32 | Surgical Treatment of Sleep-Related Breathing Disorders

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INTRODUCTION

Snoring, upper airway resistance syndrome (UARS), obstructive sleep apnea (OSA), and obstructive sleep apnea-hypopnea syndrome (OSAHS) are collectively referred to as sleep-related breathing disorders (SRBD). These terms describe a partial or complete obstruction of the upper airway during sleep. Patency of the pharyngeal airway is maintained by two opposing forces: negative intraluminal pressure and the activity of the upper airway musculature. Anatomical or central neural abnormalities can disrupt this delicate balance and result in compromise of the upper airway. This reduction of airway caliber may cause sleep fragmentation and subsequent behavioral derangements, such as excessive daytime sleepiness (EDS) (1–3). The goal of medical and surgical therapy is to alleviate this obstruction and increase airway patency.

The first therapeutic modality employed to treat SRBD was surgery. Kuhlo described placement of a tracheotomy tube in an attempt to bypass upper airway obstruction in Pickwickian patients (4). Although effective, tracheotomy does not address the specific sites of pharyngeal collapse and is not readily accepted by most patients. These sites include the nasal cavity/nasopharynx, oropharynx, and hypopharynx. Often, multilevel obstruction is present. Consequently, the surgical armamentarium has evolved to create techniques that correct the specific anatomical sites of obstruction. To eliminate SRBD, it is necessary to alleviate all levels of obstruction in an organized and safe protocol. The surgeon must counsel the patient regarding all surgical techniques, risks, complications, and alternative medical therapies prior to intervention.

Medical management is often considered the primary treatment of SRBD; however, there are exceptions. Treatment may consist of weight loss, avoidance of alcohol and sedating medications, and manipulation of body position during sleep (5–9). Currently, continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BPAP) devices are the preferred methods of treatment and the standard to which other modalities are compared. The efficacy of CPAP has clearly been demonstrated, but a subset of patients struggle to comply with or accept CPAP therapy (10–13). Patients who are unwilling or unable to comply with medical treatment may be candidates for surgery.

RATIONALE FOR SURGICAL TREATMENT

The rationale for surgical treatment of SRBD is to alleviate the pathophysiologic and neurobehavioral derangements associated with upper airway obstruction. The goal is to achieve outcomes that are equivalent to those of medical management. Ideally, this would include an improved quality of life with a reduction in cardiopulmonary and neurologic morbidity (14–17).

Table 1   Surgical Indications

Apnea-hypopnea index (AHI) $\geq 20^a$ events/hr of sleep
Oxygen desaturation nadir <90%
Esophageal pressure (P_{es}) more negative than -10 cmH$_2$O
Cardiovascular derangements (arrhythmia, hypertension)
Neurobehavioral symptoms [excessive daytime sleepiness (EDS)]
Failure of medical management
Anatomical sites of obstruction (nose, palate, tongue base)

[a]Surgery may be indicated with an AHI < 20 if accompanied by
excessive daytime fatigue.
Source: From Ref. 18.

Table 2   Relative Contraindications to Surgery

Severe pulmonary disease
Unstable cardiovascular disease
Morbid obesity
Alcohol or drug abuse
Psychiatric instability
Unrealistic expectations

Source: From Ref. 18.

SURGICAL INDICATIONS

Surgical indications are listed in Table 1. Those patients whose apnea-hypopnea index (AHI) is less than 20 may still be candidates for surgery. Surgery is considered appropriate if these patients have associated EDS, which results in altered daytime performance or comorbidities as recognized by the Center for Medicare and Medicaid Services (including stroke and ischemic heart disease). For those patients whose EDS is not explained by the severity of their sleep apnea or resolved with CPAP therapy, consideration may be given to obtaining a multiple sleep latency test (MSLT) or the maintenance of wakefulness test (MWT) to determine other etiologies of sleepiness (18,19). In these patients, surgery is unlikely to be beneficial. Other factors exist, which could predict poor surgical outcomes, and are considered relative contraindications to surgery. These factors are listed in Table 2. All patients require a comprehensive evaluation to determine if they meet the criteria for surgery. Polysomnography and a history and physical examination are essential to make this determination.

MEDICAL AND SURGICAL EVALUATION

Proper screening and selection of patients for surgery is vital to achieve successful outcomes and to minimize postoperative complications. The preoperative evaluation requires a comprehensive medical history, head and neck examination, polysomnography, fiberoptic nasopharyngolaryngoscopy, and lateral cephalometric analysis. A thorough review of this data can determine the extent of SRBD severity, uncover comorbidities, and assist in risk management. Furthermore, this systematic approach will identify probable anatomic sites of obstruction. Armed with this information, a safe, site-specific surgical protocol can be presented to the patient.

PHYSICAL EXAMINATION

A complete physical exam with vital signs, weight and neck circumference should be performed on every patient. Specific attention is focused in the regions of the head and neck that have been well described as potential sites of upper airway obstruction, such as the nose, palate, and base of tongue (20–25). Nasal obstruction can occur as a result of alar collapse,

turbinate hypertrophy, and septal deviation or sinonasal masses. These can be identified on anterior rhinoscopy. The oral cavity should be examined for periodontal disease, dental occlusion and any lesions, including torus mandibulae or torus palatinus. Examination of the oropharyngeal and hypopharyngeal regions includes a description of the palate, lateral pharyngeal walls, tonsils, and tongue base. A variety of grading systems, such as the Mallampati system, have been developed to establish a standard of describing the degree of obstruction caused by these structures (26,27). However, it was Fujita, who first proposed a classification system to define the levels of upper airway obstruction in OSA patients (28,29). Examination of the larynx is required in all patients ideally by nasopharyngolaryngoscopy.

POLYSOMNOGRAM

A polysomnogram (PSG) is an integral part of the preoperative evaluation. The surgeon must carefully review the PSG, with particular attention focused on the AHI and oxygen desaturation nadir. This data will guide appropriate surgical treatment, as well as preoperative and postoperative management. As with any intervention, a postoperative PSG is needed to assess a patient's response to surgery. Failure to obtain this study may result in an inadequately treated patient.

FIBEROPTIC NASOPHARYNGOLARYNGOSCOPY

Fiberoptic examination provides a detailed view of the entire upper airway. In particular, the larynx can be more closely observed for such abnormalities as an omega-shaped epiglottis, vocal fold paralysis, or obstructing lesions. The airway is examined at rest as well as during provocative maneuvers. One such technique, Müller's maneuver, has been evaluated by Sher et al. to identify potential sites of obstruction and to predict surgical success (30). This test involves inspiration against a closed oral and nasal airway, while keeping the glottis open. Photodocumentation of findings may prove useful for surgical planning and patient education (Fig. 1).

  Besides identifying obstruction, fiberoptic examination assists in the preoperative planning by determining the difficulty of intubation. This information can be invaluable to both the surgeon and anesthesiologist, as they determine the best method to intubate a patient.

