep Surgery Society; October 24-25, 2014; Detroit, Michigan.

REFERENCES

1. Li KK. Surgical management of obstructive sleep apnea. *Clin Chest Med*. 2003;24(2):365-370.

2. Gokce SM, Gorgulu S, Gokce HS, Bengi AO, Karacayli U, Ors F. Evaluation of pharyngeal airway space changes after bimaxillary orthognathic surgery with a 3-dimensional simulation and modeling program. *Am J Orthod Dentofacial Orthop*. 2014;146(4):477-492.

3. Holty JE, Guilleminault C. Maxillomandibular advancement for the treatment of obstructive sleep apnea: a systematic review and meta-analysis. *Sleep Med Rev*. 2010;14(5):287-297.

4. Vicini C, Dallan I, Campanini A, et al. Surgery vs ventilation in adult severe obstructive sleep apnea syndrome. *Am J Otolaryngol*. 2010;31(1):14-20.

5. Epstein LJ, Kristo D, Strollo PJ Jr, et al; Adult Obstructive Sleep Apnea Task Force of the American Academy of Sleep Medicine. Clinical guideline for the evaluation, management and long-term care of obstructive sleep apnea in adults. *J Clin Sleep Med*. 2009;5(3):263-276.

6. Waite PD, Wooten V, Lachner J, Guyette RF. Maxillomandibular advancement surgery in 23 patients with obstructive sleep apnea syndrome. *J Oral Maxillofac Surg*. 1989;47(12):1256-1261.

7. Jones R, Badlani J, Jones C. Maxillary, mandibular and chin advancement surgery for the treatment of obstructive sleep apnoea. *Aust Dent J*. 2010;55(3):314-321.

8. Li KK, Powell NB, Riley RW, Troell RJ, Guilleminault C. Long-term results of maxillomandibular advancement surgery. *Sleep Breath*. 2000;4(3):137-140.

9. Li KK, Riley RW, Powell NB, Guilleminault C. Maxillomandibular advancement for persistent obstructive sleep apnea after phase I surgery in patients without maxillomandibular deficiency. *Laryngoscope*. 2000;110(10, pt 1):1684-1688.

10. Riley RW, Powell NB, Guilleminault C. Maxillofacial surgery and nasal CPAP: a comparison of treatment for obstructive sleep apnea syndrome. *Chest*. 1990;98(6):1421-1425.

11. Riley RW, Powell NB, Guilleminault C. Maxillofacial surgery and obstructive sleep apnea: a review of 80 patients. *Otolaryngol Head Neck Surg*. 1989;101(3):353-361.

12. Riley RW, Powell NB, Guilleminault C. Maxillary, mandibular, and hyoid advancement for treatment of obstructive sleep apnea: a review of 40 patients. *J Oral Maxillofac Surg*. 1990;48(1):20-26.

13. Dattilo DJ, Drooger SA. Outcome assessment of patients undergoing maxillofacial procedures for the treatment of sleep apnea: comparison of subjective and objective results. *J Oral Maxillofac Surg*. 2004;62(2):164-168.

14. Riley RW, Powell NB, Guilleminault C, Nino-Murcia G. Maxillary, mandibular, and hyoid advancement: an alternative to tracheostomy in obstructive sleep apnea syndrome. *Otolaryngol Head Neck Surg*. 1986;94(5):584-588.

15. Arcuri F, Brucoli M, Benech R, Giarda M, Benech A. Maxillomandibular advancement in obstructive sleep apnea syndrome: a surgical model to investigate reverse face lift. *J Craniofac Surg*. 2011;22(6):2148-2152.

16. Hendler BH, Costello BJ, Silverstein K, Yen D, Goldberg A. A protocol for uvulopalatopharyngoplasty, mortised genioplasty, and maxillomandibular advancement in patients with obstructive sleep apnea: an analysis of 40 cases. *J Oral Maxillofac Surg*. 2001;59(8):892-897.

