

Upper airway surgery for obstructive sleep apnea

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KEYWORDS

Sleep apnea syndromes, surgery, pharynx, airway, soft tissue, skeletal, palate, tongue, maxillomandibular, tracheostomy, uvulopalatopharyngoplasty, polysomnography

Summary Upper airway surgical treatments for obstructive sleep apnea syndrome (OSAS) attempt to modify dysfunctional pharyngeal anatomy or by-pass the pharynx. Modifications of the pharynx diminish the bulk of soft tissue structures which abut the air column, place them under tension, others alter their spatial inter-relationships. Surgical procedures are designed to modify the retropalatal pharynx, the retrolingual pharynx, or both. There is no single surgical procedure, short of tracheostomy, which consistently results in complete elimination of OSAS. However, appropriate application of current surgical techniques (synchronously or sequentially) may achieve cure in most patients without resort to tracheostomy. Patient selection, versatility in varied surgical approaches, and willingness to utilize more than one procedure when necessary appear to be critical attributes of a successful surgical program. On the other hand, analysis of the efficacy of individual surgical interventions is thwarted by the frequent practice of reporting on the application of multiple procedures in combination with evaluation of the composite effect. Well designed, multi-center studies would help clarify the strengths and weaknesses of different treatment approaches. © 2002 Published by Elsevier Science Ltd

RATIONALE AND STRATEGY FOR UPPER AIRWAY SURGERY

Upper airway surgical treatments for obstructive sleep apnea syndrome (OSAS) attempt to modify dysfunctional pharyngeal anatomy or by-pass the pharynx (tracheotomy). Some modifications of the pharynx diminish the bulk of soft tissue structures which abut the air column, whereas others place them under tension or alter their spatial inter-relationships. The former goal is achieved through ablating pharyngeal soft tissue, while the latter are accomplished, indirectly,

by modifying the facial skeleton from which the soft tissues are suspended.

For the estimated 2% of adult OSAS patients with specific space-occupying pathological lesions, surgical removal of these lesions is corrective. Ninety-eight percent of OSAS patients do not have pathology of this type. It is conceptualized that, in the latter, "disproportionate anatomy" of the upper airway resulting from unfavorable anatomic features of the surrounding soft tissue structures and underlying maxillomandibular skeleton predisposes to OSAS. The configuration of the pharyngeal lumen is determined by the size and shape of soft tissue structures which abut it (such as faucial and lingual tonsils, tongue, soft palate) and their spatial orientation in relation to each other. The spatial orientation is determined by the orientation of underlying muscle planes established through their origins

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and insertions in the vertebral and craniofacial skeleton. The latter will depend, ultimately, on the craniofacial skeletal characteristics of the patient [1–3].

The pharynx has properties associated with a collapsible biological conduit. Collapse occurs at a discrete (less than 1 cm) locus. Data derived from studies of the pharynx with awake endoscopy, awake endoscopy with Muller maneuver, asleep (drug-induced) endoscopy, asleep (natural and drug-induced) endoscopy with continuous positive airway pressure (CPAP), asleep fluoroscopy, computed tomographic (CT) scan, and manometry suggest that the pattern of static pharyngeal narrowing and/or dynamic pharyngeal collapse is localized and patient specific, although it may shift with body position, sleep state, and following surgery [3–5]. Observed failure of surgical procedures aimed at limited loci within the pharynx is assumed to result from residual or secondary airway compromise at a remote locus not addressed. A model considers the pharynx as consisting of two loci: (a) retropalatal: located posterior to the soft palate; and

(b) retrolingual: located posterior to the vertical portion of the tongue. The pharynx is preoperatively classified as follows: (a) Type I: only the retropalatal region is compromised; (b) Type II: both retropalatal and retrolingual regions are compromised; and (c) Type III: only the retrolingual region is compromised [6]. While awake endoscopy, awake endoscopy with Muller maneuver, asleep (drug-induced) endoscopy, asleep (natural and drug-induced) endoscopy with continuous positive airway pressure (CPAP), asleep fluoroscopy, computed tomographic (CT) scan, and manometry have been applied, awake lateral cephalometry and endoscopy are currently the most commonly applied methods of pharyngeal classification (Table 1) [2, 7].

UPPER AIRWAY SURGICAL PROCEDURES

Classic otorhinolaryngological techniques to enlarge the nasal or pharyngeal airways, such as nasal septal reconstruction, turbinate mucosal cauterization, turbinate outfracture, and tonsillectomy frequently fail to correct OSAS in adults [7]. Therefore, new surgical approaches have been developed to ablate pharyngeal soft tissue or modify the position of pharyngeal soft tissue structures through mobilization and repositioning of underlying skeletal structures (Table 2).

Table 1 Patterns of pharyngeal collapse

Classification	Region of Compromise
I	Retropalatal region
II	Retropalatal region and retrolingual region
III	Retrolingual region

Table 2 Surgical procedures: mechanism and primary locus of action

Mechanism of Action	Locus of Primary Action	Procedure
Soft tissue ablation	Retropalatal	Uvulopalatopharyngoplasty (UPPP) Laser assisted uvulopalatoplasty (LAUP)
	Retrolingual	Laser midline glossectomy/lingualplasty (LMG) Radiofrequency tongue base ablation (RFTBA) Tongue base reduction with hyoepiglottoplasty (TBRHE)
	Retropalatal and retrolingual	Uvulopalatopharyngoglossoplasty (UPPGP)
Skeletal modification (soft tissue repositioning)	Retropalatal	Transpalatal advancement pharyngoplasty (TPAP)
	Retrolingual	Mandibular advancement (MA) Genioglossal advancement (GA) Hyoid myotomy and suspension of hyoid from mandible (HM-1) Hyoid myotomy and attachment of hyoid to thyroid cartilage (HM-2)
	Retropalatal and retrolingual	Maxillomandibular advancement (MMA)
By-pass upper airway		Tracheotomy

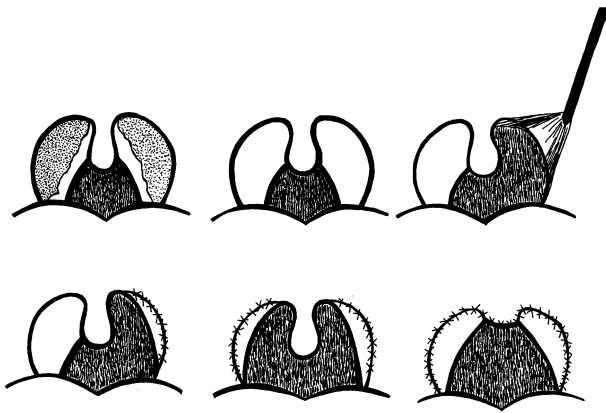


Figure 1 Uvulopalatopharyngoplasty (UPPP). Surgical steps are depicted from left to right, top row followed by bottom row. Tonsils are removed. Posterior tonsillar pillars are divided vertically from uvula to level of upper pole of tonsillar fossae, rotated across the fossae, and sutured to trimmed anterior tonsillar pillars. Sutures may tack the posterior pillars to the midportion of the fossa. Uvula and posterior soft palate are transected at approximately the upper pole of the tonsillar fossae.

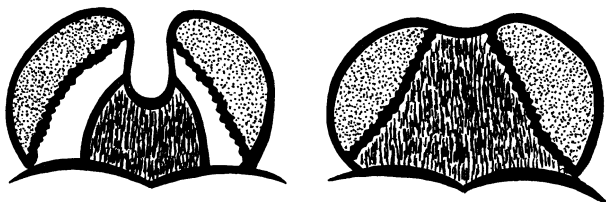


Figure 2 Laser assisted uvulopalatoplasty (LAUP). The posterior tonsillar pillars are surgically ablated as are the uvula and posterior portion of the soft palate.

