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**Original article**

# Maxillomandibular Advancement for OSA: A 25-year perspective

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*Maxillomandibular advancement / Bimaxillary advancement / MMA / Sleep apnea / OSA / Sleep surgery*

**ABSTRACT – Objective:** *The aim of this study was to evaluate the result of maxillomandibular advancement (MMA) for the treatment of obstructive sleep apnea (OSA) by a single surgeon.* **Materials and Methods:** *Patients that underwent MMA for the treatment of OSA over a 25-year period were included in the study. Patients who initially presented for revision MMA surgery were excluded. Demographics (e.g., age, gender, pre- and post-MMA body mass index [BMI]), pre- and post-MMA cephalometrics (e.g., sella-nasion-point A angle [SNA], sella-nasion-point B angle [SNB], posterior airway space base of tongue [PAS]) and pre- and post-MMA sleep study metrics (e.g., respiratory disturbance index [RDI], lowest desaturation [$SpO_2$-nadir], oxygen desaturation index [ODI], total sleep time [TST], % TST Stage N3 sleep, % TST rapid eye movement [REM] sleep) were abstracted. MMA surgical success was defined as a ≥ 50% reduction in RDI (or ODI) and post-MMA RDI (or ODI) < 20 events/hour. MMA surgical cure was defined as a post-MMA RDI (or ODI) < 5 events/hour.* **Results:** *A total of 1010 patients underwent MMA for the treatment of OSA. The mean age was 39.6 ± 14.3 years, and the majority were male (77%). Nine hundred forty-one patients with complete pre- and postoperative PSG data were analyzed. The mean ODI and RDI improved from 32.6 ± 27.4 to 7.7 ± 15.5 and 39.1 ± 24.2 to 13.6 ± 14.6 events per hour, respectively. The overall surgical success and surgical cure based on ODI was 79.4% and 71.9%, respectively. The overall surgical success and surgical cure based on RDI was 73.1% and 20.7%, respectively. Stratified by preoperative RDI showed older age, greater BMI were associated with greater preoperative RDI. Bivariate predictors of greater RDI reduction include younger age, female gender, lower preoperative BMI, higher preoperative RDI, greater BMI reduction postoperatively and greater change in SNA and PAS. Bivariate predictors of surgical cure based on RDI (RDI < 5) include younger age, female gender, lower preoperative RDI, and greater change in SNA and PAS. Bivariate predictor of RDI success (RDI < 20) include younger age, female gender, lower preoperative BMI, lower preoperative RDI, greater BMI reduction, greater increase in SNA, SNB and PAS postoperatively. Comparison of the first 500 patients and the later 510 patients demonstrate patients undergoing MMA have become younger, having lower RDI while achieving a better surgical outcome. Linear multivariate associations of greater percentage RDI reduction include younger age, greater percent change of SNA, greater preoperative SNA, lower preoperative BMI and higher preoperative RDI.* **Conclusions:** *MMA is an effective treatment to improve OSA, but the result can vary. Patient selection based on favorable prognostic factors and maximizing the advancement distance can improve outcomes.*

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## 1. Introduction

Maxillomandibular advancement (MMA) has become a well-accepted treatment of obstructive sleep apnea (OSA) since the early reports over 40 years ago[3,10,30]. However, despite numerous published case series on MMA results, prognostic factors are not well-established due to limited sample size. To improve the understanding of the impact of MMA on OSA, meta-analyses of pooled MMA data have been conducted. Patients with younger age and weight, lower apnea hypopnea index (AHI), and a greater degree of maxillary advancement were predictive of increased surgical success based on analysis of 320 subjects[8]. In a follow-up analysis of 518 subjects, preoperative AHI of fewer than 60 events per hour was shown to be the factor most strongly associated with surgical cure (AHI < 5)[31]. The rates of surgical success (AHI < 20) and cure (AHI < 5) were 389 (85.5%) and 175 (38.5%), respectively, among 455 patients with AHI data[31]. However, among the 68 patients with respiratory disturbance index (RDI) data, the impact on OSA was less dramatic. The rate of success and cure were 44 (64.7%) and 13 (19.1%), respectively.

Over the past 25 years, the authors have extensively studied the relationship between the airway and the maxillofacial skeleton. The principles of maximizing skeletal advancement, maintaining proper facial balance and occlusion while minimizing complications have been established[11-29]. This study was undertaken to assess the outcome of MMA for the treatment of OSA by a single surgeon (KKL).

## 2. Materials and Methods

Patients undergoing MMA for the treatment of OSA performed by a single surgeon (KKL) between 1997 and 2021 were retrospectively analyzed from prospectively collected clinical data. Patients with previous MMA that presented for revision surgery were excluded. The study was approved by the Stanford University review board (protocol ID # 15494) and was in accordance of the Declaration of Helsinki.

### 2.1. OSA Assessments

All patients underwent in-lab type-1 monitored polysomnography evaluations pre- and post-MMA that were performed per American Academy of Sleep Medicine's guidelines[1]. The respiratory-disturbance index (RDI) was calculated as the number of apneas (≥ 90% reduction in thermistor flow for ≥ 10 seconds) plus hypopneas (≥ 30% reduction in nasal pressure amplitude accompanied by either a ≥ 3% pulse oximeter ($SpO_2$) reduction or electroencephalogram (EEG) arousal for ≥ 10 seconds) per hour of sleep. The oxygen desaturation index (ODI) was calculated as the number of ≥ 3% $SpO_2$ reductions from baseline per hour of sleep. Sleep apnea severity was defined as mild (5-14.9 events/hour), moderate (15-29.9 events/hour) or severe (≥ 30 events/hour).

### 2.2. Medical Record and Data Abstraction

Demographics (e.g., age, gender, pre- and post-MMA body mass index [BMI]), pre- and post-MMA cephalometrics (e.g., sella-nasion-point A angle [SNA], sella-nasion-point B angle [SNB], posterior airway space base of tongue [PAS]) and pre- and post-MMA sleep study metrics (e.g., RDI, $SpO_2$-nadir, ODI, total sleep time [TST], %TST Stage N3 sleep, %TST rapid eye movement [REM] sleep) were abstracted. MMA surgical success was defined as a ≥ 50% reduction in RDI (or ODI) and post-MMA RDI (or ODI) < 20 events/hour. MMA surgical cure was defined as a post-MMA RDI (or ODI) < 5 events/hour.