CEPHALOMETRIC ANALYSIS

The lateral cephalogram is the most cost-effective radiographic study of the bony facial skeleton and soft tissues of the upper airway. Using these landmarks, Riley et al. were first to describe anthropomorphic measurements that can be performed to ascertain skeletal facial
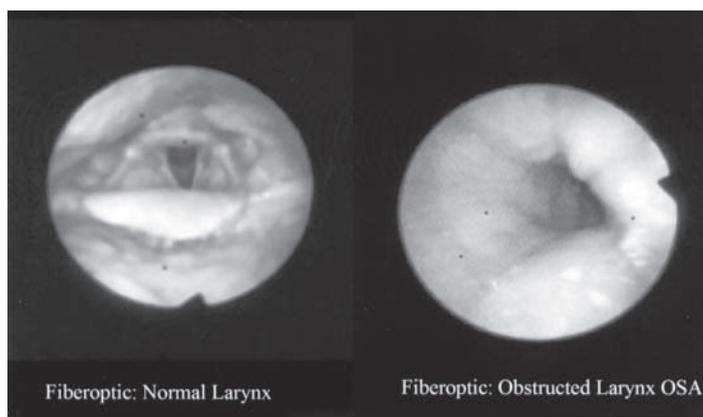

Fiberoptic: Normal Larynx   Fiberoptic: Obstructed Larynx OSA

Figure 1 Fiberoptic laryngoscopy. View of the normal larynx. Note that the entire vocal folds can be visualized (*left*). Müller's maneuver results in collapse of the velopharyngeal and hypopharyngeal airway. The vocal folds are completely obscured by redundant soft tissue in a patient with OSA (*right*).

abnormalities (31). Magnetic resonance imaging (MRI) and computed tomography (CT) scanning have proven to be effective radiographic studies; however, these tools are often reserved for investigational studies due to expense and time (32–34). Although not as detailed as CT scan or MRI, the cephalogram allows measurement of the length of the soft palate, posterior airway space (PAS), skeletal proportions, and hyoid position. Studies have shown the cephalogram to be valid in assessing obstruction, and in fact, it compares favorably to three-dimensional volumetric computed tomographic scans of the upper airway (35). The cephalogram, as with other imaging modalities, may underestimate the degree of obstruction, since they are not obtained while the patient is sleeping.

SURGICAL TREATMENT PHILOSOPHY

The goal of surgical treatment is to alleviate upper airway obstruction and its associated neurobehavioral symptoms and morbidities. No longer is a 50% reduction in the AHI deemed acceptable (Table 3). Rather, the objective is to treat to cure (normalization of respiratory events and elimination of hypoxemia). This can only be accomplished if a thorough and systematic evaluation is performed on every patient.

Since multilevel obstruction may exist, it may be necessary to treat more than one site. Failure to recognize or treat all anatomical levels will lead to persistent obstruction. Thus, the surgeon must be committed to treating the entire upper airway.

Once a surgical plan has been formulated, this must be communicated to the patient and our medical colleagues. Successful treatment of a SRBD patient typically requires a multidisciplinary team. This team will assist in the preoperative and postoperative course to minimize risk and potential complications. Prior to any intervention, the surgeon must discuss all treatment options and the associated risks and complications with the patient. Only after the patient fully understands the process and has consented to surgery can the treatment plan proceed.

A surgeon has numerous procedures available within their armamentarium to treat SRBD. Selecting the appropriate surgery for a patient can be challenging. However, we have created a two-phase surgical protocol (Powell–Riley surgical protocol) as a logically directed plan to treat the specific areas of upper airway obstruction (36,37). This protocol (Table 4) as well as other surgical techniques (Table 5) will be discussed in this chapter.

Table 3 Powell–Riley Definition of Surgical Responders

Apnea-hypopnea index (AHI) < 20 events/hr of sleep[a]
Oxygen desaturation nadir ≥ 90%
Excessive daytime sleepiness (EDS) alleviated
Response equivalent to CPAP on full-night titration

[a]A reduction of the AHI by 50% or more is considered a cure if the preoperative AHI is less than 20.
Source: From Ref. 18.

Table 4 Powell–Riley Protocol Surgical Procedures

Phase I
  Nasal surgery (septoplasty, turbinate reduction, nasal valve grafting)
  Tonsillectomy
  Uvulopalatopharyngoplasty (UPPP) or uvulopalatal flap (UPF)
  Mandibular osteotomy with genioglossus advancement
  Hyoid myotomy and suspension
  Temperature-controlled radiofrequency (TCRF)[a]—turbinates, palate, tongue base
Phase II
  Maxillomandibular advancement osteotomy (MMO)
  Temperature-controlled radiofrequency (TCRF)[a]—tongue base

[a]TCRF is typically used as an adjunctive treatment. Select patients may choose TCRF as primary treatment.

Table 5 Alternative Upper Airway Surgical Techniques

Pharyngeal obstruction
Temperature-controlled radiofrequency (TCRF)
Pillar® palatal implant system
Laser-assisted uvulopalatoplasty (LAUP)
Injection snoreplasty
Hypopharyngeal obstruction
Genial bone advancement trephine system (GBAT™)
Repose™ genioglossus advancement hyoid myotomy (GAHM)
Temperature-controlled radiofrequency (TCRF)
Midline glossectomy and lingualplasty
Airway bypass surgery
Tracheotomy

POWELL–RILEY TWO-PHASE SURGICAL PROTOCOL

This protocol consists of two distinct phases. The procedures included in each phase are listed in Table 4. Developed to prevent unnecessary surgery, this method is a conservative surgical approach to the SRBD patient. Phase II surgery has documented success rates exceeding 90%; however, a substantial number of patients may not need such extensive surgery (38,39). In fact, patients have a realistic chance to be cured by phase I surgery alone. However, it is difficult to predict surgical outcomes for an individual patient. Conservative surgery (phase I) is therefore recommended initially with the plan to perform postoperative PSG to assess response to surgery. Those patients who are incompletely treated would then be considered for phase II surgery. As with any treatment protocol, exceptions may occur. There are certain cases in which phase II surgery may be the appropriate first step, as in nonobese patients with marked mandibular deficiency and normal palates (40).

   Phase I surgery is directed towards the three potential sites of upper airway obstruction (nose, palate, and tongue base). Neither dental occlusion nor the facial skeleton is altered. Clinical response is determined by PSG. The PSG is obtained four to six months following surgery to allow for adequate healing. Patients who have persistent SRBD are offered phase II surgery.

   Phase II surgery refers to maxillomandibular advancement osteotomy (MMO) or bimaxillary advancement. MMO helps clear hypopharyngeal obstruction, which would be the only region incompletely treated by phase I. This is the only procedure that physically creates more room for the tongue to be advanced anteriorly, thus enlarging the PAS.

SURGICAL PROTOCOL OUTCOMES

Previously, reducing the AHI by 50% was considered a cure for SRBD. However, most researchers and clinicians no longer consider this parameter valid. Rather, surgical intervention aims to attain the results obtained by CPAP therapy. Consequently, a more comprehensive criterion was established to determine surgical success or cure (Table 3).

   Clinical response to phase I surgery ranges from 42% to 75% (38,41–45). Our published data have shown that approximately 60% of all patients are cured with phase I surgery (38). Factors that portend less successful outcomes are a mean respiratory disturbance index (RDI) greater than 60, oxygen desaturation below 70%, mandibular deficiency (sella nasion point B $<75°$), and morbid obesity (body mass index [BMI] > 33 kg/m^2). However, it is imprudent to discount phase I surgery in these patients, since a reasonable percentage may not need more aggressive surgery (37).

