Surgical Approaches to Obstructive Sleep Apnea

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KEYWORDS

• OSA surgery • OSA • CPAP failure • Multilevel surgery • Effectiveness • Evidence

KEY POINTS

- Contemporary obstructive sleep apnea (OSA) surgery is a key salvage treatment option for patients who have failed device use (ie, continuous positive airway pressure [CPAP] or mandibular advancement splint [MAS]).
- Nasal surgery should be considered a prephase option to facilitate subsequent CPAP or MAS or airway surgery.
- Newer variants of modified palatal and tongue surgeries are increasingly supported for their ability to achieve improved outcomes with less sacrifice of functional tissue.
- New modalities such as cranial nerve stimulation show significant promise.
- The current status of high-level literature supports a role for contemporary airway surgery in OSA, but ongoing level I and level II studies are still necessary.

INTRODUCTION

Surgery in adult obstructive sleep apnea (OSA) has undergone significant advancement in recent years and continues to evolve. It is a modality of treatment used in the context of failed device use, specifically, failed continuous positive airway pressure (CPAP) or mandibular advancement splint (MAS). In this context, the role of surgery is as salvage therapy to improve outcomes[1–3] or to facilitate better tolerance of device use. Other treatments such as weight loss, adjuvant nasal therapy (medical ± prephase nasal surgery), and positional devices may be combined with airway surgery. Both pediatric OSA, being a separate entity to adult OSA, and bariatric surgery are discussed and are considered elsewhere. In general, patients with OSA are managed with in-hospital monitoring perioperatively, but where ambulatory considerations are realistic, they are highlighted in this article.

DEFINITION OF OBSTRUCTIVE SLEEP APNEA SURGERY

Adult OSA surgery includes an array of operative procedures to open or stabilize the upper airway and is outlined in **Box 1**. It is much more than just uvulopalatopharyngoplasty (UPPP) or maxillomandibular surgery as a fall back. Procedures are rarely isolated or directed to a single level of the airway and are often concurrent or staged. Prephase nasal surgery is used to facilitate return to device use with better adherence, or before multilevel surgery.

PHILOSOPHY OF SURGERY

In real clinical context, patients who fail primary device use therapy would remain otherwise untreated without salvage options such as upper airway OSA surgery.[4] Many such patients are usually desperate for an alternative, at least to reduce

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Box 1
Sample of procedures used in obstructive sleep apnea surgery

Traditional Procedures

- Tonsillectomy
- Adenoidectomy
- UPPP
- Geniotubercle advancement
- Hyoid suspension
- Epiglottoplexy
- Maxillomandibular advancement

More Contemporary Procedures

- Modified or variant UPPP
- Expansion sphincteroplasty
- Uvulopalatal flap
- Lateral palatoplexy
- Transpalatal advancement
- Radiofrequency systems
- Coblation channeling
- Midline glossectomy
- Submucosal lingualplasty
- Lingual tonsillar reduction

symptom burden and improve quality of life, and to mitigate cardiovascular risk.

Contemporary ethos and summation of available evidence recognizes that OSA surgery allows at least partial treatment applied all the time, as opposed to CPAP, which although a complete treatment modality, may only be applied part of the time.[5] What constitutes effective CPAP use to ameliorate complications of OSA is still yet to be clarified.[6]

CLINICAL ASSESSMENT IN OBSTRUCTIVE SLEEP APNEA SURGERY, INCLUDING DYNAMIC AIRWAY ASSESSMENT

A comprehensive sleep history with focus on snoring, partner-witnessed apnea, disrupted sleep, sleep hygiene, sleep position, tiredness, sleepiness, nasal symptoms, weight, and its progression should be taken. Symptoms indicating other treatable diseases such as thyroid disorders, inflammatory conditions, and depression must be explored. This history needs to be put in the context of patient concerns, such as daytime somnolence, reduced executive function, or social and marital disruption, as well as clinician concerns for cardiovascular, motor vehicle, and industrial accident risk.

Examination includes documentation of body mass index (height and weight), neck circumference, and blood pressure. Maxillofacial assessment for significant maxillary hypoplasia, retrognathia, and unfavorable soft tissue anatomy is made. Nasal examination includes dynamic evaluation of nasal valve, anterior rhinoscopy, and nasendoscopy. The oral cavity and oropharynx are examined, and the Friedman tonsil and tongue-relative-to-palate grade is recorded.[7] Flexible nasendoscopy is performed in the erect and supine positions, combined with the modified Mueller maneuver and Woodson hypotonic method.[8–10] The airway is examined at multiple levels both in the natural position and with a jaw thrust maneuver, used to assess the magnitude of change in the airway. Sedation endoscopy may be used either in certain select cases, or in some clinician's practices, routinely.[11]

Clinical questionnaires generally include a measure of snoring (eg, Snoring Severity Scale[12]), a measure of sleepiness (eg, Epworth Sleepiness Scale [ESS][13]), a quality-of-life yardstick (eg, Functional Outcomes of Sleep Questionnaire-30 [FOSQ-30][14]), and in some practices predictive tools (eg, Berlin[15] or STOP-BANG[16]).

Formal in-laboratory polysomnography is preferred, but if unavailable, a sleep physician–requested and reviewed level II ambulatory study are performed preoperatively and after definitive surgical intervention.

