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REVIEW ARTICLE

Subglottic Stenosis: Current Concepts and Recent Advances

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ABSTRACT

Subglottic stenosis is considered one of the most complex and challenging aspects of pediatric otolaryngology, with the most common etiology being prolonged endotracheal intubation. The surgical treatment of SGS can be either endoscopic or open, but recent advances have pushed the limits of the endoscopic approach so that in practice an open laryngotracheal surgical approach is considered only after failed attempts with an endoscopic approach. In this review we discuss these advances, along with current concepts regarding the diagnosis and treatment of subglottic stenosis in children. .

Keywords: Direct laryngoscopy, Endoscopic surgery, Laryngotracheal surgery, Prolonged intubation, Subglottic stenosis.

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INTRODUCTION

The management of subglottic stenosis (SGS) in children is one of the most complex and challenging aspects of pediatric otolaryngology. It requires a team approach, including pediatric otolaryngologists, anesthesiologists, pulmonologists, and intensive care specialists.

The incidence of SGS is between 1 and 2% of intubated neonates[1] and occurs in 11% of intubated children under 5 years of age. The risk of developing SGS increases by 50% for every 5 days of intubation[2] in children under 5 years. Of note, premature infants can tolerate prolonged intubation better than infants born at term.

This review will focus on the current concepts in the management of children with SGS with special attention to lessons that have been learned through the years.

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Signs and Symptoms

The symptoms of SGS in children are closely related to the degree of airway narrowing. Grade I SGS is usually asymptomatic until an upper respiratory tract infection occurs, when respiratory distress and stridor, which are the hallmarks of SGS, appear. Grades II and III stenosis can cause biphasic stridor, air hunger, dyspnea, and suprasternal, intercostal, and diaphragmatic retractions. Prolonged or recurrent episodes of croup should raise suspicion for SGS.

At times, the appearance of SGS may be insidious and progressive. It is important to recognize that a compromised airway in a child can lead to rapid deterioration and require immediate appropriate intervention to avoid a catastrophic outcome.

Evaluation

Relevant history includes information on birth weight, prematurity, presence or absence of stridor, prior intubation, the duration of intubation, presence and quality of cry and voice, feeding difficulties, aspiration, choking events, recurrent episodes of croup, prior airway surgery, and pulmonary and cardiac status.

Physical examination should include a thorough head and neck examination and assessment of craniofacial abnormalities, retrognathia, micrognathia, macroglossia, laryngomalacia, and choanal atresia. Awake flexible fiberoptic laryngoscopy should be performed in order to assess vocal cord function and other pathology of the upper airway. However, the subglottis is not visualized adequately with a flexible fiberoptic laryngoscopy and the examination may be difficult in a combative child with abundant secretions. When aspiration is suspected, performing functional endoscopic evaluation of swallowing should be considered but may be challenging in infants. However, if the index of suspicion is high, this test should be performed prior to reconstructive surgery. A simple test by observing feeding in a child with a tracheostomy can reveal aspiration of liquids or solids when suctioning the tube after feeding.

Direct laryngoscopy (DL) and rigid bronchoscopy with video assistance under general anesthesia with spontaneous ventilation is the gold standard for the diagnosis of SGS. The subglottis is best evaluated using

a Hopkins rod-lens telescope to determine the site, size, length, and consistency of the stenosis.

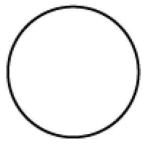
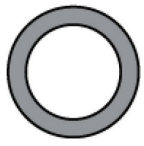
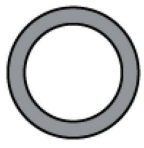
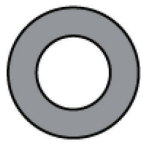
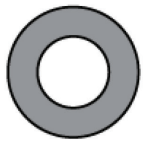
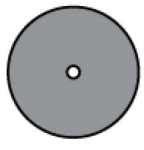
The authors currently use both three-dimensional (3D) (Visionsense™) and two-dimensional (2D) endoscopic systems. Visualization is enhanced with the 3D system, and in some cases may facilitate more gentle and precise surgery (unpublished data). A prospective study comparing these two modalities is being performed.