Technical details of each surgical procedure are found in the Glossary.

Soft tissue is ablated in uvulopalatopharyngoplasty (UPPP) [8] (Fig. 1); laser assisted uvulopalatoplasty (LAUP) [9] (Fig. 2); uvulopalatopharyngo-glossoplasty (UPPGP) [10, 11]; laser midline glossectomy (LMG) and lingual-plasty [12, 13] (Fig. 3); radiofrequency tongue base ablation (RFTBA) [14, 15] (Fig. 4); and tongue base reduction with hyopepiglottoplasty (TBRHE) [16] (Table 2).

Soft tissue is repositioned through skeletal alteration in transpalatal advancement pharyngoplasty (TPAP) [17]; mandibular advancement (MA) [18] (Fig. 5); maxillo-mandibular advancement (MMA) [19] (Fig. 6); genioglossal advancement (GA) [20] (Figs 7, 8);

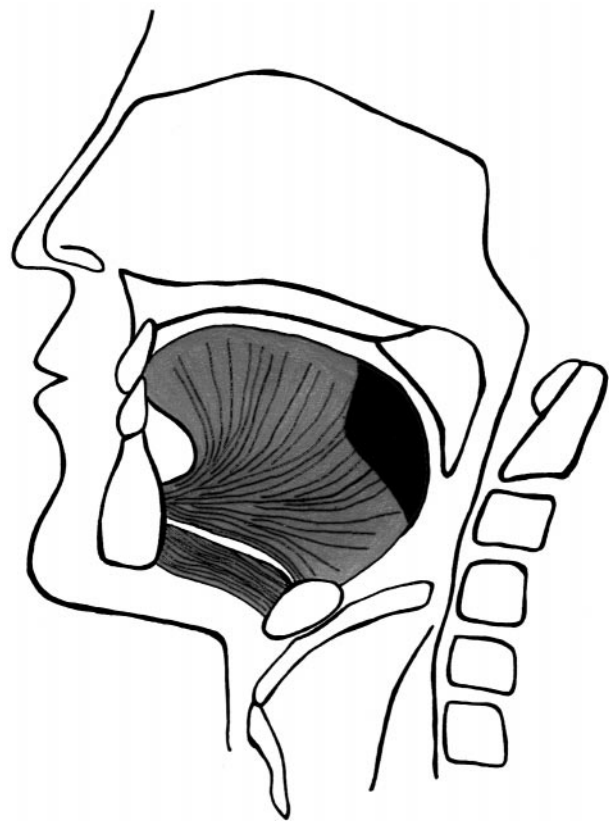


Figure 3 Laser midline glossectomy (LMG). A midline rectangular strip of posterior tongue is extirpated.

and hyoid myotomy and suspension (two variations HM-1 and HM-2) [20, 21] (Figs 9, 10) (Table 2).

Techniques which address primarily a retropalatal focus of pharyngeal compromise are UPPP, LAUP, and TPAP. Techniques which address primarily a retro-lingual focus of pharyngeal compromise are LMG, RFTBA, TBRHE, MA, GA, HM-1, and HM-2. Procedures which address both retropalatal and retro-lingual compromise are UPPGP and MMA (Table 2).

Tracheotomy is the surgical procedure which by-passes the pharyngeal airway (Table 2).

SURGICAL OUTCOMES

The first portion of this section outlines surgical outcomes for individual procedures performed as the sole surgical intervention. The second portion outlines surgical outcomes of complex upper airway modifications which consist of various permutations and combinations of individual surgical procedures. In series discussed in both sections, nasal surgery

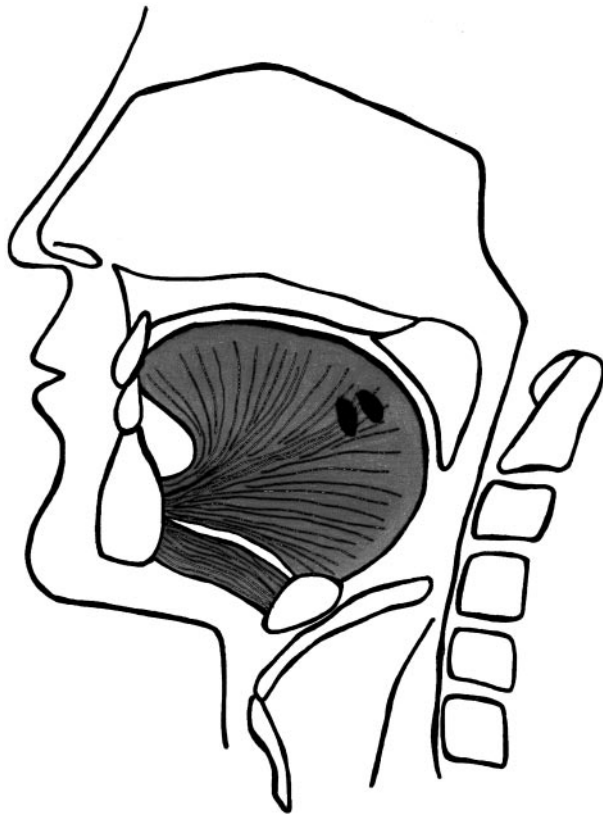


Figure 4 Radiofrequency tongue base ablation (RFTBA). Two lesions have been created in the muscle mass of the tongue using a radiofrequency needle electrode. Insulation of the proximal portion of the needle maintains the integrity of the mucosa.

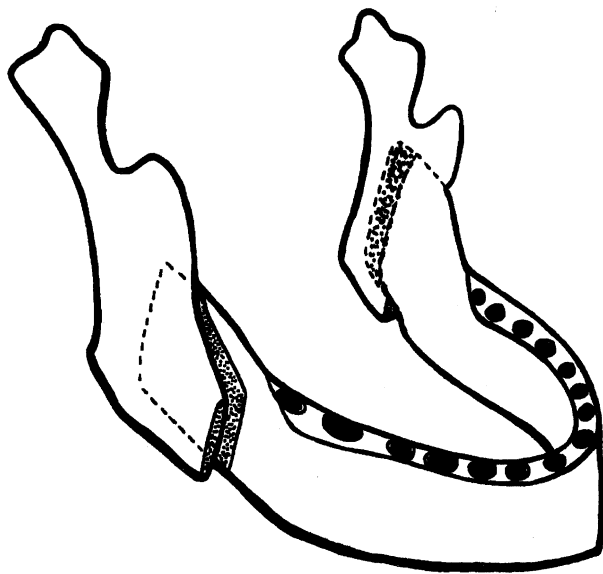


Figure 5 Mandibular advancement (MA). Sagittal mandibular osteotomies permit anterior mobilization of the anterior mandible in cases with antecedent mandibular deficiency and malocclusion.

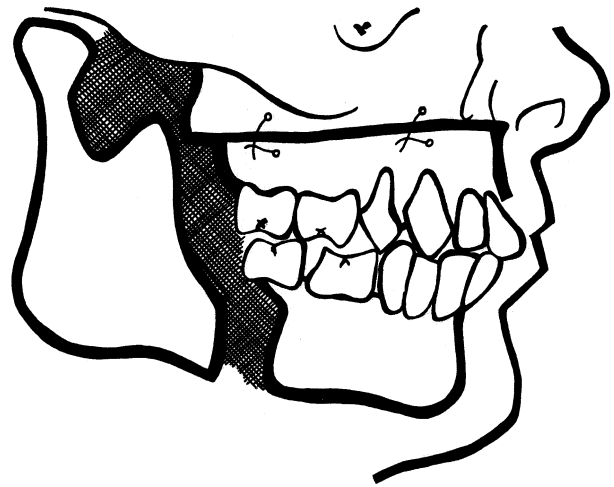


Figure 6 Maxillo-mandibular advancement (MMA). The maxilla and mandible are advanced by Le Fort I maxillary and sagittal-split mandibular osteotomies.

