Maxillomandibular Advancement Surgery in a Site-Specific Treatment Approach for Obstructive Sleep Apnea in 50 Consecutive Patients*

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Objective: To report the efficacy of maxillomandibular advancement (MMA) surgery, with a description of several innovations, as a site-specific treatment of obstructive sleep apnea syndrome (OSAS) in selected cases with disproportionate velo-orohypopharyngeal anatomy.

Design: Clinical series of 50 consecutive cases.

Setting: Surgery was performed in a hospital operating room, and perioperative management was provided in an intensive care environment. Except for polysomnography (PSG), which was performed and interpreted by independent sleep facilities/physicians, all pre- and postoperative evaluations were accomplished in a solo office private practice setting.

Patients: Patients were referred for MMA evaluation when applicable conservative therapies such as nasal continuous positive airway pressure (nCPAP) were not tolerated, refused, or unsuccessful. Case selection was based primarily on the sites of disproportionate upper airway anatomy.

Interventions: MMA consisted of a Lefort I osteotomy, bilateral sagittal split ramus osteotomies, and a new modified procedure called an anterior inferior mandibular osteotomy with indirect hyoid suspension. Some patients also received concomitant adjunctive nonpharyngeal procedures.

Measurements and results: Obtained at a mean of 5.2 months postoperatively, revealed significant improvement in all cases. Mean BPs (n=50) were lowered, subjective symptoms were ameliorated, and mean body mass index (n=50) was reduced. Cephalometric analysis (n=50), with several new modifications including standardization for phases of respiration, quantified structural changes in soft-tissue and bony landmarks. Postoperative PSG results (n=50) showed dramatic improvement over preoperative data (n=50), with therapeutic values similar to nCPAP (n=42). Mean values improved from preoperative to postoperative vs nCPAP for apnea index (34.5 to 1.0 vs 2.0, respectively), apnea-hypopnea index (59.2 to 4.7 vs 5.4, respectively), lowest arterial oxyhemoglobin desaturations (72.7% to 88.6% vs 88.6%, respectively), and number of desaturations <90% (118.8 to 6.6 vs 2.4, respectively). The success rate was 100%.

Conclusion: MMA is highly successful and safe and may be a definitive primary single-staged surgical treatment of selected OSAS cases with diffusely complex or multiple sites of disproportionate velo-orohypopharyngeal anatomy.

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Key words: cephalometric; maxillomandibular advancement; obstructive sleep apnea; polysomnography; site-specific surgery

Abbreviations: AHI = apnea-hypopnea index; AI = apnea index; AIMO = anterior inferior mandibular osteotomy; BMI = body mass index; BSSRO = bilateral sagittal split ramus osteotomies; EDS = excessive daytime sleepiness; ETT = endotracheal tube; ETV = end-tidal volume; GO-POG = gonion to pogonion; LF = Lefort I osteotomy; LSAT = lowest arterial oxyhemoglobin desaturation; MM = modified Müller maneuver; MMA = maxillomandibular advancement; MMO = maxillomandibular osteotomies; MP-H = mandibular plane to hyoid; nCPAP = nasal continuous positive airway pressure; OSA = obstructive sleep apnea; OSAS = obstructive sleep apnea syndrome; PAS = posterior airway space; PNS-P = length of soft palate from posterior nasal spine to uvula tip; PSG = polysomnography; SNA = sella nasion point A angle; SNB = sella nasion point B angle; T/A = tonsillectomy and/or adenoidectomy; UA = upper airway; UPPP = uvulopalatopharyngoplasty

Obstructive sleep apnea syndrome (OSAS) is a potentially life-threatening medical disorder with a projected prevalence of up to 18 million people in the U.S. population alone. OSAS results from repetitive collapse of the soft tissues that form or lie into or adjacent to the lumen of the supraglottic or upper airway (UA), while asleep. These pharyngeal soft tissues are suspended and supported by the cartilaginous and bony skeletal structures of the

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lower face and upper neck. UA patency during sleep is dependent on a complex interplay of anatomic and physiologic factors. The balance of constricting forces, e.g., negative inspiratory intraluminal suction generated by the diaphragm, and dilating forces of the pharyngeal musculature is dysfunctional in obstructive sleep apnea (OSA). Reduction in activity of the tensor palatini and genioglossus muscles may contribute to floppiness and collapsibility of an elongated soft palate in the velopharynx and a bulky retropositioned tongue base in the oropharynx, respectively. Efforts to enhance neuromuscular control of the abnormal pharyngeal dilator muscles with medications and nerve stimulators have been largely unsuccessful. More conventional OSA therapies seek to improve or correct abnormalities of the pharyngeal anatomic structure or physiologic function.

Comprehensive evaluation and treatment planning of OSAS cases requires a multidisciplinary team approach. The universal convenience of nasal continuous positive airway pressure (nCPAP) is that it pneumatically splints open the entire UA with a high degree of therapeutic efficacy, eliminating the need to identify specific site(s) of obstruction. However, not all OSAS patients are compliant with its required lifetime of nightly use, caused primarily by intolerance. Other devices, e.g., oral appliances, are therapeutic only if selected appropriately for the specific site(s) of obstruction, which may vary among different individuals, and also may have compliance problems with habitual use while asleep. Although it is known that weight reduction may lessen OSA, it is unknown what degree of weight loss is required. OSAS also occurs in nonobese patients. Noncompliance is a common problem in that many patients have difficulty losing weight or maintaining weight loss.

