Obstructive sleep apnea (OSA) is a common primary sleep disorder that occurs in up to 9% of women and 24% of men ages 30 to 60. OSA is a condition characterized by repetitive partial or complete upper airway collapse during sleep. The ensuing reduction in airflow leads to hypoxia and subsequent arousals from sleep, producing sleep deprivation. The effect that OSA has on general health and wellbeing has been well documented. OSA is associated with hypertension, cardiovascular disease, metabolic syndrome, stroke, and possible premature death. There is a reduction in quality of life, including diminished social function and an increased rate of motor vehicle accidents. Deficits in neuropsychological functioning occur, including diminished vigilance, executive functioning, and motor coordination.

Nasal continuous positive airway pressure (CPAP) is considered the first and most effective form of therapy to treat OSA in adults. Significant improvements in objective and subjective sleepiness, quality of life, and cognitive function have been demonstrated following the use of CPAP. Although CPAP has been shown to be highly effective, virtually eliminating OSA, long-term acceptence and adherence to therapy are relatively low. When CPAP adherence is defined as greater than 4 hours of nightly use, 46% to 83% of patients with OSA have been reported to be nonadherent to treatment. CPAP also requires lifetime nightly use.

Maxillomandibular advancement (MMA) is an orthognathic surgical procedure that has been used to manage OSA in individuals who are non-compliant with CPAP therapy. MMA is a site-specific procedure, performed for the purpose of creating an enlarged posterior airway space at multiple anatomic levels, including the nasopharynx, oropharynx, and hypopharynx. MMA involves surgical facial advancement by performance of concomitant maxillary and mandibular osteotomies (Fig. 1). MMA has been shown to significantly improve OSA, with reported short-term success rates ranging from 75% to 100%. It is considered to be comparable in clinical effectiveness to CPAP. Preliminary reports indicate that much of the short-term benefit of MMA may be maintained a long-term basis.

Although some surgeons have approached MMA as a stand-alone procedure, others have advocated a staged approach to surgery. In the staged protocol, a patient diagnosed with OSA will first undergo phase 1 surgery, which includes uvulopalatopharyngoplasty (UPPP) and possibly other adjunctive procedures, such as genioglossal advancement. If phase 1 surgery is not effective, the patient would proceed to phase 2 surgery, consisting of MMA.
Overall the success rates for the staged protocol are high and yield reductions in sleep-disordered breathing and symptomology and high patient satisfaction.\textsuperscript{23,28} The effectiveness of the individual stages of therapy, however, differs significantly. Although phase 2 surgery (MMA) has yielded success rates ranging from 93\% to 100\%,\textsuperscript{23,28} the success rates for phase 1 surgery have varied between 22\%\textsuperscript{29} and 80\%.\textsuperscript{30} Overall, success rates for phase 1 are similar to those reported for isolated UPPP. Currently it is unknown whether staged surgery provides any benefit over isolated MMA. Recently, another form of staged surgery has been reported for treatment of patients with concomitant OSA and a maxillofacial skeletal deformity.\textsuperscript{31,32} Distraction osteogenesis of the maxilla or mandible is performed as the first stage of therapy, followed by MMA as the second stage of treatment.

The main objective of this article is to provide practical guidelines for evaluating and managing OSA patients by MMA. The presentation will focus on MMA for adults, as this is the most common and clinically effective application of MMA to treat OSA.

**PATIENT EVALUATION**

The purpose of the initial surgical consultation is to confirm a diagnosis of OSA and to determine if the patient is a candidate for MMA. Commonly, the patient has been evaluated already by a sleep specialist and has undergone objective evaluation, by polysomnography, to establish a diagnosis of OSA. Furthermore, it is likely that the patient already has attempted to use CPAP. If this initial evaluation and treatment have occurred, the surgeon should confirm the findings; otherwise an overnight sleep study will need to be obtained to objectively establish a diagnosis of OSA before initiating any treatment. The patient also should be questioned about previous treatment of OSA and past response to therapy. This should include both the patient’s subjective and objective (eg, post-treatment polysomnography [PSG]) response to therapy. Patients also should be questioned about any treatment-related adverse outcomes or complications of previous therapy.

