Surgical Treatment of Pediatric Obstructive Sleep Apnea

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Kathleen M. Sarber and Stacey L. Ishman

Abbreviations

AHI	Apnea hypopnea index
CPAP	Continuous positive airway pressure
CT	Computed tomography
DEX	Dexmedetomidine
DISE	Drug-induced sleep endoscopy
GA	Genioglossus advancement
HNS	Hypoglossal nerve stimulator
HS	Hyoid suspension
IV	Intravenous
MRI	Magnetic resonance imaging
OSA	Obstructive sleep apnea
PSG	Polysomnogram
T&A	Adenotonsillectomy
TBS	Tongue base suspension

Introduction

Adenotonsillectomy (T&A) is typically recommended as the first-line treatment for children with obstructive sleep apnea (OSA), and this procedure is performed 289,000 times annually in children younger than 15 years of age in the United States [1]. Nevertheless, nearly one third of children with OSA suffer from persistent disease after T&A [2]. This chapter describes the evaluation, surgical options, and perioperative management of children with primary and persistent OSA after T&A.

K. M. Sarber
Department of Surgery, F. Edward Hébert School of Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD, USA

S. L. Ishman (✉)
Department of Otolaryngology – Head & Neck Surgery, Cincinnati Children's Hospital Medical Center, University of Cincinnati College of Medicine, Cincinnati, OH, USA
e-mail: Stacey.Ishman@cchmc.org

Adenotonsillectomy

T&A is recommended as first-line treatment for pediatric OSA by the American Academy of Sleep Medicine, the American Academy of Pediatrics, and the American Academy of Otolaryngology-Head and Neck Surgery [1, 3, 4]. This procedure is most commonly performed using monopolar electrocautery; however, many other devices are also employed in an effort to minimize damage to surrounding tissues, bleeding risk, and postoperative pain [5–8]. In addition to the number of instruments that has been utilized for tonsil removal, multiple techniques exist for removal.

Tonsillectomy involves complete removal of the tonsil, including the underlying capsule. This technique has been the gold standard for many years. Partial intracapsular tonsillotomy, also referred to as tonsillotomy, involves the removal of tonsillar tissue while leaving the capsule of the tonsil in place. The rationale for tonsillotomy is that the capsule provides a "biological dressing" for the underlying pharyngeal muscle, thereby reducing pain and providing protection to the underlying vessels [9]. Two meta-analyses of tonsillotomy [10, 11] have shown a reduction in postoperative pain by 2.6 days and a 79% decrease in the odds ratio for secondary bleeding when compared to tonsillectomy. Although tonsillotomy is associated with lower pain and bleeding rates compared to tonsillectomy, there is a risk that residual lymphoid tissue may reproliferate. One meta-analysis comparing tonsillotomy to tonsillectomy for children with OSA determined that tonsillotomy increased the risk of residual or recurrent OSA symptoms 3.33 times (95% confidence interval 1.62–6.82, $P = 0.001$) [12]. Nevertheless, given that polysomnography outcomes comparing tonsillotomy and tonsillectomy are lacking, tonsillotomy is not yet recommended for the primary treatment of pediatric OSA [13].

The risks of T&A have been well described. According to a meta-analysis of 23 studies, respiratory compromise is the most common complication which includes pulmonary edema, aspiration, laryngospasm, airway obstruction, hypoxia, and hypercapnia [14, 15]. The risk of respiratory

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compromise is even higher in children younger than 3 years of age as well as in those with obesity, severe OSA, severe oxyhemoglobin desaturations, neuromuscular disease, Down syndrome, and craniofacial disorders [15–17]. Intraoperative complications include damage to the surrounding structures of the oral cavity and oropharynx as well as the rarer anesthesia-related complications such as difficult intubation, endotracheal tube fire, and cardiac arrest [14]. In addition, prolonged throat or ear pain and dehydration may also occur after surgery. Bleeding is the most studied complication and may occur up to 2 weeks postoperatively, with rates ranging from 0.1% to 3% [14, 15, 17, 18]. Although patients may develop nasopharyngeal stenosis or velopharyngeal insufficiency, these complications are extremely rare [14, 15].