PREPHASE NASAL SURGERY

Nasal obstruction affects 25% to 40% of CPAP users,[21] and the need for nasal airway patency in the treatment of OSA is well established. Depending on the underlying disorder, this may be achieved via medical therapies, surgery, immunotherapy, or a combination. Anatomic obstructions can be addressed with prephase nasal surgery with the intention of facilitating frontline OSA therapies.[22] Nasal surgery also significantly decreases pressure requirements and improves compliance in CPAP use.[17] In isolation, it may improve apnea hypopnea index (AHI) and the symptoms of OSA, and on the rare occasion, may even obviate further treatment.[20,23,24] However, it must be emphasized that these are not the objectives of nasal surgery, and the need for further treatment is usually required.

Surgical reduction of inferior turbinate size, usually with concomitant correction of septal deviations, remains the mainstays of improving nasal airway patency and has been shown to result in the greatest decrease in CPAP pressures.[17] Other procedures include dynamic nasal valve surgery, rhinoplasty, functional endoscopic sinus surgery, polypectomy, and adenoidectomy. The type of surgery required is individualized to each patient and may require a combination of procedures to achieve optimal nasal airway. The procedures are generally well tolerated, and complete healing usually occurs within 6 weeks, during which time CPAP may still be used. Complications of nasal surgery are infrequent, and serious adverse outcomes are rare. Simultaneous nasal and pharyngeal surgery should be avoided where possible because there is an associated higher complication rate,[25] but in select cases may be necessary.

The role of nasal surgery is outlined earlier, but more specific indications are listed in **Box 2** with the supporting literature. Ambulatory prephase nasal surgery can be considered,[26] but this needs careful deliberation in the context of severity of OSA and potential perioperative complications, anesthetic risk, as well as patient and clinician preferences.

CONTEMPORARY SURGICAL INTERVENTION PARADIGMS AND SELECTION

The first 2 indications for surgery in **Box 3** have been discussed at length.[4,27,28] The latter 2 (asterisks) are open to debate, particularly when considering patients who prefer surgery but refuse outright a trial of device use under sleep physician supervision. Primary surgery in patients with favorable anatomy (such as tonsillar hypertrophy and dynamic collapse) has been a topic of recent consideration in the literature.[29]

Fig. 1 demonstrates an overview of how adult OSA patients come to surgery. Patients undergoing surgical treatment will likely initially undergo phase 1 type procedures either as staged or as multilevel procedures. However, individual circumstances may mandate bypassing of phase 1 procedures and moving straight to phase 2 surgeries. Contemporary variations on traditional techniques are noteworthy; previous surgeries involving resection of palatal soft tissue should no longer be performed. Most surgeries involve

Box 2
Indications for prephase nasal surgery

- Failed tolerance or efficacy of device use[17]
- Significant complications of device use[17]
- Significant symptoms related to nasal mucosal abnormality itself[18]
- Significant correctable structural/dynamic nasal anatomy[17,19]
- A treatment modality to improve sleep disordered breathing (in select cases)[20]

Box 3
Indications for contemporary upper airway surgery in obstructive sleep apnea

- Failed compliance/tolerance of CPAP/MAS use
- Significant complications/side effects of device use
- Patient favors/desires surgery*
- Particularly favorable anatomy for surgery*

*Indications not absolute, requires further discussion.

soft tissue work to reposition the palate, and modified variants of UPPP that focus on superolateral velopharyngeal port opening without resecting functional tissues are now standard of care.[29–33] Some investigators recommend ambulatory UPPP in selected patients[34–36]; however, this should be approached with caution in patients with moderate to severe OSA. Transpalatal advancement in patients requiring anterior repositioning or where modified UPPP has been or is likely to be inadequate, and where the arch of the palate is not excessively high and narrow, has found its place in contemporary protocols.[37] Bulky lingual tonsils can be reduced with suction diathermy or coblation. Gentle reduction of a bulky tongue can be achieved by minimally invasive coblation channeling,[30] a procedure that is well tolerated, has good safety profile, and can undergo repeat treatments. Tongue bulk can also be reduced by a variety of predominantly mucosally preserving surgeries, such as submucosal lingualplasty or the coblation-assisted Lewis and MacKay operation, and are preferred over traditional resective operations,[38,39] although newer robotic techniques are gaining momentum despite some posterior tongue mucosal sacrifice.[40]

Maxillomandibular advancement, which can be performed in conjunction with a high sliding genioplasty, is usually reserved for those who have entered the surgical pathway and are refractory to phase 1 surgical procedures or those with significant retrognathia, micrognathia, and/or maxillary hypoplasia. It involves expansion of the skeletal framework that encompasses the upper airways at all levels. Expansion of the skeletal framework is achieved via multiple transoral osteotomies of the maxilla and mandible, then advancing the entire complex 10 to 14 mm and stabilizing with hardware. A review reported that this procedure yielded superior results when compared with soft tissue surgery[41]; however, comparisons were only made to single-level airway surgery, not the multilevel surgery seen in contemporary operative management that is