### 2.3. Analyses

All univariate and multivariate analyses were performed using Statistical Package for the Social Sciences version 22 for Windows (SPSS, Chicago, IL, USA). We compared categorical variables using a Fisher's exact test and continuous variables with a 2-tailed t-test (or a one-way analysis of variance [ANOVA] test as appropriate). The normality assumption for the ANOVA was assessed via the Kolmogorov-Smirnov test and a nonparametric test used for p-value calculations. Values are reported as mean ± standard deviation. A multivariate linear regression (dependent variable % reduction in RDI) was used to estimate the associations between baseline demographics, cephalometrics, and sleep study metrics, as well as changes in cephalometrics post-MMA, in relationship to improvements in sleep apnea metrics. We assessed each variable by stepwise backwards regression using a p-value cutoff ≤ 0.1. To ensure uniformity between covariate scaling, z-scores of these variables were generated (each variable divided by its standard deviation) resulting in all regression beta values having scaled

**Table 1.** Pre and Post-MMA Characteristics*.

| | Pre-MMA | Post-MMA | P-value |
|---|---|---|---|
| **Characteristics** | | | |
| Age (n=1010) | 39.6 ± 14.3 | NA | NA |
| Male Gender (%) (n=1010) | 77.0% | NA | NA |
| BMI (kg/m$^2$)¶ (n=908) | 27.7 ± 4.3 | 27.5 ± 4.3 | <0.001 |
| **Polysomography** | | | |
| RDI (events/hour) (n=941) | 39.1 ± 24.2 | 13.6 ± 14.6 | <0.001 |
| RDI ≥ 30/hr (%) (n=941) | 54.8% | 8.5% | <0.001 |
| RDI ≥ 20/hr (%) (n=941) | 77.1% | 17.2% | <0.001 |
| $SpO_2$ Nadir (%)‡ (n=922) | 83.4 ± 10.1% | 88.9 ± 6.4% | <0.001 |
| ODI (desaturations/hour) (n=306) | 32.6 ± 27.4 | 7.7 ± 15.5 | <0.001 |
| ODI ≥ 30/hr (%) (n=306) | 47.7% | 8.5% | <0.001 |
| ODI ≥ 20/hr (%) (n=306) | 55.9% | 11.1% | <0.001 |
| Sleep Stages† | 55.9% | 11.1% | <0.001 |
| Total Sleep Time (min) (n=306) | 363.9 ± 68.2 | 378.8 ± 67.5 | 0.002 |
| REM Sleep (%) (n=306) | 10.6 ± 5.3% | 16.9 ± 6.4% | <0.001 |
| Stage N3 Sleep (%) (n=306) | 3.4 ± 5.3% | 7.6 ± 7.7% | <0.001 |
| **Cephalometrics** | | | |
| SNA (degrees) (n=305) | 80.1 ± 3.1 | 81.5 ± 3.2 | <0.001 |
| SNB (degrees) (n=305) | 77.1 ± 3.8 | 78.4 ± 3.3 | <0.001 |
| PAS (mm) (n=305) | 5.4 ± 2.2 | 8.4 ± 2.5 | <0.001 |
| MP-H (mm) (n=305) | 25.0 ± 7.1 | 22.1 ± 7.0 | <0.001 |
| PNS-P (mm) (n= 305) | 45.1 ± 4.9 | 30.9 ± 3.7 | <0.001 |
| RDI Surgical Cure (%)# (n=941) | NA | 20.7% | NA |
| ODI Surgical Cure (%)# (n=306) | NA | 71.9% | NA |
| RDI Surgical Success (%)# (n=941) | NA | 73.1% | NA |
| ODI Surgical Success (%)# (n=306) | NA | 79.4% | NA |

** Plus-minus values are mean (or percent) ± standard deviation. Values in parenthesis are the number of patients evaluated. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), ODI (oxygen desaturation index), PAS (posterior airway space – base of tongue), PNS-P (distance of posterior nasal spine to the tip of the soft palate), RDI (respiratory disturbance index), REM (rapid eye movement), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), $SpO_2$ (pulse oxyhemoglobin saturation). † Reported as a percent of total sleep time. ‡ The $SpO_2$ nadir is the lowest oxyhemoglobin saturation measured during sleep. Only patients with both pre and post-MMA $SpO_2$ nadir are included. # Surgical cure defined an RDI (or ODI) < 5 events/hour post-MMA. Surgical success defined as the percent of subjects with an RDI (or ODI) < 20/hour and a ≥ 50% reduction in the RDI (or ODI) post-MMA. ¶ Only patients with both pre and post-MMA BMI are included.*

standardized units of the independent predictors. A two-tailed p-value <0.05 was considered statistically significant.

## 3. Results

A total of 1010 patients underwent MMA for the treatment of OSA. The mean age was 39.6 ± 14.3 years, and the majority were male (77%). Nine hundred forty-one patients with complete pre- and postoperative PSG data were analyzed. The mean ODI and RDI improved from 32.6 ± 27.4 to 7.7 ± 15.5 and 39.1 ± 24.2 to 13.6 ± 14.6 events per hour, respectively. The overall surgical success and surgical cure based on ODI was 79.4% and 71.9%, respectively. The overall surgical success and surgical cure based on RDI was 73.1% and 20.7%, respectively (Table 1).

Stratified by preoperative RDI showed older age, greater BMI were associated with greater preoperative RDI (Table 2). Bivariate predictors of greater RDI reduction include younger age, female gender, lower preoperative BMI, higher preoperative RDI, greater BMI reduction postoperatively and greater change in SNA and PAS (Table 3). Bivariate predictors of surgical cure based on RDI (RDI < 5) include younger age, female gender, lower preoperative RDI, and greater change in SNA and PAS (Table 4). Bivariate predictor of RDI success (RDI < 20 include younger age, female gender, lower preoperative BMI, lower preoperative RDI, greater BMI reduction, greater increase in SNA, SNB and PAS postoperatively (Table 5). Comparison of the first 500 patients and the later 510 patients demonstrate patients undergoing MMA have become younger, having lower RDI while achieving a better surgical outcome (Table 6).

Linear multivariate associations of greater percentage RDI reduction include younger age, greater percent change of SNA, greater preoperative SNA, lower preoperative BMI and higher preoperative RDI (Fig. 1).

## 4. Discussion

The results of this study demonstrate that patients with younger age, lower BMI, lower RDI and female gender achieve a better surgical outcome as measured by PSG parameters. Furthermore, a larger advancement distance (percentage increase of SNA and SNB) and a greater impact on airway size (larger increase in PAS) resulted in a greater reduction in RDI in achieving surgical success.

The application of MMA in treating OSA has evolved over the past 25 years[11-29]. MMA has changed from a last stage operation of the phased surgical protocol to a primary, single stage treat-