According to the results of the 2013 landmark randomized controlled Childhood Adenotonsillectomy Trial (CHAT) [19], as well as multiple systematic reviews and meta-analyses [15–23], T&A results in significant improvement in OSA severity for the majority of children [2, 20–27]. All analyses report that T&A improves the apnea hypopnea index (AHI), behavior, and quality of life when compared to watchful waiting or continuous positive airway pressure (CPAP). One pooled fixed effect meta-analysis of 472 children in 3 studies (median AHI 4.8, 14.4, and 10.0 events/hour) showed a decrease in the AHI by 4.8 events/hour [22]. A second meta-analysis included 21 studies (n = 1046) which estimated that the resolution of OSA (defined as an AHI <1 event/hour) after T&A was 59.8% using a random effect model [2]. Obesity, age >7 years, black race, and the presence of genetic and metabolic syndromes (especially those associated with craniofacial and neuromuscular disorders) decrease the resolution rate of T&A to below 50% [2, 22]. In view of these findings, it is suggested that children with these risk factors undergo a postoperative polysomnogram (PSG).

Preoperative Evaluation in Children with Persistent OSA

For children with persistent OSA after T&A, CPAP is typically considered for treatment. For those who fail CPAP or prefer a surgical option [3], clinicians are focused on identifying the specific site(s) of obstruction in these patients. Office flexible endoscopy is helpful in identifying nasal obstruction, adenoid regrowth, lingual tonsil hypertrophy, tongue base position, and congenital laryngomalacia; however, because it is performed with the child awake, it requires some degree of cooperation and may miss dynamic obstruction that occurs only during sleep [28, 29]. A lateral plain film of the nasopharynx is a fast and painless alternative to endoscopy; however, small deviations of the head and palate position at the time of the X-ray can result in an overestimation or underestimation of adenoid size. Videofluoroscopy has been employed to capture anatomic information; however, this modality is rarely used due to the relatively high radiation dose [30].

Drug-Induced Sleep Endoscopy

Drug-induced sleep endoscopy (DISE) was first described in 1991 as a technique to evaluate the upper airway while the patient was in an anesthetized state intended to simulate sleep [31]. Presently, DISE is widely used to aid in surgical decision-making for children with persistent OSA [32]. In addition, it is sometimes employed prior to T&A for children with OSA who have not undergone previous surgery but are at high risk for persistent OSA (e.g., those with obesity, severe OSA, craniofacial anomalies, hypotonia, and neuromuscular impairment) [24, 33, 34]. The rationale for this is that it allows for identification of additional sites of obstruction that could be addressed concurrently or in a staged fashion. Other authors maintain that because airway dynamics can be significantly altered after surgery, DISE performed before T&A is not useful to plan for subsequent procedures [35].

DISE may also be considered in children who have small tonsils in order to identify alternative sites of obstruction that should be addressed concurrently or instead of T&A [36]. Finally, DISE is required for patients being considered for treatment with the Inspire® hypoglossal nerve stimulator (HNS) in order to evaluate the degree and pattern of velopharyngeal collapse. According to current US Food and Drug Administration guidelines, patients with complete concentric velopharyngeal collapse do not meet the established criteria for HNS implantation. Although HNS is not yet approved for children, clinical trials are underway in children with Down syndrome, 10 years of age or older, and preliminary results are promising [37].

DISE is commonly performed in the operating room with an anesthesiologist present for cardiopulmonary monitoring and sedation. During the procedure, some surgeons may place children into their preferred sleeping position to observe the effect of position on airway collapse. A jaw thrust and manual tongue protrusion can also be performed to approximate the effect on the airway by a dental appliance or tongue reduction procedures. Performing these maneuvers while visualizing the palate can also help the surgeon determine the effect of the tongue on palate obstruction.

Several scoring systems for DISE have been developed to aid in communication, uniform reporting, and the ability to compare outcomes within and between studies. The first six scoring systems seek to objectively determine the level and degree of obstruction at different sites in the upper airway [29, 38–42]. Table 37.1 summarizes the scoring systems that have been evaluated in children [39]. In general, all of these scoring systems evaluate the airway at the nasopharynx, pal-

Table 37.1 Summary of scoring systems used in pediatric drug-induced sleep endoscopy