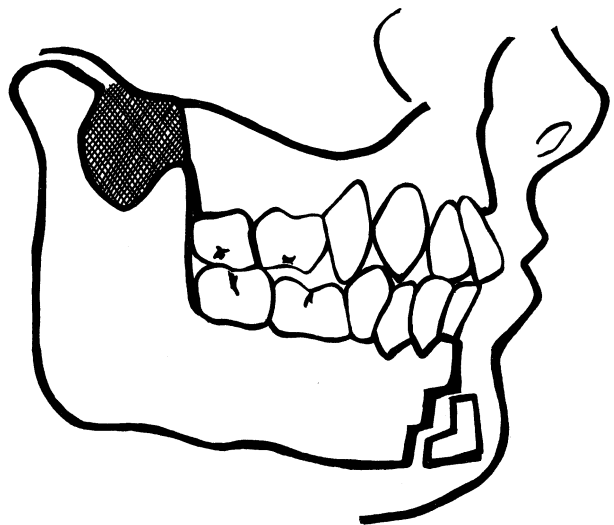


Figure 7 Genioglossal Advancement (GA) (lateral projection). Limited parasagittal mandibular osteotomy permits anterior advancement of the genial tubercle.

(including nasal septal reconstruction, nasal turbinate outfracture, nasal turbinate cauterization), and pharyngeal surgery (including tonsillectomy and adenoidectomy) may have been performed in individual patients as a concomitant or prior surgical modification, with the contribution of these procedures to the overall surgical outcome not determinable.

Authors of surgical case series have applied different criteria of improvement in PSG variables to define surgical success. These are outlined in Table 3.

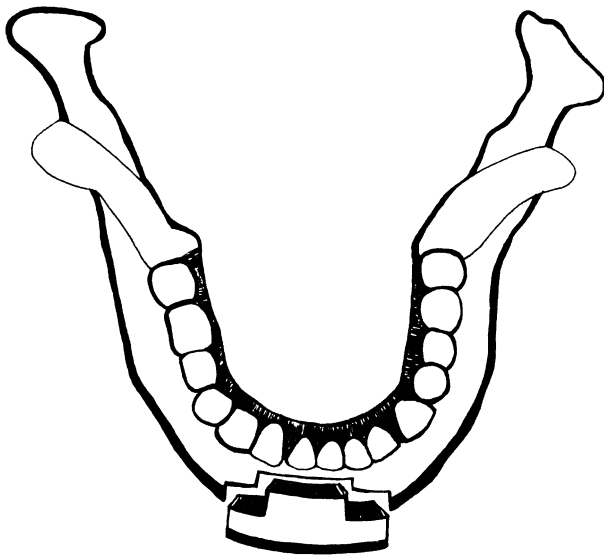


Figure 8 Genioglossal Advancement (GA) (viewed from above). Limited paraasagittal mandibular osteotomy permits anterior advancement of the genial tubercle.

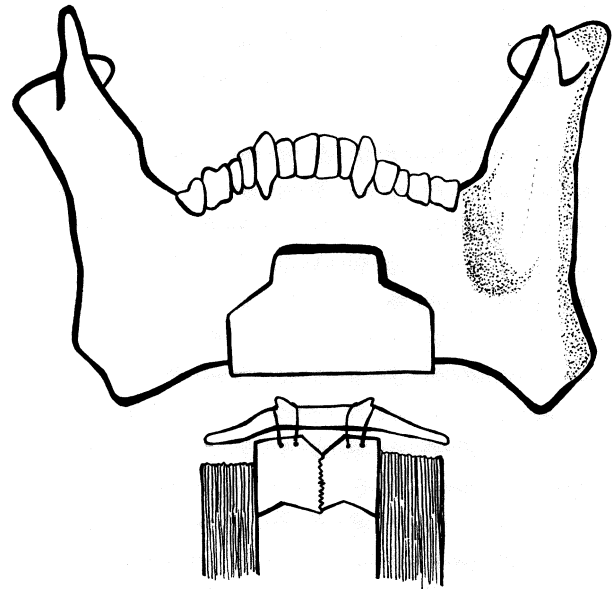


Figure 10 Hyoid Myotomy and Suspension, Type 2 (HM-2). The infrahyoid muscles are released and the hyoid is suspended from the superior margin of the thyroid cartilage by permanent sutures.

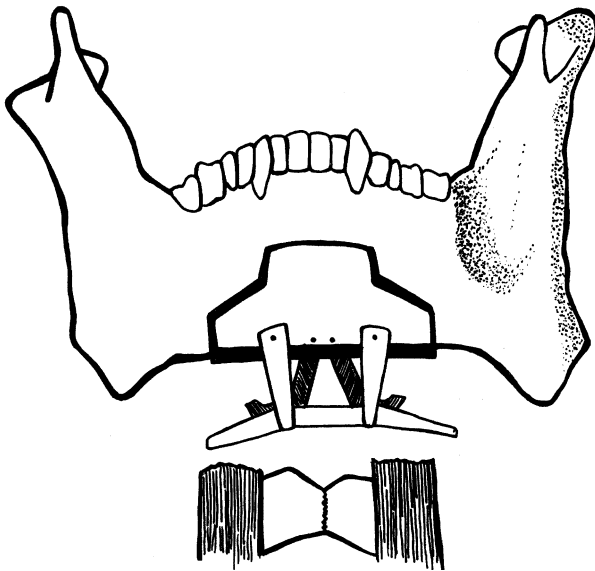


Figure 9 Hyoid myotomy and suspension, Type I (HM-1). The infrahyoid muscles are released and the hyoid is suspended from the mandible by a fascial strip.

Outcomes of individual procedures

Uvulopalatopharyngoplasty (UPPP)

Short term mean outcomes data for UPPP has been derived by metanalysis of 37 papers, each of which reports on at least 9 surgical subjects and assesses surgical outcomes through clear and unambiguous

outcome measures, i.e. a pre- and post-operative polysomnogram [7]. The mean decrease in apnea index (AI) in more than 500 patients is 55% from a mean pre-operative AI of 45 apneas/hr. The mean decrease in respiratory disturbance index (RDI) in approximately 500 patients is 38% from a mean pre-operative RDI of 60 apneas and hypopneas per h [7].

The pre-operative pattern of pharyngeal narrowing or collapse is specified to be Type I (retropalatal only), II (retropalatal and retrolingual), or III (retrolingual only) in each of 168 patients reported in nine papers. Pharyngeal classification is achieved by application of one of the following techniques: awake fiberoptic endoscopy with or without Muller maneuver, asleep endoscopy with nasal-CPAP, lateral cephalometry, airway manometry, or pharyngeal CT scan. The mean percent decrease in AI for Type I is 75% (from a mean pre-operative AI of 39 apneas per h), while for Types II or III the mean percent decrease in AI is 23% (from a mean pre-operative AI of 60 apneas per h). The mean decrease in RDI for Type I is 33% (from a mean pre-operative RDI of 57 apneas and hypopneas per h), while for Types II and III the mean percent decrease in RDI is 7% (from a mean pre-operative RDI of 65 apneas and hypopneas per h). The percentage of patients attaining success criteria 2A or 2D is 52% for Type I patients and 5% for Type II or Type III. If all patients (Types I, II, and III) are combined, 43% achieve success