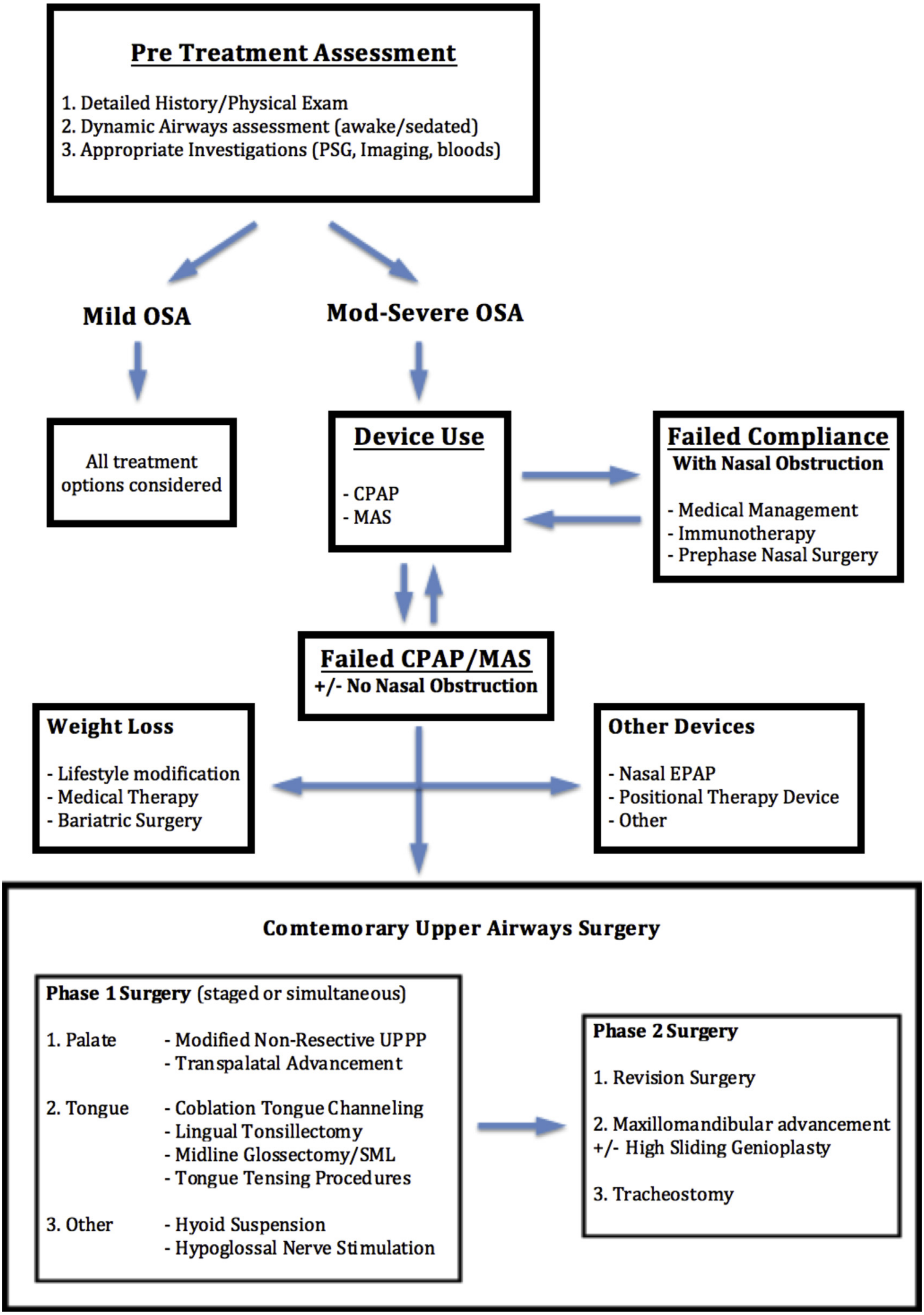

Fig. 1. Flow chart indicating patient treatment pathways.

currently performed in clinical practice. The same review also acknowledges that modern soft tissue palatal techniques may have better outcomes.[41] Recent meta-analysis shows that maxillomandibular surgery significantly reduces AHI and oxygen saturation nadir in most cases, with a “cure” achieved in 38.5% of patients.[42] However, these rates were lowered for the morbidly obese. Despite concern for complications, most patients report an improved quality of life[43] and consider it worthwhile.[44]

Tracheostomy is the ultimate procedure, because the upper airway is completely bypassed. A meta-analysis shows significant improvement in AHI, oxygen desaturation index, subjective sleepiness, and cardiovascular-related as well as overall mortality.[45] However, in both maxillomandibular advancement and tracheostomy, improvement may not apply to those over the age of 60 or those that are morbidly obese with obesity-hypoventilation syndrome and may even make their parameters worse.[46] Tracheostomy also has the inherent morbidities that come with an open-instrumented wound and is seldom a choice that most patients are willing to make.

Readers are encouraged to visit the Web site of the International Surgical Sleep Society for more information regarding the range of procedures considered to have treatment effect.[47]

COMPLICATIONS OF SURGERY

The presence of OSA is an independent risk factor for an increased complication rate and can mandate a higher level of perioperative care.[48,49] In airway reconstructive surgery, the spectrum of complications reflect the heterogeneity of the disease and surgical treatments available. The type and likelihood of complications have many influences, including factors related to the patient, anesthetic, perioperative care, surgical extent, and techniques used to address the patient-specific problem. Broadly, they can be divided into generic and procedure specific complications.