17. Abramson Z, Susarla SM, Lawler M, Bouchard C, Troulis M, Kaban LB. Three-dimensional computed tomographic airway analysis of patients with obstructive sleep apnea treated by maxillomandibular advancement. *J Oral Maxillofac Surg*. 2011;69(3):677-686.

18. Lee NR, Givens CD Jr, Wilson J, Robins RB. Staged surgical treatment of obstructive sleep apnea syndrome: a review of 35 patients. *J Oral Maxillofac Surg*. 1999;57(4):382-385.

19. Van Sickels JE, Wallender A. Closure of anterior open bites with mandibular surgery: advantages and disadvantages of this approach. *Oral Maxillofac Surg*. 2012;16(4):361-367.

20. Johnson JD Jr, Boyd SB. Obstructive sleep apnea: a case report. *J Tenn Dent Assoc*. 2002;82(3):48-51.

21. Conley RS, Legan HL. Correction of severe obstructive sleep apnea with bimaxillary transverse distraction osteogenesis and maxillomandibular advancement. *Am J Orthod Dentofacial Orthop*. 2006;129(2):283-292.

22. Colin WB. Comprehensive reconstructive surgery for obstructive sleep apnea. *J Ky Med Assoc*. 2004;102(4):154-162.

23. Lau J, Ioannidis JP, Schmid CH. Quantitative synthesis in systematic reviews. *Ann Intern Med*. 1997;127(9):820-826.

24. Moher D, Liberati A, Tetzlaff J, Altman DG; PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62(10):1006-1012.

25. Fairburn SC, Waite PD, Vilos G, et al. Three-dimensional changes in upper airways of patients with obstructive sleep apnea following maxillomandibular advancement. *J Oral Maxillofac Surg*. 2007;65(1):6-12.

26. Serra MM, Greenburg D, Barnwell M, Fallah D, Keith K, Mysliwiec V. Maxillomandibular advancement as surgical treatment for obstructive sleep apnea in active duty military personnel: a retrospective cohort. *Mil Med*. 2012;177(11):1387-1392.

27. Goh YH, Lim KA. Modified maxillomandibular advancement for the treatment of obstructive sleep apnea: a preliminary report. *Laryngoscope*. 2003;113(9):1577-1582.

28. Hochban W, Conradt R, Brandenburg U, Heitmann J, Peter JH. Surgical maxillofacial treatment of obstructive sleep apnea. *Plast Reconstr Surg*. 1997;99(3):619-626.

29. Li Y, Yi B, Wang X, Li ZL, Liang C, Wang XX. Clinical study on modified maxillomandibular advancement for the treatment of obstructive sleep apnea syndrome [in Chinese]. *Beijing Da Xue Xue Bao*. 2010;42(5):570-574.

30. Lin CH, Liao YF, Chen NH, Lo LJ, Chen YR. Three-dimensional computed tomography in obstructive sleep apneics treated by maxillomandibular advancement. *Laryngoscope*. 2011;121(6):1336-1347.

31. Brevi BC, Toma L, Pau M, Sesenna E. Counterclockwise rotation of the occlusal plane in the treatment of obstructive sleep apnea syndrome. *J Oral Maxillofac Surg*. 2011;69(3):917-923.

32. Jalbert F, Lacassagne L, Bessard J, Dekeister C, Paoli JR, Tiberge M. Oral appliances or maxillomandibular advancement osteotomy for severe obstructive sleep apnoea in patients refusing CPAP [in French]. *Rev Stomatol Chir Maxillofac*. 2012;113(1):19-26.

33. Varghese R, Adams NG, Slocumb NL, Viozzi CF, Ramar K, Olson EJ. Maxillomandibular advancement in the management of obstructive sleep apnea. *Int J Otolaryngol*. 2012;2012:373025.

34. Li KK, Riley RW, Powell NB, Gervacio L, Troell RJ, Guilleminault C. Obstructive sleep apnea surgery: patient perspective and polysomnographic results. *Otolaryngol Head Neck Surg*. 2000;123(5):572-575.