It is generally accepted that surgery is indicated when applicable conservative therapies are unsuccessful or not tolerated, and for patients with an underlying specific surgically correctable abnormality that is causing the OSAS. Surgery can provide definitive treatment and, thus, eliminate issues of patient compliance, but only if performed competently, both in terms of technical skill, as well as on the “correct” area(s) of UA obstruction. Although many surgical procedures and protocols are reported, maxillomandibular advancement (MMA), which “pulls forward” the anterior pharyngeal tissues attached to the maxilla, mandible, and hyoid to enlarge the entire velo-orohypopharynx with minimal risks of edema-induced UA embarrassment or pharyngeal dysfunction, is the most effective, excluding tracheostomy, acceptable surgical treatment of OSAS, with success rates of 95%, 96%, and 98%.

Nevertheless, the indications for MMA remain unsettled, e.g., it is often limited to severe cases of OSAS when other surgeries have failed, partly because of existing diagnostic dilemmas such as identifying and ranking, in terms of severity, the often multiple sites of obstruction, and knowing when and how to prioritize and combine surgical procedures in one or more stages, which may be influenced and perhaps biased by the surgeon’s education, training, and experience. The primary purpose of this case series is to report the efficacy of MMA, often with concomitant adjunctive nonpharyngeal procedures, as a treatment of OSAS in a site-specific approach: the methodology for the selection of specific surgical procedures was not specialty- or stage-specific, but rather, based on each individual patient’s sites of disproportionate UA anatomy.

### Materials and Methods

**Presurgical Evaluation and Treatment Planning**

Patients were evaluated for MMA only if (1) they exhibited OSAS diagnosed by independent nocturnal polysomnography (PSG) inclusion criteria of an apnea-hypopnea index [AHI] > 15 or an apnea index [AI] > 5 and a lowest arterial oxyhemoglobin desaturation [LSAT] < 90% that was clinically significant (inclusion criteria of stated excessive daytime sleepiness [EDS]); (2) all applicable conservative therapies (e.g., nCPAP, weight loss, positional therapy, reduction of late evening sedative-hypnotic medications or alcoholic beverages, oral appliances or other devices) or prior surgical procedures were unsuccessful, not tolerated, or refused, as determined by the referring sleep physician(s); and (3) they were medically stable and willing to proceed with surgery.

Presurgical evaluations were performed by the author in a single office. Detailed head and neck examination was performed clinically and radiographically, using posterior-anterior panoramic and lateral cephalometric radiographs (described below). Cephalometric prediction tracings and photographic computer imaging (Everex; United Digital Systems, Inc.; Winston-Salem, NC) were used to illustrate proposed changes in UA size and facial appearance, respectively. Body weights were measured with a foot scale, and BP was recorded with the patients sitting using a digital BP monitor (Labron; Hauppauge, NY) with a full-sized arm cuff and with a paper printout. Patients’ OSAS-related symptoms were recorded on a standard screening questionnaire form. Hospital medical staff credentialing for surgical privileges for all procedures performed (Table 1) and written informed consent for all patients were obtained.

Surgical treatment planning was “site-specific”: The selection of specific surgical procedures was individualized for each patient, based on their specific site(s) of disproportionate UA anatomy. The most severe sites were addressed first, with the hypopharynx as the area of most critical concern. MMA inclusion criterion was orohypopharyngeal narrowing caused by macroGLOSSIA with a retropositioned tongue base—determined by clinical examination and measured by cephalometric analysis (posterior airway space [PAS] < 9 mm at end-tidal volume [ETV]), described below. Macroglossia was defined clinically as an enlarged tongue base that, at rest, extended above the horizontal plane of the mandibular dentition. Velopharyngeal narrowing, by cepha-
lometry, was also treated with MMA, but only if coexistent with certain congenital craniofacial skeletal deformities, orohypopharyngeal narrowing, characterized by macroglossia or multiple sites of disproportionate UA anatomy that included mandibular lingual tori, and/or thick necks with cervicofacial lipomatosis. Many also displayed encroachment of the lateral pharyngeal walls because of medially displaced tonsillar pillars associated with dysmorphic soft palates and, less commonly, tonsillar hypertrophy. Tonsillectomy and/or adenoidectomy (T/A) had been performed earlier, usually as a child, in 26 patients, and uvulopalatopharyngoplasty (UPPP) had been performed before MMA inclusion criterion, all of these cephalometric measurements were used, to quantify the amount of: maxillary (SNA), mandibular (SNB), and genial (GO-POG) advancement; soft palatal (PNS-P) and hyoid (MP-H) suspension; as well as orohypopharyngeal enlargement (PAS).