	VOTE (2011) [40]	Bachar (2012) [41]	Fishman (2013) [29]	Boudewyns (2014) [39]	Chan (2014) [42]	SERS (2016) [38]
Nasal cavity	–	0: no obstruction 1: partial obstruction 2: complete obstruction	0: none 1: mild 2: moderate 3: severe obstruction	–	–	0: IT obstruction <90% 1: IT obstruction >90% (1 or both sides) 2: no visible patency at IT
Adenoid/ nasopharynx	–		0: none 1: mild 2: moderate 3: severe obstruction	0: no hypertrophy 1: <50% obstruction 2: 50–75% obstruction 3: >75% obstruction	0 1: 1–50% obstruction 2: 51–99% obstruction 3: complete obstruction	0: adenoids do not extend past ET 1: adenoids partially obstructing 2: complete obstruction
Palate/velum	0: no obstruction 1: partial obstruction/ palate flutter 2: complete obstruction Describe patterns as AP/lateral/ concentric	0: no obstruction 1: partial obstruction/ palate flutter 2: complete obstruction *Includes contribution from tonsils	–	0: no collapse 1: dynamic collapse	0: no obstruction 1: 1–50% obstruction 2: 50–99% obstruction 3: complete obstruction	0: <50% obstruction 1: >50% but incomplete obstruction 2: ≤1 mm or complete obstruction
Oropharynx/ lateral pharyngeal walls/tonsils	0: no obstruction 1: partial obstruction 2: complete obstruction Describe patterns as AP/lateral		0: none 1: mild 2: moderate 3: severe obstruction	0: absent 1: <50% obstruction 2: 50–90% obstruction 3: tonsils touch	0: no obstruction 1: 1–50% obstruction 2: 50–99% obstruction 3: complete obstruction *Includes contribution from tonsil	0: <50% obstruction 1: 50% but incomplete obstruction 2: ≤1 mm or complete obstruction
Tongue base/ hypopharynx	0: no obstruction 1: partial obstruction 2: complete obstruction	0: no obstruction 1: partial obstruction 2: complete obstruction	0: none 1: mild 2: moderate 3: severe obstruction	0: no obstruction 1: partial obstruction 2: complete obstruction	0: no obstruction 1: 1–50% obstruction 2: 50–99% obstruction 3: complete obstruction *Includes contribution from the epiglottis	0: able to see arytenoids 1: unable to see arytenoids 2: complete epiglottic effacement against posterior pharyngeal wall
Hypopharynx	–	0: no obstruction 1: partial obstruction 2: complete obstruction	–	0: no obstruction 1: partial obstruction 2: complete obstruction	–	–
Larynx	–	0: no obstruction 1: partial obstruction 2: complete obstruction	–	0: no obstruction 1: partial obstruction 2: complete obstruction	–	0: arytenoid prolapse causing <50% obstruction of the TVCs 1: prolapse causing >50% obstruction 2: prolapse causing ≤1 mm or complete obstruction
Supraglottis	–	–	0: none 1: mild 2: moderate 3: severe obstruction	–	0: no obstruction 1: 1–50% obstruction 2: 50–99% obstruction 3: complete obstruction *Scored during jaw thrust to resolve any tongue base obstruction	–

(continued)

Table 37.1 (continued)

	VOTE (2011) [40]	Bachar (2012) [41]	Fishman (2013) [29]	Boudewyns (2014) [39]	Chan (2014) [42]	SERS (2016) [38]
Epiglottis	0: no obstruction 1: partial obstruction 2: complete obstruction Describe patterns as AP/lateral	–	–	0: no obstruction 1: dynamic collapse	–	–
Hypotonia	–	–	–	0: absent 1: present	–	–
Laryngomalacia	–	–	–	0: none 1: present	–	–
Min-max value	0–8	0–10	0–15	0–12	0–15	0–12

SERS sleep endoscopy rating system, *IT* inferior turbinates, *ET* eustachian tube orifice, *TVCs* true vocal cords

ate/velum, oropharynx, tongue base, supraglottis, and glottis; however, the description of the level varies between systems, and the number of levels evaluated varies from 4 to 6. The trachea and main stem bronchi may also be evaluated concurrently if there is concern for tracheomalacia or bronchomalacia. Recently, Tejan et al. used videos taken during 68 separate DISE procedures to compare these scoring systems and to attempt to correlate the scores to OSA severity, age, obesity status, and oxyhemoglobin nadir [43]. These authors found no significant difference in scores between the scoring systems and no correlation between any of the scores and OSA severity, age, obesity, or oxyhemoglobin nadir. Although a universal scoring system will likely be adopted in the future, current best practice is to utilize one uniform system within an institution.