35. Hochban W, Brandenburg U, Peter JH. Surgical treatment of obstructive sleep apnea by maxillomandibular advancement. *Sleep*. 1994;17(7):624-629.

36. Ronchi P, Novelli G, Colombo L, et al. Effectiveness of maxillo-mandibular advancement in obstructive sleep apnea patients with and without skeletal anomalies. *Int J Oral Maxillofac Surg*. 2010;39(6):541-547.

37. Li KK, Powell NB, Riley RW, Zonato A, Gervacio L, Guilleminault C. Morbidly obese patients with severe obstructive sleep apnea: is airway reconstructive surgery a viable treatment option? *Laryngoscope*. 2000;110(6):982-987.

38. Wagner I, Coiffier T, Sequert C, Lachiver X, Fleury B, Chabolle F. Surgical treatment of severe sleep apnea syndrome by maxillomandibular advancing or mental transposition [in French]. *Ann Otolaryngol Chir Cervicofac*. 2000;117(3):137-146.

39. Ronchi P, Cinquini V, Ambrosoli A, Caprioglio A. Maxillomandibular advancement in obstructive sleep apnea syndrome patients: a retrospective study on the sagittal cephalometric variables. *J Oral Maxillofac Res*. 2013;4(2):e5.

40. Schendel SA, Broujerdi JA, Jacobson RL. Three-dimensional upper-airway changes with maxillomandibular advancement for obstructive sleep apnea treatment. *Am J Orthod Dentofacial Orthop*. 2014;146(3):385-393.

41. Jaspers GW, Booij A, de Graaf J, de Lange J. Long-term results of maxillomandibular advancement surgery in patients with obstructive sleep apnoea syndrome. *Br J Oral Maxillofac Surg*. 2013;51(3):e37-e39.

42. de Lange J, de Graaf J, Veldhuijzen van Zanten L, Waalkens HA. Treatment of snoring and sleep apnea: maxillo-mandibular advancement osteotomy [in Dutch]. *Ned Tijdschr Tandheelkd*. 2004;111(7):287-290.

43. Hoekema A, de Lange J, Stegenga B, de Bont LG. Oral appliances and maxillomandibular advancement surgery: an alternative treatment protocol for the obstructive sleep apnea-hypopnea syndrome. *J Oral Maxillofac Surg*. 2006;64(6):886-891.

44. Yu CC, Hsiao HD, Lee LC, et al. Computational fluid dynamic study on obstructive sleep apnea syndrome treated with maxillomandibular advancement. *J Craniofac Surg*. 2009;20(2):426-430.

45. Sencimen M, Bayar GR, Akcam T, et al. Management of obstructive sleep apnea by maxillomandibular advancement surgery in an edentulous patient. *J Craniofac Surg*. 2012;23(6):e582-e585.

46. Schendel S, Powell N, Jacobson R. Maxillary, mandibular, and chin advancement: treatment planning based on airway anatomy in obstructive sleep apnea. *J Oral Maxillofac Surg*. 2011;69(3):663-676.

47. Matsuo A, Nakai T, Toyoda J, Takahashi H, Suzuki I, Chiba H. Good esthetic results after modified maxillomandibular advancement for obstructive sleep apnea syndrome. *Sleep Biol Rhythms*. 2009;7(1):3-10.

48. El AS, El H, Palomo JM, Baur DA. A 3-dimensional airway analysis of an obstructive sleep apnea surgical correction with cone beam computed tomography. *J Oral Maxillofac Surg*. 2011;69(9):2424-2436.

49. Doff MH, Jansma J, Schepers RH, Hoekema A. Maxillomandibular advancement surgery as alternative to continuous positive airway pressure in morbidly severe obstructive sleep apnea: a case report. *Cranio*. 2013;31(4):246-251.

50. Corcoran S, Mysliwiec V, Niven AS, Fallah D. Development of central sleep apnea after maxillofacial surgery for obstructive sleep apnea. *J Clin Sleep Med*. 2009;5(2):151-153.

