Tracheostomy: Pediatric Considerations

Ellen S Deutsch MD

Pediatric patients for whom tracheotomy is a consideration have different anatomy, medical conditions, and prognoses than adults; even the tracheotomy tubes are different. Indications for pediatric tracheotomy generally include bypassing airway obstruction, providing access for prolonged mechanical ventilation, and facilitating tracheobronchial toilet. Subglottic stenosis is an important indication for tracheotomy in children; its etiology, prevention, and alternative options for management are presented. Discussion includes the benefits, risks, impact on families, techniques for tracheotomy tube changes, and alternatives to tracheotomy, with illustrative photographs and diagrams. *Key words: pediatric; tracheotomy; tracheotomy tube; mechanical ventilation; subglottic stenosis.* [Respir Care 2010;55(8):1082–1090. © 2010 Daedalus Enterprises]

Introduction

The anatomy, medical conditions, and prognoses of children undergoing tracheostomy are often different from those in adults, and this paper will concentrate on those differences. But there are also important common principles. As in adults, tracheotomies in children can be used to provide respiratory support, or to bypass proximal airway obstruction. Tracheotomies do not prevent aspiration, but may be of help in its management by facilitating pulmonary toilet.

Because a tracheotomy bypasses some of the functions of the larynx, it is helpful to have a basic understanding of laryngeal anatomy and function in order to best manage, or compensate for, a tracheotomy. The glottis is a specialized region composed primarily of the true vocal folds, which are also informally called the vocal cords. The supraglottis is above (cephalad to) the glottis, and includes the epiglottis, arytenoids, and aryepiglottic folds. The subglottis begins just below the vocal folds and extends to the lower margin of the cricoid cartilage (Fig. 1).[1] Most of these components of the larynx (the supraglottis, glottis, and subglottis), are contained within the structural framework of the thyroid and cricoid cartilages.

Normal laryngeal function includes protecting the lower airway, regulating air flow, and contributing to phona-

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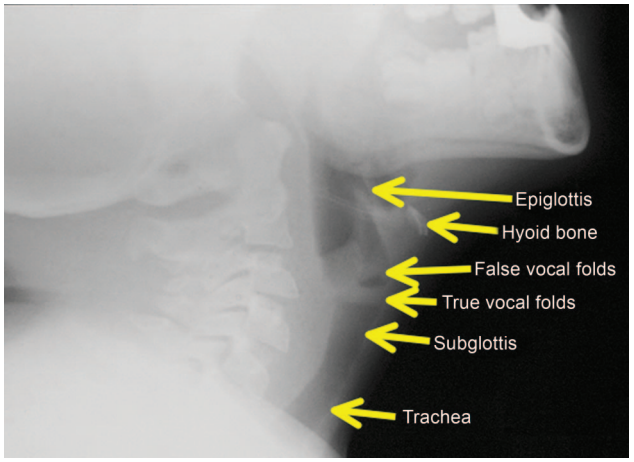

Fig. 1. Lateral neck radiograph; anatomic structures are labeled.

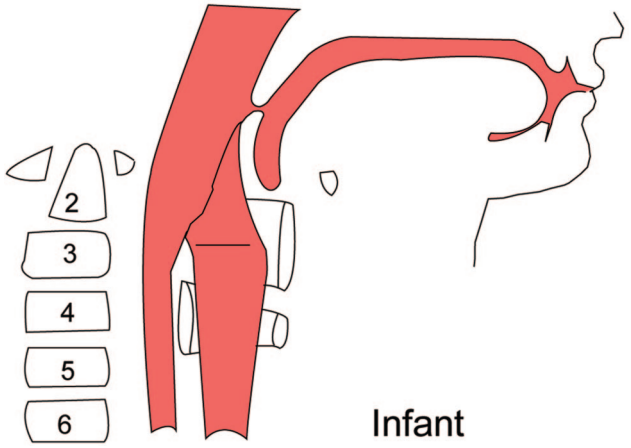

Fig. 2. Note the cephalad position of the larynx, as well as the close proximity of the epiglottis to the palate in the newborn airway. (Adapted from Reference 3.)

tion.[2] In children, the larynx is located more cephalad than in adults, so the mandible also provides some protection (Fig. 2).[3] In newborns, breathing is prioritized over voice. As children develop and mature, the proportion of the larynx supporting phonation becomes relatively larger, accompanying increasingly sophisticated vocalization skills. Most authors consider the subglottis to be the narrowest portion of an infant's larynx,[3] but some authors consider the vocal folds to be the narrowest portion,[4] as in adults.