Many anesthetic protocols have been used to perform DISE. Because of the known respiratory suppression of inhaled anesthetics and opioids (especially in patients with OSA), these drugs are generally avoided during DISE. Propofol has a fast onset of action and rapid drug clearance and is commonly administered in adults and titrated with bispectral index monitoring [44]. It is known to have a dose-dependent effect on airway collapsibility and decreased genioglossus neuromuscular tone [44]. In children with severe OSA, one study found that using propofol administered during cine magnetic resonance imaging (MRI) resulted in the need for an oral airway more often than when dexmedetomidine (DEX) was administered. In a comparison of propofol and DEX during DISE in adults, collapse patterns were similar; however, there were more severe collapse and oxyhemoglobin desaturation using propofol [45]. This decreased respiratory suppression makes DEX a more desirable agent for this procedure for many pediatric otolaryngologists [46], who often pair it with ketamine for its amnestic properties and minimal effect on respiration. Drawbacks of DEX as compared to propofol include its longer onset of action and slower drug clearance, adding time to both procedure and post-anesthesia recovery and its increased cost [47].

Cine MRI

Both computed tomography (CT) and MRI have been used to image OSA patients both awake and asleep in order to assess their degree of airway narrowing and obstruction. Dynamic images can now be created with both modalities as sequential images are stacked at multiple slices per second to provide a "movie" or cine sequence that be gated to respiration and can be viewed in three dimensions (axial, coronal, sagittal) and reformatted together for a 4D view.

MRI avoids ionizing radiation and the need for contrast that is required with CT and provides superior soft tissue resolution. Cine MRI was first described in 1992 [48] in awake patients with known OSA. Since that time, its use has expanded to patients anesthetized to approximate sleep with sedation protocols similar to those discussed above. This modality allows visualization of the airway in its entirety, thereby enabling the surgeon to identify primary and secondary sites of obstruction such as a large tongue occluding the airway while causing palatal elevation and obstruction. Additionally, lingual tonsil size and morphology are easily quantifiable, enabling the surgeon to distinguish between macroglossia and lingual hypertrophy [49]. Cine MRI can also allow the surgeon to visualize the movement of the tongue during sedation in order to distinguish dynamic glossoptosis (i.e., abnormal posterior motion of the tongue) from macroglossia (i.e., a large tongue encroaching on the airway, thus causing more static collapse) [50]. Although cine MRI has been used in large academic institutions, its widespread use is likely limited by time constraints on the use of MRI scanners, cost, the expertise of the radiologist and technician who carry out the protocol, and the need for ancillary staff (including an anesthesia provider) to monitor the patient. Figure 37.1 is an example of a sagittal image taken during cine MRI to evaluate for obstruction. The colors indicate the anatomic areas that may be obstructive, and the text below summarizes the surgeries that address the obstruction.