   Incomplete treatment by phase I surgery is primarily due to persistent hypopharyngeal obstruction. Phase II surgery (MMO) would then be offered to those patients who have been incompletely treated by phase I surgery. MMO is a more aggressive surgery, which requires more intensive operative and postoperative care. Patients must be prepared for a recovery period of 4 to 6 weeks. Despite a longer convalescence period, documented success rates of MMO exceed 90% (38,46–49).

SURGICAL PREPARATION—RISK MANAGEMENT

Ensuring that a patient is medically stable for the operative procedure can reduce the risk of postoperative complications. This would include obtaining the appropriate laboratory, cardiopulmonary, and radiographic tests. In patients with existing comorbid medical conditions (diabetes, hypothyroidism, cardiovascular disease, and pulmonary disease), consultation with the appropriate medical specialist should be sought.

Preoperative CPAP can alleviate the issues associated with sleep deprivation and may reduce the risk of postobstructive pulmonary edema. Consequently, all patients who are tolerant of CPAP are encouraged to use this modality for at least two weeks prior to surgery (50). In 1988, Powell et al. recommended the use of preoperative CPAP for all patients who have an RDI greater than 40 and an oxygen desaturation of 80% or less. According to this protocol, the surgeon must consider insertion of a temporary tracheotomy for those patients with severe OSA (RDI greater than 60 and/or SaO_2 less than 70%) who are intolerant of CPAP therapy (51). Tracheotomy is rarely needed at our center and must be determined on a case-by-case basis.

SURGICAL PROCEDURES—PHASE I

Nasal Reconstruction

A patent nasal airway is essential to normal respiration and sleep. Obstruction can increase airway resistance and result in mouth breathing. Opening of the mouth rotates the mandible posteriorly, which in turn allows the tongue to prolapse into the PAS and narrow the hypopharyngeal airway. Nasal obstruction can occur due to septal deviations, incompetent nasal valves, or enlarged turbinates. A multitude of techniques (septoplasty, alar grafting, and turbinate reduction) exist to treat nasal obstruction. These techniques and their results have been well established in the head and neck literature. The choice of procedure depends on surgeon preference and experience.

Nasal reconstruction can improve quality of life and may improve OSA in select patients (52,53). In addition, improvement of the nasal airway may improve a patient's tolerance of nasal CPAP (54). Rarely, however, will alleviating nasal obstruction cure OSA.

While most treatments of the nasal cavity are well established, treatment of the turbinates is an evolving technique. Our preferred method is submucosal turbinoplasty with a radiofrequency probe. Submucosal turbinoplasty can be performed with radiofrequency or a microdebrider. Radiofrequency is rarely associated with complications such as bleeding or crusting. However, the ultimate goal of reducing submucosal erectile tissue, while preserving the ciliated, surface mucosa is the same (55,56).

Uvulopalatopharyngoplasty/Uvulopalatal Flap

Uvulopalatopharyngoplasty (UPPP) was introduced by Ikematsu for the treatment of habitual snoring (57). Subsequently, this technique was adapted to treat SRBD and snoring by Fujita et al. in 1981 (29). Since this time, many variations have been developed to treat the obstructing tissues of the soft palate, lateral pharyngeal walls, and tonsils.

UPPP is an excellent technique to alleviate isolated retropalatal (Table 6) obstruction (Fujita type I). Performed under general anesthesia, a portion of the palate, uvula, lateral pharyngeal walls, and tonsils may be removed (Fig. 2). Unfortunately, due to the intensity of postoperative pain and variable cure rates there is often a stigma associated with UPPP.

A metaanalysis of the cure rate of UPPP was performed by Sher et al. in 1996. UPPP was found to have a success rate of 39% for curing OSA (46). Unrecognized hypopharyngeal

Table 6 Fujita Classification of Obstructive Regions

Type I palate (normal base of tongue)
Type II palate and base of tongue
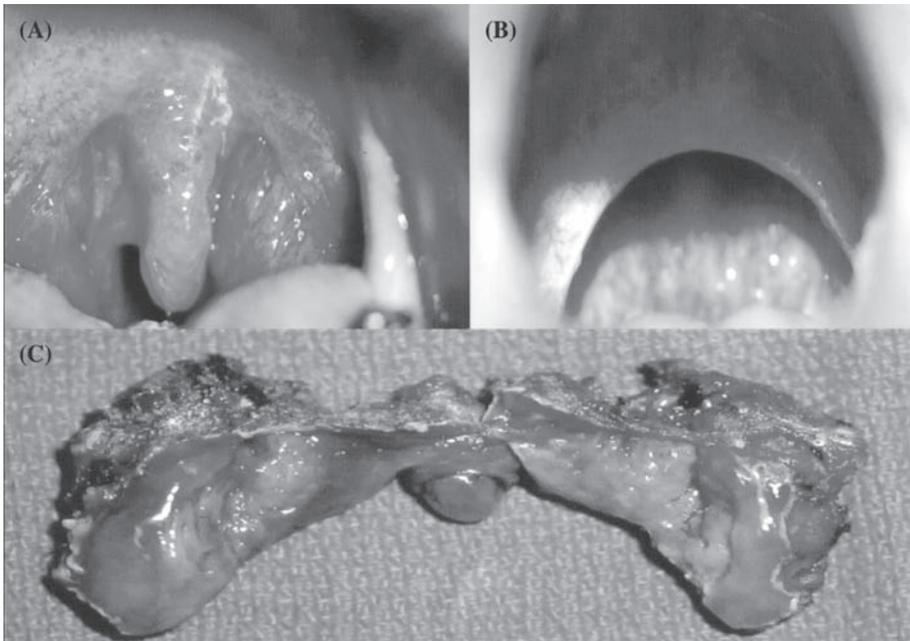Type III base of tongue (normal palate)

Source: From Ref. 28.

Figure 2 Uvulopalatopharyngoplasty (UPPP). (**A**) Physical exam reveals tonsillar hypertrophy, an elongated uvula, and redundant tissue of the lateral pharyngeal wall resulting in obstruction at the palatal region. (**B**) Postoperative view of the palate following excision of the tonsils, lateral pharyngeal wall mucosa, and soft palate mucosa. Note the markedly widened airway. (**C**) Excised surgical specimen.

obstruction is thought to be the primary reason for such a high failure rate. While capable of improving select patients, UPPP is seldom credited with curing moderate or severe SRBD. In fact, this procedure may be overutilized as an isolated surgical procedure to cure SRBD by those who have failed to identify tongue base obstruction. However, if UPPP is used appropriately or combined with procedures aimed at other anatomical sites of obstruction the results can be much more gratifying.

The indications and rationale for performing the uvulopalatal flap (UPF) are the same as UPPP. However, this flap is contraindicated in patients with excessively long and thick palates. In these patients, the flap created will be too bulky and could potentially eliminate a favorable outcome.

The UPF was introduced by Powell et al. as a modification of the UPPP in 1996 (Figs. 3 and 4). The goal was to reduce the risk of velopharyngeal insufficiency (VPI) and stenosis by using a potentially reversible flap that could be "taken down" early in the recovery period if complications arose. Furthermore, the UPF technique was found to have less postoperative pain on a visual analogue scale, as compared with traditional UPPP. This reduction in pain is due to the fact that no sutures are placed on the free edge of the palate (59). Major complications (myocardial infarction, complete airway obstruction, severe hemorrhage) following UPPP are less than 1.5% (60). Typically, patients complain of postoperative pain and palatal swelling. Voice changes, taste disturbances, and dysphagia have been reported, but are usually transient. Although rare, VPI and nasopharyngeal stenosis are often the result of poor surgical technique. The temptation to maximize results by removing large portions of the palate should be resisted to prevent VPI. Judicious resection of tissue and proper patient selection can aid in preventing these complications.