PSG

Although there were several referring physicians associated with different facilities, each patient had both their pre- and postoperative PSG performed and interpreted independently by the same respective facility. Although different types of instrumentation were used, all stated their PSG methods were in accordance with conventional criteria, as described elsewhere. Obstructive apnea and hypopnea were defined as a cessation and diminishment, respectively, of airflow, despite respiratory effort, for ≥ 10 s.

Surgical Principles and Rationale

MMA (Figs 2 and 3) opens the velo-, oro-, and hypopharynx by “pulling forward” the anterior pharyngeal soft-tissue com-

![Figure 1. Lateral cephalometric analysis. Measurements obtained were SNA, 82 ± 2°; SNB, 80 ± 2°; PNS-P, 35 ± 3 mm; PAS, 11 ± 1 mm; MP-H, 15 ± 2 mm; and GO-POG, 84 ± 5 mm.](http://publications.chestnet.org/pdfaccess.ashx?url=/data/journals/chest/21934/ on 04/01/2017)
nents, which are attached to the maxilla, mandible, and hyoid. Mandibular advancement pulls forward the tongue base and suprahyoid muscles attached to the genial tubercles and the anterior inferior mandible to open the orohypopharynx. Maxillary advancement anterosuperiorly tightens the soft palate, which is suspended from the palatine bone of the maxilla, to open thevelopharynx and, thus, may obviate surgery of the soft palatal tissues.

The soft palate is a tissue organ whose known primary function is to prevent reflux of air and liquids into the nasopharynx during speech and swallowing, respectively. Also, its role in snoring may be a warning sign or “bell” (to the bed partner) of partial or impending UA obstruction, which may progress to OSA. A dysmorphic or abnormal-looking soft palate may be an anatomic variant of normal, which ensures compensatory functioning; and may not always be a cause of OSAS. Retropalatal narrowing and collapse, often induced by swallowing, eg, during nasopharyngolaryngoscopy, should be understood as normal velopharyngeal closure, rather than perhaps misinterpreted as a site of obstruction dictating surgery. A long or bulky soft palate does not necessarily mandate a UPPP,46 laser-assisted uvuloplasty,47 palatopharyngoglossoplasty,48 uvulopalatopharyngoglossoptasty,49 somnoplasty (Somnus Medical Technologies Inc; Sunnyvale, CA), or radiofrequency volumetric tissue reduction.50 Surgical ablation or distortion may produce dysfunction (eg, velopharyngeal insufficiency,51–53 nasopharyngeal stenosis,51 voice changes,51 or dysphagia52,53) and, in cases of snoring amelioration, may produce silent apnea—either of immediate and/or weight gain. Soft palatal surgery may also produce severe pain, hemorrhage,51–54 and UA obstruction in the immediate postoperative period because of velopharyngeal edema that, particularly if compounded with coexisting untreated hypopharyngeal narrowing, can result in death.51,52,54

MMA not only preserves the functional integrity of the pharyngeal tissues but also minimizes the risk of worsened OSA in the immediate postoperative period because minimal edema occurs within the unoperated pharyngeal soft tissues. The edema resulting from the intraoral labial vestibular MMA incisions is physiologically shielded from the UA by the underlying bony structures and, thus, is confined to the facial soft tissues. Although this extraosseous edema may produce pronounced facial swelling, it does not extend to or compromise the UA, which is more patent at the moment of skeletal advancement, ie, like the immediate UA opening produced by a cardiopulmonary resuscitation jaw-thrust maneuver. Furthermore, rigidly fixated MMA osteotomy segments, unlike pharyngeal soft tissues that are operated on, do not move and, therefore, are not painful during the normal functions of swallowing, coughing, and vocalization. Maxillary and mandibular branches of the trigeminal (sensory) nerve, encased within bony canals, that innervate the intraoral and lower facial tissues are typically surgically traumatized or stretched, resulting in numbness, rather than severe pain.

The primary functions of the maxilla and mandible, speech articulation and mastication, are determined by their interrela-
tionship and enhanced by a harmonious dental occlusion. Except for isolated mandibular horizontal deficiency with severe class II malocclusion characterized by pronounced incisal overjet (none seen in this series), mandibular advancement requires synchronous maxillary advancement to maintain a functional occlusion. Orthodontic therapy was performed in four patients to decompensate severely recumbent maxillary incisors to maximize mandibular advancement. However, in most patients with malocclusions who refused orthodontics, as well as in the patients with relatively normal occlusions, the maxilla and mandible were advanced the same amounts, maintaining the same presurgical occlusal relationship.

Adjunctive nonpharyngeal surgical procedures (described under “Surgical Techniques”) were performed concomitantly with MMA because these additional sites could be operated on safely with minimal risk of postoperative edema-induced airway embarrassment. T/A, UPPP, laser-assisted uvuloplasty, palatopharyngoglossoplasty, uvulopalatopharyngoglossoplasty, radiofrequency volumetric tissue reduction, laser midline glossectomy, or lingualplasty could conceivably be performed with MMA, but only if immediate tracheostomy, endotracheal tube (ETT) intubation, or nCPAP or bilevel pressure ventilation were to be used for several days during the resolution of postoperative pharyngeal edema. In this latter situation it would be difficult to know what pressures would be therapeutic—possibly requiring a continuous titration, eg, auto-adjusting continuous positive airway pressure—with increased risk of hemorrhage caused by barotrauma of the recently operated on pharyngeal tissues. Thus, pharyngeal soft-tissue surgery was not attempted simultaneously with MMA.