Grading

The classic SGS grading system (Graph 1) was proposed by Cotton and is accepted worldwide. The modified Cotton–Myer grading scale[3] was introduced in 1994 and is based on the percentage of obstruction calculated by passing an endotracheal tube through the stenosis resulting in approximation of the stenotic diameter divided by the age-appropriate endotracheal tube size (Graph 2). There are disadvantages to such a grading system. Vocal fold mobility has a great impact on the treatment of SGS. In a grade 1 stenosis but with bilateral vocal fold immobility, treatment of the stenosis will not result in an adequate airway. Other factors to be considered are the length of the stenosis. A severe stenosis that consists of a thin scar web is easily treated endoscopically, whereas a long but less narrow segment may be resistant to endoscopic procedures. The consistency of the stenosis (scar tissue *vs* granulation tissue) also has an impact on treatment.

Imaging

The diagnosis of SGS should be confirmed by direct laryngoscopy, and hence routine neck computed tomography or magnetic resonance imaging (MRI) is not recommended for most children. Magnetic resonance angiography should be performed when one suspects that the stenosis is caused by a vascular anomaly or tumor. Computed tomography (CT) or MRI is also indicated when DL shows complete or near-complete obstruction of the subglottis, in order to measure the length of the stenotic segment and assess framework defects.

Classification	From	To
Grade I	 No Obstruction	 50% Obstruction
Grade II	 51% Obstruction	 70% Obstruction
Grade III	 71% Obstruction	 99% Obstruction
Grade IV	No Detectable Lumen	

Graph 1: Cotton–Myer grading scale Typesetter

Congenital SGS

Subglottic stenosis is considered to be congenital when there is no history of prior endotracheal intubation or any of the causes of acquired SGS. It is the 3rd most common congenital disorder of the larynx.[4] Acquired SGS is much more common than congenital SGS because of prolonged endotracheal intubation. The symptoms are closely related to the degree of the narrowing. In severe cases, stridor is present at birth, while in milder cases, the symptoms present only after a few months.

Patient Age		Percentage of Obstruction with Actual Endotracheal Tube Size:								
		ID=2.0	ID=2.5	ID=3.0	ID=3.5	ID=4.0	ID=4.5	ID=5.0	ID=5.5	ID=6.0
Premature	No Detectable Lumen	40	30	26	22	20	10	17	16	
0-3 mo		58	48	41	38	35	32	30		
3-9 mo		68	59	53	50	45	43			
9 mo - 2 yr		75	67	62	57	54				
2 yr		80	74	68	64					
4 yr		84	78	73						
6 yr		86	81							
		89								
	Grade IV	**Grade III**			**Grade II**		**Grade I**			

Graph 2: Modified Cotton–Myer grading scale

Congenital anterior glottic webs are frequently associated with SGS due to a malformed cricoid ring. It is also occasionally reported in children with Down's syndrome.

Acquired SGS

Acquired SGS is the most common cause of narrowing in the larynx. It is usually due to prolonged endotracheal intubation in children. Endotracheal intubation causes stenosis for a number of reasons. First, the respiratory epithelium lining the subglottis is delicate and is easily injured by an endotracheal tube. Second, the cricoid cartilage is a complete circular ring, thus edema caused by trauma or pressure impinges directly on the internal diameter. Third, the subglottic region is the narrowest area of the airway in children. Fourth, significant edema can develop in the subglottic region quickly because of the loose areolar tissue that comprises the submucosa in that region.[5] Thus, a relatively minor injury causes a greater narrowing that compromises the airway in children.

Acquired SGS in neonates and infants is responsible for approximately 90% of all cases.[6,7] The reported incidence of SGS after intubation ranges from less than 1 to 8.3%.[8-12] Of note, Walner et al[13] reported a downward trend in the incidence of neonatal SGS in the last two decades, probably due to a better understanding of the pathophysiology of the entity and the more appropriate use and care for endotracheal tubes. Attention to the tube size to ensure an air leak and avoidance of tube movement by nasotracheal intubation have resulted in less trauma to the pediatric larynx.[5]

Other causes of SGS are "high" tracheotomy causing damage to the cricoid, emergent cricothyroidotomy, excessive laser treatments, smoke inhalation, caustic ingestion, burns, and trauma. Neoplasms can also cause SGS, including subglottic hemangioma, and far less commonly chondroma or fibroma. Other causes include chronic inflammatory diseases—Wegener's granulomatosis, pemphigoid, relapsing polychondritis, amyloidosis, major aphthous ulceration and laryngo-oculo-cutaneous syndrome. Chronic infections such as tuberculosis and syphilis can also lead to SGS.