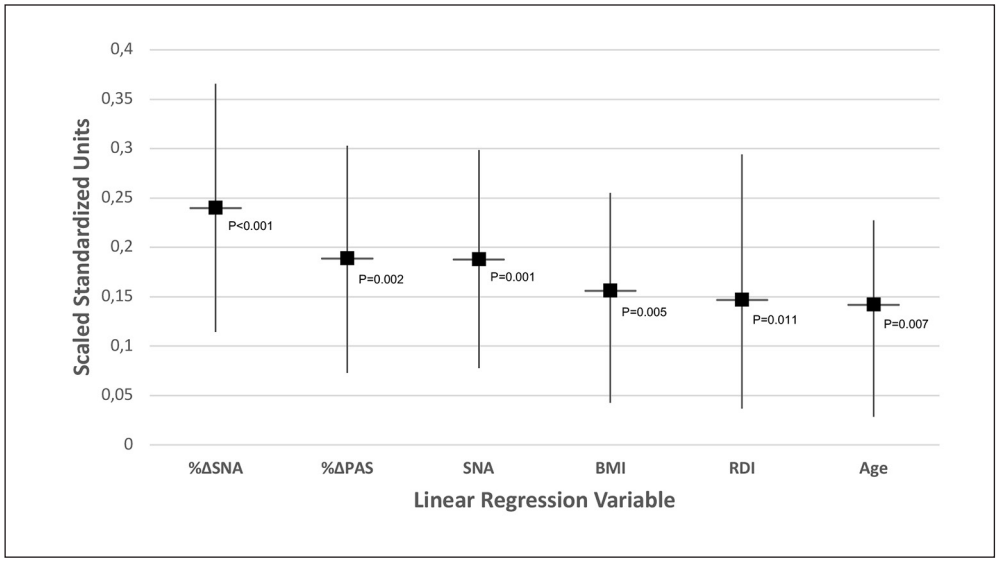


Figure 1

Multivariate Associations with Percent RDI Reduction Post MMA. Linear regression model with percent reduction in RDI (continuous variable) as dependent variable. All regression beta values are scaled standardized units of the independent predictors. Regression beta point estimate with 95% confidence intervals shown for each included variable. Initial model variables included age, pre-MMA BMI, male gender, pre-MMA RDI, pre-MMA SNA, pre-MMA SNB, pre-MMA PAS, post-MMA BMI percent change, post-MMA percent change SNA, post-MMA percent change SNB, and post-MMA percent change PAS. Final model developed utilizing backwards elimination (p-value < 0.10 cutoff). Predictors of increased percent RDI reduction post MMA in final model include greater positive percent change in SNA ($\beta = 0.240$, $p < 0.001$), greater positive percent change in PAS ($\beta = 0.189$, $p = 0.002$), greater pre-MMA SNA angle ($\beta = 0.188$, $p = 0.001$), lower pre-MMA BMI ($\beta = 0.154$, $p = 0.005$), greater pre-MMA RDI ($\beta = 0.147$, $p = 0.011$), and younger age ($\beta = 0.142$, $p = 0.007$). Model R2 is 0.201 (adjusted for number of predictors). Including various interaction terms (age*RDI, BMI*RDI, Male*RDI, SNA*RDI, SNB*RDI, PAS*RDI, Male*BMI, Age*Male) and/or polynomial variables (age2, BMI2, RDI2, RDI3) did not improve data fit and were not included in final model. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), PAS (posterior airway space –base of tongue), RDI (respiratory disturbance index), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), %ΔPAS (percent PAS reduction), and %ΔSNA (percent SNA reduction).

**Table 2.** Patient Characteristics Stratified by Pre-MMA RDI*.

| Characteristics | Pre-MMA RDI | | | P-value† |
|---|---|---|---|---|
| | < 30/hour (n=425) | 30-59.9/hour (n=338) | ≥ 60/hour (n=178) | |
| **Pre-MMA** | | | | |
| Age (years) | 33.7 ± 13.9 (425) | 44.5 ± 12.3 (338) | 45.7 ± 12.2 (178) | **<0.001** |
| Male (%) | 69.9% (425) | 81.4% (338) | 91.6% (178) | **<0.001** |
| BMI (kg/m$^2$) | 26.0 ± 2.5 (412) | 27.8 ± 4.1 (338) | 31.4 ± 5.6 (175) | **<0.001** |
| BMI > 30 kg/m$^2$ (%) | 5.9% (412) | 20.1% (338) | 52.2% (175) | **<0.001** |
| **Cephalometrics** | | | | |
| SNA (degrees) | 80.2 ± 2.7 (60) | 80.6 ± 3.2 (117) | 79.8 ± 3.2 (136) | 0.118 |
| SNB (degrees) | 77.3 ± 3.6 (60) | 77.3 ± 3.9 (117) | 76.9 ± 3.8 (135) | 0.765 |
| PAS (mm) | 6.3 ± 2.4 (60) | 5.5 ± 2.2 (111) | 4.9 ± 2.0 (135) | 0.602 |
| **Polysomnography** | | | | |
| RDI (events/hour) | 19.2 ± 5.9 (425) | 42.7 ± 9.0 (338) | 79.7 ± 15.8 (178) | **<0.001** |
| $SpO_2$ Nadir (%) | 88.9 ± 5.4% (421) | 82.9 ± 8.2 (331) | 71.4 ± 10.9 (177) | **<0.001** |
| ODI (desaturations/hour) | 7.4 ± 6.9 (60) | 19.9 ± 14.9 (111) | 54.3 ± 24.7 (135) | **<0.001** |
| REM Sleep (% TST) | 13.5 ± 5.6% (60) | 11.1 ± 4.5% (111) | 8.8 ± 5.2 (135) | **0.003** |
| Stage III/IV Sleep (% TST) | 6.8 ± 7.4% (60) | 3.4 ± 4.6% (111) | 1.8 ± 3.7% (135) | **0.002** |
| **Post-MMA** | | | | |
| BMI (kg/m$^2$) | 25.9 ± 2.6 (379) | 27.7 ± 4.2 (308) | 31.4 ± 5.6 (172) | **<0.001** |
| Percent Change in BMI (%) | -0.7 ± 1.3% (378) | -0.7 ± 1.2% (303) | -0.5 ± 3.5% (172) | 0.443 |
| **Cephalometrics** | | | | |
| SNA (degrees) | 80.6 ± 2.9 (59) | 81.7 ± 2.9 (111) | 81.8 ± 3.5 (135) | 0.039 |
| Change in SNA (degrees) | 0.004 ± 0.02 (59) | 0.01 ± 0.02 (111) | 0.02 ± 0.03 (135) | **<0.001** |
| SNB (degrees) | 77.5 ± 0.03 (59) | 78.5 ± 0.03 (111) | 78.7 ± 0.03 (135) | 0.055 |
| Change in SNB (degrees) | 0.003 ± 0.01 (59) | 0.01 ± 0.02 (111) | 0.02 ± 0.02 (135) | **<0.001** |
| PAS (mm) | 8.2 ± 2.6 (59) | 8.5 ± 2.3 (111) | 8.5 ± 2.6 (135) | 0.639 |
| Change in PAS (mm) | 1.9 ± 2.2 (59) | 3.0 ± 2.1 (111) | 3.7 ± 2.4 (135) | **<0.001** |
| **Polysomnography** | | | | |
| RDI (events/hour) | 8.2 ± 6.1 (425) | 15.2 ± 11.7 (338) | 23.2 ± 24.9 (178) | **<0.001** |
| Percent Change in RDI (%) | -56.0 ± 35.3% (425) | -63.8 ± 27.6% (338) | -70.0 ± 32.1% (178) | **<0.001** |
| RDI 5-14.9/hour (%) | 58.6% (425) | 47.3% (338) | 36.0% (178) | **<0.001** |
| RDI 15-29.9/hour (%) | 11.5% (425) | 29.3% (338) | 25.3% (178) | **<0.001** |
| RDI ≥ 30/hour (%) | 0.1% (425) | 4.0% (338) | 4.4% (338) | **<0.001** |
| $SpO_2$ Nadir (%) | 91.8 ± 3.9% (418) | 88.5 ± 4.5% (332) | 83.3 ± 9.3% (177) | **<0.001** |
| Percent Change in $SpO_2$ Nadir (%) | 3.5 ± 5.5% (417) | 7.6 ± 10.9% (328) | 18.5 ± 17.5% (177) | **<0.001** |
| REM Sleep (% TST) | 17.1 ± 6.1% (60) | 16.2 ± 6.2% (111) | 17.1 ± 6.7 (135) | 0.829 |
| Percent Change in REM Sleep (%) | 70.7 ± 216.3% (60) | 81.9 ± 187.5% (111) | 207.8 ± 346.6% (135) | 0.558 |
| Stage III/IV Sleep (% TST) | 10.9 ± 8.6% (60) | 6.6 ± 6.2% (111) | 6.9 ± 8.0% (135) | **0.002** |
| Percent Change in Stage III/IV (%) | 221.8 ± 495.7% (60) | 235.7 ± 473.1% (111) | 335.7 ± 567.3 (135) | **0.868** |
| ODI (desaturations/hour) | 2.2 ± 4.5 (60) | 5.2 ± 9.5 (111) | 12.1 ± 20.7 (135) | **<0.001** |
| RDI Surgical Cure (%)‡ | 29.6% (425) | 12.1% (338) | 15.7% (178) | **<0.001** |
| ODI Surgical Cure (%) | 86.7% (60) | 73.9% (111) | 63.7% (135) | **0.004** |
| RDI Surgical Success (%)‡ | 73.2% (425) | 74.0% (338) | 66.3% (178) | 0.148 |
| ODI Surgical Success (%) | 85.0% (60) | 82.9% (111) | 80.7% (135) | 0.759 |