OSA-specific anesthetic considerations exist. Preoperative assessment and optimization are critical to avoid major perioperative cardiovascular and respiratory events. Mortality related to OSA surgery is rare; however, the need for overnight monitoring and higher level care, such as intensive care unit, is appropriate in most cases and should always be considered, especially in multilevel surgery and more severe OSA, but is not mandatory.[34] Potential airway obstruction must be anticipated. It may occur on induction of anesthesia or postoperatively, leading to inability to extubate, the need to reintubate, or necessitating a tracheostomy. Fortunately, airway obstruction is an increasingly infrequent event, likely due to better understanding of OSA perioperative management, steroid use, and limiting respiratory depressants.[50,51]

Bleeding, infection, and pain resulting in odynophagia and consequential dehydration are ubiquitous risks in all OSA surgery. Bleeding is an uncommon but potentially major concern. Bleeding may occur directly into the upper aerodigestive tract or formation of a hematoma. Negation of bleeding diathesis and careful blood pressure control are achieved through activity modification and sometimes medication. All surgical wounds in the upper aerodigestive tract are inevitably colonized by pathogens, and antibiotics are generally prescribed for major airways procedures, although this may be contentious. Pain is by far the most notable issue from the patient perspective, particularly when tonsillectomy or lingual tonsillectomy forms a part of the procedure. For most, the pain peaks at day 4 to 7 and is managed by regular analgesia, and on occasion, steroids.

Palatal surgery is associated with velopalatal insufficiency and nasopharyngeal stenosis, but is less common and usually transient in contemporary nonresective operations. Globus, altered voice (in particular loss of guttural sounds), and palatal paraesthesia may also occur, usually transiently. Surgical procedures on the hard palate can cause mucosal flap necrosis, oronasal fistulae with an estimated incidence of 2% to 3%, and very rarely, eustachian tube dysfunction from loss of tensor veli palatini action.

Expansion of the retrolingual space is achieved via numerous methods. Tongue reduction procedures can injure the neurovascular bundle and cause hypoglossal nerve injury, dysgeusia, tongue paraesthesia, and globus. Geniotubercle advancement may result in mandibular fracture, mental nerve injury, disruption of the dental roots, genioglossal avulsion from the tubercle, cosmetic defect, and exposure/infection/failure of implanted hardware. Hyoid suspension has a preponderance for aspiration and dysphagia. Maxillomandibular advancement is the most morbid and extensive procedure; complications include altered cosmetics, dental malocclusion, paraesthesia, temporomandibular dysfunction, and hardware-related failures.

EFFECTIVENESS OF OBSTRUCTIVE SLEEP APNEA SURGERY: CURRENT STATUS OF LITERATURE: NONRANDOMIZED TRIALS

Over many years, high-level cohort studies have demonstrated a role for (salvage) airway surgery in adult OSA. Weaver and colleagues[1] followed 20,000 US War Veterans and actually found a survival advantage with surgery over CPAP provision (not CPAP application) at 4 years. Similarly, Marti and colleagues concluded that successful treatment with surgery (and indeed CPAP, MAS, and weight loss) reverted death risk to that of the general population.[2] A large Gothenburg cohort study of 370 patients (182 middle-aged men) demonstrated reduction in cardiovascular risk over 7 years in efficiently treated patients, where one of the treatment modalities was surgery.[3]

Other cohort studies confirming surgery can achieve important quality-of-life outcomes have been published in recent years, including articles by Rotenberg and colleagues[29] and Robinson and colleagues.[27] Both of these articles carry added importance given the use of real-life staged surgical interventions. In addition, recent literature confirms improvement in depression scores with surgery[52] and increase in baroreflex sensitivity with modified palatal and tongue reduction surgery.[53] The latter is particularly relevant in the context of awareness that depressed baroreflex sensitivity is a major contributor to cardiovascular morbidity/mortality in OSA.[54–56]

Some investigators have questioned the economic value of OSA surgery,[57] but a recent cost-effectiveness analysis has firmly established the benefit of palatopharyngeal reconstructive surgery using semi-Markov modeling.[58]

EFFECTIVENESS OF OBSTRUCTIVE SLEEP APNEA SURGERY: CURRENT STATUS OF LITERATURE AND CHALLENGES OF RANDOMIZED CONTROLLED TRIALS

Randomized controlled trials (RCTs) in surgery for OSA carry significant challenges related to methodology, design, and real-life execution. These challenges vary from how to define surgery and comparator groups, how to recruit patients, inclusion and exclusion criteria, maintaining a control group, generalizability of outcomes, and choice of outcome measures.

How to Define Obstructive Sleep Apnea Surgery

OSA surgery can be complex to characterize and is broadly defined as previously indicated. Procedures are often multilevel simultaneous or staged and based on comprehensive history, airway assessment, polysomnographic findings, and patient preferences.

In randomized trials, interventions may be single level only to reduce complexity, permit greater reproducibility, and avoid ethics ramifications. Such single-level RCTs may achieve excellent results[33] but not reflect more commonly applied real-life multilevel surgeries. Staged surgical protocol[27,28,59] can be harder to apply in a high-level surgical RCT. In RCT level studies, individual surgeon-dictated variations in specific cases may be subjugated to achieve rigid, reproducible protocols that might be detrimental to patient outcome.

Patient Selection

Patients should desire surgery, and the surgeon must establish that it is an appropriate option in each case.[60] In a randomized surgery trial, inclusion and exclusion criteria may lead to variance in usual practice case-to-case modifications. Some studies recruit among vulnerable populations, such as children,[61] and may enroll subgroups who are less able to achieve “successful” surgery due to equipoise, because the population one wants to study may be less appropriate for the intervention.

Recruitment/Enrollment

Patients worried about complications of their disease may be concerned about being randomized away from surgery. If it remains their only option after CPAP/device use failure, they may avoid joining a trial. These patients and those that have private insurance might elect surgery outside of a trial, thereby skewing the study population.