The MMA surgical consultation visit combines the components of both a sleep evaluation for OSA and a routine orthognathic surgery consultation for correction of maxillofacial skeletal deformities (MSDs). Major components of the sleep evaluation include a comprehensive history, clinical examination, imaging studies, and sleep study. Although similar orthognathic surgical techniques are used to treat OSA, there are multiple important differences that exist between MSD and OSA patients. It is essential for the treating surgeon to understand these differences to facilitate effective and safe surgical care for the OSA patient. Important differences between the two groups include: goals of therapy, patient profile, underlying medical conditions, and magnitude of surgical movement. Most MSD patients are adolescents or young adults in good general health. In contrast, the typical OSA patient is a middle-aged, obese male, with significant co-morbid medical conditions. The OSA patient has anatomic abnormalities of the upper airway, and larger surgical movements (10 mm or greater) of the maxilla and mandible routinely are required to effectively treat obstruction of the upper airway during sleep.

**Symptoms and History**

A thorough sleep-specific history and comprehensive medical history are essential components of the evaluation. Important elements of the sleep history include: presence and character of snoring, level of daytime sleepiness, self-reported or observed nocturnal episodes of breathing cessation, and the perceived quality and quantity of sleep. The Epworth Sleepiness Scale (ESS) is an eight-item questionnaire that commonly is used to subjectively assess the patient’s level of daytime sleepiness.\textsuperscript{33,34} The patient also may relate various symptoms related to a decreased quality of life, such as poor job performance, decreased ability to concentrate, memory loss,
and fatigue. The Calgary Sleep Apnea Quality of Life Index (SAQI)\textsuperscript{35,36} and the Functional Outcomes of Sleep Questionnaire (FOSQ)\textsuperscript{37} are two valid and reliable sleep-specific quality-of-life questionnaires that may be used.

A comprehensive medical history must be obtained, because OSA is associated with a wide spectrum of medical conditions that may affect surgical treatment and the patient’s overall health. If there is presence or a suspicion of a significant medical condition, it will be important to obtain indicated consultations to establish the status of the disease, determine if the patient is a candidate for surgery, determine what can be done to optimize the patient's condition before surgery, and to obtain recommendations for intraoperative and postoperative management of the patient in regard to each significant medical condition. This assessment is essential to determine the risk/benefit ratio for surgical intervention. One of the most common medical conditions is hypertension, and it is important to optimize blood pressure preoperatively, because patients typically will have modified hypotensive anesthesia administered during surgery.

**Physical Examination**

A comprehensive head and neck examination should be performed for each patient. This physical examination should include measurement of the patient’s body mass index (BMI), resting blood pressure, and neck circumference. The OSA clinical evaluation is very similar to a routine orthognathic surgery evaluation, with special attention directed to potential sites of upper airway obstruction.

It is important to carefully perform all aspects of the routine orthognathic surgery baseline clinical examination to facilitate surgical treatment planning and to determine if presurgical orthodontic care would be of benefit (Fig. 2). The clinical examination should include assessment of temporomandibular joint function and mandibular mobility, occlusion, status of the dentition, neurosensory function, and facial esthetics. For most middle-aged adults, adaptations in the dentition have occurred (eg, wear and restorations) to maximize occlusal relations of the teeth, and the patient may not benefit significantly from orthodontic therapy before surgery.

Important augmented components of the upper airway examination include: inspection of the nasal cavity to determine sites of possible obstruction and description of the size, character, and function of the tonsils, soft palate, lateral and posterior pharyngeal walls, and base of tongue. In addition to direct visual examination, endoscopic examination (fiberoptic nasopharyngoscopy) of the upper airway may be of benefit to aid in the visualization of the upper airway and identification of the site(s) of pharyngeal collapse and obstruction.

**Imaging**

A standardized lateral cephalometric radiograph should be taken, with the patient positioned in adjusted natural head position with the mandible in centric relation and the facial soft tissues in repose (see Fig. 2C). A cephalometric analysis then is performed to assist in the identification of potential sites of upper airway obstruction (posterior airway space) and to characterize craniofacial morphology. If the patient proceeds to surgery, the cephalometric radiograph will be used for both surgical treatment planning and assessment of changes in the facial skeleton and upper airway that occur as a result of surgery. The major limitation of the cephalometric radiograph is that obtaining the radiograph in an upright and awake position may not reflect the anatomic characteristics of the upper airway accurately when the patient is sleeping in a supine position.

Facial and intraoral digital photographs should be taken to document the clinical examination, and these may be linked to the lateral cephalometric radiograph to develop computerized surgical prediction images (see Fig. 2). This is important, because the magnitude of the surgical movement (10 mm or more of facial advancement) may have a significant impact on facial appearance. Additionally, the prediction images allow the patient to see the type (not necessarily the actual result) of facial esthetic changes that may occur as a result of surgery.

Computed tomography (CT) imaging has not been used routinely for the surgical treatment of adults with OSA. Because three-dimensional CT imaging recently has become available in an outpatient office setting (eg, cone beam technology), however, use of this technology may be beneficial. CT has the ability to visualize the entire upper airway and can demonstrate the association between three-dimensional changes in the facial skeleton as a result of surgery and the upper airway.  