** Mean (or percent) ± standard deviation. The number of patients is shown in parentheses. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), ODI (oxygen desaturation index), PAS (posterior airway space – base of tongue), REM (rapid eye movement), RDI (respiratory disturbance index), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), $SpO_2$ (pulse oxyhemoglobin saturation). † P-value assesses whether mean differences between the groups are statistically significant. ‡ Surgical cure defined an RDI (or ODI) < 5 events/hour post-MMA. Surgical success defined as the percent of subjects with an RDI (or ODI) < 20/hour and a ≥ 50% reduction in the RDI (or ODI) post-MMA.*

**Table 3.** Patient Characteristics Stratified by Percent Reduction in RDI Post-MMA*.

| Characteristics | Percent RDI Reduction | | | | P-value† | P-value‡ |
|---|---|---|---|---|---|---|
| | ≥ 75.0% (n=367; 39.0%) | 50-74.9% (n=362; 38.5%) | 25-49.9% (n=120; 12.8%) | < 24.9% (n=92; 9.8%) | | |
| **Pre-MMA** | | | | | | |
| Age (years) | 38.8 ± 14.3 (367) | 38.4 ± 14.4 (362) | 41.9 ± 14.4 (120) | 46.8 ± 10.0 (92) | **<0.001**\|\| | **<0.001** |
| Age > 50 years (%) | 24.8% (367) | 25.7% (269) | 33.3% (120) | 42.4% (92) | **0.003** | **0.001** |
| Male (%) | 80.4% (367) | 72.1% (362) | 80.0% (120) | 90.2% (92) | **0.001** | **0.031** |
| BMI (kg/m$^2$) | 28.3 ± 4.8 (363) | 26.4 ± 3.0 (343) | 27.9 ± 3.8 (116) | 30.0 ± 5.4 (91) | **0.048**\|\| | **0.030** |
| BMI > 30 kg/m$^2$ (%) | 24.5% (363) | 9.3% (343) | 24.1% (116) | 40.7% (91) | **<0.001** | **0.002** |
| **Cephalometrics** | | | | | | |
| SNA (degrees) | 80.0 ± 3.1 (164) | 80.3 ± 2.8 (75) | 80.9 ± 3.2 (26) | 80.0 ± 3.5 (48) | 0.696# | 1.000 |
| SNA < 80 degrees (%) | 41.5% (164) | 30.7% (75) | 34.6% (26) | 41.7% (48) | 0.404 | 0.554 |
| SNB (degrees) | 76.8 ± 4.0 (164) | 77.4 ± 3.7 (74) | 77.4 ± 3.7 (22) | 77.4 ± 3.7 (46) | 0.219# | 0.818 |
| SNB < 80 degrees (%) | 72.6% (164) | 74.3% (74) | 81.8% (22) | 76.1% (46) | 0.805 | 0.392 |
| PAS (mm) | 5.1 ± 2.2 (164) | 5.8 ± 2.1 (74) | 5.4 ± 2.0 (22) | 5.7 ± 2.4 (46) | 0.076# | 0.354 |
| **Polysomnography** | | | | | | |
| RDI (events/hour) | 47.6 ± 27.3 (367) | 32.0 ± 17.7 (362) | 33.8 ± 22.8 (120) | 39.8 ± 25.0 (92) | **<0.001**\|\| | **0.049** |
| $SpO_2$ Nadir (%) | 81.3 ± 10.6% (362) | 85.9 ± 8.1% (357) | 86.0 ± 7.7% (120) | 78.4 ± 13.1% (90) | 0.521\|\| | 0.214 |
| ODI (desaturations/hour) | 36.1 ± 28.3 (164) | 23.6 ± 20.4 (74) | 31.5 ± 32.1 (22) | 35.2 ± 29.1 (46) | 0.484\|\| | 0.998 |
| **Post-MMA** | | | | | | |
| BMI (kg/m$^2$) | 28.2 ± 4.9 (346) | 26.3 ± 3.1 (320) | 28.0 ± 3.9 (104) | 30.0 ± 5.5 (89) | **0.027**\|\| | **0.026** |
| Percent Change in BMI (%) | -0.8 ± 1.9 (345) | -0.7 ± 1.2 (315) | -0.6 ± 1.1 (104) | -0.1 ± 3.7 (89) | **0.005**# | **0.008** |
| **Cephalometrics** | | | | | | |
| SNA (degrees) | 82.3 ± 3.0 (163) | 80.9 ± 2.9 (74) | 80.8 ± 3.0 (22) | 80.1 ± 3.5 (46) | **<0.001**#\|\| | **<0.001** |
| SNA < 80 degrees (%) | 17.8% (163) | 21.6% (74) | 36.4% (22) | 41.3% (46) | **0.004** | **0.001** |
| Percent Change in SNA (%) | 3.0 ± 3.8% (163) | 0.9 ± 2.2% (74) | 0.2 ± 1.1% (22) | 0.2 ± 1.2% (46) | **<0.001**\|\| | **<0.001** |
| SNB (degrees) | 78.8 ± 3.2 (163) | 78.1 ± 3.1 (74) | 78.1 ± 3.3 (22) | 77.5 ± 3.8 (46) | **0.016**# | **0.103** |
| SNB < 80 degrees (%) | 57.7% (163) | 68.9% (74) | 81.8% (22) | 76.1% (46) | **0.023** | **0.016** |
| Percent Change in SNB (%) | 2.7 ± 3.6% (163) | 1.0 ± 2.7% (74) | 0.2 ± 1.1% (22) | 0.2 ± 1.2% (46) | **<0.001**\|\| | **<0.001** |
| PAS (mm) | 9.1 ± 2.2 (163) | 8.4 ± 2.4 (74) | 7.0 ± 2.6 (22) | 6.8 ± 2.6 (46) | **<0.001**#\|\| | **<0.001** |
| Percent Change in PAS (%) | 114.4 ±109.9% (163) | 59.8 ± 62.8% (74) | 32.9 ± 33.2% (22) | 28.8 ± 53.6 (46) | **<0.001**\|\| | **<0.001** |
| Change in PAS (mm) | 4.1 ± 2.2 (163) | 2.6 ± 2.0 (74) | 1.6 ± 1.6 (22) | 1.1 ± 1.9 (46) | **<0.001**#\|\| | **<0.001** |
| **Polysomnography** | | | | | | |
| RDI (events/hour) | 6.2 ± 4.5 (367) | 11.6 ± 6.6 (362) | 20.8 ± 14.6 (120) | 41.4 ± 24.2 (92) | **<0.001**\|\| | **<0.001** |
| Percent Change in RDI (%) | -86.0 ± 7.0% (367) | -63.0 ± 7.1% (362) | -38.6 ± 7.0% (120) | 12.8 ± 42.2% (92) | **<0.001**\|\| | **<0.001** |
| $SpO_2$ Nadir (%) | 89.8 ± 3.9% (360) | 90.4 ± 4.8% (358) | 88.3 ± 6.4% (119) | 80.9 ± 11.8% (90) | **<0.001**\|\| | **<0.001** |
| ODI (desaturations/hour) | 1.4 ± 2.3 (164) | 5.3 ± 9.2 (74) | 16.7 ± 17.7 (22) | 29.5 ± 25.6 (46) | **<0.001**\|\| | **<0.001** |
| RDI Surgical Cure (%)§ | 45.5% (367) | 7.7% (334) | 0.0% (120) | 0.0% (92) | **<0.001** | **<0.001** |
| ODI Surgical Cure (%) | 92.7% (164) | 73.0% (74) | 22.7% (22) | 19.6% (46) | **<0.001** | **<0.001** |
| RDI Surgical Success (%)§ | 98.6% (367) | 90.1% (362) | 0.0% (120) | 0.0% (92) | **<0.001** | **<0.001** |
| ODI Surgical Success (%) | 97.0% (164) | 89.2% (66) | 50.0% (22) | 34.8% (46) | **<0.001** | **<0.001** |