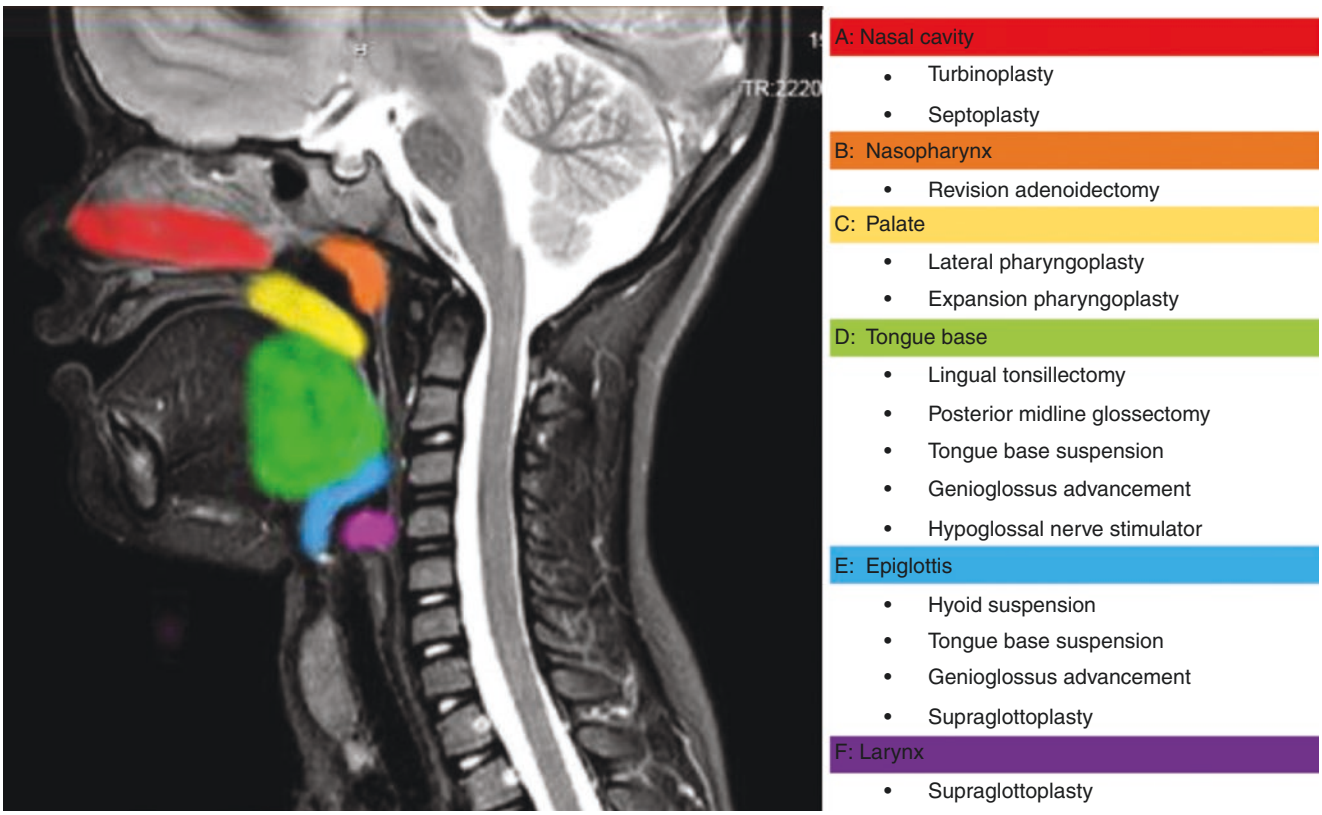

Fig. 37.1 Sagittal T2-weighted MRI of the upper airway with colors indicating the possible anatomic areas of obstruction that may be surgically addressed for obstructive sleep apnea

Nasal and Nasopharyngeal Surgery

Nasal breathing stimulates barometric reflexes that maintain airway patency during inspiration [51]. Mouth breathing due to nasal obstruction leads to an increase in airway resistance and reduces the size of the upper airway by retrodisplacing the tongue and soft palate [52]. In addition, chronic nasal obstruction has been shown to affect normal facial growth and to contribute to the development of OSA by reducing the vertical height of the mandible [53–57]. Although literature that supports addressing nasal obstruction in children with OSA is sparse, a meta-analysis of adult patients reported that nasal surgery can reduce the AHI by 11 events/hour [58]. Nasal surgery has also been shown to reduce CPAP pressures [59], potentially improving compliance.

Historically septoplasty has been avoided in children due to concerns about its effects on nasal growth based on animal studies. More recent literature has, however, shown that a limited septoplasty that spares all unobstructing cartilage and the bony septum can be safely performed, especially in children older than age 6 [60].

Turbinoplasty is a commonly performed procedure to improve nasal breathing in children with turbinate hypertrophy and signs of nasal airway obstruction. The goal of the procedure is to prevent turbinate swelling that can occur in response to supine positioning or allergic inflammation. It is generally considered a mucosal-sparing surgery in which an incision is made at the head of the turbinate and a volumetric reduction of the submucosal erectile tissue is performed to stimulate scarring. Reduction can be performed with a microdebrider, bipolar cautery, radiofrequency ablation, or turbinate wand or needle; no technique has been shown to be clearly superior [61]. An outfracture of the concha bone can also be performed to maximize airflow through the inferior nasal cavity. Although no studies have evaluated the efficacy of turbinoplasty alone on pediatric OSA, one study showed that T&A in combination with turbinoplasty resulted in a higher rate of OSA resolution compared to T&A alone in children with allergic rhinitis and nasal obstruction [62]. Turbinates are also frequently identified as a site of obstruction during DISE [63, 64]. The major risk of turbinoplasty is bleeding. Nasal crusting and rhinorrhea are expected for several weeks after surgery; less common complications include prolonged crusting secondary to infection or focal necrosis.

Though rare, scarring may lead to synechiae between the turbinate and septum. Finally, it is not uncommon for turbinate hypertrophy to recur 1–3 years after the procedure with a rate of 7.5% reported [61].

Adenoid regrowth is another cause of nasal obstruction. Revision adenoidectomy is commonly performed to address persistent pediatric OSA, although there is no data reporting the success rate of revision adenoidectomy alone. Retrospective assessment of adenoidectomy revision rates for any indication ranges from 0.5% to 2.5% [65–68]. Revision adenoidectomy is associated with age less than 5 years at the time of initial surgery, large adenoids, and extraesophageal reflux, although surgical technique was not [66, 69]. In two retrospective reviews of DISE-directed surgery to address persistent OSA, an adenoidectomy was performed in 42–57% of cases [63, 64, 70]. The risks of revision adenoidectomy are similar to those of primary adenoidectomy.