**Surgical Techniques**

The author, always assisted by another surgeon, operated on all patients with hypotensive general anesthesia in a hospital operating room. A LeFort I osteotomy (LF) with allogeneic bone graft and rigid internal fixation using custom-bent bone plates was performed for maxillary advancement with anterosuperior tightening of the soft palate and to enlarge the velopharynx. Bilateral sagittal split ramus osteotomies (BSSRO) with rigid internal and/or maxillomandibular fixation was performed for mandibular advancement. An anterior inferior mandibular osteotomy (AIMO) was performed for additional advancement of the genial tubercles with attached tongue-related (eg, genioglossus) and suprahypopharynx muscles for additional advancement of the tongue base and an indirect hyoid suspension. The AIMO is a separate and distinct osteotomy, performed via incisions not connected with the BSSRO. Nevertheless, BSSRO and AIMO together are additive in terms of “doubling” the anterior inferior mandibular with genial tubercle advancement for oropharyngeal enlargement.

The AIMO used as an integral component of MMA is a modification of previously reported similar osteotomies. New trapezoid-shaped osteotomy, which preserves chin contour and muscle attachments, is made with one continuous bony cut and no sharp angles so as to minimize risk of anterior mandibular fracture. The cut is directed superiorly toward the lingual cortex to ensure capture of the entire genial tubercles, but yet staying inferior labially to avoid cutting teeth apices. Physiologic (indirect) hyoid suspension via anterosuperior tension on the intact suprahypopharyngeal musculature obviates additional hyoid surgery, eg, hyoid myotomy for suspension with fascia lata or hyoid fixation to the thyroid cartilage. The distal segment is advanced maximally the full thickness of the bicornical region and secured with interosseous wire fixation with a resultant protrusive chin and minimal bony contact that warrants concomitant (1) allogeneic cancellous bone grafting to prevent soft-tissue ingrowth between the osteotomy segments and to promote a complete bony union; and (2) reduction osteoplasty of the distal segment’s labial cortex for a tension-free soft-tissue closure to prevent wound dehiscence and infection.

In addition to LF, BSSRO, and AIMO, which were performed concomitantly, when indicated (Table 1). Septoplasty and turbinate reduction were performed in 28 and 26 patients with septal deviation and turbinate hypertrophy, respectively. Enlargement of the piriform rims for additional relief of nasal obstruction, as well as removal of polyoid antral tissues (for biopsy) in 13 patients with chronic sinus problems were also performed with the maxilla down-fractured. Cervicofacial subcutaneous lipoctomy was performed in 26 cases via a syringe-aspiration technique. Because weight loss may reduce OSA by a proportionate reduction of adipose tissue affecting the airway, selective removal of bulky adipose tissue from the cervicofacial area might reduce the weight of these tissues against the underlying tongue-related muscles, which are in a state of flaccid paralysis during sleep and, thus, might reduce the extraluminal soft-tissue forces of collapse against the posterior pharyngeal walls, particularly when supine. In one patient, bilateral anterior mandibular lingual tori were removed to increase tongue space in the mouth floor.

**Postsurgical Management and Evaluation**

Because the UAAs were immediately more patent after MMA and to minimize potential ETT-induced glottic edema, early ETT extubation was accomplished, even in the setting of maxillomandibular fixation, usually in the operating room before patient transport to the recovery area. A long-acting local anesthetic, 0.5% bupivacaine with 1,200,000 epinephrine was injected intraorally postsurgically for wound hemostasis and to minimize the need for centrally-acting opiate or opioid narcotics, which can cause respiratory depression. Patients were carefully monitored, including continuous pulse oximetry with paper printout recordings, in an ICU environment while weaning off supplemental oxygen onto room air. Nurses and respiratory therapists were instructed to allow minor desaturations of <90% on room air and without nCPAP, provided the lower limit established for each individual patient was significantly higher than preoperative diagnostic PSG LSAT, to determine the early postoperative OSA status to be expected in the patient’s home the following nights.

Patients were followed up with weekly visits at the author’s office for >3 months. Nutritional counseling was provided for liquids the first 2 weeks, followed by a strict nonchewing diet for 2 months. Controlled weight reduction was encouraged and often expedited by maxillomandibular fixation in the morbidly obese patients. Overnight PSG was performed by the referring sleep facility at approximately 7 weeks postsoperatively. Additional PSG at 6 months postoperatively and annually thereafter was encouraged. BP, weight, clinical examination, panoramic and cephalo-

<table>
<thead>
<tr>
<th>Table 2—Demographics, Orthodontics, and Hospital Stay*</th>
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<tbody>
<tr>
<td>Characteristics</td>
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<tr>
<td>Age, yr</td>
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<tr>
<td>Gender</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Orthodontic therapy cases</td>
</tr>
<tr>
<td>Hospital stay, No. of nights</td>
</tr>
</tbody>
</table>

*Values given as No. or mean (SD) (range).
metric radiographs, and the patient’s symptoms were recorded by the same methods described above (in the presurgical evaluation) during the office visit closest to (usually the day after) each PSG obtained. Statistical analysis was performed using the paired Student’s t test. A p value, 0.05 determined statistical significance. Mean values are presented with SD.