Recruiting from private, community, and academic facilities may make RCT results more generalizable, and offering surgery to all control patients at study completion may help. Low-risk surgery can at least make the intervention closer to pill and placebo studies,[62] possibly increasing participation but again reducing real-life applicability.

Economics

Industry sponsorship is common in medication and device RCTs[63] but less frequent in surgical studies, and insurance companies may not fund operations if part of a trial, because it is considered “experimental.” Less expensive procedures, such as radiofrequency to the palate and tongue,[64] might not reflect real world generalizability, but are ambulatory, reduce costs, and may demonstrate treatment effect.

These minor procedures are attractive to mitigate direct costs and inpatient fees,[62,64] which might be borne by the patient. Ambulatory sleep studies might also reduce costs, but they can also reduce reliability, compared with formal in-laboratory studies.[65]

Comparator Group

Placebo or "sham" CPAP devices may be applied as a comparator group intervention. "Sham" surgery is somewhat more difficult to institute in a trial and complex for Ethics committees to approve. Adult OSA surgery is usually applied in clinical practice when CPAP or oral appliances have failed,[27] and thereby, a common comparator group should be those with no treatment or conservative measures only. To ask a patient to randomize to or away from a treatment such as CPAP (a device) or medication is relatively acceptable, but to ask them to randomize to or away from a surgical intervention that carries immediate risk is vexed.[66] The patient must be willing to enroll and take the chance of being placed into a control group with no treatment. The result of untreated disease in OSA (when randomized to control arm) may result in significant morbidity and mortality.[54] Surgery trials might only achieve ethics approval if mild OSA is studied, given the risks to the control arm in severe disease.

Comparative effectiveness trials may not be practical, because surgery compared with another treatment is likely to need a large sample size to show a difference in effect. Such sample sizes are harder to achieve in surgical trials compared with device/medication trials. Efficacy measures favor CPAP over OSA surgery, creating added complexity in a surgery—CPAP trial.

Surgical RCTs comparing surgery with intent to treat and "sham" operations are neither practical nor ethical. Pain, anatomic rearrangements, and recovery will likely be perceived by patients, making patient blinding difficult. Randomization to a procedure that induces discomfort in a placebo arm without the benefit is also likely to be ethically inappropriate.

Outcome Measures

As indicated in the previous section on nonrandomized evidence, long-term cohort studies suggest critical outcome measures, such as death,[1,2] cardiovascular risk,[3] and quality-of-life parameter measures,[27] are similar between CPAP and surgery. Effectiveness of CPAP use in the community differs to in-laboratory polysomnographic efficacy, detracting from conclusions that might be drawn from certain studies, unless mean disease alleviation is applied.[67]

Hence, objective measures may be discordant with symptom and quality-of-life improvement.[68] OSA RCTs comparing surgery to CPAP are likely to favor the latter if surrogate polysomnography parameters are used, and using death and cardiovascular measures might lengthen a trial beyond what is feasible.

Despite all of these challenges, published RCTs have demonstrated a role for surgery in OSA. A 4-year Scandinavian study showed significant AHI reduction with modified UPPP, and in real-life clinical practice, such surgery would often be combined with tongue reduction procedures or other interventions to conceivably achieve even better outcomes.[33]

An extension of this article also revealed important quality-of-life, sleepiness, and vigilance benefits.[69] Radiofrequency RCTs have identified key roles for treatment directed to turbinates[62] and the tongue and palate,[64] with the latter demonstrating impact on apnea and vigilance. Inspire Medical sponsored a study of the hypoglossal nerve stimulator with 126 patients experiencing a significant reduction in AHI from 29 to 9.[70] In the withdrawal component of the study, the problem of an untreated comparator arm was overcome by instigating a "stimulator turn-off/turn-on" policy.[71]

The same patients also demonstrated a significant improvement in ESS, FOSQ-30, FOSQ-10, and partner subjective snoring reports.[72] The benefits seen were maintained for at least 24 months. Other RCTs, including evaluating multilevel surgery across multiple centere, are in progress.

RCTs in OSA surgery are difficult to achieve for all the reasons outlined, but these challenges should not excuse the need to expand the volume of RCTs in this important field, nor should it overshadow the existing cohort level literature supporting a role for contemporary surgical intervention.

RECENT/CURRENT INNOVATIONS

Developments in recent years in OSA surgery can be broadly divided into newer technique variations, upper airway stimulation, and robotic surgery.

Newer technique variations have been covered earlier, particularly reconstructive and modified UPPPs and modified tongue reduction.

Upper airway stimulation has been evaluated over some years, but recent hypoglossal nerve stimulation (HGNS) trials have shown this to be an exciting evolution.[73] At this time, it is available only in the United States and other select countries. The current HGNS involves a surgically implanted complex of 3 components: an upper chest pulse generator, a cuffed electrode with stimulation lead on the hypoglossal nerve (or selective medial fibers), and an intercostal space sensor lead, to detect respiratory effort. Stated advantages of HGNS include probable "coupling" of retropalatal and retrolingual segments to afford reduction of multilevel collapse, ability to titrate to control of apnea and symptoms, and avoidance of endoluminal airway complications related to traditional upper airway surgery. Other similar, but less invasive devices are also being developed. Current literature supports an emerging role as a second-line therapy. Disadvantages include lifelong requirement of an implantable device and attachments, sleep disruption, and surgical risks, such as infection, hematoma, and cranial nerve injury.