51. Barrera JE, Powell NB, Riley RW. Facial skeletal surgery in the management of adult obstructive sleep apnea syndrome. *Clin Plast Surg*. 2007;34(3):565-573.

52. Barrera JE. Virtual surgical planning improves surgical outcome measures in obstructive sleep apnea surgery. *Laryngoscope*. 2014;124(5):1259-1266.

53. Banhiran W, Vachiramon A, Metheetrairut C, Chierakul N, Tubpentha Y. Maxillomandibular advancement (MMA) for the treatment of severe obstructive sleep apnea syndrome (OSAS): the first case report in Thailand. *Siriraj Med J*. 2007;59:369-372.

54. Kezirian EJ, Weaver EM, Criswell MA, de Vries N, Woodson BT, Piccirillo JF. Reporting results of obstructive sleep apnea syndrome surgery trials. *Otolaryngol Head Neck Surg*. 2011;144(4):496-499.

55. Sher AE, Schechtman KB, Piccirillo JF. The efficacy of surgical modifications of the upper airway in adults with obstructive sleep apnea syndrome. *Sleep*. 1996;19(2):156-177.

56. Friedman M, Wilson M. Re-redefining success in airway surgery for obstructive sleep apnea [comment]. *Sleep*. 2009;32(1):17.

57. Elshaug AG, Moss JR, Southcott AM, Hiller JE. Redefining success in airway surgery for obstructive sleep apnea: a meta analysis and synthesis of the evidence. *Sleep*. 2007;30(4):461-467.

58. Habukawa M, Uchimura N, Nose I, et al. Emotional states and quality of life in patients with obstructive sleep apnea. *Sleep Biol Rhythms*. 2005;3(3):99-105.

59. Becker HF, Jerrentrup A, Ploch T, et al. Effect of nasal continuous positive airway pressure treatment on blood pressure in patients with obstructive sleep apnea. *Circulation*. 2003;107(1):68-73.

60. Guilleminault C, Tilkian A, Dement WC. The sleep apnea syndromes. *Annu Rev Med*. 1976;27(1):465-484.

61. Riley RW, Powell NB, Guilleminault C. Obstructive sleep apnea syndrome: a surgical protocol for dynamic upper airway reconstruction. *J Oral Maxillofac Surg*. 1993;51(7):742-747.

62. Pirklbauer K, Russmueller G, Stiebellehner L, et al. Maxillomandibular advancement for treatment of obstructive sleep apnea syndrome: a systematic review. *J Oral Maxillofac Surg*. 2011;69(6):e165-e176.

63. Prinsell JR. Maxillomandibular advancement surgery in a site-specific treatment approach for obstructive sleep apnea in 50 consecutive patients. *Chest*. 1999;116(6):1519-1529.

64. Bettega G, Pépin JL, Veale D, Deschaux C, Raphaël B, Lévy P. Obstructive sleep apnea syndrome: fifty-one consecutive patients treated by maxillofacial surgery. *Am J Respir Crit Care Med*. 2000;162(2, pt 1):641-649.

65. Riley RW, Powell NB, Li KK, Troell RJ, Guilleminault C. Surgery and obstructive sleep apnea: long-term clinical outcomes. *Otolaryngol Head Neck Surg*. 2000;122(3):415-421.

66. Van Sickels JE, Hatch JP, Dolce C, Bays RA, Rugh JD. Effects of age, amount of advancement, and genioplasty on neurosensory disturbance after a bilateral sagittal split osteotomy. *J Oral Maxillofac Surg*. 2002;60(9):1012-1017.

67. Li KK, Riley RW, Powell NB, Zonato A. Fiberoptic nasopharyngolaryngoscopy for airway monitoring after obstructive sleep apnea surgery. *J Oral Maxillofac Surg*. 2000;58(12):1342-1345.

68. Camacho M, Certal V, Brietzke SE, Holty JEC, Guilleminault C, Capasso R. Tracheostomy as treatment for adult obstructive sleep apnea: a systematic review and meta-analysis. *Laryngoscope*. 2014;124(3):803-811.