Table 3 Criteria defining surgical success

Criterion	Definition
IA	$\frac{\text{Postop RDI}}{\text{Preop RDI}} \leq 50\%$
IB	$\frac{\text{Postop AI}}{\text{Preop AI}} \leq 50\%$
2A	$\frac{\text{Postop RDI}}{\text{Preop RDI}} \leq 50\%$ (and) Postop RDI ≤ 20 apneas and hypopneas per h
2B	$\frac{\text{Postop RDI}}{\text{Preop RDI}} \leq 50\%$ (and) Postop RDI ≤ 15 apneas and hypopneas per h
2C	$\frac{\text{Postop RDI}}{\text{Preop RDI}} \leq 50\%$ (and) Postop RDI ≤ 10 apneas and hypopneas per h
2D	$\frac{\text{Postop AI}}{\text{Preop AI}} \leq 50\%$ (and) Postop AI ≤ 10 apneas per h
3	$\frac{\text{Postop RDI}}{\text{Preop RDI}} \leq 40\%$ (and) $\frac{\text{Postop AI}}{\text{Preop AI}} \leq 40\%$ (and) <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> $\left\{ \begin{array}{l} \text{Postop AI} < 10 \text{ apneas per h} \\ \text{Postop RDI} < 15 \text{ apneas and hypopneas per h} \\ \text{and Postop AI} < 15 \text{ apneas per h} \end{array} \right.$ </div> <div style="font-size: 2em;">}</div> </div>

Table 4 Effect of pattern of pharyngeal collapse on outcome of uvulopalatopharyngoplasty (UPPP)

Pattern of Collapse	Preop AI \bar{x} (apneas/h)	Preop RDI \bar{x} (apneas & hypopneas/h)	Decrease in AI (\bar{x}) %	Decrease in RDI (\bar{x}) %	Success Rate (Criteria 2A or 2D) %	n	Reference
I	39	57	75	33	52	111	7
II or III	60	65	23	7	5	57	7

Table 5 Short term outcome of uvulopalatopharyngoplasty (UPPP)

Rate of Success (%)	Criterion	n	Reference
53	IA	375	7
60	IB	352	7
39	2A	189	7
43	2D	185	7

criterion 2D, and 39% achieve success criterion 2A. If achievement of either of these criteria defines surgical success, 41% of patients respond to UPPP (Tables 4, 5) [7].

Efficacy of UPPP may diminish over time: 60% success (criterion IA) at mean of 6 months postoperatively to 50% at mean of 46 months postoperatively; 64% success (criterion 2C) at mean of 6 months postoperatively to 48% success at 48–96 months postoperatively; and 67% success (criterion IA) at 3–6 months postoperatively to 33% at mean of 88 months postoperatively. Weight gain has been implicated as an explanation for long term recurrence in some but not all cases (Table 6) [23–25].

Surgical complications described in 640 patients for whom complications are delineated include velopharyngeal insufficiency (VPI) for greater than one month (2%), post-operative bleeding (1%), nasopharyngeal

stenosis (1%), voice change (1%), successfully managed peri-operative upper-airway obstruction (0.3%, two cases), and death secondary to upper-airway obstruction (0.2%, one case). However, since more than half of the papers do not comment on the presence or absence of post-operative complications, it is impossible to determine the true incidence of complications in the entire population [7]. In two series focusing on UPPP complications, the death rate from unsuccessfully managed upper-airway obstruction is approximately 1% [26, 27]. The incidence of post-operative VPI is shown to be heavily dependent on the definition of VPI applied. Its incidence 2 years after UPPP in 71 patients varies from 39% to 3% (39% with subclinical reflux of liquids, apparent only on nasal endoscopy; 16% with nasal reflux when the patient bends over a water fountain to drink water; 7% with subclinical nasal regurgitation, i.e. patients feeling bubbles in the nose after drinking gaseous drinks; and 3% with mild nasal reflux for liquids) [28]. One series of 91 patients reports complaints of dry throat and "swallowing abnormalities" one year after UPPP in 31 and 10%, respectively [27].

Laser-assisted uvulopalatoplasty (LAUP)

Patients subjected to LAUP and evaluated postoperatively with PSG have a success rate ranging from 0–87% (criterion 1A) and 0–48% (criterion 2A) [9, 29–34]. Two series demonstrate relatively similar success rates for patients with mild, moderate and severe OSAS [32, 33]. In most reported case series selection bias results from reporting preoperative PSG data on a small fraction of operated cases and postoperative PSG data on only a fraction of those who had preoperative PSG. While this represents a deficiency of the surgical literature for OSAS in general, the extreme measure to which it is true of LAUP reporting may result from a perception that LAUP is an operation appropriate for snoring only, not OSAS. Consequently, third party carriers often do not authorize preoperative or

postoperative PSG when LAUP is contemplated or performed.

LAUP patients studied by PSG, videoendoscopy and MRI within three days after surgery demonstrate exacerbation of OSAS severity in the early post-operative period. In seven patients having PSG at 48–72 h after surgery, the mean pre-operative RDI of 11 doubles to 22 apneas and hypopneas per h, and the mean pre-operative AI of 3 is multiplied by a factor of more than 4 (to 14 apneas per h). The pharyngeal cross sectional area at 72 h post-operatively is decreased by 48% from the pre-operative cross sectional area, resulting in a risk of post-operative airway compromise [35]. This is particularly important, since LAUP is generally performed in the physician's office, and the patient is not observed during the first night of sleep, which occurs at home. Analysis of the dimensions and configuration of the pharynx before and after LAUP and UPPP in ten patients (peroral photography of the oropharynx; nasopharyngoscopy of the velopharyngeal region; and lateral and frontal cephalometry with contrast enhancement) demonstrates that UPPP results in enlargement of the velopharyngeal space, but LAUP results in diminished velopharyngeal space. The authors conclude that LAUP may prove deleterious for OSAS patients [36].

Uvulopalatopharyngo-glossoplasty (UPPGP)

Short term success is reported to be 50% ($n=20$, criterion 1A) and 67% ($n=19$, criterion 1B) [10, 11].

Laser midline glossectomy (LMG) and lingualplasty

In patients who fail UPPP and are documented to have retrolingual narrowing by physical examination, radiographic evaluation, and fiberoptic endoscopy with Muller maneuver, rate of salvage by LMG ($n=12$, criterion 1A) is 42%. Patients with similar physical

Table 6 Long term outcome of uvulopalatopharyngoplasty (UPPP)

Success Rate Early (%)	Time Post-Op (Months)	Success Rate Late (%)	Time Post-Op (Months)	Criterion	Reference
60	Mean 6	50	Mean 46	1A	23
64	Mean 6	48	Range 48–96	2B	24
67	Range 3–6	33	Mean 88	1A	25

characteristics undergoing combined UPPP and LMG (or lingualplasty) have a success rate of 77% ($n = 22$, criterion 2A). No permanent complications are reported [12, 13].

Radiofrequency tongue base ablation (RFTBA)

Radiofrequency ablation of tongue base tissue in 56 patients without palate or nasal obstruction (mean preoperative RDI 41 apneas and hypopneas per h) have a response rate of 20% (criterion 2A) or 33% (criterion 2D), but subjective outcomes comparable with a CPAP control group [14, 15].

Tongue base reduction with hyoepiglottoplasty (TBRHE)

There are no reports known to the author of TBRHE performed as a sole surgical maneuver, and TBRHE has been reported only in conjunction with other pharyngeal procedures.

Transpalatal advancement pharyngoplasty (TPAP)

TPAP performed after UPPP ($n = 6$) incrementally increases pharyngeal cross sectional area and decreases pharyngeal collapsibility (compared to post-UPPP measurements). Overall clinical success of the combined procedure is 67% ($n = 6$; mean preoperative RDI 70 per h; success criterion 2A) [17, 37].