Indications for Tracheotomy

Indications for pediatric tracheotomy generally include bypassing upper and central airway obstruction, providing access for prolonged mechanical ventilation, and facilitating tracheobronchial toilet.[5-8] In general, a greater proportion of pediatric tracheotomies are performed to bypass upper-airway obstruction, whereas in adults a greater proportion of tracheotomies are performed to support long-term mechanical ventilation,[9] but descriptions of indications are not standardized. Table 1 contains the indications for tracheotomy in infants and children by various authors in several countries. Airway obstruction may be caused by congenital or acquired lesions. Lesions that cause airway obstruction by interfering with breathing proximal to the trachea include conditions that affect the mouth and nose (eg, Robin sequence and other craniofacial abnormalities); lesions that affect the larynx directly (eg, severe laryngomalacia and vocal fold paralysis); and lesions that can occur in various locations in the airway (eg, neoplasms such as hemangiomas and lymphangiomas). Airway obstruction can result from infection and from physical, chemical, or burn-induced trauma; as well as from neurologic deficits that interfere with the patient's ability to breathe, swallow, cough effectively, or otherwise protect the airway.

Tracheotomy is recommended for patients requiring prolonged mechanical ventilation. Extended periods of ventilatory support may be required to manage lung disease, such as bronchopulmonary dysplasia in premature infants, as well as to manage respiratory failure directly or indirectly related to congenital or acquired neurologic, pulmonary, and cardiovascular abnormalities. In adults, early tracheotomy is variously defined as a tracheotomy within 2 to 10 days of intubation in selected patients, generally when prolonged intubation is anticipated.[10] Defining the duration of "prolonged intubation" in infants is difficult, as some infants tolerate intubation for weeks to months without adverse laryngeal effects,[10] but extended periods of intubation do interfere with normal development, and can contribute to laryngotracheal damage. Interim endoscopic evaluations, and possibly optical coherence tomography in the future, may help distinguish patients with findings suggestive of reversible edema versus findings suggestive of substantial irreversible subglottic damage (Fig. 3).[11]

Figure 4 shows the age distribution of children at the time of tracheostomy at a tertiary-care children's hospital in New Zealand over the period 1987–2003.[5]

A tracheotomy tube, even with a cuff, will not prevent aspiration, but it can be useful in managing aspiration by providing access for pulmonary toilet. Finally, placing a tracheotomy allows a greater variety of placement options for individual children, including the potential to receive care in their own homes, rather than remaining in a hospital setting.

Tracheotomy Tubes

Pediatric tracheotomy tubes differ from adult tubes in several respects. Historically, pediatric tracheotomy tube size designation was arbitrary, with a size 00 tracheotomy tube being smaller than a size 0, which was in turn smaller

Table 1. Primary indications for tracheotomy as noted by various authors[5-8]

Mahadevan (New Zealand)[5]	*n* (%)	Davis[6]	*n* (%)	Parrilla[7] (Italy)	*n* (%)	Carron[8] (USA)	*n* (%)
Airway obstruction	86 (70)	Unsafe or obstructed airway	36 (55)	Neuromuscular or respiratory problems	17 (45)	Airway obstruction	65 (32)
Craniofacial dysmorphism	40 (33)	Subglottic stenosis*	13 (20)	Congenital malformations (4 laryngotracheal anomaly, 3 cardiovascular anomaly, 1 pulmonary anomaly)	8 (21)	Upper-airway obstruction	38 (19)
Subglottic stenosis*	18 (15)	Subglottic hemangioma	4 (6)			Subglottic stenosis*	13 (6)
Central nervous system	6 (5)	Vocal cord palsy	4 (6)			Tracheomalacia	8 (4)
Vocal cord palsy	6 (5)	Other (craniofacial syndromes, glossoptosis, pharyngeal hypotonia, epiglottitis)	15 (23)			Pharyngeal stenosis	2 (1)
Hemangioma	5 (4)					Subglottic hemangioma	2 (1)
Laryngomalacia	4 (3)					Tracheal stenosis	2 (1)
Cavernous lymphangioma	4 (3)					Other	11 (5)
Other	3 (2)			Craniofacial syndromes/ obstructive sleep apnea syndromes	6 (16)	Craniofacial syndromes (5 Robin, 5 Treacher Collins, 3 Beckwith-Wiedemann, 2 Nager, 2 CHARGE, 2 Pfeiffer, 8 other syndromes, sequences or associations)	27 (13)
				Acquired subglottic stenosis*	5 (13)		
				Tracheoesophageal burn	1 (3)		
		Mechanical ventilation	15 (23)	Trauma	1 (3)		
Prolonged ventilation	36 (30)	Central nervous system abnormality	5 (8)				
Trauma							
Postoperative	9 (7)	Cyanotic heart disease	4 (6)				
Infection	9 (7)	Respiratory failure	4 (6)			Prolonged intubation	53 (26)
Neurological	8 (7)	Respiratory infection	1 (2)			Prematurity or bronchopulmonary dysplasia	37 (18)
Bronchopulmonary dysplasia	4 (3)	Sepsis	1 (2)				
	3 (2)					Congenital heart disease	3 (1)
Ondine's curse	3 (2)	Tracheobronchial toilet, aspiration risk	14 (22)			Pneumonia	2 (1)
		Trauma-related head injury	10 (15)			Other	11 (5)
		Hypoxic brain injury	2 (3)			Neurologic impairment	56 (27)
		Intracerebral hemorrhage	1 (2)			Cerebral palsy	18 (9)
		Respiratory infection	1 (2)			Encephalopathy	10 (5)
						Werdnig-Hoffmann syndrome	4 (2)
						Spina bifida	3 (1)
						Chromosomal abnormality	3 (1)
						Myasthenia gravis	2 (1)
						Other	16 (8)
						Trauma	15 (7)
						Closed head injury	12 (6)
						Laryngeal or tracheal injury	2 (1)
						Cervical spine fracture	1 (< 1)
						Vocal fold paralysis	15 (7)
						Hydrocephalus	3 (1)
						Leukodystrophy	1 (< 1)
						Sandhoff disease	1 (< 1)
						Neurofibromatosis	1 (< 1)
						Mobius syndrome	1 (< 1)
						Idiopathic or unspecified	8 (3)
Totals	122 (100)		65 (100)		38 (100)		204 (100)