Results

Demographic data of the 50 MMA patients are summarized in Table 2. Forty-four patients were male and six were female. The mean age was 42.7 years, with a range of 19 to 66 years. The postoperative data presented in Tables 3 – 6 were obtained at the longest complete follow-up evaluation. The mean length of follow-up was 5.2 months, with the longest at 4 years 3 months postoperatively. PSG results are summarized in Table 3 and illustrated in Figures 4 and 5. Postoperative results (n = 50) show significant improvement in all variables of AI, AHI, LSAT, number of desaturations, and percent (% stage 3 & 4 sleep, percent rapid eye movement sleep, and percent sleep efficiency as compared with preoperative data (n = 50), with success similar to that of nCPAP (n = 42). All 50 patients were successful responders to MMA based on the criteria of an LSAT > 80%, an AHI < 15, and AI < 5 or a > 60% reduction in AHI and AI, with all patients having an AI < 10, for a success rate of 100%.

OSAS-related symptoms, as subjectively reported by these patients, are shown in Table 4. Patients with preoperative EDS (n = 50), memory loss (n = 34), and impaired concentration (n = 28) all reported amelioration of these symptoms. Snoring was eliminated in 44 of 50; depression, moodiness, and/or irritability was reduced in 36 of 39; and morning headaches were alleviated in 28 of 29 patients. BP and body mass index (BMI) data are stated in Table 5. Both systolic and diastolic pressures improved significantly, lowering 15.0 and 9.6 mm Hg (difference of mean values), respectively (n = 50). BMI (n = 50) also improved significantly.

Cephalometric results (n = 50) are summarized in Table 6. The average amount (difference of mean values) of maxillary (via LF) and mandibular (via BSSRO solely, without AIMO) advancement, as measured by SNA and SNB, was 7.4° and 6.9°, respectively. GO-POG showed an average advancement of the genial region (via the additive affects of AIMO together with BSSRO) of 14.4 mm. PAS enlarged considerably postoperatively, both at ETV (6.5 mm) and during the MM (4.9 mm). PAS was more narrow during the MM, consistent with hypopharyngeal collapse induced by negative inspiratory forces generated against an occluded UA. PNS-P shortened slightly, both at ETV (1 mm) and during the MM (1.3 mm), because of anterosuperior tightening of the soft palate (via LF). MP-H results show the hyoid moved superiorly postoperatively, consistent with anterosuperior tension on the suprahyoid strap muscles attached to the anterior inferior mandible (via AIMO in combination with BSSRO).

Discussion

A comprehensive review of the OSA surgery literature33 showed that UPPP has been one of the most commonly performed, yet one of the least effective, surgeries for OSAS. Using the criteria of postoperative AHI < 20 or AI < 10 or > 50% reduction in either value, 137 of 337 patients from 37 independent

Table 3—PSG Results*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative</th>
<th>nCPAP</th>
<th>Postoperative†</th>
<th>p Value‡</th>
<th>p Value§</th>
</tr>
</thead>
<tbody>
<tr>
<td>AI</td>
<td>34.5 (27.9)</td>
<td>2.0 (4.0)</td>
<td>1.0 (1.9)</td>
<td>0.001</td>
<td>0.078</td>
</tr>
<tr>
<td>AHI</td>
<td>59.2 (28.4)</td>
<td>5.4 (6.8)</td>
<td>4.7 (5.9)</td>
<td>0.001</td>
<td>0.306</td>
</tr>
<tr>
<td>LSAT, %</td>
<td>72.7 (13.6)</td>
<td>88.6 (6.3)</td>
<td>88.6 (3.9)</td>
<td>0.001</td>
<td>0.450</td>
</tr>
<tr>
<td>No. of desaturation events &lt; 90%</td>
<td>118.8 (160.7)</td>
<td>2.4 (4.7)</td>
<td>6.6 (12.2)</td>
<td>0.001</td>
<td>0.022</td>
</tr>
<tr>
<td>% Stage 3 &amp; 4</td>
<td>6.2 (13.6)</td>
<td>10.1 (14.1)</td>
<td>9.0 (13.6)</td>
<td>0.037</td>
<td>0.210</td>
</tr>
<tr>
<td>% REM</td>
<td>9.9 (7.7)</td>
<td>23.1 (19.5)</td>
<td>16.5 (7.4)</td>
<td>0.001</td>
<td>0.036</td>
</tr>
<tr>
<td>Sleep efficiency, %</td>
<td>83.2 (11.9)</td>
<td>83.1 (16.7)</td>
<td>86.7 (9.9)</td>
<td>0.054</td>
<td>0.139</td>
</tr>
</tbody>
</table>

*Values given as mean (SD), unless otherwise indicated. REM = rapid eye movement sleep. †Obtained at 5.2 months (mean) postoperatively. ‡Postoperative vs preoperative. §Postoperative vs nCPAP.