Subglottic Hemangioma

This etiology merits special consideration because its treatment is unique. Children with subglottic hemangioma are typically asymptomatic during the newborn period.[14] Proliferation typically begins at 2 months of age, causing stridor, feeding difficulties, and respiratory distress. The mainstay of treatment is administration of systemic beta-blockers with surgical modalities reserved for failure of medical therapy or increasing symptoms of airway obstruction while on treatment.[15]

TREATMENT

The treatment paradigm is based on the presenting clinical severity of breathing, history, previous interventions and their results, vocal cord mobility, age of the child, comorbidities including neurological and developmental, aspiration, and coexisting airway lesions. Taking all these into consideration along with the findings on DL and tracheoscopy are necessary in order to make the appropriate treatment decisions.

Immediate Intervention

Obviously, an infant presenting to the emergency room in respiratory distress requires immediate attention and intervention. The most important sign of impending disaster is increased effort of breathing despite normal oxygen saturation levels. The child can decompensate suddenly. Therefore, when there is stridor and increasing effort of breathing, a quick decision on the safest way to secure the airway must be made. The safest place for securing the airway in this situation is the operating room where DL or rigid bronchoscopy can be performed if endotracheal intubation is difficult. Setup for emergent tracheostomy should be prepared as a backup if attaining the airway is unsuccessful. Cricothyroidotomy is an unsafe procedure in children due to the size and collapsibility of the airway and should be avoided. As a stabilizing measure on the way to definitive treatment, inhalation of nebulized adrenaline with saline and the use of heliox can help reduce the child's work of breathing while preparing for airway intervention.

Observation

Children with a grade I or a mild grade II SGS without a tracheotomy may not require surgical treatment and can be observed.[16] This can be done only in children with very mild stridor at rest or only exertional stridor, who were never hospitalized for imminent airway compromise.

Another reason for watchful waiting and avoiding surgical intervention is a "reactive larynx" in children that have a tracheostomy tube. A larynx is considered "reactive" when inflammatory process with resulting edema and granulation tissue formation is identified. These children tend to heal poorly after surgery and hence open airway reconstruction should be deferred until the larynx is no longer "reactive."

Reconstructive airway surgery is relatively contraindicated in children with low weight (less than 10 kg), aspiration causing recurrent pneumonia, in children

with neurologic disease with high potential for recurrent aspiration, and those with severe pulmonary disease.[16]

SURGICAL TREATMENT

The surgical treatment of SGS can be either endoscopic or open. As a rule of thumb, endoscopic surgery is usually effective for the treatment of grades I or II stenosis. Grade III and IV stenosis (Fig. 1) usually require open surgery, that is, laryngotracheoplasty (LTP), laryngotracheal reconstruction (LTR), or cricotracheal resection (CTR). However, recent advances, technology, and increased experience have pushed the limits of the endoscopic approach so that in practice an open surgical approach is considered only after failed attempts with an endoscopic approach.

Anesthesia

Endoscopic surgery of the pediatric airway requires a dedicated airway team. These procedures are usually performed under general anesthesia on a nonintubated airway. Therefore, general total intravenous anesthesia with spontaneous ventilation is preferred. The child should be deep enough to allow the procedure to be performed but not too deep so as to abolish spontaneous respiration. This balance is an art that requires continuous communication between the surgeon and anesthesiologist before, during, and after the procedure.

ENDOSCOPIC TREATMENT

The introduction of new surgical tools and the use of adjuvant therapies have broadened the indications for endoscopic management.

Laser Treatment

For more than three decades, CO_2 lasers and to a lesser extent KTP (potassium-titanyl-phosphate) laser have been the mainstay of airway management.[17,18] In the last decade, many additional lasers have been used, including the pulse dye laser for recurrent respiratory papillomatosis[19] and neodymium-doped yttrium aluminum garnet for the treatment of subglottic hemangioma.[20] CO_2, argon, or holmium lasers can be used to treat SGS. Due to their hemostatic abilities, they are effective in highly vascular tissue, like a subglottic hemangioma. The ability to administer laser treatment using fiber-optic fiber enables surgeons to treat children with pathologies that are located in regions which were previously considered not amenable to laser therapy.[21] However, laser tissue removal or incision and dilation can actually increase scar formation and worsen the lesion. Therefore, if after one or two treatments no improvement is seen, further treatment with laser should be discouraged.