* Note the prevalence of subglottic stenosis.
CHARGE = an association that includes: coloboma of the eye, heart defects, atresia of the choanae, retardation of growth and/or development, genital and/or urinary abnormalities, and ear abnormalities and deafness.

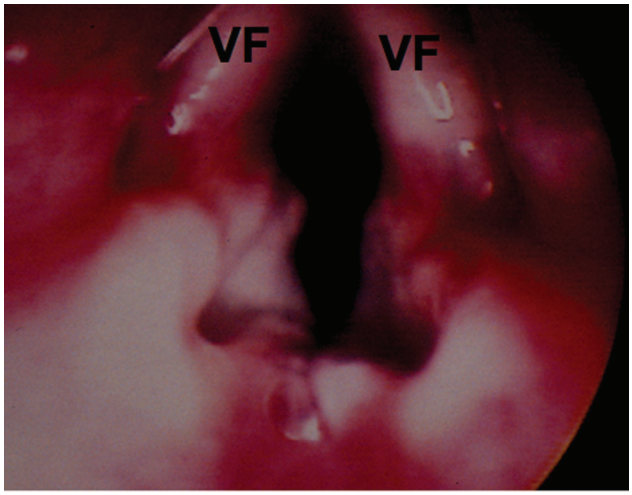

Fig. 3. Glottis of premature infant after prolonged intubation, demonstrating bilateral erosion of posterior glottis. VF = vocal fold.

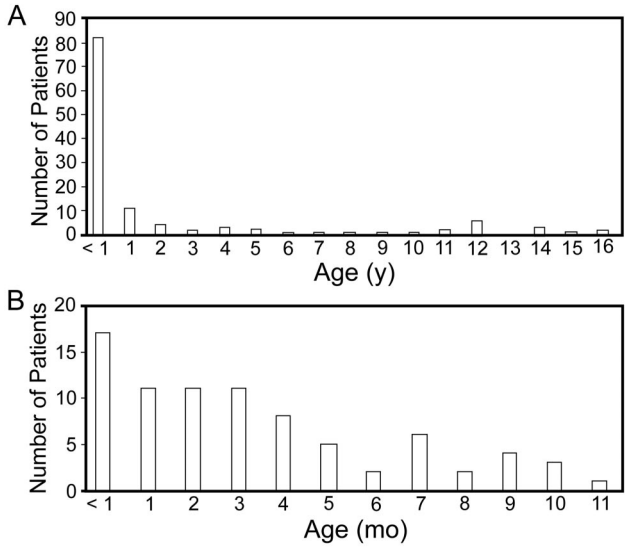

Fig. 4. Age at time of tracheotomy. (Adapted from Reference 5, with permission.)

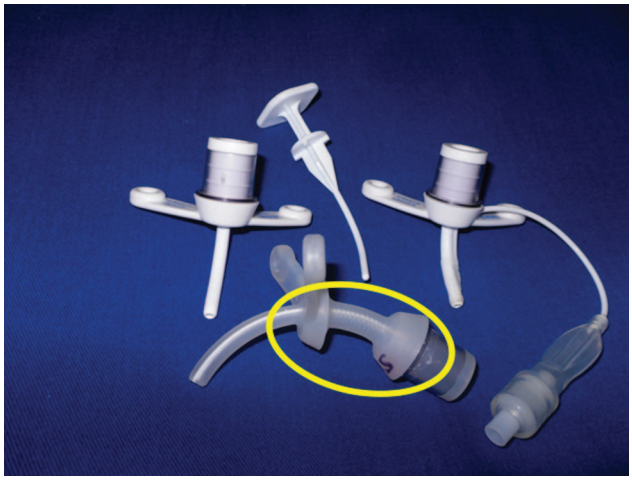

Fig. 5. Sample pediatric tracheotomy tubes, demonstrating (left to right) a cuffless pediatric tube, an obturator, a cuffed neonatal tube, and (bottom) a tube with an extension anterior to the flange (circled).