Table 4—Subjective Symptoms

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Preoperative</th>
<th>Postoperative*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive daytime sleepiness</td>
<td>50</td>
<td>0</td>
</tr>
<tr>
<td>Snoring</td>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>Depression, moodiness, irritability</td>
<td>39</td>
<td>3</td>
</tr>
<tr>
<td>Memory loss</td>
<td>34</td>
<td>0</td>
</tr>
<tr>
<td>Morning headaches</td>
<td>29</td>
<td>1</td>
</tr>
<tr>
<td>Impaired concentration</td>
<td>28</td>
<td>0</td>
</tr>
</tbody>
</table>

*Obtained at 5.2 months (mean) postoperatively.
dent case series were successful responders, for a combined success rate of only 41%. Furthermore, surgery directly on the pharyngeal tissues, eg, soft palate, may produce life-threatening postoperative UA edema and permanent disfigurement with functional impairment. Tracheotomy bypasses the entire UA with all its potential sites of obstruction but has significant psychosocial and medical management problems and, thus, is no longer recognized as an ideal treatment of OSAS in relatively healthy ambulatory patients. Excluding tracheotomy, MMA, which opens the entire velo-orohypopharynx via an extrapharyngeal operation with minimal risks of UA embarrassment or pharyngeal dysfunction, is the most effective surgical treatment of OSAS.

Riley et al36 reported the largest series of maxillo-mandibular osteotomies (MMO), in which 89 of 91 OSAS patients were successfully treated, based on postoperative AHI < 20 or > 50% reduction in AHI, for a success rate of 98%. However, it is perhaps misleading that MMO was labeled a phase II procedure in that 67 of the 91 patients did not participate in phase I of their two-phase protocol. Waite et al35 reported improvement in 22 of 23 patients, based on a mean postoperative AHI of 15, for a success rate of 96%, in which MMA was performed as a primary procedure, often in combination with adjunctive procedures. Hochban et al34 reported a 95% success rate, based on relatively rigid criterion of postoperative AHI < 10 in a series of 21 consecutive OSAS cases in which MMA was performed as a definitive primary surgery, without any adjunctive procedures. In Hochban’s series of carefully selected cases, which included only healthy nonobese patients with specific craniofacial skeletal deformities and pharyngeal narrowing, a “stepwise” algorithm of staged surgical procedures was “not justified.”

A difficult diagnostic dilemma is deciding when and how to stage surgery in patients with diffusely

Table 5—BP and BMI*

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative</th>
<th>Postoperative†</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic</td>
<td>138.9 (15.6)</td>
<td>123.9 (13.8)</td>
<td>0.001</td>
</tr>
<tr>
<td>Diastolic</td>
<td>89.8 (12.3)</td>
<td>80.2 (11.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>BMI</td>
<td>30.7 (4.5)</td>
<td>28.6 (3.9)</td>
<td>0.001</td>
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</tbody>
</table>

*Values given as mean (SD), unless otherwise indicated.
†Obtained at 5.2 months (mean) postoperatively.

Table 6—Lateral Cephalometric Analysis*

<table>
<thead>
<tr>
<th>Cephalometric Analysis</th>
<th>Preoperative</th>
<th>Postoperative†</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNA, degrees</td>
<td>79.0 (4.2)</td>
<td>86.4 (4.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>SNB, degrees</td>
<td>74.7 (4.1)</td>
<td>81.6 (4.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>GO-POG, mm</td>
<td>72.1 (4.7)</td>
<td>86.3 (5.7)</td>
<td>0.001</td>
</tr>
<tr>
<td>PNS-P, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETV</td>
<td>37.9 (6.7)</td>
<td>36.9 (6.0)</td>
<td>0.003</td>
</tr>
<tr>
<td>MM</td>
<td>30.6 (6.8)</td>
<td>38.3 (6.4)</td>
<td>0.001</td>
</tr>
<tr>
<td>MP-H, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETV</td>
<td>24.3 (5.8)</td>
<td>22.4 (6.0)</td>
<td>0.002</td>
</tr>
<tr>
<td>MM</td>
<td>37.1 (10.6)</td>
<td>33.7 (9.0)</td>
<td>0.003</td>
</tr>
<tr>
<td>PAS, mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ETV</td>
<td>5.1 (2.4)</td>
<td>11.6 (3.4)</td>
<td>0.001</td>
</tr>
<tr>
<td>MM</td>
<td>0.8 (1.5)</td>
<td>5.7 (3.9)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

*Values given as mean (SD), unless otherwise indicated.
†Obtained at 5.2 months (mean) postoperatively.
complex or multiple sites of disproportionate UA anatomy. One approach is to perform certain procedures in a stepwise manner or particular order according to a methodical protocol, e.g., UPPP first, then if unsuccessful, a hyoid suspension, then if that fails, a mandibular advancement, and so on. However, this may result in unnecessary additional surgery, which may be painful, dysfunctional, expensive, nontherapeutic, and, ultimately, a deterrent for patients to seek definitive surgical treatment. Riley et al. reported an overall success rate of only 61% (145 of 239 patients) for phase I surgery, which consisted of UPPP and/or genioglossus advancement with hyoid myotomy suspension. Furthermore, only 24 of the 94 patients who had failed phase I surgery elected to proceed with phase II of their protocol, even though MMO was known to be highly successful.

