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## Core Messages

- › Due to the rostral position of the thyroid cartilage in the neck, laryngeal release procedures do not induce dysphagia and aspiration in infants and small children.
- › When performing a vertical laryngofissure, it is important to transect the anterior commissure of the larynx, precisely in the midline.
- › The conus elasticus creates a dome-shaped subglottis that cannot accommodate the proximal end of a Montgomery T-tube without causing significant complications.
- › When a paediatric airway stenosis is resected, the length must be measured by the number of tracheal rings, and not in centimetres.
- › In surgeries requiring resection of a diseased airway segment, the surgeon must have a detailed anatomical understanding of the larynx's and the trachea's blood and nerve supply.
- › Surgeons and anaesthetists should use a chart detailing airway dimensions and their matching endotracheal tubes, tracheostomy cannulae and rigid bronchoscopes.
- › Normal age-related endotracheal tubes are always slightly too large for the posterior paediatric interarytenoid glottis.
- › Proper stents must be used for splinting airway reconstructions in order to avoid undue laryngotracheal damage.
- › Tubular (cigar-shaped) stents are inadequate for splinting the glottis and subglottis.
- › A dedicated, soft and atraumatic laryngotracheal stent is essential for preventing damage to the reconstructed airway.

This chapter does not attempt to provide a comprehensive description of laryngotracheal anatomy, which has already been given in other textbooks [5, 26, 29, 30, 57, 60]. Instead, it highlights the relevant anatomical features that are specific to surgical or endoscopic airway procedures for paediatric airway surgeons. This chapter also examines airway dimensions in relation to endotracheal tubes (ETT), tracheostomy cannulae, rigid bronchoscopes and stents used in these procedures.

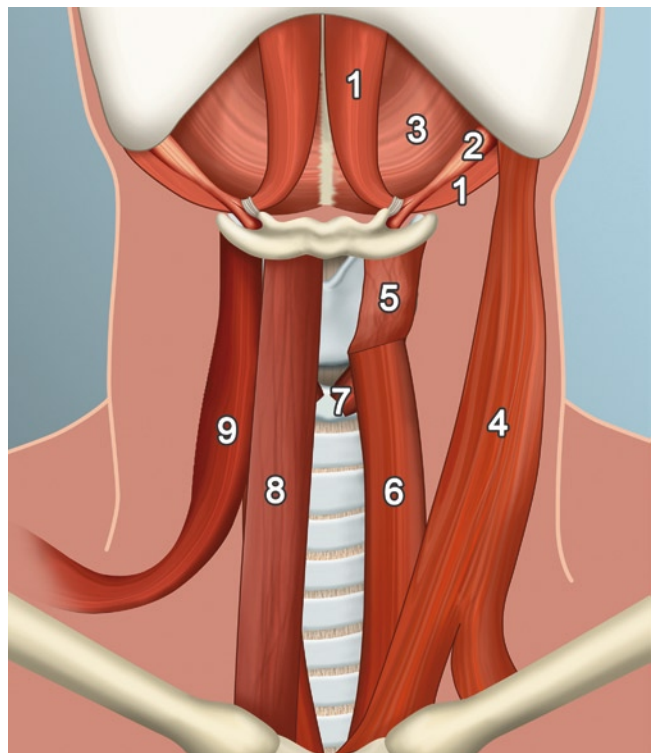
## 2.1 Position of the Larynx and Trachea in the Neck

The larynx is suspended posteriorly at the skull base by the constrictor muscles and attached anteriorly to the hyoid bone and mandible by the thyrohyoid, digastric, stylohyoid, geniohyoid and mylohyoid muscles (Fig.2.1). Because of a shortened thyrohyoid membrane, the upper rim and the thyroid cartilage notch rest posterior or just inferior to the hyoid bone. Thus, a laryngeal release procedure (see Sect. 20.7, Chap. 20), combined with an airway resection, does not provoke