Mandibular Osteotomy with Genioglossus Advancement

Genioglossus advancement is indicated for patients with documented hypopharyngeal (Table 6) obstruction (Fujita type II–III). Considered part of phase I of the Powell–Riley protocol, it may be used alone or in combination with other procedures depending on the regions of obstruction. The rationale of this surgery is to enlarge the PAS by preventing prolapse of the tongue during sleep.
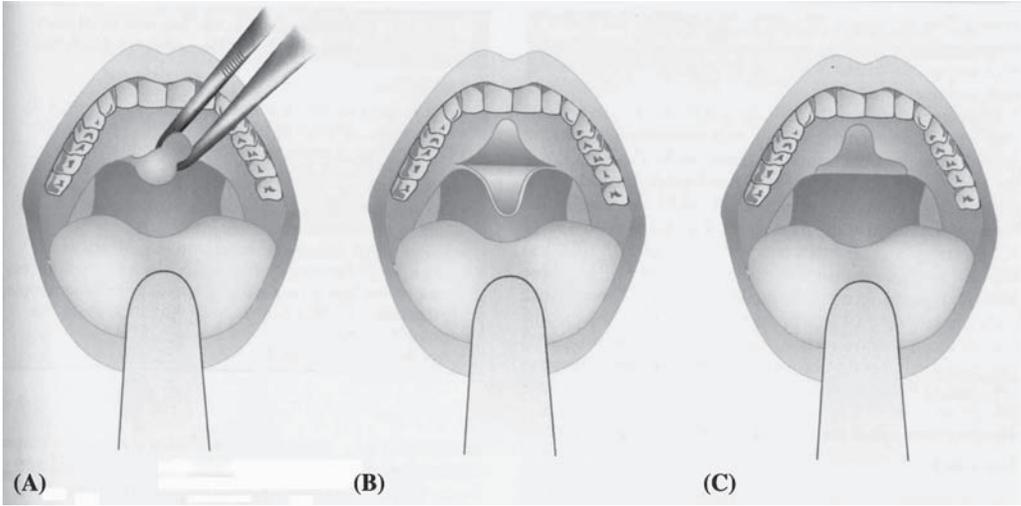
Figure 3 Uvulopalatal flap technique (UPF). (**A**) The mucosal crease is identified by reflecting the uvula. This marks the superior limit of dissection. (**B**) Incision is planned on the lingual aspect of the soft palate. (**C**) Wound is closed with 3-0 Vicryl sutures. These sutures may be removed to release the flap if VPI should occur. *Source*: From Ref. 58.
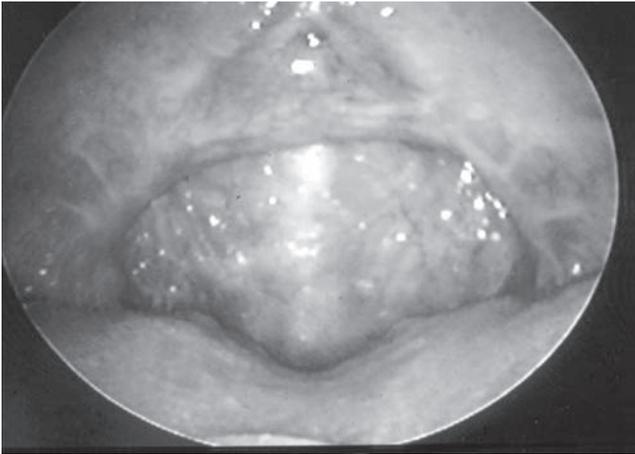

Figure 4 Uvulopalatal flap (UPF). Post-operative view of a UPF.

Essentially, the genial tubercle and the attached genioglossus muscle are advanced anteriorly. This advancement places tension on the tongue musculature and thereby limits posterior displacement during sleep. The degree of advancement is dependent on the thickness of the anterior portion of the mandible and the compliance of the genioglossus muscle. Less muscle compliance will provide a greater degree of tension. Unfortunately, there is no study to determine the compliance of the genioglossus muscle preoperatively. The position of the jaw and dental occlusion remain unchanged. However, a limitation of this surgery is that no additional room is created for the tongue, in contrast to maxillomandibular advancement.

Surgery can be performed under intravenous sedation or general anesthesia. A lateral cephalometric radiograph and a panoramic dental radiograph are required in the preoperative planning. The panoramic radiograph allows the surgeon to identify the genial tubercle and to assess the root length of the mandibular canine and central incisor teeth. Sclerotic bone in the symphyseal region of the mandible aids in locating the genial tubercle. Furthermore, the film should be reviewed for evidence of periodontal disease.

Knowledge of the anatomy is essential to capture the genioglossus muscle fibers within the rectangular osteotomy and to avoid complications. As the muscle's insertion includes the genial tubercle and the lingual surface of the mandible adjacent to the tubercle, the osteotomy must be designed to encompass this region. Thus, the width of the bone fragment should be at least 14 mm and the height about 10 mm (61,62). To avoid injury to the roots of the canine teeth, the vertical osteotomies should be medial to the canine dentition. Careful planning is also required in performing the horizontal osteotomies. The surgeon must be cognizant of the roots of the incisor dentition and the inferior border of the mandible. It is recommended that the superior osteotomy be placed at least 5 mm inferior to the root apices to avoid injury (63). In addition, the inferior osteotomy should be approximately 10 mm above the inferior border of the mandible to prevent a potential fracture.

In 1986, Riley et al. developed the rectangular osteotomy technique (Fig. 5) to advance the genial tubercle for patients with hypopharyngeal obstruction (64). This modification of genioglossus advancement maintained the integrity of the inferior border of the mandible. Subsequently, they evaluated 239 patients who completed phase I surgery and underwent postoperative PSG. Most of these patients had genioglossus advancement with hyoid suspension and UPPP. The overall success rate was 61%. The data was further extrapolated to determine the correlation between disease severity and response rates. Patients with mild disease had a cure rate of 77%, while those with severe disease had a cure rate of 42% (38). Similar results were reported in other studies (43–45,65). In Sher's metaanalysis of patients who only underwent UPPP, the overall responder rate was 39% (46). Thus, it became clear that the addition of genioglossus advancement could substantially increase success rates for treating SRBD.
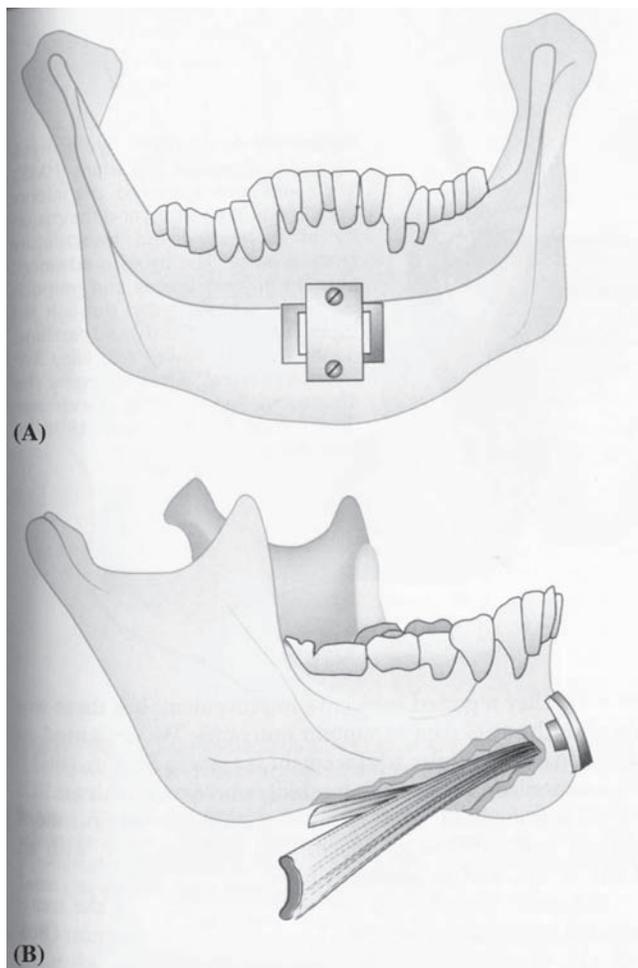