In this series, the approach and methodology of surgical treatment planning was site-specific: the selection of specific surgical procedures was based primarily on each individual patient’s sites of disproportionate UA anatomy. MMA was performed first for diffusely complex or multiple sites of disproportionate UA anatomy to enlarge and stabilize the velo-oropharyngeal airway to either (1) definitively treat the OSAS and, thus, eliminate additional unwarranted surgery or (2) reduce the risk of postoperative edema-induced UA embarrassment caused by secondary pharyngeal procedures, if still necessary in the setting of clinically significant residual OSAS. Unlike other less successful procedures, which focus on particular anatomic structures or segmental areas by operating within the UA, MMA addresses the entire velo-oropharyngeal airway by operating outside of the pharyngeal airway tissues. MMA was not confined by a staging algorithm and reserved only for the most severe OSAS cases as a last resort when all other surgery had failed; nor was it restricted to a set of craniofacial skeletal characteristics. Rather, it was also performed in some patients with mild OSAS, as well as in some who did not exhibit craniofacial skeletal deformities such as retrognathia.

The results show that MMA, often performed concomitantly with adjunctive nonpharyngeal procedures, was a safe and successful primary single-staged operation—even for those with morbid obesity and coexisting lateral pharyngeal tonsillar hypertrophy and/or dysmorphic soft palates with medially displaced tonsillar pillars. T/A and/or UPPP were not required subsequently in any of the 24 or 40 patients in whom T/A or UPPP, respectively, had not been performed before MMA (Table 1). Nevertheless, those patients were informed that with advancing age and/or weight gain, the UA could progressively narrow to such a degree as to necessitate T/A and/or UPPP as second-stage surgery if applicable conservative therapies, e.g., nCPAP, were not tolerated, refused, or unsuccessful. In the setting of variable complex UA heterogeneity of the OSAS population referred for MMA, particularly in those with scar distortion from prior, often dissimilar surgery in which anatomically similar cohorts are not readily discernible, it is unknown how each individual procedure contributed to the results in this, as well as other, uncontrolled clinical case series.

The surgical principles and techniques introduced in this series (e.g., incorporation of the innovative AIMO with BSSRO and LF as an integral component of MMA, the understanding of which and when nonpharyngeal adjunctive procedures can be performed safely with MMA vs staged operations, early ETT extubation, and avoidance of narcotic analgesics) may have served to hasten postoperative recovery and convalescence, with minimal morbidity and no mortality. Waite et al. and Riley et al. reported mean hospital stays of 7.8 and 2.4 days, respectively. The results (Table 2) in this series show a mean hospital stay of 1.6 days: no patient required a hospital stay of >2 days; and 21 of the last 23 patients were discharged home on the first postoperative day. There were no episodes of postoperative hemorrhage or edema-induced UA embarrassment, and postoperative nCPAP was not used in any patient. Postoperative discomfort was typically minimal. Those who experienced residual neurosensory deficits, the most common complication of MMA, reported significant resolution, which did not adversely affect their quality of life. MMA was not disfiguring, e.g., no facial scars because all incisions were intraoral. On the contrary, all patients, especially those with preoperative craniofacial skeletal deformities such as retrognathia, accepted changes in facial appearances, predicted by preoperative computer imaging, as aesthetically pleasing. All resumed their normal lifestyles, usually returning to work full-time within 2 weeks postoperatively, with substantial improvement in their preoperative OSAS-related signs and symptoms.

The results (Table 5) show that weight loss and a lowering of systolic and diastolic BP occurred after MMA. Riley et al. reported that 7 of 13 MMO patients no longer required antihypertensive medicines. Although OSAS can exacerbate and perhaps cause some cases of hypertension, these results suggest that resolution of OSAS after MMA may normalize hypertension in some cases. However, the hemodynamic significance of these data is unknown. Initial weight reduction, particularly in the morbidly obese, resulted primarily from controlled dietary restrictions, whereas weight loss maintenance after...
restoration of normal masticatory function may have resulted, in part, from increased metabolic rates associated with the resolution of OSAS-related EDS. It is unknown to what extent the weight loss contributed to the PSG results and whether those patients might eventually gain or regain weight and, therefore, experience progressive worsening of any residual OSAS. Furthermore, the relatively low mean BMI in this series may not represent the true general OSAS population. Other limitations of the results are that recording the patients’ stated symptoms (Table 4) was subjective and qualitative; and that potential variability in the methodology of data collection and interpretation by different sleep facilities and physicians existed.