than a size 1, et cetera. The size designations of modern pediatric tracheotomy tubes are based approximately on the inner diameter, similar to the size designations of endotracheal tubes (ETTs). Neonatal tubes are similar to pediatric tubes in their inner and outer diameters, but shorter in length than the comparable pediatric tubes (Fig. 5). The small inner diameters of neonatal and pediatric tracheotomy tubes make inner cannulas impractical, so cleaning or changing the tracheotomy tube requires removing the entire tracheotomy tube. For very specialized purposes, such as during multi-step laryngotracheal reconstruction, metal tracheotomy tubes with inner cannulas are available. Similarly, inflatable cuffs and self-expanding foam cuffs are not commonly used, but may be indicated for specific patients, such as those requiring high airway pressures. Pediatric tracheotomy tubes are not fenestrated. The external connector is universally sized, so it may be rather large relative to the neck of an infant, and can interfere with normal head positioning. Some tracheotomy tubes include an extension anterior to the tracheotomy flange, allowing the universal adaptor to project further forward, thereby decreasing interference with positioning and motion of the patient's chin. Some tracheotomy tube shafts contain wire reinforcement, which can interfere with radiologic imaging.

Tracheotomy tubes may be managed both by appropriate healthcare providers and by family members with adequate training and medical supervision. Management skills include the ability to assess tracheotomy-related problems, to suction and change the tube, and to provide cardiopulmonary resuscitation if necessary. Although tracheotomy tubes, suction catheters, et cetera, are sterile before use, the tubes can be changed using a "clean" protocol, including hand-washing, wearing gloves, and avoiding contamination of the portion of the tracheotomy tube that is inserted internally. The tracheotomy obturator should be used routinely. There are several ways to remove and replace a tracheotomy tube, but all methods for nonemergency tracheotomy tube changes include gathering the appropriate supplies, proper preparation of the replacement tube, appropriate positioning of the child (lying supine, with the neck extended so that the stoma is easily accessed), adequate restraint if the child is unable to cooperate, and immediate availability of additional personnel if problems occur. I prefer that the same person who is going to place the new tube is the person who removes the old one.

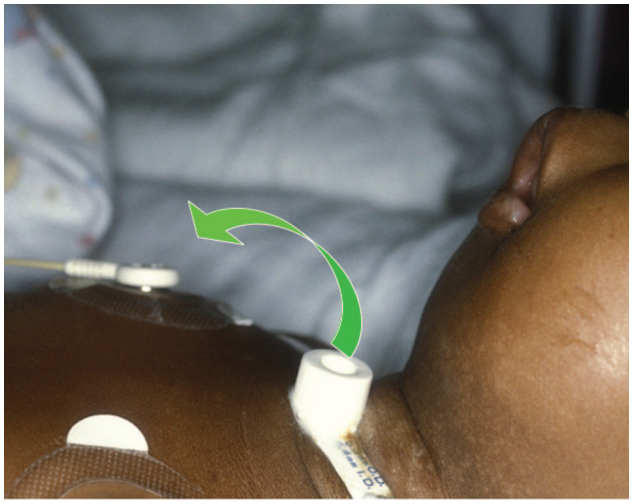

Fig. 6. Patient with a tracheotomy tube in place. The arrow indicates curved path of motion to be followed during removal of the tracheotomy tube; this path is reversed for re-insertion of a tracheotomy tube.

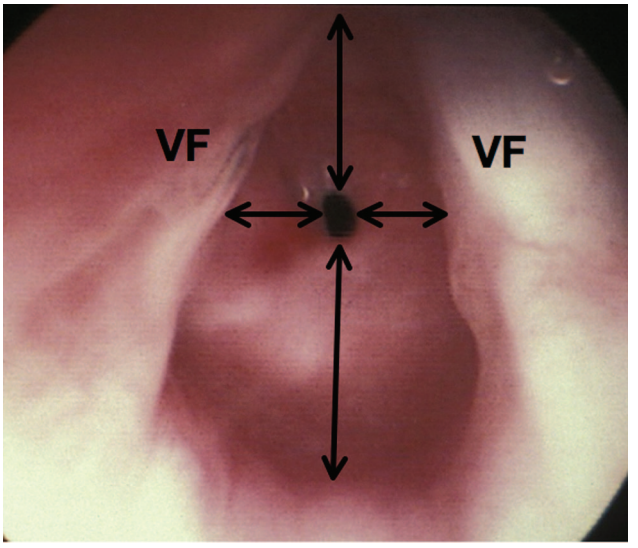

Fig. 7. Endoscopic view of grade 3 subglottic stenosis. Arrows indicate severe narrowing of the subglottis, below the level of the vocal folds (VF). This patient has a tracheotomy in place below (distal to) the subglottic stenosis.