**Indications for MMA**

Once the evaluation has been completed, it can be determined if the patient is a surgical candidate. The indications for MMA are as follows:

Significant OSA (apnea + hypopnea index greater than 15) as objectively diagnosed by PSG, with concomitant symptoms
Failure of CPAP because of nonacceptance or poor adherence to therapy
Craniofacial abnormalities (eg, children with micrognathia)
Ability to undergo surgical treatment (consideration of concomitant medical conditions)

It is also important to determine if the patient is a candidate for other forms of treatment. For example, if the patient has mild OSA, oral appliance therapy could be considered as a viable nonsurgical form of therapy. Bariatric surgery may be considered for the extremely obese patient (BMI greater than 35). Additionally, it should be determined if the patient is a candidate for surgical-orthodontic care, although this is uncommon.

**Presurgical Treatment Planning**

Because of the combined maxillary and mandibular movement and the large magnitude of facial advancement, it is recommended that a facebow transfer and mounting of dental casts on a semi-adjustable articulator be used to provide an accurate assessment of the anatomic position of the maxilla and mandible. A model platform then is used to accurately simulate the planned three-dimensional movements of the maxilla and mandible. The final surgical plan will be based upon the patient’s individual findings (eg, presence or absence of a pre-existing dentoskeletal deformity), but generally a minimum of 10 mm of mandibular advancement is recommended to produce the most improvement in OSA. In the patient who does not undergo concomitant

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**Fig. 2.** Frontal facial (A), lateral facial (B), lateral cephalometric (C), and intraoral (D–H) pretreatment images of 59-year-old man with severe obstructive sleep apnea (AHI = 45), decreased posterior airway space, and concomitant maxillofacial skeletal deformities (mandibular retrognathia, transverse maxillary hypoplasia, and transverse mandibular hypoplasia). *(Modified from 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):284; with permission.)*
orthodontic care, the maxilla will move an equivalent distance to the mandible, to maintain the patient’s pre-existing occlusal relations.

Following completion of the model surgery, an interim splint is constructed using the advanced maxillary cast referenced to the uncut mounted mandibular cast (Fig. 3). The interim splint will facilitate accurate anteroposterior and transverse positioning of the maxilla, because the author’s preferred sequence of surgery is to perform the maxillary surgery before the mandibular surgery. If the patient has an intact, stable dentition before surgery, it is unlikely that a final surgical splint will be necessary, because the patient can be placed in a stable, reproducible occlusion following performance of the maxillary and mandibular osteotomies.

SURGICAL TREATMENT

Anesthetic and Medical Management Considerations

It is very beneficial for the surgeon and attending anesthesiologist to discuss management of the airway, anesthetic techniques, and medical management of the patient before surgery to minimize the chance of perioperative complications. Fiberoptic nasopharyngeal intubation (possibly awake) with a Ring, Adair, Elwin tube provides a secure airway and ample access to the surgical field. A tracheotomy is not routinely indicated to secure the airway, but it is recommended where there is concern about the ability to safely perform nasopharyngeal intubation or where long-term postoperative airway management is required. Proper patient positioning and padding (eg, gel pads) are important to reduce the risk of pressure ischemia, which may be increased because of obesity, use of hypotensive anesthesia, and length of the procedure. Judicious intravenous fluid administration and use of intraoperative corticosteroids are helpful to diminish postoperative facial and parapharyngeal edema.

It is advantageous to use a modified hypotensive anesthetic technique during performance of the maxillary and mandibular osteotomies, to reduce blood loss and to improve visualization of the surgical field. The ability to achieve this level of reduction in blood pressure depends upon the patient having a near-normal blood pressure preoperatively and underscores the importance of adequately treating any hypertension that was identified at the consultation visit. In addition to hypertension, patients with OSA may have a history of ischemic heart disease, myocardial infarction, and possibly stroke. In these individuals, it is especially important to maintain adequate organ perfusion. Although it is uncommon that blood transfusion will be necessary intraoperatively, the patient is presented the option of donating 2 units of autologous blood before surgery, so blood will be immediately available if needed.

Surgical Technique and Sequencing of Care

A LeFort 1 total maxillary osteotomy followed by bilateral sagittal split ramus osteotomies of the mandible are the author’s preferred surgical technique and sequencing of care. Additionally, if indicated, a genial advancement is performed after completion of the maxillary and mandibular osteotomies. As a preliminary step, maxillary and mandibular arch bars are placed, unless the patient has undergone presurgical orthodontic care.