Oropharyngeal Surgery

Uvulopalatopharyngoplasty (UPPP), which involves removal of the excessive tissue of the lower soft palate and uvula, was first described by Fujita in 1981 as a treatment for OSA in adults [71]. However, complications such as velopharyngeal insufficiency (VPI), voice changes, globus, and airway stenosis have been shown to occur in up to 58% of patients [72]. Consequently, the traditional UPPP has undergone several modifications. Multiple techniques have been described which share the goal of expanding the airway while minimizing tissue excision.

The term lateral pharyngoplasty refers to suturing the palatopharyngeus (posterior tonsillar pillar) to the palatoglossus (anterior tonsillar pillar). Several studies have been carried out, but none have shown improvement in the postoperative AHI when performing this procedure concurrent with T&A compared to T&A alone [73–75].

Expansion pharyngoplasty was first described by Pang and Woodson to treat adults with OSA, small tonsils, and collapse of the palate and pharyngeal walls [76]. In contrast to traditional UPPP, this procedure involves transection and repositioning of the palatopharyngeus to a more superior/anterior position within the lateral soft palate, thereby reducing the bulk of the lateral pharyngeal wall and allowing the palatopharyngeus muscle to open the airway. Soft tissue is removed only when there is redundant mucosa elongating the uvula. In a 2014 retrospective review, 25 children with lateral pharyngeal collapse on DISE underwent T&A and expansion pharyngoplasty [77]. Demographics and preoperative and postoperative PSG results were compared to those of 25 children who underwent T&A alone. Although the pharyngoplasty group was older and had a higher body mass index, the median postoperative AHI was significantly lower in the pharyngoplasty group (2.0 vs. 6.2 events/hour), which also had a significantly higher cure rate (AHI <1; 64% vs. 8%). Neither VPI nor voice changes were noted in either group. In summary, newer techniques minimize the risks associated with the UPPP as described by Fujita; nevertheless, larger prospective studies are needed to verify the indications and outcome of pharyngoplasty in children.

Surgery to Address Tongue Base Collapse

Tongue base collapse can be secondary to macroglossia, glossoptosis, lingual tonsil hypertrophy, retrognathia, hypotonia, or a combination of these factors. The goal of tongue base surgery is to increase the retrolingual airway space either by volumetric reduction of the tongue base or by repositioning the hyoid or mandible to advance the tongue musculature. With the exception of lingual tonsillectomy, investigations of the techniques, risks, and outcomes of these procedures are more widely reported in the adult literature.

Tongue Base Reduction

Lingual tonsil hypertrophy is a frequent cause of persistent OSA and is most frequently reported in children with Down syndrome and/or obesity [50, 78, 79]. Lingual tonsillectomy involves removal of the lingual tonsil lymphoid tissue from the base of the tongue. Similar to T&A, this procedure can be performed using a variety of instruments. Two small meta-analyses [80, 81] that reviewed a total of 6 studies (n = 233 children) showed success rates of 51–52% to obtain an AHI <5 events/hour and 12.5–17% to obtain an AHI <1 event/hour, respectively. The small number of patients in these studies precludes the determination of a precise complication rate; however, tongue edema causing airway obstruction, intraoperative and postoperative bleeding, and pneumonia were encountered. The largest single institution study [82] reported an overall complication rate of 9.8%; complications included bleeding, dysphagia, decreased oral intake, and voice changes. Two of 92 patients (2.2%) required return to the operating room for hemorrhage control.

Posterior midline glossectomy is performed via posterior wedge resection or by submucosal volumetric reduction. Reporting of wedge resection outcomes in children is limited to 1 retrospective study of 16 patients (mean age of 14.2 years) in which the surgery was combined with a lingual tonsillectomy in some cases [83]. These authors reported a significant improvement in the AHI (from a mean of 47 to 5.6 events/hour) was found in children with a normal BMI. The improvement in AHI, however, decreased with

increasing BMI, and no postoperative improvement was found in obese patients. Lingual tonsillectomy results in significant postoperative pain similar to that seen after T&A. A meta-analysis in the adult literature [84] reported that the most common complications were bleeding (4.2%) and transient change in taste (5.85%), which sometimes persisted for 2 months after surgery. Oropharyngeal stenosis, a morbid and difficult to treat complication, occurred in fewer than 1% of cases.