** Mean (or percent) ± standard deviation. The number of patients analyzed is shown in parentheses. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), ODI (oxygen desaturation index), PAS (posterior airway space – base of tongue), RDI (respiratory disturbance index), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), $SpO_2$ (pulse oxyhemoglobin saturation). † P-value assesses whether differences between the groups are statistically significant (Weighted linear trend for continuous data; Fisher's exact 2-sided p-value used for categorical data). ‡ P-value assesses whether difference between ≥ 75% vs < 24.9% groups are statistically significant (Tukey [Levene's p > 0.05] or Games-Howell test for linear; Fisher's exact 2-sided for categorical data). §Surgical cure defined as an RDI (or ODI) < 5 events/hr post-MMA. Surgical success defined as the percent of subjects with an RDI (or ODI) <20/hour and a ≥50% reduction in the RDI (or ODI) post-MMA. # Levene's test was not statistically significant (p > 0.05) for the one-way ANOVA comparison, suggesting the variances are homogenous. || Welch's ANOVA p-value < 0.05.*

**Table 4.** Predictors of Post-MMA OSA Surgical Cure*.

| Predictor | Post MMA | | | Post MMA | | |
|---|---|---|---|---|---|---|
| | Cure (RDI < 5) (n=195; 20.7%) | No Cure (RDI ≥ 5) (n=746; 79.3%) | P-value‡ | Cure (ODI < 5) (n=220; 71.9%) | No Cure (ODI ≥ 5) (n=86; 28.1%) | P-value‡ |
| **Pre-MMA** | | | | | | |
| Age (years) | 32.6 ± 13.8 (195) | 41.8 ± 13.7 (746) | **<0.001** | 45.8 ± 11.7 (220) | 51.3 ± 10.9 (86) | **<0.001** |
| Age > 50 years (%) | 11.8% (195) | 32.2% (746) | **<0.001** | 37.7% (220) | 58.1% (86) | **0.001** |
| Male (%) | 70.8% (195) | 80.0% (746) | **<0.001** | 92.7% (220) | 98.8% (86) | **0.048** |
| BMI (kg/m$^2$) | 27.1 ± 4.6 (193) | 27.9 ± 4.2 (720) | 0.051 | 29.8 ± 5.7 (220) | 32.5 ± 5.5 (86) | **<0.001** |
| BMI > 30 kg/m$^2$ (%) | 17.1% (193) | 21.3% (720) | 0.228 | 40.9% (220) | 66.3% (86) | **<0.001** |
| **Cephalometrics** | | | | | | |
| SNA (degrees) | 79.8 ± 3.4 (66) | 80.3 ± 3.0 (247) | 0.376 | 80.2 ± 3.0 (219) | 80.0 ± 3.5 (86) | 0.635 |
| SNA < 80 degrees (%) | 42.4% (66) | 37.2% (247) | 0.477 | 37.3% (220) | 43.0% (86) | 0.364 |
| SNB (degrees) | 76.7 ± 4.1 (66) | 77.3 ± 3.7 (247) | 0.292 | 77.0 ± 3.9 (220) | 77.4 ± 3.6 (86) | 0.471 |
| SNB < 80 degrees (%) | 72.7% (66) | 74.6% (247) | 0.753 | 73.2% (220) | 76.7% (86) | 0.564 |
| PAS (mm) | 5.4 ± 2.1 (66) | 5.4 ± 2.3 (240) | 0.938 | 5.4 ± 2.3 (220) | 5.3 ± 2.0 (86) | 0.658 |
| **Polysomnography** | | | | | | |
| RDI (events/hour) | 31.0 ± 25.2 (195) | 41.2 ± 23.5 (746) | **<0.001** | 52.9 ± 27.5 (220) | 63.4 ± 24.1 (86) | **0.001** |
| RDI ≥ 20 events/hr (%) | 55.4% (195) | 82.7% (746) | **<0.001** | 86.4% (220) | 100.0% (86) | **<0.001** |
| $SpO_2$ Nadir (%) | 85.5 ± 9.1% (193) | 82.9 ± 10.2% (736) | **0.001** | 75.0 ± 10.0 (220) | 69.4 ± 10.4 (86) | **<0.001** |
| ODI (desaturations/hour) | 27.0 ± 27.7 (66) | 34.2 ± 27.2 (240) | 0.066 | 28.5 ± 26.8 (220) | 43.1 ± 26.2 (86) | **<0.001** |
| ODI ≥ 20 events/hr (%) | 43.9% (66) | 59.2% (240) | **0.035** | 49.1% (220) | 73.3% (86) | **<0.001** |
| **Post-MMA** | | | | | | |
| BMI (kg/m$^2$) | 27.1 ± 4.7 (181) | 27.8 ± 4.3 (678) | 0.055 | 29.7 ± 5.7 (219) | 32.4 ± 5.5 (86) | **<0.001** |
| % Change in BMI (%) | -0.9 ± 2.5% (181) | -0.6 ± 1.7% (672) | 0.108 | -0.1 ± 0.7 (219) | -0.1 ± 0.3 (86) | 0.401 |
| **Cephalometrics** | | | | | | |
| SNA (degrees) | 82.0 ± 3.0% (66) | 81.4 ± 3.2 (239) | 0.202 | 82.0 ± 3.0 (219) | 80.5 ± 34.7 (86) | **0.001** |
| SNA < 80 degrees (%) | 19.7% (66) | 24.7% (239) | 0.513 | 18.7% (219) | 36.0% (86) | **0.002** |
| Change in SNA (degrees) | 2.1 ± 3.0 (66) | 1.3 ± 2.3 (239) | **0.030** | 1.8 ± 2.7 (219) | 0.5 ± 1.5 (86) | **<0.001** |
| SNB (degrees) | 78.4 ± 3.2 (66) | 78.4 ± 3.4 (239) | 0.913 | 78.5 ± 3.2 (219) | 78.0 ± 3.6 (86) | 0.230 |
| SNB < 80 degrees (%) | 62.1% (66) | 65.7% (239) | 0.662 | 62.1% (219) | 72.1% (86) | 0.111 |
| Change in SNB (degrees) | 1.7 ± 2.6 (66) | 1.2 ± 2.3 (239) | 0.138 | 1.5 ± 2.5% (219) | 0.6 ± 1.8% (86) | **<0.001** |
| PAS (mm) | 9.1 ± 2.1 (66) | 8.3 ± 2.6 (239) | **0.013** | 8.9 ± 2.3 (219) | 7.3 ± 2.6 (86) | **<0.001** |
| Change in PAS (mm) | 3.7 ± 2.3 (66) | 2.9 ± 2.4 (239) | **0.024** | 3.5 ± 2.4 (219) | 2.0 ± 2.0 (86) | **<0.001** |
| **Polysomnography** | | | | | | |
| RDI (events/hour) | 2.6 ± 1.2 (195) | 16.4 ± 15.2 (746) | **<0.001** | 9.0 ± 7.5 (220) | 42.4 ± 25.7 (86) | **<0.001** |
| % Change in RDI (%) | -86.1 ± 11.0% (195) | -55.0 ± 33.2% (746) | **<0.001** | -76.6 ± 30.9% (220) | -29.4 ± 37.6% (86) | **<0.001** |
| RDI < 20 events/hr (%) | 100.0% (195) | 88.8% (746) | **<0.001** | 94.1% (220) | 17.4% (86) | **<0.001** |
| $SpO_2$ Nadir (%) | 91.6 ± 3.3% (192) | 88.3 ± 6.8% (735) | **<0.001** | 87.2 ± 3.1% (220) | 74.8 ± 9.8% (86) | **<0.001** |
| % Change in $SpO_2$ Nadir (%) | 8.4 ± 11.4% (192) | 7.7 ± 12.2 (730) | 0.479 | 18.4 ± 16.9% (220) | 9.1 ± 15.4% (86) | **<0.001** |
| ODI (desaturations/hour) | 0.4 ± 0.7 (66) | 9.7 ± 17.0 (240) | **<0.001** | 1.1 ± 1.4 (220) | 24.6 ± 21.4 (86) | **<0.001** |
| % Change in ODI (%) | -95.8 ± 16.7% (66) | -43.8 ± 225.0% (240) | **<0.001** | -87.3 ± 34.1% (220) | 27.7 ± 3.6% (86) | **0.004** |
| **RDI Surgical Success (%)†** | 100.0% (195) | 66.1% (746) | **<0.001** | 92.7% (220) | 16.3% (86) | **<0.001** |
| **ODI Surgical Success (%)†** | 98.5% (66) | 74.2% (240) | **<0.001** | 93.6% (220) | 43.0% (86) | **<0.001** |