The LeFort 1 total maxillary osteotomy is performed using standard techniques with a modified step design (Fig. 4). The purpose of the step modification of the maxillary lateral wall osteotomies is to facilitate bony interfacing and presumably enhance the stability of the maxillary advancement. After completion of the osteotomy, the maxilla is mobilized until it can be passively positioned forward to the planned surgical position, as verified with the interim splint. To facilitate complete mobilization, slow, deliberate controlled force is used, usually in conjunction with a Rowe forceps (KLS-Martin, Jacksonville, FL). Force is modified accordingly to maintain adequate perfusion to the maxilla, which is monitored visually during the mobilization. The magnitude of the maxillary advancement may create a level of stimulation that produces a trigemino-cardiac reflex with resultant bradycardia or even asystole. Release of stretch on the maxilla and associated soft tissues generally will stop the reflex and allow
the heart rate to return to normal. If the reflex inhibits the ability to adequately mobilize the maxilla, the reflex can be blocked by the use of atropine or glycopyrrolate. Adequate local anesthesia of the trigeminal nerve is also important to block the afferent pathway of the reflex.

Once the maxilla has been mobilized adequately, the interim splint is placed, and maxillomandibular fixation is secured. The complex then is passively rotated superiorly to the planned vertical position, as confirmed by an external reference pin. Judicious bone removal is performed as indicated, to remove any interference, in an effort to maximize bony interfacing. The piriform rim then is recontoured, and the anterior nasal spine is reduced (see Fig. 1) to minimize overprojection and widening of the nasolabial soft tissues that may occur as a result of the large advancement of the maxilla.

Then the maxilla is fixated with 2.0 mm L-shaped bone plates, placed at the piriform rim and zygomaticomaxillary buttress regions bilaterally, where the bone is thickest (see Fig. 4). The configuration of these plates produces a buttressing effect, which presumably enhances stability of the maxilla. Using this technique, the author has observed very good long-term stability of the maxilla and has not found it necessary to place any bone grafts. The potential benefits of not having to perform a bone graft include: decreased operative time, elimination of any donor site morbidity, and earlier patient ambulation after surgery. Each of these factors is very important for a postoperative OSA patient who is obese and has medical comorbid conditions.

Once the patient is released from fixation and proper maxillary advancement has been confirmed, the maxillary soft tissue wound is closed using an alar base cinch suture and V-Y closure of the upper lip (at the midline). These two techniques are designed to maintain proper anatomic position of the nasolabial tissues.

Bilateral sagittal split ramus osteotomies (BSSRO) of the mandible then are completed using standard techniques. The mandible is split using a slow deliberate method of controlled force to facilitate visualization of the inferior alveolar nerve and diminish the chance of injury to the nerve. Minimizing surgical trauma to the inferior alveolar nerve is especially important, because OSA patients are generally middle-aged and presumably have a decreased ability to recover from a nerve injury. Once the split is completed, care is taken to maintain soft tissue attachments so the entire hard tissue-soft tissue complex is advanced, for the purpose of increasing the posterior airway space. The mandibular osteotomies then are stabilized in the
advanced position by either bone plates and monocortical screws, or three bicortical screws (see Fig. 4). After final assessment of maxillary and mandibular position, the mandibular wound is closed in standard fashion.

A genial advancement is performed if indicated, after completion of the LeFort 1 osteotomy and BSSRO. Various methods have been used for genial advancement, ranging from a standard genioplasty to a more isolated genial tubercle advancement. The main objective of the procedure is to advance the genioglossal musculature for the purpose of advancing the tongue and presumably increasing the posterior airway space.

**Postoperative Care and Monitoring**

Once the surgical procedure has been completed and the patient is sufficiently awake to meet criteria for extubation, the nasopharyngeal tube typically is removed in the operating room. This protocol has the advantage of having both the treating anesthesiologist and surgeon present at the time of extubation, as well as all necessary equipment immediately available if reintubation is necessary. Using this protocol, it is very uncommon for a patient to require reintubation. After extubation and stabilization, the patient is transported to the ICU for overnight monitoring. The patient’s airway and associated medical conditions will need to be monitored closely. The patient is observed closely for any apneic events and oxygen supplementation is administered by face mask to maintain adequate oxygen saturation. Using this protocol, generally few apneic episodes, are observed and adequate oxygen saturations can be maintained, so postoperative CPAP has not been used routinely. For the first postoperative night, pain is controlled through the use of incremental intravenous dosing of narcotic analgesics. Close observation of the airway occurs during administration of the analgesics, as respiratory depression may occur at even low doses of narcotics in OSA patients.