Since Vicini and colleagues established the concept of using transoral robotic surgery in 2010,[40,74] advocates have highlighted its potential improved access to the base of tongue and lingual tonsil. Three-dimensional depth perception and robotic arms are used to reduce tissue bulk in this area, and a growing body of evidence supports its use.[40] Possible disadvantages include restricted financial access to equipment and lack of mucosal preservation.

FUTURE DIRECTIONS AND INNOVATIONS

As the body of literature evolves for contemporary multilevel airway surgery in CPAP failure, it is becoming important to test such surgery at higher levels of evidence. A National Health and Medical Research Council–funded randomized controlled clinical trial is underway in Australia assessing multilevel palatal and tongue surgery compared with best conservative medical care in device failure/rejection patients. It is hoped such trials will support a role for salvage surgery and encourage similar such investigations worldwide.

Physiologic phenotyping offers an exciting modality, if it can be combined with sound clinical and anatomic assessment, to improve patient selection for contemporary airway surgery. Preoperative patient advisement and predictability of improvement are the ultimate goals of surgical interventions, and correlation between particular polysomnographic parameters of disease, clinical findings, and outcomes will support such endeavors.

Finally, OSA airway modeling and simulation to allow subsequent assessment of newer biotechnology, smart polymers, and molecular alterations represent a possible future pathway for minimal surgical interventions to achieve stabilized airways in sleep, while avoiding disruption to normal upper aerodigestive tracts during wakefulness.

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REFERENCES

1. Weaver EM, Maynard C, Yueh B. Survival of veterans with sleep apnea: continuous positive airway pressure versus surgery. Otolaryngol Head Neck Surg 2004;130:659–65.
2. Marti S, Sampol G, Muñoz X, et al. Mortality in severe sleep apnoea/hypopnoea syndrome patients: impact of treatment. Eur Respir J 2002;20(6):1511–8.
3. Peker Y, Hedner J, Norum J, et al. Increased incidence of cardiovascular disease in middle-aged men with obstructive sleep apnea; a 7-year follow-up. Am J Respir Crit Care Med 2002;166:159–65.
4. Weaver EM. Judging sleep apnea surgery. Sleep Med Rev 2010;14(5):283–5.
5. Ravesloot MJL, de Vries N, Stuck BA. Treatment adherence should be taken into account when reporting treatment outcomes in obstructive sleep apnea. Laryngoscope 2014;124:344–5.
6. Crawford MR, Bartlett DJ, Coughlin SR, et al. The effect of continuous positive airway pressure usage on sleepiness in obstructive sleep apnoea: real effects or expectation of benefit? Thorax 2012;67:920–4.
7. Friedman M, Ibrahim H, Bass L. Clinical staging for sleep disordered breathing. Laryngoscope 2004;114(3):454–9.
8. Hsu PP, Tan BYB, Chan YH, et al. Clinical predictors in obstructive sleep apnea patients with computer-assisted quantitative videoendoscopic upper airway analysis. Laryngoscope 2004;114:791–9.
9. Hsu PP, Han HNC, Chan YH, et al. Quantitative computer-assisted digital-imaging upper airway analysis for obstructive sleep apnoea. Clin Otolaryngol Allied Sci 2004;29:522–9.
10. Woodson BT, Feroah T, Connolly LA, et al. A method to evaluate upper airway mechanics following intervention in snorers. Otolaryngology 1997;18(5):306–14.
11. Eichler C, Ulrich Sommer J, Stuck BA, et al. Does drug-induced endoscopy change the treatment concept of patients with snoring and OSA? Sleep Breath 2013;17(1):63–8.
12. Morris LG, Kleinberger A, Lee KC, et al. Rapid risk stratification for obstructive sleep apnea, based on snoring severity and body mass index. Otolaryngol Head Neck Surg 2008;139(5):615–8.
13. Johns MW. A new method for measuring daytime sleepiness: the Epworth sleepiness scale. Sleep 1991;14(6):540–5.
14. Weaver TE, Laizner AM, Evans LK, et al. An instrument to measure functional status outcomes for disorders of excessive sleepiness. Sleep 1997;20:835–43.