The SMILE technique (submucosal minimally invasive lingual excision) was developed to minimize the morbidity of wedge resection [85]. The surgery begins with a small incision in the tongue. The tissue is then submucosally removed using a coblator; ultrasound and endoscopy are often used to aid visualization. The incision is left open to avoid hematoma or seroma formation in the remaining cavity. This technique was first used in children with persistent OSA, and changes in the AHI were reported for only two children.

Tongue Repositioning Procedures

Tongue base suspension (TBS) is a minimally invasive technique that loops a permanent suture through the tongue to form a sling that is suspended from a titanium screw inserted into the inner table of the mandible. This sling advances the genioglossus forward and prevents glossoptosis during sleep. One retrospective study of 31 children who underwent TBS along with adjunctive procedures for persistent OSA reported that 16 (52%) children had an AHI <5 following surgery [86]. Complications attributed to TBS were two seromas at the surgical site. Although dysphagia was also noted, the number of patients affected was not reported. A more recent study of children with cerebral palsy and OSA reported polysomnographic outcomes for seven patients who underwent TBS with UPPP and T&A [87]. Five (71%) of these patients exhibited an AHI <5 events/hour following surgery. There were no complications reported in this study. While it is difficult to determine the effect of TBS alone on persistent OSA, one meta-analysis in the adult literature [88] reported that average success is 48.7% (success for adults defined as a reduction in the AHI >50% and postoperative AHI <20). The complication rate ranged from 10% to 30.8% with postoperative pain, delayed wound infection, and transient dysphagia being the most common.

Hyoid suspension (HS) is a procedure performed to rotate the epiglottis forward and to prevent glossoptosis during sleep by advancing and stabilizing the hyoglossus, genioglossus, and geniohyoid muscles. The hyoid bone may be advanced to the mandible using a suture looped to a screw on the inner table of the mandible (similar to TBS). Alternatively, it may be brought forward and secured to the thyroid lamina [89]. In adults, this procedure has a success rate of 38.3–50.7%, depending on the suspension technique [90]. There are no reports analyzing the surgical outcomes of this technique in children, although the senior author (SLI) uses this procedure for children 6 years of age and older.

Genioglossus advancement (GA) was first described by Riley et al. in 1984 [91]. The procedure involves creating a rectangular osteotomy at the midline of the mandible. This rectangle of the bone includes the bulk of the origin of the genioglossus muscle. The rectangle is then advanced forward, turned 90 degrees, and screwed or plated in place to permanently advance the origin of the genioglossus. The outer table of the bone can be removed to avoid cosmetic defect. Similarly, the sliding genioplasty can be used for patients with permanent teeth with the lower portion of the mandible (including the genioglossal tubercle) pulled forward and plated into position. These procedures are rarely performed in children due to growth concerns of the mandible and damage to growing teeth. Complications include the floor of mouth hematoma, chin numbness, and rarely mandible fracture.

The hypoglossal nerve stimulator (HNS) is an implanted device that sends electrical stimulation to the hypoglossal nerve during sleep, causing tongue protrusion and relief of retrolingual airway collapse. The Inspire® HNS was approved in the United States in 2014 for use in adults 22 years of age and older with moderate to severe OSA. A relative indication for the implant was a BMI less than 32 kg/m^2. As discussed earlier, HNS is not recommended for patients with complete concentric collapse at the palate; thus, DISE is required prior to determining if a patient is a candidate. Additionally, it is not recommended for use in patients whose central apnea index is greater than 25% of the total AHI or those whose AHI is greater than 65 events/hour. Although this device is not currently approved for use in children, a prospective trial is underway to evaluate the efficacy of HNS on adolescents with Down syndrome who have been diagnosed with OSA. The initial outcomes of the first 20 patients (median age of 16.0 years) have been reported and showed a 75–92% reduction in the AHI with HNS and median nightly use of 9.21 hours/night [37]. These are promising results in a population of children with a high incidence of persistent OSA.

Supraglottoplasty

Laryngomalacia is a condition that causes intermittent obstruction of the larynx by supraglottic structures. Although it is more commonly diagnosed in awake infants by flexible endoscopy, it has also been identified in older children with OSA who have no daytime symptoms but have supraglottic collapse during DISE [79]. This type of laryngomalacia has

been termed sleep-dependent, state-dependent, late-onset, or occult laryngomalacia and is an indication for supraglottoplasty. Supraglottoplasty may include excision of redundant arytenoid tissue, incision of tight aryepiglottic folds, or pexy of the epiglottis to the tongue base based on the findings seen during DISE. Complications are rare and include recurrent or residual laryngomalacia, failure to extubate (requiring subsequent tracheostomy in some cases), aspiration, supraglottic granuloma and stenosis, and abscess.