The tracheotomy stomal pathway is a curve, rather than an opening that proceeds straight back into the neck. When the old tube is removed, it is removed in a curving motion, following and feeling the curved pathway defined by the combination of the tracheotomy tube and the tracheotomy stoma, and creating a mental model of this pathway, so that when the new tube is inserted, this pathway can be followed in reverse (Fig. 6). Additional techniques that may be helpful if problems are anticipated or encountered include changing the tracheotomy tube over a suction catheter, or, in the event that it becomes difficult to insert the new tube, using a tube that is smaller than the original tube.

Subglottic Stenosis

Subglottic stenosis is an important indication for tracheostomy in infants and children (Fig. 7). A normal subglottic lumen in a full-term neonate is at least 4 mm,[12] so a subglottic lumen of less than 4 mm is considered stenotic in newborns. In larger children, abnormal narrowing proportional to the normal size of the subglottis is also considered stenosis, and the severity is commonly graded using the Myer-Cotton grading system.[13] Currently most subglottic stenosis in infants is "acquired" as a result of intubation. Infants are at risk of acquired subglottic stenosis for several reasons. The subglottis is contained within the only true complete cartilaginous ring in the airway; therefore it cannot expand to accommodate distention by an ETT (Fig. 8). It is lined with pseudostratified ciliated columnar epithelium, with loose areolar submucosa, which has the potential to become edematous when inflamed.[12] Because of its limited diameter, even small amounts of edema, from intubation, instrumentation, or other causes, will result in large decreases in the caliber of the airway. If narrowing in the subglottis matures into a firm scar, it becomes subglottic stenosis. Stenosis is considered congenital if there is no history of airway instrumentation, trauma, or infection.

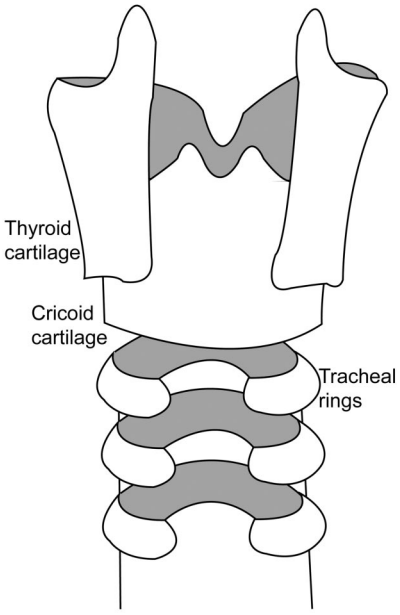

Fig. 8. Diagrammatic representation of the airway, from a posterolateral view, demonstrating the cricoid as a complete ring, in contrast to the tracheal cartilages. (Adapted from Reference 2.)

Management of acquired subglottic stenosis should begin with prevention, but the factors contributing to the

development of subglottic stenosis are not well understood. Theories include orotracheal intubation, repeated intubations, tight-fitting ETT, low birth weight, young gestational age, patient activity, patient propensity to keloid formation, immuno-inflammatory processes, underlying occult congenital subglottic stenosis, and laryngopharyngeal reflux.[14,15] Motion of the tube relative to the child may result from repeated extubations and re-intubations, or from the child moving while the tube is tethered. Despite the fact that younger and younger infants are surviving, and often require prolonged respiratory support, Walner et al reviewed the literature and reported a trend toward a decreasing incidence of subglottic stenosis, conjecturing that the current incidence is zero to 2.0% or less.[16]

For selected patients who develop subglottic stenosis, expectant management is feasible if the subglottic stenosis is mild and does not interfere with respiratory function or growth. Options for medical management may include treatment for suspected or proven extra-esophageal reflux. A short course of steroids around the time of extubation may help ameliorate edema related to intubation. Currently, dilation, done under general anesthesia with direct visualization, is advocated as a method to enlarge the airway lumen in selected patients, particularly those with stenosis caused by thin webs (Fig. 9). Dilation procedures using lateral expansion, rather than shearing, are used in an effort to minimize trauma that could result in subsequent re-stenosis.[17] Applications of mitomycin C at the time of or following a surgical procedure are intended to prevent re-stenosis by inhibiting fibroblast proliferation and synthesis of extracellular matrix proteins, thereby modulating wound healing and scarring.[18]

Several surgical procedures have been developed to bypass or alleviate subglottic stenosis. A tracheotomy will bypass the stenosis. A cricoid split procedure can be performed in infants in an attempt to alleviate the need for a tracheotomy by expanding the airway. A horizontal incision is made in the anterior neck providing exposure to the cricoid cartilage. A vertical incision in the anterior aspect of the cricoid cartilage allows it to spring open a bit, thus expanding the subglottic lumen. Sometimes a cartilage graft, harvested from the thyroid ala or the hyoid bone, which is still cartilaginous in infants, is inserted. For larger children with mature subglottic stenosis, surgical options include laryngotracheal reconstruction (laryngotracheoplasty) or cricotracheal resection.