** Surgical cure defined as an RDI (or ODI) < 5 events/hour post-MMA. Mean (or percent) ± standard deviation. The total number of patients is shown in parentheses. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), ODI (oxygen desaturation index), PAS (posterior airway space – base of tongue), RDI (respiratory disturbance index), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), $SpO_2$ (pulse oxyhemoglobin saturation). † Surgical success defined as the percent of subjects with an RDI (or ODI) < 20/hour and a ≥ 50% reduction in the RDI (or ODI) post-MMA. ‡ Equal variances not assumed for p-value calculation. Fisher's exact 2-sided p-value used for categorical data.*

**Table 5.** Predictors of Post-MMA OSA Surgical Success*.

| Predictor | Post MMA | | | Post MMA | | |
|---|---|---|---|---|---|---|
| | RDI Success (n=688; 73.1%) | No Success (n=253; 26.9%) | P-value‡ | ODI Success (n=243; 79.4%) | No Success (n=63; 20.6%) | P-value‡ |
| **Pre-MMA** | | | | | | |
| **Age (years)** | 38.2 ± 14.3 (688) | 44.2 ± 12.9 (253) | **<0.001** | 46.3 ± 12.0 (243) | 51.5 ± 9.9 (63) | **0.001** |
| **Age > 50 years (%)** | 24.4% (688) | 37.5% (253) | **<0.001** | 40.7% (243) | 54.0% (243) | 0.065 |
| **Male (%)** | 75.7% (688) | 84.6% (253) | **0.003** | 93.0% (243) | 100.0% (63) | **0.028** |
| **BMI (kg/m²)** | 27.2 ± 4.1 (668) | 29.0 ± 4.6 (245) | **<0.001** | 30.1 ± 5.8 (243) | 32.3 ± 5.7 (63) | **0.010** |
| **BMI > 30 kg/m² (%)** | 15.7% (668) | 33.1% (245) | **<0.001** | 44.4% (243) | 61.9% (63) | **0.016** |
| **Cephalometrics** | | | | | | |
| **SNA (degrees)** | 80.2 ± 3.0 (219) | 80.0 ± 3.5 (94) | 0.631 | 80.1 ± 3.0 (243) | 80.0 ± 3.6 (63) | 0.865 |
| **SNA < 80 degrees (%)** | 37.9% (219) | 39.4% (94) | 0.801 | 38.3% (243) | 41.3% (63) | 0.666 |
| **SNB (degrees)** | 77.1 ± 3.9 (219) | 77.3 ± 3.6 (88) | 0.637 | 77.0 ± 3.8 (243) | 77.5 ± 3.8 (63) | 0.353 |
| **SNB < 80 degrees (%)** | 72.5% (218) | 78.4% (88) | 0.315 | 74.5% (243) | 73.0% (63) | 0.872 |
| **PAS (mm)** | 5.3 ± 2.2 (218) | 5.5 ± 2.2 (88) | 0.461 | 5.4 ± 2.3 (243) | 5.3 ± 2.0 (63) | 0.696 |
| **Polysomnography** | | | | | | |
| **RDI (events/hour)** | 38.1 ± 23.5 (688) | 41.8 ± 26.0 (253) | **0.049** | 52.9 ± 27.5 (220) | 63.4 ± 24.1 (86) | 0.954 |
| **RDI ≥ 20 events/hr (%)** | 76.5% (688) | 78.7% (253) | 0.541 | 86.4% (220) | 100.0% (86) | 0.056 |
| **$SpO_2$ Nadir (%)** | 84.1 ± 9.4% (688) | 81.6 ± 11.3% (250) | **0.002** | 75.0 ± 10.0 (220) | 69.4 ± 10.4 (86) | 0.253 |
| **ODI (desaturations/hour)** | 30.8 ± 26.6 (218) | 37.0 ± 28.9 (88) | 0.084 | 28.5 ± 26.8 (220) | 43.1 ± 26.2 (86) | 0.991 |
| **ODI ≥ 20 events/hr (%)** | 54.6% (218) | 59.1% (88) | 0.525 | 49.1% (220) | 73.3% (86) | 0.088 |
| **Post-MMA** | | | | | | |
| **BMI (kg/m²)** | 27.1 ± 4.2 (630) | 29.0 ± 4.8 (229) | **<0.001** | 30.0 ± 5.7 (242) | 32.1 ± 5.7 (63) | **0.010** |
| **% Change in BMI (%)** | -0.8 ± 1.7% (624) | -0.4 ± 2.4% (229) | **0.031** | -4.2 ± 2.1% (242) | -3.7 ± 9.5% (63) | 0.774 |
| **Cephalometrics** | | | | | | |
| **SNA (degrees)** | 82.1 ± 2.8 (217) | 80.1 ± 3.6 (88) | **<0.001** | 81.9 ± 3.0 (242) | 80.2 ± 3.5 (63) | **0.001** |
| **SNA < 80 degrees (%)** | 17.5% (217) | 38.6% (88) | **<0.001** | 19.4% (242) | 39.7% (63) | **0.001** |
| **Change in SNA (degrees)** | 1.9 ± 2.7 (217) | 0.3 ± 1.1 (88) | **<0.001** | 1.8 ± 2.7 (242) | 0.2 ± 0.9 (63) | **<0.001** |
| **SNB (degrees)** | 78.7 ± 3.1 (217) | 77.7 ± 3.7 (88) | **0.027** | 78.6 ± 3.2 (242) | 77.7 ± 3.6 (63) | 0.097 |
| **SNB < 80 degrees (%)** | 60.8% (217) | 75.0% (88) | **0.024** | 62.4% (242) | 74.6% (63) | 0.077 |
| **Change in SNB (degrees)** | 1.6 ± 2.5 (217) | 0.4 ± 1.4 (88) | **<0.001** | 1.6 ± 2.5 (242) | 0.2 ± 1.2 (63) | **<0.001** |
| **PAS (mm)** | 9.0 ± 2.2 (217) | 7.1 ± 2.6 (88) | **<0.001** | 8.9 ± 2.3 (242) | 6.8 ± 2.4 (63) | **<0.001** |
| **Change in PAS (mm)** | 3.7 ± 2.2 (217) | 1.6 ± 2.0 (88) | **<0.001** | 3.5 ± 2.3 (242) | 1.5 ± 1.7 (63) | **<0.001** |
| **Polysomnography** | | | | | | |
| **RDI (events/hour)** | 7.9 ± 4.7 (688) | 29.0 ± 20.3 (253) | **<0.001** | 11.4 ± 11.2 (243) | 45.3 ± 28.2 (63) | **<0.001** |
| **% Change in RDI (%)** | -75.2 ± 13.4% (688) | -23.9 ± 39.0% (253) | **<0.001** | -74.9 ± 30.1% (243) | -18.6 ± 37.9 (63) | **<0.001** |
| **RDI < 20 events/hr (%)** | 100.0% (688) | 36.0% (253) | **<0.001** | 85.6% (243) | 22.2% (63) | **<0.001** |
| **$SpO_2$ Nadir (%)** | 90.5 ± 3.7% (678) | 84.9 ± 9.5% (249) | **<0.001** | 86.3 ± 4.3% (243) | 73.8 ± 11.1% (63) | **<0.001** |
| **% Change in $SpO_2$ Nadir (%)** | 8.9 ± 12.5% (673) | 4.9 ± 10.1% (249) | **<0.001** | 18.8 ± 16.4% (243) | 4.1 ± 13.9% (63) | **<0.001** |
| **ODI (desaturations/hour)** | 1.5 ± 2.3 (218) | 23.0 ± 22.4 (88) | **<0.001** | 2.4 ± 3.8 (243) | 28.2 ± 24.4 (63) | **<0.001** |
| **% Change in ODI (%)** | -90.0 ± 22.4% (218) | 31.8 ± 359.1% (88) | **0.002** | -91.8 ± 11.6% (243) | 87.0 ± 414.0% (63) | **0.001** |
| **RDI Surgical Success (%)†** | 28.3% (688) | 0.0% (253) | **<0.001** | 26.7% (243) | 1.6% (63) | **<0.001** |
| **ODI Surgical Success (%)†** | 93.6% (688) | 18.2% (88) | **<0.001** | 84.8% (243) | 22.2% (63) | **<0.001** |