Lee et al. analyzed PSG changes after supraglottoplasty in infants who underwent this procedure as the primary surgery for OSA and in older children who underwent the procedure for persistent OSA. These authors found a significant improvement in the AHI for both groups (primary change, −9.5 events/hour; 95% CI −14.8 to −4.3; change in persistent OSA, −7.1 events/hour; 95% CI, −10.9 to −3.3) [92]. A meta-analysis of supraglottoplasty in children with OSA reported that patients with neuromuscular disorders, cardiac disease, and laryngomalacia associated with complex medical comorbidities have a lower rate of success after supraglottoplasty [93].

Tracheostomy

Tracheostomy allows complete bypass of obstructive upper airway structures for the treatment of OSA. Although there are no guidelines regarding the indications for tracheostomy, it is generally considered a salvage treatment for children with severe OSA after other options have failed. It may, however, be considered a first-line treatment for infants with severe OSA and no identifiable site of obstruction, failure to thrive, or contraindications to other upper airway surgeries (especially those with neurologic impairment) [94]. In a meta-analysis of tracheostomy for pediatric OSA [94], all 196 patients from 11 studies (mean age, 4.2 years; range, newborn to 18 years) were found to have severe OSA and had either a congenital syndrome (in particular, syndromes that affect facial growth) or significant comorbidities, most commonly, neuromuscular disorders. Tracheostomy was successful in treating OSA in all cases that reported PSG results in this meta-analysis. This procedure is life-altering for both the child and family and is associated with a complication rate ranging from 43% to 77% of cases. These complications include bleeding, granuloma formation, and tracheoesophageal fistula [93, 95]. Although death (most commonly after accidental decannulation) is rare (0.7–3%) [95, 96], this possibility should be discussed when considering tracheostomy for a disease that is not immediately life-threatening.

A review of 29 patients from 4 institutions [97] showed that most patients remained tracheostomy-dependent 2 years after tracheostomy. Of the six patients who were successfully decannulated, five underwent a capped PSG prior to decannulation. Although this practice is not universal, it should be considered as part of the clinical evaluation to determine if decannulation can be safely attempted [98–100].

Perioperative Considerations in Pediatric OSA

OSA is associated with an increased risk for perioperative complications. The American Academy of Otolaryngology-Head and Neck Surgery thus recommends detailed communication between the surgeon and the anesthesia team, ensuring that there is an understanding of OSA severity so to appropriately tailor anesthesia [1]. Given that patients with OSA have an increased sensitivity to opioids and inhaled anesthetics, these drugs should be carefully dosed to avoid over-sedation and airway obstruction [46, 101, 102]. Following extubation, children with OSA are at a higher risk of airway obstruction, laryngospasm, oxygen desaturations, pulmonary edema, and respiratory failure than are those without OSA [103]. All children with OSA should be monitored for a period of time after surgery until they are fully awake and oxygen saturations are stable [104]. Postoperative hospital admission should be considered for children younger than 3 years of age, those with severe OSA, and those with OSA and hypoventilation. It should also be considered for obese children and children with comorbid conditions, including cystic fibrosis, genetic syndromes, asthma, and cardiac disease [103, 105, 106]. Children should be given adequate pain control medications; however, opioids should be cautiously prescribed and avoided if necessary due to their known respiratory depressant effects. Additionally, codeine should be avoided in all children, especially those with OSA, as some children are considered ultrarapid metabolizers, which may result in fatal respiratory depression [107].

Conclusion

Although T&A is the primary surgical treatment for pediatric OSA, studies show a high rate of persistent OSA in children with severe OSA, black race, obesity, and genetic and metabolic syndromes. Therefore, a postoperative PSG should be considered for these children. Surgical treatment of persistent OSA can be effective; however, the choice of surgical procedure depends on accurate identification of the patient's site(s) of obstruction. This can be determined by physical exam and procedures such as cine CT, cine MRI, and DISE. Surgeries that may be considered include revision adenoidectomy, turbinoplasty, septoplasty, palatoplasty,

tongue base reduction and repositioning, hyoid suspension, hypoglossal nerve stimulator, and supraglottoplasty (Fig. 37.1). Tracheostomy is usually considered a salvage procedure except in rare cases. In view of the elevated risk of complications in children with OSA, the surgical team should be cognizant of the severity of OSA so the team can plan a safe perioperative course that will optimize the child's outcome.

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