Since alternatives such as the microdebrider and balloon dilations have emerged, many pediatric airway centers are now using laser less frequently. In addition to lower costs and shorter set-up time when using these alternatives, treatment with a laser risks fire[21] and a tendency to cause substantial amount of scarring.

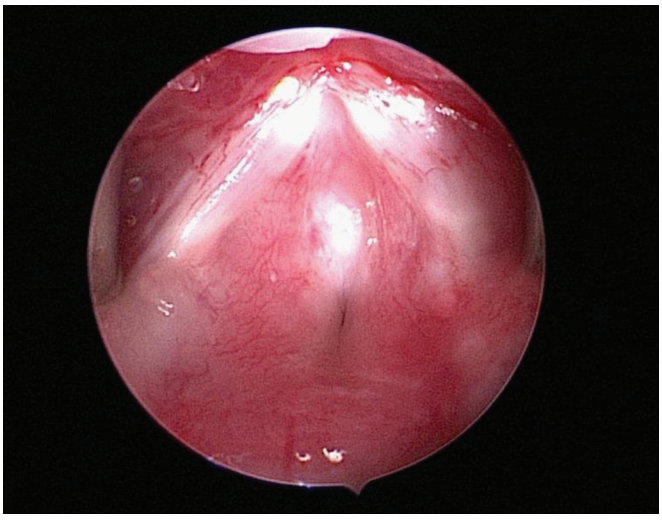


Fig. 1: Grade IV SGS requiring cricotracheal resection

Microdebrider

The microdebrider, which is widely used in sinus surgery, is also suitable for laryngeal endoscopic surgery using skimmer blades.[21] It is mainly used to treat recurrent respiratory papillomatosis, but can also be used to treat subglottic granulomas or fibromas, subglottic cysts, and hemangiomas. The advantage is the accuracy of tissue removal without thermal damage to adjacent healthy tissue.

Balloon Dilation

Endoscopic balloon dilations have gained popularity as an effective alternative to open reconstructive procedures in patients with SGS. It can be performed as either primary or secondary treatment. A recently published meta-analysis reports a 66% success rate in preventing tracheostomy or LTR.[22] In addition, the complication rate is relatively low.[22]

Bougie Dilations

Serial dilations with steel (Bougie) dilators can also be used, but their popularity is declining as most surgeons prefer to perform balloon dilations. However, results using laryngeal dilators are probably similar to balloon dilations.

Repeat Procedures

Treatment of SGS is essentially wound care, the problem being that the wound is in the airway. Thus multiple procedures may be required and the parents should be informed that performing multiple procedures will be

necessary in most cases until healing of the wound and resolution of the stenosis occur.

Adjuvant Treatment

As previously mentioned, propranolol has become the medical treatment of choice for subglottic hemangiomas and has been proven to be very successful.

Other treatments have been suggested as adjunctive to endoscopic procedures. Mitomycin C has been used off-label to prevent scarring and granulation tissue formation so as to improve the outcomes of endoscopic procedures. It is applied directly to the stenotic area toward the end of the procedure using cottonoids. There is no agreement regarding duration or dosage. The results are variable and efficacy is questionable.[23]

Intralesional steroid injection has also been used in an attempt to modify the scarring process. As with mitomycin C, dosage and results are variable and not supported by high-quality studies.[24]

Anti-reflux medications are almost universally used following surgery to aid in healing and prevent the deleterious effects of acid reflux on the endolaryngeal wound. Although prospective blinded data to support the use of antireflux medication are not available, antireflux medication is universally used in pre- and postoperative protocols.[25]

In summary, these adjuvant treatments have not been proved to be beneficial in randomized, double-blind controlled studies.[26] Their use depends on individual experience and practice.

OPEN SURGERY

Open surgery includes tracheotomy, LTP, LTR, or CTR.