Figure 5 Mandibular osteotomy with genioglossus advancement. A rectangular osteotomy is created in the anterior mandible. The genial tubercle and the attached genioglossus muscle are advanced anteriorly. The bony fragment is rotated 90° to overlap the inferior border of the mandible and secured to the mandible with a titanium screw. *Source*: From Ref. 58.

Major complications following genioglossus advancement are uncommon. Obstruction of the airway due to edema or hematoma is the most distressing complication following surgery but it has not been observed in our series. The use of CPAP in the early postoperative period reduces edema and maintains the patency of the airway (66,67). Meticulous hemostasis and aggressive antihypertensive management are critical to prevent hematoma formation. Mild postoperative floor of mouth edema or ecchymosis is common and is usually self-limiting. As previously mentioned, inferior border mandible fractures can occur if the osteotomy is incorrectly designed. This complication has been essentially eliminated by performing a rectangular osteotomy that leaves the inferior border of the mandible intact. Any technique that violates the inferior border increases the risk of a pathologic fracture. Minor complications, such as wound infection, transient anesthesia of the teeth or lower lip, and root injury requiring endodontic therapy have an incidence rate of 2%, 6%, and 1%, respectively, at our center.

Hyoid Myotomy and Suspension

The rationale for hyoid myotomy and suspension is to alleviate hypopharyngeal obstruction by advancing the hyoid complex in an anterior direction. This procedure is considered part of phase I surgery and may be performed as an isolated procedure or in combination with other techniques. The genioglossus and geniohyoid muscles as well as the middle pharyngeal constrictors insert on the hyoid bone. Consequently, the position of the hyoid complex is important in maintaining the integrity of the hypopharyngeal airway. Van de Graaff et al. reported that anterior hyoid advancement improved the PAS in a canine model (68). In 1984, Kaya was the first to demonstrate this concept in human subjects (69).

Currently, we rarely perform hyoid suspension simultaneously with genioglossus advancement. The additional trauma to the hypopharyngeal region can be problematic for the patient to tolerate, and it may prolong recovery. Furthermore, UPPP and genioglossus advancement may have enlarged the PAS, so as to obviate the need for additional surgery. Hyoid myotomy and suspension has become an adjunctive procedure to treat tongue base obstruction for those who previously underwent genioglossus advancement and have evidence of a posteriorly displaced epiglottis.

Originally, this surgery involved suspending the hyoid to the mandible with fascia lata (64). However, this required additional incisions and dissection to harvest the fascia lata and expose the mandible. To reduce the extent of surgery, the technique has been modified to suspend the hyoid bone to the superior border of the thyroid cartilage (42). A single horizontal incision is made at the level of the hyoid. Both the hyoid bone and thyroid cartilage are exposed. The hyoid is advanced anteriorly and secured to the thyroid cartilage with three or four permanent sutures (Fig. 6). Either general or local anesthesia may be utilized (70).
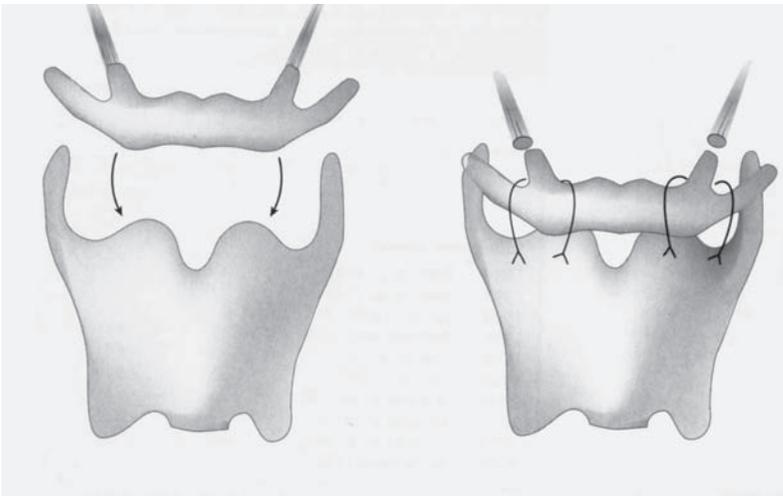

Figure 6   Hyoid myotomy and suspension. The hyoid bone and thyroid cartilage are exposed via a small neck incision. The hyoid bone is advanced anteriorly and secured to the thyroid cartilage with three or four permanent sutures. *Source*: From Ref. 58.

As stated previously, the overall success rate for phase I surgery was 61%. However, the majority of patients underwent genioglossus advancement with hyoid suspension and UPPP (38). Riley and Powell found that hyoid myotomy and suspension improved SRBD and corrected EDS in 75% of consecutively treated patients ($n = 15$) with documented sleep apnea (42). Yet, these patients also had previous genioglossus advancement. Two studies have reviewed the outcomes of patients treated with hyoid suspension alone without concurrent or previous genioglossus advancement for hypopharyngeal obstruction. The success rate from these studies ranged from 17% to 78% (70,71). Our experience has indicated that hyoid suspension is not efficacious as primary treatment for hypopharyngeal obstruction, but rather may be reserved as an adjunctive therapy.

Major complications are exceedingly rare with this surgery. The potential for airway obstruction exists, but this has not been observed at our center. Seroma or hematoma formation are prevented by the insertion of surgical drains for at least 24 hours. Transient aspiration or dysphagia can be observed but usually will resolve within 10 days. If these symptoms persist, removal of the suspension sutures should alleviate this problem (72). Meticulous dissection of the suprahyoid musculature protects vital structures. Specifically, dissection should not extend lateral to the lesser cornu or superior to the upper border of the hyoid to avoid injury to the superior laryngeal nerve and hypoglossal nerve, respectively. Infection can be managed with wound care and antibiotics should it occur.

SURGICAL PROCEDURES—PHASE II

Maxillomandibular Advancement Osteotomy

MMO, also referred to as bimaxillary surgery, is considered phase II of the Powell–Riley two-phase surgical protocol. The rationale for MMO is to ameliorate refractory hypopharyngeal obstruction by advancing the mandible and maxilla forward.