Typically, the patient will be stable enough to be transferred to a step-down unit on the first postoperative day. Pain control can be maintained by a patient-controlled anesthesia (PCA) pump or liquid medications administered orally. Normal postoperative recovery will be initiated including ambulation and consumption of a liquid diet, similar to a typical orthognathic surgery patient.

![Fig. 5.](image-url) Maxillary distraction of patient shown in Fig. 2. (A) Bonded maxillary expansion appliance. (B) Maxillary LeFort 1 osteotomy without downfracture and osteotome used for midpalatal osteotomy. (C) Completed transverse distraction of maxilla. (D) Pre-MMA alignment of maxillary dentition. (Modified from 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):286; with permission.)
It is recommended that nighttime oxygen saturations be monitored by pulse oximetry until the patient can maintain near-normal oxygen saturations on room air while sleeping.

The typical hospital stay is 2 to 3 days. The patient then will be evaluated on an outpatient basis every 1 to 2 weeks for about 6 to 8 weeks following surgery. A nocturnal polysomnography study should be completed about 3 to 6 months following surgery to objectively evaluate treatment outcome.

**Variations in Surgical Technique**

Most of the OSA patients presenting for surgical treatment by MMA can be managed by the protocol that has been described. Some patients, however, will have OSA and a concomitant MSD. When present, the patient is a candidate for combined management of the MSD and OSA. Most maxillofacial skeletal deformities that occur in the vertical and anteroposterior dimensions can be treated by presurgical orthodontics followed by MMA. There will be a differential movement of the maxilla and mandible to facilitate correction of the MSD and the OSA. In development of the surgical plan, it is important to confirm that the mandibular advancement will be at least 10 mm, to ensure clinically effective treatment of OSA.

If a component of the MSD occurs in the transverse dimension, the patient may benefit from two-stage surgical treatment. The first stage of treatment will include maxillary distraction osteogenesis (Fig. 5) and possibly mandibular symphyseal distraction osteogenesis (Fig. 6). The maxillary procedure is similar to a standard LeFort 1 maxillary osteotomy with a step design, without downfracture. The lateral wall step is modified slightly (by widening the bone cut), to facilitate transverse expansion without contacting the adjacent bone. If interferences exist, an open bite could be created during the distraction, as the posterior maxilla may ramp downward during the expansion. A midpalatal osteotomy then is completed to the posterior aspect of the hard palate, using an osteotome and mallet with digital palatal palpation to minimize the chance of perforating the mucosa. Once the osteotomy is completed, the appliance is activated temporarily about 1 to 2 mm to ensure that the maxilla can be expanded without significant resistance and the expansion is occurring without any bony interference. The inferior border and body of the

![Fig. 6. Mandibular distraction of patient shown in Fig. 2. (A) Completed midline vertical symphyseal osteotomy with placement of combined tooth-borne and bone-borne distraction appliance. (B) Mandibular distraction in progress. (C) Pre-MMA alignment of mandibular dentition. (Modified from 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):287; with permission.)](image)
mandibular symphyseal osteotomy are completed with a reciprocating saw. A fine bur then is used to initiate the alveolar component of the osteotomy, and it then is completed using a fine spatula osteotome and mallet. Then the distraction osteogenesis appliance is secured to the mandible (see Fig. 6A). There is a latency period of 7 days before distraction is begun for the maxillary and mandibular osteotomies; this period is followed by distraction of 1 mm per day. Once the distraction is complete and the osseous segments have consolidated, conventional orthodontic therapy is performed to obtain well-coordinated and well-aligned dental arches (see Fig. 5D and Fig. 6C). After completion of orthodontic therapy, MMA will be performed to treat both the OSA and remaining MSD (Fig. 7).

**SUMMARY AND FUTURE DIRECTIONS**

MMA is a clinically effective treatment alternative for individuals with obstructive sleep apnea, who cannot adhere to CPAP therapy. To date, published reports indicate that MMA is a very effective surgical treatment, especially for patients with severe OSA. Additionally, MMA, in conjunction with orthodontics and other reconstructive procedures (such as distraction osteogenesis), can be used to treat concomitant OSA and maxillofacial skeletal deformities. Accurate and comprehensive documentation of OSA treatment outcomes (both objective and subjective) has gained increased importance, as those responsible for paying for health care focus on the delivery of cost-effective care. Treatment outcome research is needed.
to elucidate the long-term clinical effectiveness and safety of MMA, as well as identification of positive and negative predictors of treatment outcome. Additionally comparative effectiveness research is needed, to determine the effectiveness of MMA compared with other modes of therapy such as CPAP and oral appliances.

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