Mandibular advancement (MA)

Individual reports describe successful treatment of OSAS by mandibular advancement (MA) in patients with severe mandibular deficiency resulting from developmental or post-traumatic deformity or from temporomandibular joint ankylosis. These patients, described as having "birdlike" facial profiles, have mandibular deficiency in the absence of significant maxillary deficiency. While the reported cases are few in number, they are of historical significance for demonstrating that mandibular deficiency can result in OSAS, and that mandibular advancement can result in resolution of OSAS. While few OSAS patients are candidates for MA, these early reports resulted in the subsequent development of more widely applicable

procedures to enlarge the retrolingual airway in OSAS patients who are not candidates for MA [18, 38].

Maxillo-mandibular advancement (MMA)

MMA applied as a primary surgical approach in non-obese, maxillo-mandibular deficient patients (who may present dolichofacial characteristics) has a response rate of 95% ($n = 38$; success criterion 2A) and 100% ($n = 7$; success criterion 2A). In a series in which patient selection is not fully described, success rate is 40% ($n = 5$; success criterion 2A) [39–41].

Genioglossal advancement (GA)

There are no reports known to the author of GA performed as a sole surgical maneuver, and GA has been reported only in conjunction with other pharyngeal procedures.

Hyoid myotomy and suspension (HM-1 and HM-2)

There are no reports known to the author of HM-1 or HM-2 performed as a sole surgical maneuver, and HM-1 and HM-2 have been reported in conjunction with other pharyngeal procedures.

Outcomes of individual procedures performed in combination

Reports present outcomes of complex surgical modifications which incorporate two or more of the following procedures performed either in one surgical episode or in sequential episodes: UPPP, GA, HM-1, HM-2, MMA, TBRHE, as follows:

- UPPP and GA;
- TRBHE and UPPP;
- GA and HM-1;
- GA and HM-2;
- UPPP and GA and HM-1;
- UPPP and GA and HM-2;
- UPPP and MMA;
- GA and MMA;
- GA and HM-1 and MMA;
- UPPP and GA and MMA;
- UPPP and GA and HM-1 and MMA.

Uvulopalatopharyngoplasty and genioglossal advancement (UPPP and GA)

UPPP and GA has a success rate of 78% ($n = 9$, success criterion 2C), 69% ($n = 35$, success criterion 2A), and 38% ($n = 24$, success criterion 2A). Incomplete demographic data prevents rigorous comparison of the populations [21, 42, 43].

Tongue base reduction with hyoepiglottoplasty and uvulopalatopharyngoplasty (TRBHE and UPPP)

TBRHE is performed on 10 patients (six with previous unsuccessful UPPP and three with concomitant UPPP). All patients lack craniofacial skeletal abnormalities on lateral cephalometry. The success rate is 80% (mean preoperative RDI 70 apneas and hypopneas per hour; criterion 2A) [16].

Genioglossal advancement and hyoid myotomy and suspension-1 (GA and HM-1)

GAHM-1 is performed in six patients with retrolingual collapse in the absence of retropalatal collapse with a response rate of 66% (criterion 2A) [40].

Genioglossal advancement and hyoid myotomy-2 (GA and HM-2)

Patients with retrolingual narrowing in the absence of retropalatal narrowing) undergo GAHM-2 as an isolated surgical procedure with a response rate of 100% ($n = 3$, mean preoperative RDI 55 apneas and hypopneas per hour; criterion 2A) [21].

Uvulopalatopharyngoplasty and genioglossal advancement and hyoid myotomy and suspension-1 (UPPP and GA and HM-1)

UPPP and GA and HM-1 achieves a success rate of 57% in a large series ($n = 233$, criterion 2A). Patients with mild and moderately severe OSAS (RDI < 60 apneas and hypopneas per h, lowest SaO₂ > 70%) have a success rate of 75%, while patients with severe OSAS have a success rate of 42% [40]. Success rate

(criterion 2A) in 12 patients (mean RDI 49 apneas and hypopneas per h) is 42% [44].

Uvulopalatopharyngoplasty and genioglossal advancement and hyoid myotomy and suspension-2 (UPPP and GA and HM-2)

The response rate is 73% ($n = 11$; mean preoperative RDI 80 apneas and hypopneas per h; criterion 2A); 57% ($n = 14$; criterion 2A); and 23% ($n = 44$, mean preoperative RDI 45 apneas and hypopneas per h; criterion 2B) [21, 45, 46].

Maxillomandibular advancement with/without uvulopalatopharyngoplasty and/or genioglossal advancement with/without hyoid myotomy and suspension-1 (UPPP and GA and HM-1 and MMA; GA and HM-1 and MMA; UPPP and GA and MMA; UPPP and MMA; GA and MMA)

MMA performed as a salvage procedure after failed UPPP and/or GA and HM-1 has a salvage rate of 95% ($n = 164$; mean preoperative RDI 72 apneas and hypopneas per h; criterion 2A) and 100% ($n = 3$; mean preoperative RDI 74 apneas and hypopneas per h; criterion 2C) [42, 47]. MMA performed with GA has a success rate of 100% ($n = 40$; 10 failures after prior UPPP; mean preoperative RDI 59 apneas and hypopneas per hour; criterion 3) [48]. MMA performed alone ($n = 5$) has a success rate of 40%, while MMA performed in conjunction with one or more ancillary procedures (UPPP, GA, partial glossectomy) ($n = 18$) has a success rate of 78% (criterion 2A) [41]. MMA performed alone in maxillomandibular deficient patients (mean BMI 26 kg/m², $n = 7$) or performed after UPPP and GA and HM-2 (mean BMI 27 kg/m², $n = 13$) resulted in an overall success rate of 75% (criterion 2B) [46].

Outcomes of Tracheotomy

Early resolution of OSAS occurs in 83%, and delayed resolution occurs in the remainder as central apnea that appears immediately after tracheostomy resolves. Eighty-two to 100% of patients achieve resolution of excessive daytime sleepiness ($n = 98$) [19, 49, 50]. Hypertension improves or resolves in 40% [49, 50]. Hypercapnia, cor pulmonale, and cardiac arrhythmias

improve or resolve [49]. Patients who lose weight after tracheostomy tend to gain it back in 6 months [49]. Complications include psychosocial problems, local granulation tissue (resulting in hemoptysis or obstruction), and recurrent bronchitis [49].

DISCUSSION

The role of upper airway surgery for obstructive sleep apnea is in evolution. The complex etiology of sleep apnea has resulted in an array of treatment options. These modalities include behavioral approaches (weight reduction, postural conditioning), application of devices (intra-oral devices, positive airway pressure devices), and surgical approaches (upper airway modification, tracheostomy, bariatric surgery). Etiological variability, differences in severity, co-morbidity, and patient temperament make each patient a relatively unique clinical entity around which to customize a treatment strategy by choosing from and possibly combining treatment options. While behavioral measures remain an integral part of the treatment program, patient ability to lose weight or alter sleep position is generally limited. Nasal CPAP is highly effective when applied under laboratory conditions, but the considerable issue of patient non-compliance was underestimated until the development of technology capable of objective assessment [51]. Intra-oral devices appear to have efficacy in some cases, and there is ongoing research into the objective assessment of patient compliance with these devices [52]. Tracheotomy may remain the "gold standard" of treatment (despite the obvious drawbacks) in that it assures elimination of the pathological event (transient airway obstruction), and its effectiveness is not dependent on patient compliance. However, the negative impact of tracheostomy is significant.

Surgical upper airway modification strives to eliminate OSAS without dependence on behavioral modification, mechanical devices, or tracheostomy. There is no single surgical procedure, short of tracheostomy, documented to consistently cure OSAS in all patients. On the other hand, published data suggests that current surgical techniques can potentially be applied in such a manner as to achieve surgical cure in most OSAS patients without resort to permanent tracheostomy. Patient selection, versatility in varied surgical approaches, and willingness to utilize more than one procedure when necessary appear to be important components of a successful surgical program.