Kuo et al. and Bear and Priest were the first to report the treatment of SRBD with skeletal surgery (73,74). Subjective improvements in SRBD were noted, but there was no postoperative objective data (PSG) to support these claims. Subsequently, our group used PSG to document an improvement in sleep apnea following mandibular advancement (75). Numerous studies have since confirmed these findings (49,76,77).

MMO enlarges both the hypopharyngeal and pharyngeal airway by expanding the skeletal facial framework. It is the only surgery in our protocol that physically creates more space for the tongue in the oral cavity. In addition, it exerts further tension on the velopharyngeal and suprahyoid musculature to prevent their posterior collapse. Advancements of 10 to 15 mm are usually required to adequately clear the PAS of obstruction.

Typically, we reserve MMO for those patients who are incompletely treated with phase I surgery. Some authors have advocated maxillomandibular advancement as primary therapy for hypopharyngeal obstruction, however our experience has demonstrated reasonable response rates with phase I treatment (36,78). Thus, we attempt less invasive surgery prior to MMO surgery.

MMO was originally advocated for patients with maxillomandibular deficiency. However, only approximately 40% of patients with SRBD have contributing craniofacial deficiency (79). Concerns existed that performing MMO in patients without mandibular or maxillary deficiency could create temporomandibular joint dysfunction or unfavorable facial esthetics. Conversely, studies have since proven that MMO is effective in these patients without resulting in these complications. In fact, skeletal facial advancement may impart a more youthful esthetic appearance (80,81).

Maxillomandibular advancement had been used for many years to treat malocclusion. The surgery has undergone several modifications for the treatment of SRBD. The primary modification is a bony advancement of 10 to 15 mm, which tends to be greater than those needed to treat malocclusion. Care must be taken to preserve the descending palatine arteries of the maxilla, and, the dental occlusion should be preserved. This is accomplished by placing arch bars or orthodontic bands prior to the osteotomies. A Le Fort I maxillary osteotomy is performed above the roots of the teeth. The maxilla is down fractured and then advanced anteriorly. Stabilization of the maxilla is accomplished with rigid plate fixation. Mandibular advancement is achieved by a sagittal split osteotomy (Fig. 7). Care is taken to preserve the
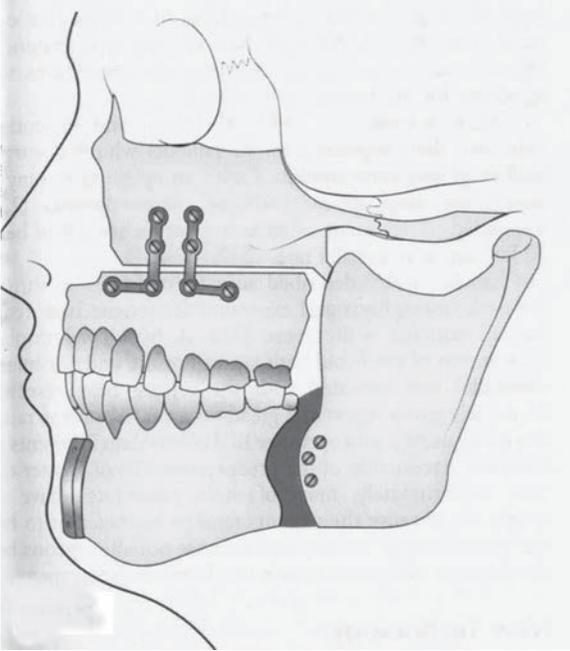
Figure 7 Maxillomandibular advancement osteotomy (MMO). The maxilla and mandible are advanced 10–15 mm. A Lefort I osteotomy and bilateral sagittal split mandibular osteotomy are performed. The advanced segments of bone are stabilized with titanium screws and rigid plate fixation. Note the genioglossus advancement performed prior to MMO. *Source*: From Ref. 58.
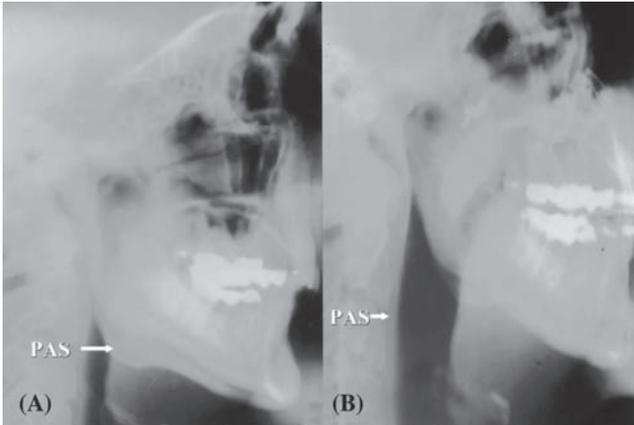

Figure 8 Lateral cephalogram films. This patient underwent both phase I and phase II of the Powell–Riley protocol for SDB. (**A**) Preoperative film. (**B**) Postoperative film—note the markedly widened posterior airway space (PAS).

inferior alveolar nerves. Fixation is maintained by bicortical screws and monocortical plating. Proper alignment of the dental occlusion is needed prior to fixation.

Published data regarding the results of MMO has been well established (47,49,78,82,83). In 1992, we reported 91 patients who underwent bimaxillary surgery. The success rate of phase II therapy was 97% (38). Despite the potential for some skeletal relapse, the long-term success of MMO remains greater than 90% (84). An enlarged PAS can be visualized on postoperative cephalograms (Fig. 8). Ultimately, in order for surgery to be considered efficacious, it must achieve rates of cure similar to CPAP therapy. In 1990, Riley et al. demonstrated no statistical difference between nasal CPAP and surgery in improving sleep architecture and SRBD (85). Consequently, if a logical, stepwise surgical approach is used in treating SRBD patients, cure rates similar to that of medical management can be offered.

As mentioned previously, airway obstruction is the most feared complication following surgery. Risk can be reduced by appropriately utilizing preoperative CPAP and controlling blood pressure (66,67). Necrosis of the palate has been observed as a result of compromised blood supply, although it is quite rare (86). Identifying and protecting the descending palatine vessels can prevent this complication. Skeletal relapse with resulting malocclusion may occur

in 15% of patients. This usually does not result in recurrence of SRBD, and can easily be managed with occlusal equilibration. Pain is well controlled with oral analgesics and is not as intense as palatal surgery. Perhaps the most common complaint following MMO surgery is anesthesia or paresthesias of the dentition and perioral region. This symptom is expected in the early recovery period and will resolve within 6 to 12 months for most patients.

ALTERNATIVE TREATMENT OPTIONS FOR PHARYNGEAL RECONSTRUCTION

Temperature-Controlled Radiofrequency of the Palate

Radiofrequency ablation (RF) of tissue has been used extensively in many medical and surgical fields. It has been used to treat Wolfe–Parkinson–White syndrome and benign prostatic hypertrophy (87,88). Powell and Riley adapted this modality to treat redundant tissue of the upper airway in patients with SRBD. Histologic assessments revealed a well-circumscribed lesion with normally healing tissue without damage to peripheral nerves. Volumetric analysis noted an initial inflammatory response that resolved within 48 hours. A 26.3% volumetric reduction of tissue was documented on the tenth postoperative day (89). Based on the positive studies in animal models, RF was attempted on human palates to treat snoring and SRBD. Subsequent trials were then applied to the nasal turbinates and tongue base.