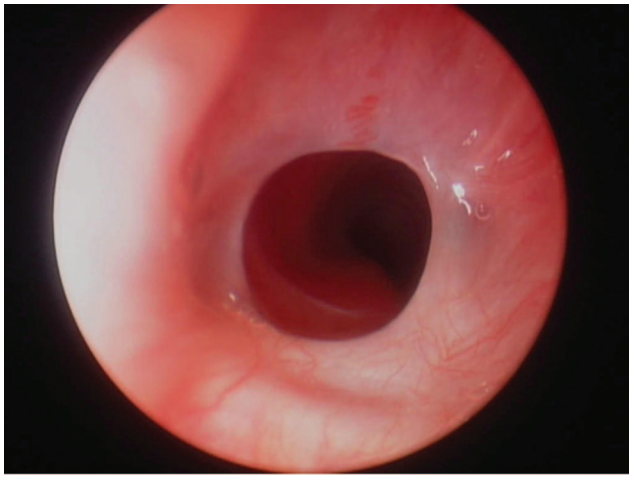

Fig. 9. Endoscopic view of thin subglottic web.

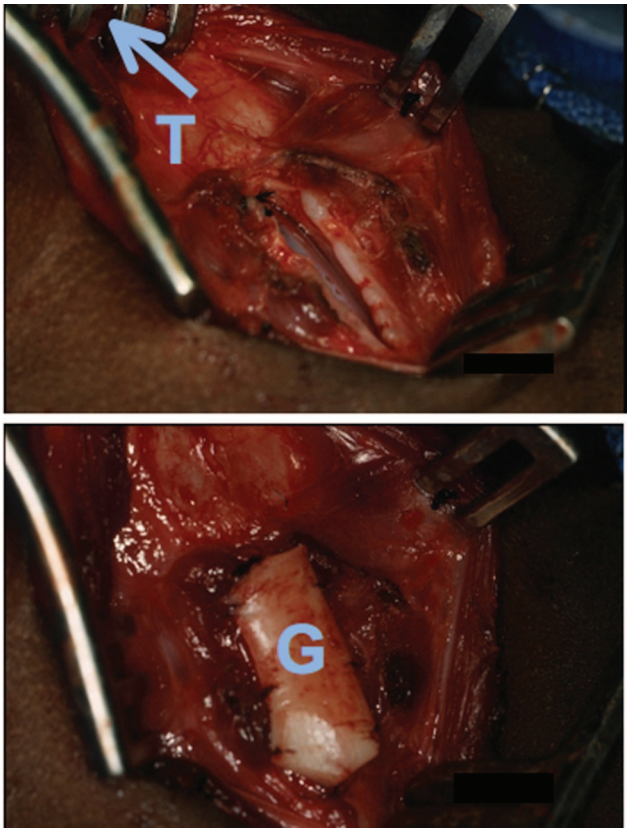

Fig. 10. Airway after anterior incision in cricoid ring and proximal trachea, before and after placement of costochondral graft. Note tracheal rings, and endotracheal tube within the airway lumen. The arrow indicates the cephalad direction. T = thyroid cartilage. G = graft.

During a laryngotracheal reconstruction, vertical incisions are made in the anterior and/or posterior cricoid cartilage and the tracheal cartilages; then cartilage grafts, often from the ribs, are inserted to expand the dimensions of the airway framework (Fig. 10). The procedure is sometimes accomplished in stages, and may require the use of stents. Cricotracheal resection, in contrast, is based on the principle of removing the stenotic area, and performing an end-to-end anastomosis of the distal end of the cricoid cartilage and the proximal end of the remaining tracheal cartilages.[19] After each of these procedures the patient