The PSG results also support the use of cephalometry, although obtained in awake erect patients, as a reliable diagnostic adjunct to clinical examination. Although only ETV PAS < 9 mm was used as an MMA inclusion criterion, the cephalometric data (Table 6) show that the maxilla and mandible advanced, the hyoid elevated, the soft palate tightened, and, most important, the oropharynx enlarged postoperatively. In comparison with other reputable diagnostic modalities (eg, invasive nasopharyngolaryngoscopy, intraluminal pressure transducers, somnoflouroscopy, CT scans, and MRI), cephalometry is comfortably noninvasive, safe with minimal radiation exposure, easy to perform in an outpatient setting, inexpensive, and with results that are objective, standardized, and reproducible.

Two cephalometric modifications have been introduced. First, PAS was selected as the most critical measurement in that it quantitated (in a two-dimensional plane viewed laterally) the (velo)-orohypopharyngeal opening and, thus, was measured at the most narrow level of oropharyngeal anteroposterior collapse, rather than at a level determined by skeletal landmarks. Second, pharyngeal volumetric changes associated with different phases of respiration were standardized by obtaining two films—one at ETV and the other during MM, to simulate pharyngeal soft-tissue collapse associated with negative inspiratory forces generated during OSA events. The results show that PAS (1) enlarged significantly after MMA in all patients and (2) was always larger at ETV than during an MM, which suggests that the measurement of PAS should be standardized for breathing phases.

The relatively short-term success of MMA in this series may equate with a definitive cure. Progressive worsening of OSAS in adults may be caused, in part, by aging of anatomically disproportionate pharyngeal soft tissues, which gradually lose neuromuscular tone, leading to increasing floppiness and collapsibility. In addition to structural enlargement of the pharyngeal lumen, MMA via tightening of the pharyngeal soft tissues attached to or suspended from the advanced skeletal structures may also enhance or rejuvenate neuromuscular tone of the anterior pharyngeal dilator musculature, such as the tensor palatini and genioglossus, to both open and stabilize the entire velo-orohypopharyngeal airway. Although these rejuvenated tissues will continue to lose neuromuscular tone with advancing age, advancement LF and BSSRO, which have been performed routinely and successfully for half a century (eg, as orthognathic surgery) do not relapse significantly, in that osteotomies, once healed to a bony union, are relatively stable. Hence, the surgically improved or corrected UA may be sufficiently patent and stable as to simulate an anatomically and physiologically normal UA, which can withstand normal soft-tissue aging without redeveloping OSAS.

MMA as a potential definitively successful primary single-staged surgical treatment of OSAS, particularly when performed in a relatively young OSAS population, may result in a significant reduction in OSAS-related health risks (eg, hypertension, cardiovascular dysrhythmias, stroke, and myocardial infarction, as well as EDS-induced injuries such as motor vehicular accidents and neuropsychiatric disorders such as depression and cognitive dysfunction), which, when projected over a normal lifetime, should represent a considerable financial savings on the health-care system. The one-time costs of early MMA is probably far less expensive than multiple less successful operations (with multiple hospitalizations), or even a lifetime of nCPAP with its associated costs of repeat sleep studies, eg, retractions, equipment maintenance and replacement, technical support, and compliance counseling.

CONCLUSION

This clinical series of 50 consecutive OSAS patients reports a 100% success rate of MMA, often performed concomitantly with adjunctive nonpharyngeal procedures, as a safe primary single-staged type of site-specific surgical treatment for selected patients with diffusely complex or multiple sites of disproportionate velo-orohypopharyngeal anatomy. Although there is variation in the OSAS literature as to what specific criteria determine success, these results support previously reported data that MMA is the best surgical alternative to tracheostomy, with a therapeutic efficacy equal to nCPAP. The long-term validity and significance of these results, as well as the innovative techniques and postulates presented, are unknown. Additional studies with larger numbers of patients and longer follow-up are warranted.
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APPENDIX

PSGs were performed and interpreted at the following facilities, which are listed alphabetically: Astwani Neurology, P.C., Sleep Disorders Lab, Dublin, GA; Athens Regional Medical Center, Neurodiagnostics and Sleep Lab, Athens, GA; Cape Fear Memorial Hospital, Inc., Sleep Disorders Center, Wilmington, NC; Cobb Hospital, Sleep Center, Austell, GA; Dekalb Medical Center, Sleep Disorders Center, Decatur, GA; Dunwoody Medical Center, Sleep/Wake Center, Atlanta, GA; Floyd Medical Sleep Disorders Center, Rome, GA; Georgia Baptist Medical Center, Atlanta Center for Sleep Disorders, Atlanta, GA; Kennestone Hospital, Sleep Disorders Center, Marietta, GA; National Sleep Dynamics, Woodstock, GA; Neurology Associates, Neurodiagnostic and Sleep Disorders Center, Macon, GA; N. Broward Medical Center, Sleep Disorders Center, Pompano Beach, FL; Northlake Regional Medical Center, Sleep Disorders Laboratory, Tucker, GA; Northside Hospital, Sleep Disorders Center, Atlanta, GA; Piedmont Hospital, Sleep Laboratory, Atlanta, GA; Redmond Regional Medical Center, Sleep Disorders Center, Rome, GA; Sleep Disorders Center of Georgia, Atlanta, GA; and Staten Island University Hospital, Sleep Disorders Center, Staten Island, NY.

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