Tracheotomy

Performing a tracheotomy can sometimes be the safest way to secure the airway in a child with SGS. It can also serve as a "bridge" before reconstructive surgery becomes feasible. This is especially important when the larynx appears inflamed and "active" making reconstructive surgery prone to failure.

On the other hand, tracheostomy carries both morbidity and mortality—as inadvertent decannulation or plugging of the cannula can sometimes occur. For these reasons, the authors prefer to perform a "Starplasty" as described by Koltai[27] which minimizes such risks. In addition, development of language skills can be delayed in children with a tracheotomy.

Anterior Cricoid Split

Anterior cricoid split evolved as an alternative to tracheostomy in premature neonates who fail extubation despite adequate lung function. It was initially introduced as an open procedure to decompress the pressure of the endotracheal tube on subglottic edema.[16] Endoscopic anterior cricoid split combined with balloon dilations was reported by Mirabile et al[28] to have an 83% success rate (15 out of 18 children), but larger series are required to further establish the outcomes of this novel procedure.

LTR and LTP

For more than three decades, LTR and LTP have been the "workhorse" for the treatment of SGS. The terms are used interchangeably. It involves splitting the cricoid cartilage, the lower third of the thyroid cartilage and the first tracheal ring, and expanding the framework with a cartilage graft or grafts, harvested from one of the costal ribs, preferably on the right side. It can be performed either as a single- or two-stage procedure. Single-stage LTP is defined as not leaving a tracheostomy tube at the end of the surgery and placing a nasotracheal tube as a stent for a period of 5 to 7 days. Two-stage LTP is defined by the patient having a tracheotomy tube at the end of the procedure that is removed several weeks after the primary procedure. The decision to perform single- or a two-stage LTP is based on many variables and should be tailored individually. Similarly, the decision whether to perform an anterior graft, posterior graft, or both should be based on the findings on the DL that precedes the LTP/R. Good results have been reported from different institutions around the world, with overall reported success rates approaching 90%, ranging from 83% for grade IV SGS and 100% for grade I SGS.[29,30]

Currently, there is no consensus as to how long these children should be kept sedated following surgery.[31,32] When single-stage LTP is performed, nasotracheal tube is kept in place throughout and after the surgery. The child is paralyzed and sedated for 48 hours, after which the drugs are weaned off. Once fully awake, ventilation is stopped and the child breaths spontaneously through the nasotracheal tube, which serves both as a stent and as an artificial airway. Mild sedation may be needed for the child to tolerate the tube. Extubation is performed in the pediatric intensive care unit between 3 and 5 days after the LTP. Of note, this method is feasible only in children older than 5 years, and a preoperative conversation with the child and parents regarding this postoperative course is highly recommended for full compliance. In our experience, early cessation of sedation and spontaneous breathing result in lower rate of respiratory complications.

In a two-stage LTP, various stents have been used as adjuncts and kept in place for 3 to 6 weeks. There is disagreement about the best material and duration of stenting. It is the opinion of the authors that ideally, no

stent should be used. The initial damage to the airway in most cases was inflicted by an artificial airway, that is, an endotracheal tube, and hence solving the problem with a stent may cause a similar problem with granulation tissue and scarring. However, in some children, a stent is required to hold grafts in place or to support the reconstructed airway and prevent scar contracture.[16] In these children, we prefer to use the Montgomery T-tube because it has the advantage of serving both as a stent and as a tracheostomy tube.

Partial CTR

Partial CTR involves separation of the trachea from the esophagus, mobilization of the upper tracheal rings, and excision of the stenotic segment with preservation of the posterior cricoid plate. Next, supralaryngeal release is performed, followed by thyrotracheal end to end anastomosis.[33,34] It can be performed either as a single-stage procedure or as a two-stage procedure, with or without stenting. Reported success rates for SGS grades III and IV range from 91 to 95%.[16,35-40] The procedure requires advanced surgical expertise due to the risk of damage to the recurrent laryngeal nerves and the high precision that thyrotracheal anastomosis requires.

SUMMARY

Treatment of SGS in children is challenging. Avoiding a tracheostomy is a noble goal, but an inadequate airway is life threatening for a child and tracheotomy can sometimes be life saving. Eventually, following successful surgical treatment, most children can be decannulated. As experience and technology advance, we will be able to offer better treatment for these children and achieve a noble goal that no child with SGS should have a permanent tracheostomy.

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