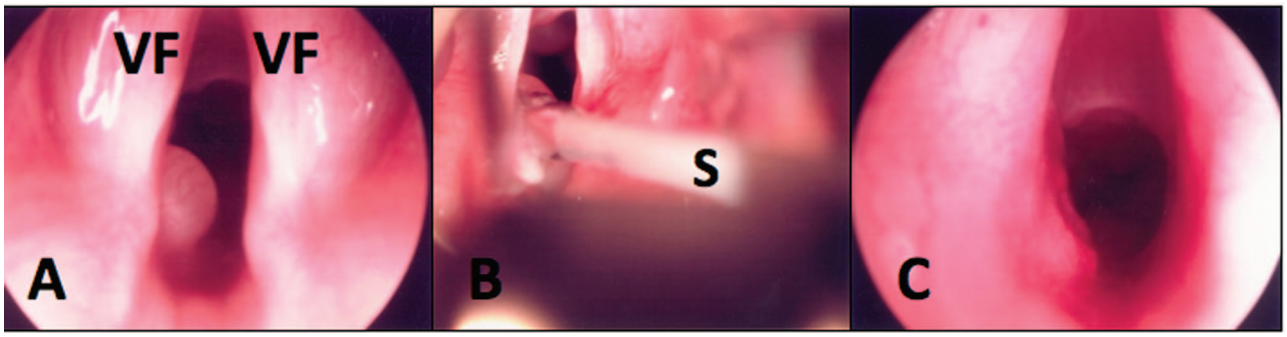

Fig. 11. A: Subglottic cyst, visualized during direct (rigid) microlaryngoscopy. B: Marsupialization using microlaryngeal scissors (S). C: Larynx immediately after removal of the cyst roof. VF = vocal fold.

often remains intubated for about a week, and may require additional supportive intensive care for another week or more, as well as additional endoscopy or other procedures. Sometimes the tracheotomy tube is removed at the time of the initial surgery, and sometimes it is removed in a staged fashion.

Can a Tracheotomy Be Avoided?

Other strategies may be useful to avoid tracheotomy in patients with specific conditions. Immediately after extubation, systemic or inhaled steroids may alleviate post-intubation subglottic edema; heliox may be of use in optimizing ventilation while edema subsides. For patients with micrognathia, such as those with Robin sequence, distraction osteogenesis may alleviate upper-airway obstruction. Patients with severe laryngomalacia may benefit from epiglottoplasty. Airway examination such as direct (rigid) laryngoscopy and bronchoscopy occasionally identifies reversible causes of airway obstruction, such as subglottic cysts, or posterior glottis synechiae (Figs. 11 and 12). One caveat should be considered in children who are brought to the operating room intubated and are extubated for the duration of the endoscopy. When the ETT is removed to allow examination of the airway, the airway will have been stented by the tube, and will initially be patent. However, in some children who remain extubated, edema may occur over a matter of minutes to hours, obstructing the airway.

For some children, a tracheotomy is not something to be avoided, but rather may be the best option. The risks and inconvenience of a tracheotomy may be less than those of an unprotected airway, or even an ETT. For children requiring prolonged ventilation, a tracheotomy, once healed, is safer than an ETT, as it can be replaced by trained but non-professional caregivers such as family members. Compared with intubation, a tracheotomy allows more physical freedom and removes some of the barriers challenging parents who want to hold their own children. Children with tracheotomies have greater ability to participate in physical therapy and exercise. Unless other conditions are present, such as neurologic deficits, children with tracheotomies can communicate orally and can eat, both of which support developmental progress. Older children can participate in a variety of sports, with the exception of sports requiring immersion in water, such as swimming.

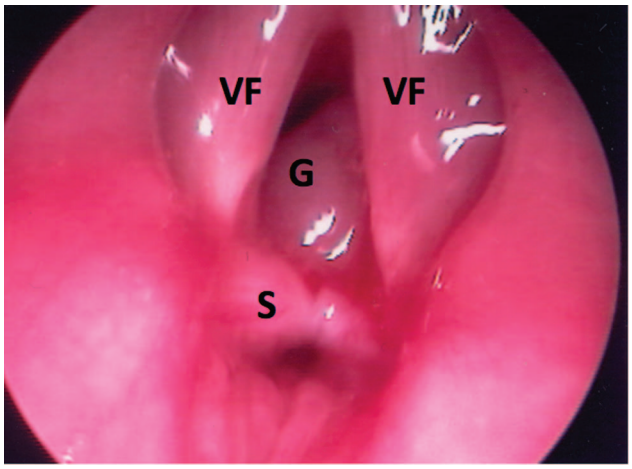

Fig. 12. Endoscopic view of posterior glottic synechiae (S) and granulation tissue (G). VF = vocal folds.

Risks of Tracheotomy

The risks of tracheotomy can be thought of as intra-operative risks, early postoperative risks, and long-term risks. Intra-operative complications directly related to the procedure include: lack of airway control, with inability to ventilate; bleeding; pneumothorax; esophageal injury; and creation of a false passage. Because many children requiring tracheotomy also have other underlying medical problems, risks also include cardiac arrest and death.[5,20]

During the early postoperative period, before the stoma has healed, replacing the tracheotomy tube in the event of inadvertent decannulation can be difficult. The surgeon performs the first postoperative tube change to confirm