Temperature-controlled radiofrequency (TCRF) has several advantages as compared with traditional techniques when treating SRBD. This procedure is minimally invasive and can be performed on an outpatient basis. Lower temperatures allow for more precise treatment and reduce thermal injury to adjacent tissue. TCRF heats treated tissue from 47°C to 90°C. Electrocautery and laser procedures can heat tissue from 750°C to 900°C. More precise control of thermal energy and limited submucosal tissue injury results in less morbidity without sacrificing efficacy.

Treatment is administered by inserting an electrode probe into the submucosal layer of the tissue to be ablated. Low frequency (465 kHz), low heat electromagnetic energy is administered to denature tissue protein. This region of necrosis is resorbed by the body with resulting volumetric reduction and stiffening of the tissue. By sparing the mucosal layer of tissue, patients experience less postoperative pain.

TCRF treatment of the palate reduced subjective snoring scores by 77% and reduced EDS (90). Multiple studies have demonstrated that TCRF of the palate improves snoring as effectively as other treatment modalities (91–93). Relapse of snoring has been noted at rates similar to those obtained by other treatment protocols (94). However, patients are more likely to undergo repeat RF treatments than more invasive procedures. While outcomes may be similar for different treatment options for snoring, the main advantage RF offers is minimal postoperative pain. Narcotics are usually not required to alleviate pain following TCRF, while they are needed in nearly all patients who undergo UPPP or laser-assisted palatoplasty (95). In fact, ibuprofen is adequate for analgesia after TCRF. Although improvement in SRBD has been documented following TCRF, it is unlikely to cure palatal obstruction as primary therapy. Blumen et al. have demonstrated a significant reduction in RDI following TCRF of the palate in patients with mild to moderate disease (96). It is our experience that, due to the bulk of tissue, which needs to be reduced, TCRF is best utilized as an adjunctive technique to treat palatal obstruction.

TCRF is well tolerated. The incidence of postoperative complications is exceedingly low. A study of the postoperative outcomes demonstrated no major complications and less than a 1% chance of minor complications (97). Mucosal ulceration or sloughing was defined as a minor complication. Airway obstruction, hemorrhage, palatal fistula, and severe dysphagia are potential serious negative outcomes.

PILLAR® PALATAL IMPLANT SYSTEM

The Pillar palatal implant (Restore Medical, Inc., St. Paul, MN) was introduced as a treatment for snoring in 2003. These implants are composed of polyethylene terephthalate (PET). This material is biocompatible and inert resulting in minimal tissue reaction to the implant. The nature of the material allows tissue ingrowth to stabilize the material. Histologic analysis of the

implant system indicates that a chronic inflammatory response occurs as a result of PET implantation. Inflammation results in the formation of a fibrous capsule. This process should be complete within four weeks.

The rationale for this procedure is to reduce palatal flutter and snoring by stiffening the soft palate. Implantation of the PET material imparts a degree of rigidity to the palate. Additional stiffening of the palate is achieved by fibrosis and formation of capsule in response to the inflammatory reaction (98).

The procedure is minimally invasive and can be performed in the clinic setting. A handheld applicator is used to insert the PET implants. The palate must have a length >25 mm to be eligible to receive an implant. After the palate is anesthetized, an 18 mm by 1.5 mm implant is placed in the midline above the uvula. The implants should be positioned in the muscular layer of the soft palate. Two additional implants are placed 2 mm lateral to the midline on each side. Postoperative antibiotics are given to prevent infection. Pain can usually be controlled with over-the-counter analgesics (99,100).

The Pillar Implant received U.S. Food and Drug Administration (FDA) clearance for the treatment of snoring and mild to moderate OSA. Initially, this implant was studied to determine its role in eliminating snoring. The outcomes of these studies indicate that the implant system has efficacy and relapse rates similar to other treatment modalities (99–102). However, these studies often excluded patients with OSA and did not always obtain a PSG. More recently, Nordgård evaluated 25 patients with mild to moderate sleep apnea to determine if palatal implants could alleviate SRBD. All patients underwent PSG before and after treatment. Inclusion in the study required an AHI of 10 to 30 and a BMI of ≤30. AHI was reduced from a mean of 16.2 to a mean of 12.1. The AHI was reduced to below 10 in 48% of patients at 90 days postimplant (103).

Mild palatal swelling and pain can occur postoperatively, yet they are transient. Extrusion of the implants is the most common complication. Different rates of extrusion have been noted from 2.7% to 8.8% (99,100). The most feared negative outcome would be aspiration of an extruded implant. This has not been documented in the literature. Surgeon inexperience and short palatal length may increase the incidence of implant extrusion.

Laser-Assisted Uvulopalatoplasty

The rationale and indications for laser-assisted uvulopalatoplasty (LAUP) are the same as for traditional UPPP. However, this surgery was developed as an office-based procedure to treat snoring and SRBD.

The technique attempts to shorten and stiffen the soft palate via a series of carbon dioxide laser incisions. A portion of the uvula is resected and vertical incisions are made lateral to the uvula. Redundant tissue of the lateral pharyngeal may be excised. Local anesthesia is used for this procedure. Walker et al. demonstrated a 48% success rate; however, 21% of patients had worsening of their SRBD following LAUP (104).

LAUP is associated with significant palatal edema and scarring. Furthermore, concerns exist regarding the safety of performing this procedure in the office. Terris et al. noted a fourfold increase in the apnea index and a significant narrowing of the airway at 72 hours following LAUP. These findings prompted them to discourage LAUP in patients with moderate or severe sleep apnea (105). With the advent of less painful techniques, the popularity of LAUP has waned. In fact, a variety of procedures are now available with similar cure rates to treat the palate with less pain and morbidity. Additionally, the American Academy of Sleep Medicine released an evidence-based review in 2000, in which they did not recommend LAUP for the treatment of SRBD (106).

Injection Snoreplasty

Palatal injection sclerotherapy (injection snoreplasty) was introduced as a minimally invasive and inexpensive office procedure that treats palatal flutter snoring. Essentially, a sclerotherapy agent is injected into the submucosal layer of the soft palate to promote fibrosis and scarring (107). Several different sclerotherapy agents have been employed to stiffen the soft palate. The two most commonly used agents are 3% sodium tetradecyl sulfate (sotradecol) and 50% ethanol (108). The average number of injections required to achieve adequate reduction in snoring was 1.2 injections per patient. Exclusion criteria for this modality include comorbid diseases that interfere with wound healing (uncontrolled diabetes, uncontrolled

hypothyroidism, and periodontal disease), marked tonsillar hypertrophy, previous surgical procedures for snoring, and significant OSA. Complete cessation or a significant reduction in snoring was reported by 92% of patients or bed partners. However, the rate of snoring relapse was 18% at long-term follow-up (107,109). The success and relapse rates of injection snoreplasty are similar to those of other modalities used to treat snoring (94,110,111).

The primary advantage of injection snoreplasty is the minimal postoperative pain. In fact, most patients experience no interruption in the activities of daily life. This procedure can be performed during a routine office visit. The most common reported complications are palatal swelling and superficial mucosal breakdown. These are managed with observation. Other more serious complications include mucosal ulceration, palatal fistulae, VPI, and anaphylaxis to the agent. This technique has not shown to significantly reduce the RDI (107,109).