15. Netzer NC, Stoohs RA, Netzer CM, et al. Using the Berlin Questionnaire to identify patients at risk for the sleep apnea syndrome. Ann Intern Med 1999;131:485–91.
16. Vasu TS, Doghramji K, Cavallazzi R, et al. Obstructive sleep apnea syndrome and postoperative complications: clinical use of the STOP-BANG questionnaire. Arch Otolaryngol Head Neck Surg 2010;136:1020–4.
17. Camacho M, Riaz M, Capasso R, et al. The effect of nasal surgery on continuous positive airway pressure device use and therapeutic treatment pressures: a systematic review and meta-analysis. Sleep 2015;38(2):279–86.
18. Georgalas C. The role of the nose in snoring and obstructive sleep apnea: an update. Eur Arch Otorhinolaryngol 2011;268(9):1365–73.
19. Friedman M, Tanyeri H, Lim J, et al. Effect of improved nasal breathing on OSA. Otolaryngol Head Neck Surg 2000;122(1):71–4.
20. Bican A, Kahrman A, Bora I, et al. What is the efficacy of nasal surgery in patients with obstructive sleep apnea? J Craniofac Surg 2010;21(6):1801–6.
21. Brander PE, Soirinsuo M, Lohela P. Nasopharyngeal symptoms in patients with obstructive sleep apnea syndrome. Effect of nasal CPAP treatment. Respiration 1999;66:128–35.
22. Epstein LJ, Kristo D, Strollo PJ, et al. Clinical guideline for the evaluation, management and long-term care of obstructive sleep apnea in adults. J Clin Sleep Med 2009;5:263–76.
23. Nakata S, Noda A, Yasuma F. Effects of nasal surgery on sleep quality in obstructive sleep apnea syndrome with nasal obstruction. Am J Rhinol 2008;22(1):59–63.
24. Park CY, Hong JH, Lee JH, et al. Clinical effect of surgical correction for nasal pathology on the treatment of obstructive sleep apnea syndrome. PLoS One 2014;9(6):e98765.
25. Mickelson S, Hakim I. Is pre-operative intensive care monitoring necessary after uvulopalatopharyngoplasty? Otolaryngol Head Neck Surg 1998;119(4):352–6.
26. Bhattacharyya N. Unplanned revisits and readmissions after ambulatory sinonasal surgery. Laryngoscope 2014;124:1983–7.
27. Robinson S, Chia M, Carney AS, et al. Upper airway reconstructive surgery long-term quality-of-life outcomes compared with CPAP for adult obstructive sleep apnea. Otolaryngol Head Neck Surg 2009;141(2):257–63.
28. Mackay SG, Jefferson N, Marshall NS. Beyond uvulopalatopharyngoplasty for obstructive sleep apnoea: single surgeon case series of contemporary airway reconstruction. J Laryngol Otol 2013;127(12):1184–9.
29. Rotenberg BW, Theriault J, Gottesman S. Redefining the timing of surgery for obstructive sleep apnea in anatomically favorable patients. Laryngoscope 2014;124:S1–9.
30. MacKay S, Carney S, Woods C, et al. Modified uvulopalatopharyngoplasty and coblation channeling of the tongue for obstructive sleep apnea: a multi-centre Australian trial. J Clin Sleep Med 2013;9:117–24.
31. Pang KP, Woodson BT. Expansion sphincter pharyngoplasty: a new technique for the treatment of obstructive sleep apnea. Otolaryngol Head Neck Surg 2007;137:110–4.
32. Cahali MB, Formigoni GG, Gebrim EM, et al. Lateral pharyngoplasty versus uvulopalatopharyngoplasty: a clinical, polysomnographic and computed tomography measurement comparison. Sleep 2004;27(5):942–50.
33. Browaldh N, Nerfeldt P, Lysdahl M, et al. SKUP3 randomised controlled trial: polysomnographic results after uvulopalatopharyngoplasty in selected patients with obstructive sleep apnoea. Thorax 2013;68(9):846–53.
34. Kandasamy T, Wright E, Fuller J, et al. The incidence of early post-operative complications following uvulopalatopharyngoplasty: identification of predictive risk factors. J Otolaryngol Head Neck Surg 2013;42(1):15.
35. Hathaway B, Johnston JT. Safety of uvulopalatopharyngoplasty as outpatient surgery. Otolaryngol Head Neck Surg 2006;134(4):542–4.
36. Bhattacharyya N. Revisits and readmissions following ambulatory uvulopalatopharyngoplasty. Laryngoscope 2015;125(3):754–7.
37. Woodson BT, Robinson S, Lim HJ. Transpalatal advancement pharyngoplasty outcomes compared with uvulopalatopharygoplasty. Otolaryngol Head Neck Surg 2005;133(2):211–21.
38. Mackay SG, Jefferson N, Grundy L, et al. Coblation-assisted Lewis and MacKay operation (CobLAMO): new technique for tongue reduction in sleep apnoea surgery. J Laryngol Otol 2013;127(12):1222–5.
39. Gunawardena I, Robinson S, Mackay S, et al. Submucosal lingualplasty for adult obstructive sleep apnea. Otolaryngol Head Neck Surg 2013;148(1):157–65.
40. Crawford JA, Montevechi F, Vicini C, et al. Transoral robotic sleep surgery: the obstructive sleep apnea–hypopnea syndrome. Otolaryngol Clin North Am 2014;47(3):397–406.
41. Caples SM, Rowley JA, Prinsell JR, et al. Surgical modifications of the upper airways for obstructive sleep apnea in adults: a systemic review and meta-analysis. Sleep 2010;33(10):1396–407.
42. Zaghi S, Holty JE, Certal V, et al. Maxillomandibular advancement for treatment of obstructive sleep apnea: a meta-analysis. JAMA Otolaryngol Head Neck Surg 2016;142(1):58–66.