A model of the upper airway in OSAS likens it to a simple collapsible tube. The tendency of the upper airway to collapse can be expressed quantitatively in terms of a critical pressure (P_{crit}), which is the pressure surrounding the area of collapse. If atmospheric pressure is designated zero, then airway collapse will occur whenever P_{crit} is a positive number (indicating that it is higher than atmospheric pressure). P_{crit} levels are higher during sleep than during wakefulness in both normal individuals and OSAS patients. In normals, P_{crit} rises from awake values that are more negative than -41 cm H₂O to sleep values of -13 cm H₂O [53–55]. This means that, in normals, atmospheric pressure is greater than P_{crit} even during sleep, and the pharynx will not collapse. In OSAS patients, the spectrum of awake values of P_{crit} is -40 cm H₂O to -17 cm H₂O, and P_{crit} during sleep is $+2.5$ cm H₂O [53, 54, 56, 57]. Although the pharyngeal airway of awake OSAS patients tends to be more collapsible than that of awake normals, P_{crit} does not cross the critical line of zero (i.e. atmospheric pressure) except when the individual with OSAS has sleep onset, and OSAS results [53]. Patients who have varying degrees of partial pharyngeal collapse have intermediate, but negative, levels of P_{crit} during sleep: -6.5 cm H₂O for asymptomatic snorers and -1.6 cm H₂O for patients with hypopneas but no apneas [53, 57]. In general, P_{crit} must be below -5 cm H₂O to eliminate sleep disordered breathing [53]. P_{crit} for an OSAS patient can, alternatively, be defined as the lowest level of nasal CPAP at which airflow is maintained.

Examples of the decrement in P_{crit} that can be achieved by non-surgical interventions are -6 cm H₂O through the loss of 15% of body weight; -3 to -4 cm H₂O through protriptyline treatment; and -4 to -5 cm H₂O through the avoidance of sleeping in the supine position [53]. P_{crit} decrement in response to upper airway surgery has been documented for UPPP and TPAP. When 13 patients undergo UPPP, P_{crit} decreases from a level of 0 to a level of -3 cm H₂O ($P=0.016$). In those patients who have greater than 50% decrease in RDI in non-REM sleep, P_{crit} decreases from -1 to -7 cm H₂O ($P=0.01$). The degree of improvement in sleep disordered breathing is correlated significantly with the change of P_{crit} ($P=0.001$), and the decrease in RDI is determined by the magnitude of the fall in P_{crit} rather than by the initial level of P_{crit} . No significant change in P_{crit} is detected in non-responders [4]. Sequential performance of TPAP after UPPP results in incremental decrease in P_{crit} to a level below that resulting from UPPP. Four patients undergo TPAP after previous UPPP. Mean post-UPPP P_{crit} of 5 is

decreased after TPAP to -4 ($P < 0.01$). TPAP increases the retropalatal airway cross sectional area by 321% compared to the post-UPPP cross sectional area ($29\text{--}95\text{ cm}^2$, $P < 0.01$) [37]. It is likely that each surgical procedure decreasing OSAS severity also decreases P_{crit} , and that procedures performed concomitantly or in sequence result in incremental decreases in P_{crit} . Further data is needed for verification. It is suggested that the application of P_{crit} as an indirect measure of OSAS treatment efficacy might prove valuable in patient selection, treatment selection and treatment evaluation [53, 58].

UPPP was introduced in 1981 as the first surgical procedure specifically designed to treat OSAS. After an initial period of enthusiasm, UPPP fell into disfavor because of a failure rate exceeding 50%. However, analysis of UPPP failure and additional scientific data on the complex nature of OSAS, suggested that UPPP addresses only one vulnerable site in the upper airway, the upper, or retropalatal, pharynx. UPPP failure was assumed to result from lack of modification of additional or secondary sites of pharyngeal obstruction in the lower, or retrolingual, pharynx. This was supported by documentation that OSAS resulting from retrolingual compromise secondary to extreme mandibular deficiency could be successfully treated by MA. This observation resulted in the development of new surgical procedures to modify the retrolingual pharynx of patients who do not have a major degree of mandibular deficiency and are, therefore, not candidates for MA. LMG (and lingualplasty) and RFTBA result in ablation of a portion of the posterior tongue with laser or radiofrequency energy, while GA and HM-1 and HM-2 advance the tongue base in an anterior direction. Both procedures tend to augment the retrolingual airway. Both approaches achieve surgical salvage in some UPPP failures. There is uncertainty about the degree of contribution of HM-1 and HM-2 to the treatment protocol. There is limited data by which to assess the relative efficacy of HM-1 and HM-2 and the efficacy and safety of HM-2. MMA moves both palate and tongue in an anterior direction, thus enlarging both the retropalatal and retrolingual airway. MMA serves to salvage patients who have failed at various combinations of UPPP, GA, HM-1 and HM-2, with a high rate of success.

The Stanford Protocol was developed to systematically approach reconstruction of the upper airway based on the hypothesis that pharyngeal classification could serve as an effective basis for establishing a treatment plan for each patient (Fig. 8). The goal was to apply limited, regionally specific anatomical

modification as Phase I of surgical therapy (UPPP, GA, HM), the specific procedures selected in accordance with the pharyngeal classification based on fiberoptic endoscopy and lateral cephalometry. Patients were studied polysomnographically after completion of Phase I surgery. If they demonstrated significant residual OSAS, and elected to complete the surgical protocol, they were treated with Phase 2 of the protocol: MMA. The goal of the protocol was to strive for cure of OSAS while minimizing the degree of surgical intervention. Response was defined by criterion 2A in conjunction with sleep parameters consistent with a night on CPAP. The response rate for Phase I surgery was approximately 60% (75% for patients with mild and moderate OSAS and 40% for patients with severe OSAS). The response rate for those patients who went on to Phase II after failing Phase I surgery was 95% [40]. This protocol was amended when HM-2 was substituted for HM-1 [21, 47]. In the hands of the Stanford group, substitution of HM-2 for HM-1 boosted the rate of success to 73% [21, 47]. However, in a series of patients undergoing UPPP, GA, and HM-2 ($n = 44$) the rate of success was only 23%. Salvage by MMA was achieved in approximately 75% of failures [46].

The Stanford protocol permitted an exception to the multi-phase approach (by-passing Phase I surgery and proceeding immediately to MMA) in patients who, on initial presentation, demonstrated severe maxillo-mandibular disproportion with sequelae in addition to OSAS (such as dental malocclusion, temporomandibular joint syndrome, or cosmetic concerns). These patients were allowed to enter the protocol at Phase 2 instead of Phase I. The response rate for those with severe skeletal deformity having primary MMA (by-passing Phase I) was 100% [40]. MMA was applied as a primary surgical approach, rather than "in salvage" by other investigators. Available data suggest that MMA may be highly effective and appropriate as the primary surgical approach in patients who are not obese and in whom the apparent etiology of OSAS is maxillomandibular deficiency. On the other hand, in a less selected group of patients, frequently manifesting varying degrees of obesity and relatively subtle degrees of maxillomandibular deficiency, neither Phase I of the Stanford protocol nor primary MMA assures a one-step cure. When applied primarily to relatively unselected patient populations, both approaches have significant failure rates. Failure of each approach mandates secondary "salvage" surgery through application of additional surgical armamentarium not applied primarily. Application of "salvage" procedures

when necessary affords a high likelihood of cure. A recent study documents excellent results obtained by applying primary MMA and GA in 40 patients (only ten of whom had prior failed UPPP) [48]. TBRHE may provide another option, but further experience is needed [16].