** Surgical success defined as the percent of subjects with an RDI (or ODI) < 20/hour and a ≥ 50% reduction in the RDI (or ODI) post-MMA. Mean (or percent) ± standard deviation. The total number of patients is shown in parentheses. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), ODI (oxygen desaturation index), PAS (posterior airway space –base of tongue), RDI (respiratory disturbance index), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), $SpO_2$ (pulse oxyhemoglobin saturation). † Surgical cure defined as an RDI (or ODI) < 5 events/hour post-MMA. ‡ Equal variances for linear data not assumed for p-value calculation. Fisher's exact 2-sided p-value used for categorical data.*

**Table 6.** First 500 vs Last 510 MMA Characteristics*.

| | First MMA N=500 | Last MMA N=510 | P-value |
|---|---|---|---|
| **Characteristics** | | | |
| **Age** | 44.8 ± 13.0 (500) | 34.6 ± 13.7 (510) | **<0.001** |
| **Male Gender (%)** | 84.8% (500) | 69.4% (510) | **<0.001** |
| **PreMMA BMI (kg/m²)** | 29.3 ± 5.1 (495) | 25.8 ± 1.8 (481) | **<0.001** |
| **PostMMA BMI (kg/m²)** | 29.2 ± 5.1 (491) | 25.5 ± 1.7 (423) | **<0.001** |
| **Percent Change BMI** | -0.3 ± 2.2% (489) | -1.0 ± 2.3% (419) | **<0.001** |
| **PreMMA Polysomography** | | | |
| **RDI (events/hour)** | 48.0 ± 26.3 (498) | 28.4 ± 16.8 (507) | **<0.001** |
| **RDI ≥ 30/hr (%)** | 69.9% (498) | 36.7% (507) | **<0.001** |
| **$SpO_2$ Nadir (%)‡** | 78.6 ± 11.2% (491) | 88.8 ± 4.4% (495) | **<0.001** |
| **ODI (desaturations/hour)** | 32.6 ± 27.4 (306) | - | NA |
| **ODI ≥ 30/hr (%)** | 47.7% (306) | - | NA |
| **PostMMA Polysomography** | | | |
| **RDI (events/hour)** | 17.1 ± 18.3 (484) | 9.9 ± 7.8 (458) | **<0.001** |
| **RDI ≥ 30/hr (%)** | 13.4% (484) | 3.3% (458) | **<0.001** |
| **Percent Change RDI (%)** | -59.0 ± 40.3% (484) | -64.0 ± 21.4% (457) | **0.017** |
| **$SpO_2$ Nadir (%)‡** | 86.0 ± 7.3% (479) | 92.1 ± 2.7% (449) | **<0.001** |
| **Percent Change $SpO_2$ Nadir (%)** | 11.5 ± 15.5% (476) | 3.9 ± 3.8 (449) | **<0.001** |
| **ODI (desaturations/hour)†** | 7.7 ± 15.5 (306) | - | NA |
| **ODI ≥ 30/hr (%)** | 8.5% (306) | - | NA |
| **Percent Change ODI (%)** | -55.0 ± 2.0 (306) | - | NA |
| **PreMMA Cephalometrics†** | | | |
| **SNA (degrees)** | 80.2 ± 3.1 (321) | - | NA |
| **SNB (degrees)** | 77.1 ± 3.8 (306) | - | NA |
| **PAS (mm)** | 5.4 ± 2.2 (306) | - | NA |
| **PostMMA Cephalometrics†** | | | |
| **SNA (degrees)** | 81.5 ± 3.2 (305) | - | NA |
| **SNB (degrees)** | 78.4 ± 3.3 (305) | - | NA |
| **PAS (mm)** | 8.4 ± 2.5 (305) | - | NA |
| **RDI Surgical Cure (%)#** | 17.8% (484) | 23.9% (457) | **0.024** |
| **ODI Surgical Cure (%)#,†** | 71.9% (306) | - | NA |
| **RDI Surgical Success (%)#** | 66.7% (484) | 77.9% (457) | **<0.001** |
| **ODI Surgical Success (%)#,†** | 79.4% | - | NA |