43. Boyd SB, Walters AS, Waite P, et al. Long-term effectiveness and safety of maxillomandibular advancement for treatment of obstructive sleep apnea. J Clin Sleep Med 2015;11(7):699–708.
44. Goodday R, Bourque S. Subjective outcomes of maxillomandibular advancement surgery for treatment of obstructive sleep apnea syndrome. J Oral Maxillofac Surg 2012;70(2):417–20.
45. Camacho M, Certal V, Brietzke SE, et al. Tracheostomy as treatment for adult obstructive sleep apnea: a systematic review and meta-analysis. Laryngoscope 2014;124(3):803–11.
46. Camacho M, Teixeira J, Abdullatif J, et al. Maxillomandibular advancement and tracheostomy for morbidly obese obstructive sleep apnea: a systematic review and meta-analysis. Otolaryngol Head Neck Surg 2015;152(4):619–30.
47. Available at: http://www.surgicalsleep.org/isss-position-statement-on-sleep-surgery. Accessed May 16, 2016.
48. Vasu TS, Grewal R, Doghramji K. Obstructive sleep apnea syndrome and perioperative complications: a systematic review of the literature. J Clin Sleep Med 2012;8(2):199–207.
49. Adesanya AO, Lee W, Greilich NB, et al. Perioperative management of obstructive sleep apnea chest. Chest 2010;138(6):1489–98.
50. Pang KP, Siow JK, Tseng P. Safety of multilevel surgery in obstructive sleep apnea: a review of 487 cases. Arch Otolaryngol Head Neck Surg 2012;138(4):353–7.
51. Talei B, Cossu AL, Slepian R, et al. Immediate complications related to anesthesia in patients undergoing uvulopalatopharyngoplasty for obstructivesleep apnea. Laryngoscope 2013;123(11):2892–5.
52. Ishman SL, Benke JR, Cohen AP, et al. Does surgery for obstructive sleep apnea improve depression and sleepiness? Laryngoscope 2014;124(12):2829–36.
53. Huang CC, Lin WC, Chen HL, et al. Improvement of baroreflex sensitivity in patients with obstructive sleep apnea following surgical treatment. Clin Neurophysiol 2015;127(1):544–50.
54. Marin JM, Carrizo SJ, Vicente E, et al. Long-term cardiovascular outcomes in men with obstructive sleep apnoea-hypopnoea with or without treatment with continuous positive airway pressure: an observational study. Lancet 2005;365(9464):1046–53.
55. Partinen M, Jamieson A, Guilleminault C. Long-term outcome for obstructive sleep apnea syndrome patients. Mortality. Chest 1988;94(6):1200–4.
56. Ryan S, Ward S, Heneghan C, et al. Predictors of decreased spontaneous baroreflex sensitivity in obstructive sleep apnea syndrome. Chest 2007;131(4):1100–7.
57. Elshaug AG, Watt AM, Mundy L, et al. Over 150 potentially low-value health care practices: an Australian study. Med J Aust 2012;197(10):556–60.
58. Tan KB, Toh ST, Guilleminault C, et al. A cost-effectiveness analysis of surgery for middle-aged men with severe obstructive sleep apnea intolerant of CPAP. J Clin Sleep Med 2015;11(5):525–35.
59. Stewart S, Huang J, Mohorikar A, et al. AHI outcomes are superior after upper airway reconstructive surgery in adult CPAP failure patients. Otolaryngol Head Neck Surg 2016;154:553–7.
60. Field CJ, Robinson S, Mackay S, et al. Clinical equipoise in sleep surgery: investigating clinical trial targets. Otolaryngol Head Neck Surg 2011;145(2):347–53.
61. Marcus CL, Moore RH, Rosen CL, et al. A randomized trial of adenotonsillectomy for childhood sleep apnea. N Engl J Med 2013;368(25):2366–76.
62. Powell NB, Zonato AI, Weaver EM, et al. Radiofrequency treatment of turbinate hypertrophy in subjects using continuous positive airway pressure: a randomized, double-blind, placebo-controlled clinical pilot trial. Laryngoscope 2001;111(10):1783–90.
63. Miller FG, Shorr AF. Ethical assessment of industry-sponsored clinical trials: a case analysis. Chest 2002;121(4):1337–42.
64. Steward DL, Weaver EM, Woodson BT. Multilevel temperature-controlled radiofrequency for obstructive sleep apnea: extended follow-up. Otolaryngol Head Neck Surg 2005;132(4):630–5.
65. Portier F, Portman A, Czernichow P, et al. Evaluation of home versus laboratory polysomnography in the diagnosis of sleep apnea syndrome. J Resp Crit Care Med 2000;162(3):814–8.
66. Young JM, Solomon MJ, Harrison JD, et al. Measuring patient preference and surgeon choice. Surgery 2008;143(5):582–8.
67. Vanderveken OM, Dieltjens M, Wouters K, et al. Objective measurement of compliance during oral appliance therapy for sleep-disordered breathing. Thorax 2013;68(1):91–6.
68. Weaver EM, Woodson BT, Steward DL. Polysomnography indexes are discordant with quality of life, symptoms, and reaction times in sleep apnea patients. Otolaryngol Head Neck Surg 2005;132(2):255–62.
69. Browaldh N, Bring J, Friberg D. SKUP3 RCT; continuous study: changes in sleepiness and quality of life after modified UPPP. Laryngoscope 2015. http://dx.doi.org/10.1002/lary.25642.
70. Strollo PJ, Soose RJ, Maurer JT. Upper-airway stimulation for obstructive sleep apnea. N Engl J Med 2014;370:139–49.
71. Woodson BT, Gillespie MB, Soose RJ, et al. Randomized controlled withdrawal study of upper airway stimulation on OSA short- and long-term effect. Otolaryngol Head Neck Surg 2014;51(5):880–7.
72. Woodson BT, Soose RJ, Gillespie MB, et al, STAR Trial Investigators. Three-year outcomes of cranial nerve stimulation for obstructive sleep apnea: the

STAR trial. Otolaryngol Head Neck Surg 2016; 154(1):181–8.

73. Malhotra A. Hypoglossal-nerve stimulation for obstructive sleep apnea. N Engl J Med 2014; 370(2):170–1.

74. Vicini C, Dallan I, Canzi P, et al. Transoral robotic tongue base resection in obstructive sleep apnoea-hypopnoea syndrome: a preliminary report. ORL J Otorhinolaryngol Relat Spec 2010; 72:22–7.