More work is needed to define which of these approaches minimizes morbidity and cost and maximizes success and patient satisfaction. It appears that the regimen of choice may be patient-specific with OSAS severity, degree of maxillomandibular deficiency, degree of obesity, and co-morbidity all factoring into the decision-making process. If co-morbidity or patient preference preclude any of these surgical approaches, and non-surgical options are unsuccessful or rejected, tracheostomy should be considered.

While lateral cephalometry and fiberoptic endoscopy are widely applied for preoperative characterization of the pharyngeal airway, questions remain about the efficacy of these procedures. Both procedures are applied in the awake patient, while OSAS occurs in the sleeping patient. Both are generally applied sitting, while the sleeping patient rarely assumes this position. Lateral cephalometry is adynamic and views the airway in only two dimensions, whereas airway collapse in OSAS is dynamic and occurs in three dimensions. Nonetheless, pharyngeal classification into Types I, II, and III by techniques which include fiberoptic endoscopy and lateral cephalometry permitted identification of two subgroups with markedly different rates of success with UPPP (52% for Type I and 5% for Types II and III) [7]. It also provided the foundation for development of surgical strategies whereby surgical procedures were developed to "salvage" UPPP failures and raise the overall surgical success rate. Several reports document OSAS cure rates close to 100% achieved through application of complex upper airway modification. Depending upon the complexity of anatomical compromise, one or multiple procedures may be required [16, 40, 47, 48]. On the other hand, the pharyngeal classification system offers no explanation for failure of UPPP in 48% of patients classified as Type I. Investigators describe differing degrees of success in prognosticating UPPP outcome when fiberoptic endoscopy is used to preoperatively characterize the pharyngeal airway [7, 59–61]. It is likely that there are nuances of pharyngeal anatomy or function not discerned by fiberoptic endoscopy or lateral cephalometry. These nuances may differ in patients classified Type I who fail UPPP and those who succeed. However, it must also be considered that interpretation of endoscopic data, which is highly subjective in

nature, may vary from physician to physician, and even by the same physician at different times. Similarly, lateral cephalometry performed on the same patient may suggest different pharyngeal soft tissue relationships unless there is careful adherence to technique. Studies comparing fiberoptic endoscopy with pharyngeal manometry (awake and asleep) demonstrate disagreement between these techniques in identifying pharyngeal dynamics, as well as discrepancies in observation with the same technique in wakefulness and sleep [62–64]. Alternatively, UPPP may not be sufficiently robust to consistently cure all Type I patients, even if they are properly classified. The issue of inadequacy of UPPP as a surgical strategy vs inadequacy of the strategy for preoperative pharyngeal classification remains unresolved.

LAUP was introduced several years after UPPP, and differs primarily in the magnitude of surgical modification and the nature of surgical instrument applied. UPPP routinely includes tonsillectomy unless the patient had prior tonsillectomy. Tonsillectomy is not generally performed as part of LAUP, although serial ablation of tonsil tissue with laser is possible, though cumbersome. Limited data suggests that OSAS of varying degrees of severity, from mild to severe, may respond to LAUP. Additional data is needed. It might be hypothesized that LAUP and UPPP should achieve similar results in previously tonsillectomized patients. On the other hand, in the absence of concomitant or prior tonsillectomy, LAUP might be expected to have lessened impact on OSAS, particularly if tonsils are of considerable volume. However, concerns have been voiced that the documented pattern of healing and scar formation in LAUP differs from that of UPPP and may be detrimental for OSAS. While data suggests that LAUP may be effective across a spectrum of OSAS severity, care should be exercised in applying LAUP to patients with significant potential for postoperative airway obstruction. The airway is further compromised in the early postoperative period, and there is exacerbation of OSAS. This issue is of great importance because postoperative LAUP patients sleep at home unmonitored after surgery.

Criteria for surgical success and failure have evolved over the two decades since Fujita introduced UPPP, and this evolution is reflected in the criteria applied in the succession of papers on surgical treatment. Fujita established as the criterion for surgical success decrease in AI of at least 50% from its preoperative value. Current perceptions of pathophysiology of OSAS mandate a more restrictive criterion for success, one that takes into account not only apneas but also

hypopneas and sub-obstructive events that result in arousal [65–70]. The ideal definition of response may require development of a paradigm (applied preoperatively and postoperatively) which integrates parameters of sleep architecture, arousal, and excessive daytime sleepiness (and, possibly, other measures of quality of life) with measures of respiratory disturbance and oxygenation. Such a complex descriptor of disease severity might be designed in a manner akin to the TNM (tumor-node-metastasis) tumor classification. Identification of which metrics and levels of severity best reflect thresholds of morbidity and mortality will be clarified by such investigations as the NIH Sleep Heart Health Study. However, the lack of uniform universal criteria for reporting surgical results poses difficulty in interpretation of surgical outcomes. There are steps underway to standardize reporting [71]. While two randomized studies of surgical patients evaluate outcomes in terms of cardiorespiratory and quality of life measures, neither study includes physiological measurement of sleep and sleep architecture. One study randomizes patients to oral appliance and UPPP treatment groups. Quality of life measures improve in both treatment groups, but lack of relationship between change in cardiorespiratory and quality of life parameters is noted [72]. The other study randomizes patients to surgical (UPPP, mandibular osteotomy, hyoid myotomy and suspension) and control (conservative management) treatment groups. Change in cardiorespiratory parameters in the surgical group and control group do not differ, whereas the quality of life measure (subjective assessment of somnolence) is significantly improved in the surgical group compared to the control group [73]. Lack of physiological measurement of sleep and sleep architecture in both studies confounds interpretation of these differences.

Analysis of the efficacy of individual surgical procedures is thwarted by the practice of many investigators to apply multiple procedures in various combinations in single operative sessions and assess the composite effect by postoperative PSG. The nature of the combination of procedures may vary from study to study, even in different studies performed by the same investigator. In many series, relevant upper airway surgery, such as nasal surgery and tonsillectomy, are performed sporadically and mentioned coincidentally but not formally tallied as part of the surgical intervention. This obscures their contribution to the overall surgical outcome. The tendency to perform multiple surgical maneuvers at one operative session results from the clinicians' desire to maximize the likelihood of

success while minimizing exposure to anesthesia risk, patient inconvenience and cost. However, this practice clearly compromises data interpretation. The difficulty is compounded by lack of standardization of surgical techniques for individual procedures performed by different surgeons, or even performed by the same surgeon at different times.

Bias is frequently introduced by retrospective study design and nonrandom loss to follow-up. This is most poignant in the LAUP literature. The number of patients exposed to the surgical procedure often exceeds the number having preoperative PSG. The number having preoperative PSG often exceeds the number having postoperative PSG. While especially characteristic of the LAUP literature, this deficiency is commonly observed throughout the surgical literature. Studies are not randomized and few have control groups. Sample size tends to be low, and statistical power is low. Papers do not present confidence bounds that might distinguish between statistical and clinical significance. Missing data and missing and inconsistent definitions are common. Most papers report only short term follow-up and infrequent repeat follow-up. Few papers associate polysomnographic data with patient-based quality of life measures [72].

A patient's decision to pursue surgical treatment should follow full disclosure of the risks of untreated sleep apnea, the risks and benefits of non-surgical modalities, and the risks and benefits of surgical modalities. It would appear prudent to suggest a trial of non-surgical treatment in most cases, reserving surgical approaches for those who reject or undergo unsuccessful non-surgical interventions. Patients with discrete upper airway pathology that is amenable to surgical correction would be exceptions to this policy, as might apnea patients who have physical complaints (in addition to OSAS) related to surgically correctable maxillo-mandibular deficiency.