Table 2. Potential Complications in Children With Tracheotomy Tubes

Intraoperative Risks
Lack of airway control
Inability to ventilate
Bleeding
Pneumothorax
Esophageal injury
Creation of false passage
Cardiac arrest, death
Early Postoperative Risks
Inability to replace the tracheotomy tube
Unintended decannulation, inability to recannulate
Stomal breakdown
Neck skin erosion
Creation of false passage
Disconnection or other problems with tracheotomy tubing or ventilator
Interstitial air (emphysema, pneumomediastinum, pneumothorax)
Respiratory arrest
Long-Term Risks
Unintended decannulation, inability to recannulate
Stomal granulomata, bleeding, cellulitis, infection
Tube occlusion
Lower respiratory tract infections, aspiration pneumonia
Hemorrhage
Subglottic stenosis
Suprastomal collapse, tracheomalacia
Tracheocutaneous fistula
Ventilatory failure caused by air leak around the tube
Tracheitis

(Adapted from References 5, 6, 20, and 21.)

adequate healing of the stoma. At that time any stay sutures can be removed, and after which time tube changes can be delegated to appropriately trained personnel. The tube can be safely changed in many patients 3 days after the tracheotomy is placed,[21] but many surgeons wait 4 to 7 days.[5,20] The timing of the first tracheotomy tube change is determined by the surgeon, based on specific anatomic or medical considerations for the individual patient, such as poor wound healing.

Additional early postoperative risks are noted in Table 2. The risk of neck skin erosion may be decreased by using a "trach tie," which includes an elastic component; the addition of hook and loop fasteners often makes adjusting the tightness of the tie easier. A subset of children will be able to release the fastener, but not understand the risks. So, for these children, additional security may require knotted, padded twill ties or other devices.

Tracheotomy tube occlusion is a common problem, occurring at a rate of up to 72% of premature and newborn children with tracheotomies, and, less frequently, at a rate of up to 14%, in children 1 year and older.[6] The higher rate in younger children is probably related to the narrow inner radius of small tracheotomy tubes, and the common condition of bronchopulmonary dysplasia with concomitant viscous bronchial secretions in premature infants.[6]

Long-term risks of tracheotomy are also listed in Table 2. Suprastomal collapse often improves if the tracheotomy is removed. Tracheomalacia, including tracheomegaly, can be caused by pressure from the cuff of a tracheotomy tube. If the tracheotomy has been in place for a relatively short period of time before decannulation, the stoma may close completely. If the tracheotomy tube has been in place for a prolonged period, the stoma usually shrinks down to a non-functional size but does not close completely, leaving a tracheocutaneous fistula. After waiting a suitable amount of time to ensure that the tracheotomy is no longer necessary, the tracheocutaneous fistula can be surgically excised and the opening closed; this also provides the opportunity to convert a circular, sometimes unattractive scar, into a more subtle and cosmetic horizontal closure.

In Davis's review, the overall risk of mortality in children with tracheotomy was 18%, usually from unrelated causes.[6] Mahadevan et al note 2 deaths from tracheotomy-related complications in their series of 122 pediatric tracheotomies performed over 17 years: one from early acute respiratory arrest, and one from accidental decannulation in the community.[5]

When is a Tracheotomy the Best Option?

Of course, the risks of placing a tracheotomy must be balanced against the risks of not placing a tracheotomy. If a child requires intubation, risks include laryngeal trauma as well as the potential consequences of lack of success during intubation attempts. In addition to the process of inserting an ETT, its maintenance also involves risks and costs, including the potential development of subglottic stenosis or other complications, the need for professional caretakers, and developmental limitations imposed by the inability to feed orally and the need to keep the tube secured.

Managing the Tracheotomy Tube

During the informed-consent discussion parents should also receive anticipatory guidance about long-term care considerations. Parents who will be taking home a child with a tracheotomy should learn how to perform routine tracheotomy care, how to identify and manage tracheotomy complications, and how to perform cardiopulmonary resuscitation. Families will also need home nursing support, tracheotomy care equipment and supplies, and access to speech therapy. Because a tracheotomy bypasses glottic closure, the tracheotomy interferes with achieving vocal volume, effective cough, and Valsalva maneuvers. In se-

lected patients, some of these limitations can be ameliorated by using a one-way speaking valve; and some children learn to occlude exhalation through the tracheotomy by performing manual occlusion of the tracheotomy tube.

Simulation can be used to teach some tracheotomy-related surgical skills, as well as for teaching parents how to identify and manage problems related to the tracheotomy. Most physical models currently available for teaching tracheotomy tube changes incorporate a hole that goes straight back into the neck of the model, lacking the appropriate anatomic downward curve of the tract between the stoma and the trachea.

Summary

Tracheotomies in children are most frequently performed to manage airway obstruction and pulmonary disease. Infants generally tolerate prolonged intubation better than adults, but complications, such as subglottic stenosis, can occur. The smaller size of the airway does not provide room to include an inner cannula within the tracheotomy tube; uncuffed tubes are used for most pediatric patients with tracheotomies.

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