ALTERNATIVE TREATMENT OPTIONS FOR HYPOPHARYNGEAL OBSTRUCTION

Genial Bone Advancement Trephine System

The genial bone advancement trephine system (GBAT™) system (Stryker Leibinger Corporation, Kalamazoo, MI) attempts to alleviate tongue base obstruction by advancing the genial tubercle. This system is a modification of the rectangular mandibular osteotomy with genioglossus advancement. The rationale and indications for the GBAT procedure are the same as for traditional genioglossus advancement.

Identification of the genial tubercle is essential to perform the surgery. A circular osteotomy is created in the mandible with the provided trephine (12 mm or 14 mm). The bone segment with the attached genioglossus muscle is advanced and secured to the anterior mandible with a rigid plate (112). The surgeon must ensure that the mandible has sufficient size to accommodate the osteotomy without violating the apices of the tooth roots and the inferior border of the mandible.

As this technique is a simple modification of existing genioglossus advancement, one would expect similar outcomes. Miller et al. studied 35 patients who underwent the GBAT procedure with simultaneous UPPP for SRBD. The RDI and apnea index were reduced by 70%. Furthermore, the lowest oxygen desaturation increased from 80% to 88% and the PAS increased by 4.7 mm. Overall, the cure rate was 67% (112). Studies have demonstrated subjective improvement in SRBD with the GBAT procedure (113). However, long-term objective studies have not documented the success rate of the GBAT technique when used as primary treatment for SRBD.

The GBAT was developed to allow the surgeon to perform an osteotomy with greater ease and speed. While the device is effective in capturing the genial tubercle, there are significant complications (112–114). Major complications have been noted to be as high as 15% (112). These complications include exposure of the hardware, persistent infection, and hematoma of the floor of the mouth requiring drainage. The potential for tooth root injury and pathologic fracture of the mandible exists. Other minor complications noted in traditional genioglossus surgery can occur with the GBAT system. However, the most worrisome complication is avulsion of the genioglossus muscle by the trephine. The circular motion of the trephine places the muscle at greater risk of avulsion as compared with the rectangular osteotomy technique.

While the GBAT system is capable of capturing the genial tubercle and has an acceptable rate of cure, it does not offer a significant advantage versus traditional surgery. Traditional genioglossus osteotomy can be performed in a similar amount of time. Furthermore, the GBAT system lacks the tactile sensation provided by a sagittal saw, which could potentially result in trauma to the floor of the mouth and muscle avulsion. Lastly, once the genioglossus muscle is avulsed, it is exceedingly difficult to salvage the surgery.

Repose™ Genioglossus Advancement Hyoid Myotomy

The Repose (Influent, Inc., San Francisco, California, U.S.) genioglossus advancement hyoid myotomy (GAHM) suspension suture technique is a minimally invasive procedure to treat hypopharyngeal obstruction (115). The concept of the surgery is to place tension on the tissues

of the tongue base and/or the hyoid complex by anchoring a suture to the mandible. These sutures are passed through the base of the tongue or the hyoid bone. No tissue is removed and there is minimal dissection. Thus, the procedure can be performed quickly and with less trauma.

The surgery is performed under general anesthesia. A small incision is placed in the floor of the mouth. A screw is then inserted into the lingual surface of the mandible for the tongue procedure. A suture is passed through the base of the tongue and secured to the screw anchored to the mandible. For the hyoid procedure, a screw is inserted into the inferior border of the mandible. A permanent suture attached to the screw is tunneled to the level of the hyoid bone. The suture is passed around the hyoid bone with resulting anterior displacement of the hyoid complex.

The Repose system has been evaluated as primary therapy and in combination with UPPP to treat SRBD. Subjective improvements in snoring and daytime fatigue have been noted. Also, a reduction of the RDI and apnea index with improvement of oxygen saturation was observed. Unfortunately, the overall cure rate was approximately 20% in several studies (116,117).

Mild complications include sialoadenitis (salivary gland inflammation), wound infection, dysphagia, and trauma to the neurovascular bundle of the tongue. In terms of the long-term efficacy of this technique, a significant concern exists whether or not the suture is able to prevent the hypopharyngeal muscles from prolapsing into the PAS.

Temperature-Controlled Radiofrequency of the Tongue

TCRF applied to the tongue has been shown to improve the RDI; however, the results have varied (118,119). While TCRF may have a role as primary therapy for mild SRBD or UARS, we consider this to be an adjunctive therapy for most patients. Similar to the palate and turbinates, TCRF of the tongue can be performed in the office. However, most patients will require multiple treatments. Thus, therapy can be extended over several months. However, this protocol is intended to prevent complications associated with delivering large amounts of energy to the tongue in a single treatment.

Complications are extremely uncommon and are similar to those of other sites treated with TCRF. If performed properly, this procedure is safe and offers promising outcomes for patients.

Midline Glossectomy and Lingualplasty

Midline glossectomy (MLG) has been used for many years to treat macroglossia. However, this procedure is quite invasive and results in significant postoperative pain. In addition, many patients require a tracheotomy to protect their airway as a result of massive tongue edema. Thus, patients are reluctant to undergo this surgery.

A variation of traditional glossectomy surgery is the laser glossectomy and lingualplasty described by Woodson and Fujita (120). They reported a 77% responder rate using the criteria of a postoperative RDI less than 20. Despite these encouraging results, a complication rate of 27% was noted. Other transcervical submucosal approaches have been developed to resect a portion of the tongue base (121). However, these procedures can be complicated and require extensive dissection. Typically, these surgeries require placement of a tracheotomy tube and thus meet patient resistance.

AIRWAY BYPASS SURGERY

Tracheotomy

Tracheotomy was once the only treatment available for SRBD. By creating an external opening in the trachea, the obstructing tissue of the upper airway was bypassed. This provided immediate resolution of airway obstruction during sleep. However, tracheotomy is poorly accepted by patients. This prompted a search for site-specific surgical procedures. In addition, the advent of CPAP provided a nonsurgical method to prevent upper airway obstruction. The efficacy of CPAP has markedly reduced the number of patients needing tracheotomy (51).

Yet, indications still exist for the insertion of a tracheotomy tube. A tracheotomy should be inserted when there is a need to secure an airway prior to a multiphased protocol. Furthermore, it should be considered in morbidly obese patients with severe SRBD and an

oxygen desaturation below 70%, especially in those who cannot tolerate CPAP. Patients with significant cardiac disease may not be able to tolerate hypoxemia following surgery; thus a tracheotomy may be warranted. A tracheotomy may be temporary if the upper airway is subsequently reconstructed to alleviate obstruction.

CONCLUSIONS

A multidisciplinary approach is indicated for the optimal management of patients with SRBD. Although CPAP is considered first-line treatment, a referral for a surgical evaluation should be offered to patients, especially in those struggling to tolerate nasal CPAP. It is the obligation of the surgeon to educate a patient regarding complications and expected efficacy. Patients should have a realistic expectation of outcomes. Armed with this knowledge, a patient can make an informed decision regarding their care.

Surgery can achieve long-term cure rates similar to nasal CPAP (85). A systematic evaluation of each patient and a rationale stepwise surgical approach are necessary to produce these outcomes. While not all procedures have similar outcomes, new technology is evolving to offer less invasive options to patients.

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