In general, multi-center studies of surgical treatments for sleep apnea would help to clarify the strengths and weaknesses of different approaches and determine the reproducibility of surgical outcomes in the hands of different surgical teams. The cost of effective treatment for obstructive sleep apnea will have to be compared to the cost of lack of treatment, both to the patient and to society as a whole. The relative costs of surgical and non-surgical approaches will have to be compared with the relative benefit of each, to be defined through adequate outcomes assessment. Only in this way will the appropriate role for non-surgical and surgical approaches be firmly established.

GLOSSARY

Details of surgical procedures

Uvulopalatopharyngoplasty (UPPP) enlarges the retropalatal airway by excision of the tonsils (if present), trimming and reorientation of the posterior and anterior tonsillar pillars, and excision of the uvula and posterior portion of the palate [8] (Fig. 1).

Laser assisted uvulopalatoplasty (LAUP) enlarges the retropalatal airway by ablation of the uvula and posterior margin of the soft palate with carbon dioxide laser. While tonsil ablation can be accomplished with laser, LAUP as reported frequently does not include tonsil ablation. LAUP is generally performed under topical and local anesthesia in the physician's office [9] (Fig. 2).

Uvulopalatopharyngo-glossoplasty (UPPGP) combines UPPP with limited resection of the tongue base, enlarging retropalatal and retrolingual portions of the airway [10, 11].

Laser midline glossectomy (LMG) and lingualplasty enlarge the retrolingual airway by laser extirpation of a 2.5 cm × 5 cm midline rectangular strip of posterior tongue and, in lingualplasty, additional lateral wedges. Laser lingual tonsillectomy, reduction of the aryepiglottic folds, and partial epiglottectomy are performed in selected patients [12, 13] (Fig. 3).

Radiofrequency tongue base ablation (RFTBA) enlarges the retrolingual airway by applying radiofrequency energy to the tongue base with a needle electrode. Radiofrequency tongue base ablation is generally performed under topical and local anesthesia in the physician's office [14, 15] (Fig. 4).

Tongue base reduction with hyoepiglottoplasty (TBRHE) enlarges the retrolingual airway by excision of tongue base. The excision is performed through a trans-cervical incision. The neurovascular bundle is identified and protected. The hyoid is suspended from the mandible under tension. Unlike LMG and lingualplasty and RFTBA, which are performed transorally, TBRHE is performed through a cervical incision [16].

Transpalatal advancement pharyngoplasty (TPAP) enlarges the retropalatal airway by resection of the posterior hard palate with advancement of the soft palate in an anterior direction into the defect [17].

Mandibular advancement (MA) enlarges the retrolingual airway utilizing sagittal mandibular osteotomies to effect anterior mobilization of the insertion of the tongue at the genial tubercle. There must be significant antecedent mandibular deficiency and dental malocclusion to permit the requisite degree of anterior movement of the mandible and mandibular teeth. [18] (Fig. 5).

Maxillo-mandibular advancement (MMA) provides maximal enlargement of the retrolingual airway and some enlargement of the retropalatal airway. It permits significant mandibular advancement in patients lacking maxillomandibular disproportion. The maxilla and mandible are both advanced by means of Le Fort I maxillary and sagittal-split mandibular osteotomies. The degree of mandibular advancement achieved, if performed without maxillary advancement, would result in mandibular prognathism and dental malocclusion. The exception would be the patient with severe mandibular deficiency but normal maxillary development, who would then be a candidate for MA

Glossary

Abbreviation	Procedure
GA	Genioglossal advancement
HM-1	Hyoid myotomy and suspension of hyoid from mandible
HM-2	Hyoid myotomy and attachment (with permanent suture) of hyoid to thyroid cartilage
LAUP	Laser assisted uvulopalatoplasty
LMG	Laser midline glossectomy (referred to in modified form as lingualplasty)
MA	Mandibular advancement
MMA	Maxillomandibular advancement
RFTBA	Radiofrequency tongue base ablation
TBRHE	Tongue base reduction with hyoepiglottoplasty
TPAP	Transpalatal advancement pharyngoplasty
UPPP	Uvulopalatopharyngoplasty
UPPGP	Uvulopalatopharyngoglossoplasty

rather than MMA. Details of MMA depend on the patient's dental occlusion [19] (Fig. 6).

Genioglossal advancement (GA) places the tongue under anterior traction. It does so without altering dental occlusion, and is achieved by performing limited parasagittal mandibular osteotomy and anterior advancement of the genial tubercle [20] (Figs 7, 8). This procedure has undergone various modifications over time.

Hyoid myotomy and suspension (two variations, HM-1 and HM-2) tends to enlarge the retro-lingual airway and exerts anterior traction on the tongue, hyoid and supra-hyoid musculature, with release of the infrahyoid muscles. Two techniques have been described: (a) suspension of the hyoid from the mandible by a fascial strip (HM-1); (b) suspension of the hyoid from the superior margin of the thyroid cartilage by permanent suture (HM-2) [20, 21] (Figs 9, 10).

Tracheotomy creates a percutaneous opening into the trachea. The tracheostomy is usually stented and maintained by inserting a rigid or semirigid hollow tube. The patient breathes through the tube when the external end is unplugged. Since the tracheostomy opens into the airway proximal to the pharynx, it bypasses the region of collapse. When the patient is awake, the external end of the tube is plugged. The tube is of sufficiently small diameter that, when plugged, it permits air to enter the trachea from the pharynx and larynx, passing around the tube. The increased resistance to airflow created by the presence of the plugged tube occupying a portion of the tracheal lumen can be decreased by using a tube that has distal ventilating holes through which air can flow. Alternatively, it may be possible to fashion a tracheostomy that does not require a cannula, or utilize a stomal plug instead of cannula [22].

Practice Points

1. Modalities of treatment for OSAS include behavioral approaches (weight reduction, postural conditioning), application of devices (intra-oral devices, positive airway pressure devices), and surgical approaches (upper airway modification, tracheostomy, bariatric surgery).
2. Etiological variability, differences in severity, co-morbidity, and patient temperament make each patient a relatively unique clinical entity around which to customize a treatment strategy by choosing from and possibly combining treatment options.

3. Surgical airway modification strives to eliminate OSAS without dependence on behavioral modification, mechanical devices, or tracheostomy.
4. Tracheotomy remains the "gold standard" of treatment, but has obvious drawbacks.
5. There is no single surgical procedure, short of tracheostomy, which consistently cures OSAS in all patients.
6. UPPP is successful about 50% of the time.
7. UPPP failure may result from limited airway modification which does not adequately address secondary sites of pharyngeal collapse in the lower, or retrolingual, pharynx.
8. Lateral cephalometry and fiberoptic endoscopy are applied for preoperative characterization of the pharyngeal airway.
9. Genioglossal advancement, hyoid myotomy and suspension, laser lingual resection, radio-frequency tongue base ablation, mandibular advancement, and maxillomandibular advancement address collapse in the retrolingual pharynx.
10. Current surgical techniques can be applied in such a manner as to achieve surgical cure in most OSAS patients without resort to permanent tracheostomy.
11. Patient selection, ability to perform varied surgical approaches, and willingness to utilize more than one procedure when necessary are the cornerstones of a successful surgical program.

Research Agenda

In the future we need:

1. Development of uniform criteria for defining surgical success, possibly in the form of a paradigm (applied preoperatively and post-operatively) which integrates parameters of sleep architecture, arousal, and excessive daytime sleepiness with measures of respiratory disturbance and oxygenation (possibly in the form of the TNM cancer classification).
2. Evaluation of contribution to success of each individual component of complex surgical procedures.
3. Evaluation of reproducibility of surgical results.
4. Comparison of cost (to the patient and to society as a whole) of effective treatment with cost of lack of treatment.
5. Comparison of costs of surgical and non-surgical approaches with relative benefit of each.

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