** Plus-minus values are mean (or percent) ± standard deviation. Values in parenthesis are the number of patients evaluated. Abbreviations: BMI (body mass index), MMA (maxillomandibular advancement), ODI (oxygen desaturation index), PAS (posterior airway space – base of tongue), PNS-P (distance of posterior nasal spine to the tip of the soft palate), RDI (respiratory disturbance index), REM (rapid eye movement), SNA (sella-nasion-Point A angle), SNB (sella-nasion-Point B angle), $SpO_2$ (pulse oxyhemoglobin saturation). † ODI and cephalometric data only available on a subset of MMA patients that were exclusively within the first 500 subjects studied. ‡ The $SpO_2$ nadir is the lowest oxyhemoglobin saturation measured during sleep. Only patients with both pre- and post-MMA $SpO_2$ nadir are included. # Surgical cure defined an RDI (or ODI) < 5 events/hour post-MMA. Surgical success defined as the percent of subjects with an RDI (or ODI) < 20/hour and a ≥ 50% reduction in the RDI (or ODI) post-MMA.*

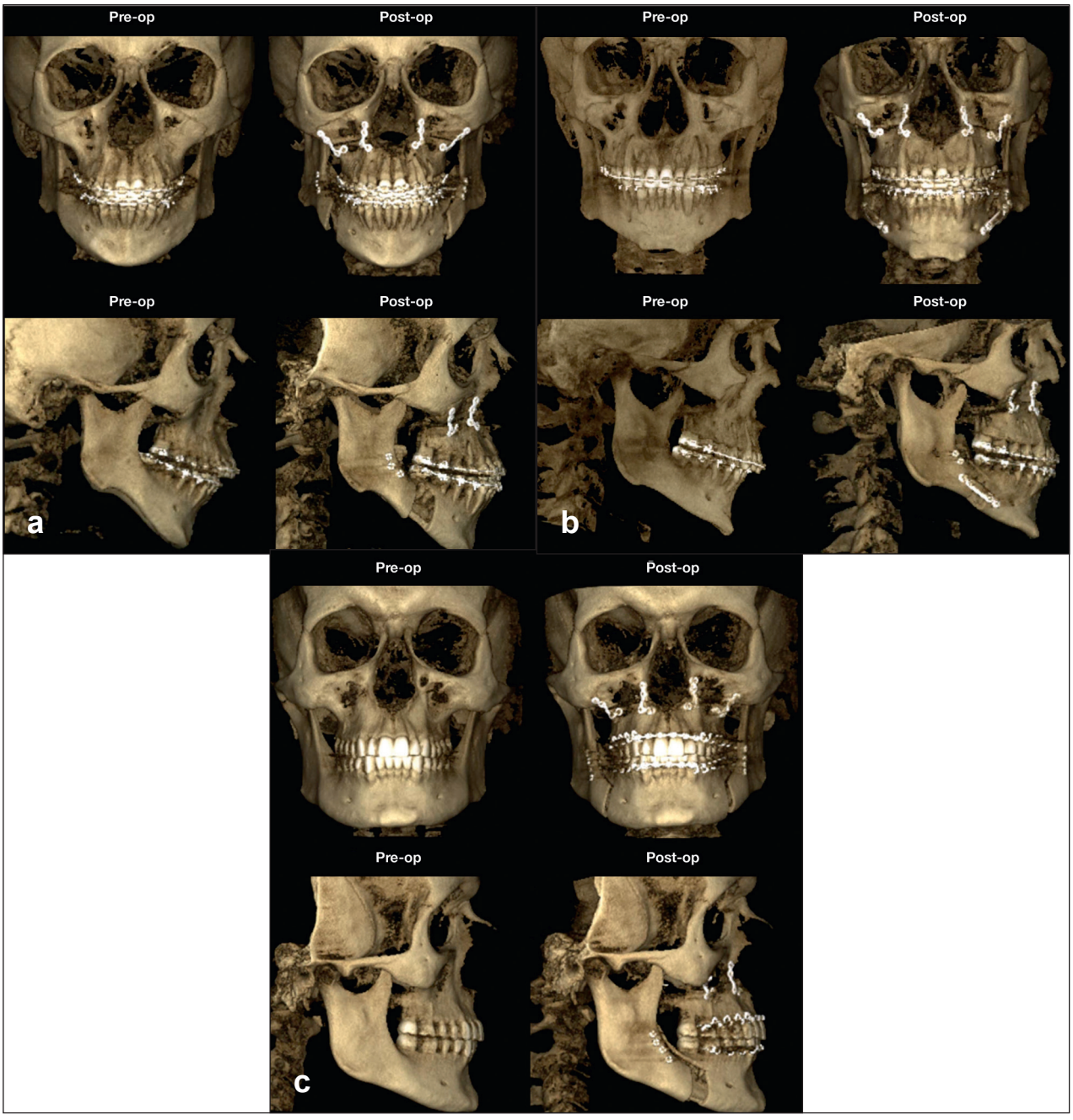


Figure 2

(a-c) Pre- and post-MMA imaging demonstrating different surgical plans but the main objective of maximizing the advancement within the physiologic limitation of the soft tissues is maintained.

ment option in properly selected patients. We have seen a trend of younger patients with less severe OSA increasingly opting for MMA as the treatment of choice. The improved surgical outcome with greater percentage reduction in RDI and surgical success/cure in patients with younger age, lower RDI and lower BMI are quite evident when comparing the first 500 patients versus the later 510 patients (Table 6). The differences in the patient population reflected the clinical insights gained over the years in the patient selection for MMA. The improved outcome is also likely related to the advances in surgical expertise and technique in the more recently treated patients.

The RDI was chosen as one of the primary outcome variables. This is due to the improved understanding of the impact of respiratory effort-related arousals (RERA) in causing sleep fragmentation affecting daytime function and quality of life[1,6,7]. The results clearly demonstrate that MMA significantly reduces the RDI in the majority of the patients where the overall surgical success and surgical cure based on RDI were 73.1% and 20.7%, respectively. The RDI outcome compares favorably to the meta-analysis from 2016 with the rate of success and cure of 44 (64.7%) and 13 (19.1%), respectively[31]. This could be related to the small sample size in the meta-analysis with only 68 patients as well as the heterogeneity of the pooled data[31]. The comparison of the first 500 patients to the more recent 510 patients also showed that the outcome has improved in the rate of surgical success (77.9% versus 66.7%) and surgical cure (23.9% versus 17.8%). Again, the improved outcome could be related to better patient selection and surgical execution.

The maxillofacial anatomy as a risk factor in patients with OSA based on cephalometric data has been published extensively since the initial report by Guilleminault's group in 1986[9]. The analysis on cephalometric measurements in this study showed that a greater increase in SNA, SNB and PAS postoperatively resulted in improved outcome (Table 5). This finding suggests that greater advancement distance results in greater OSA improvement. Therefore, it must be emphasized that the goal of MMA is not to "normalize" cephalometric measurements since many patients with "normal" measurements have OSA[18] but rather, it is to maximize the advancement distance in optimizing airway expansion. This objective must be adhered to because OSA remained even when advancement was maximized. It is recognized that lower OSA severity, neurocognitive symptoms and cardiovascular sequelae remain[2,4,5]. Clearly, maximizing the advancement must be balanced with the alteration of facial esthetics. Therefore, the surgical plan must be a collaborative decision between the surgeon and the patient. A comprehensive discussion of prognostic factors and the impact of advancement on airway and esthetics is essential so an ideal surgical plan can be formulated based on a collaborative effort between the patient and the surgeon (Fig. 2).

## 5. Conclusions

MMA is an effective treatment to improve OSA, but the result can vary. Patient selection based on favorable prognostic factors and maximizing the advancement distance can improve outcomes.

## Links of interest

The authors declare that they have no interest in the data published in this article.

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