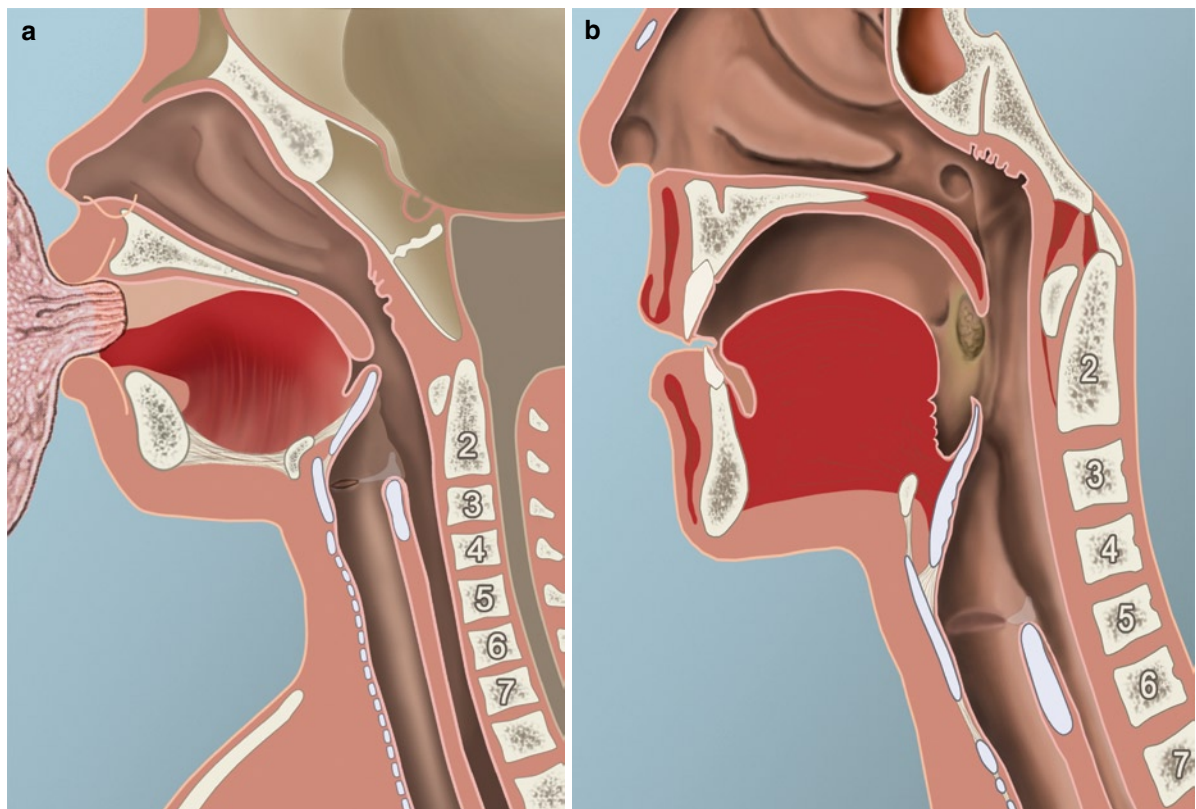
swallowing or aspiration problems in paediatric patients, provided that the vocal cord function is preserved. In infants and children, this procedure is markedly better tolerated than in adults.

The high position of the infant larynx in the neck explains why the cervical trachea segment is proportionally longer than in adults. In newborns, there are approximately 10 tracheal rings above the sternal notch. In adolescents and young adults, there are approximately eight tracheal rings, while in older adults there are six or less, depending on individual anatomy [26]. Due to this greater number of tracheal rings, surgical airway resections are technically easier to perform in children than in adults. Children's tissue elasticity also facilitates cranial mobilisation of the tracheal stump during surgery.

On sagittal section, the infant larynx is located at the level of the third or fourth cervical vertebra, and it starts to descend at around 2 years of age, reaching the level of the sixth or seventh vertebra by adulthood [30, 34] (Fig.2.2). Phylogenetically, the newborn is similar to non-human primates [35]. The tip of the epiglottis rests behind the soft palate in both species. This anatomical situation allows simultaneous breathing and suckling without any risk of aspiration, also explaining



**Fig. 2.1** Anterior muscular suspension of the larynx in the neck: One strap muscle, the thyrohyoid, suspends the larynx to the hyoid bone, while the suprahyoid muscles indirectly suspend the larynx to the mandible. Please note the high position of the thyroid cartilage in the neck and the ensuing long cervical trachea segment. Extrinsic laryngeal muscles: (1) digastric, (2) stylohyoid, (3) mylohyoid, (4) sternocleidomastoid, (5) thyrohyoid, (6) sternothyroid, (7) cricothyroid, (8) sternohyoid and (9) omohyoid



**Fig. 2.2** Sagittal section of the infant and adult larynges: (a) The infant larynx is positioned high in the neck at C3–C4 level. (b) As a result of the acquisition of articulated speech during the

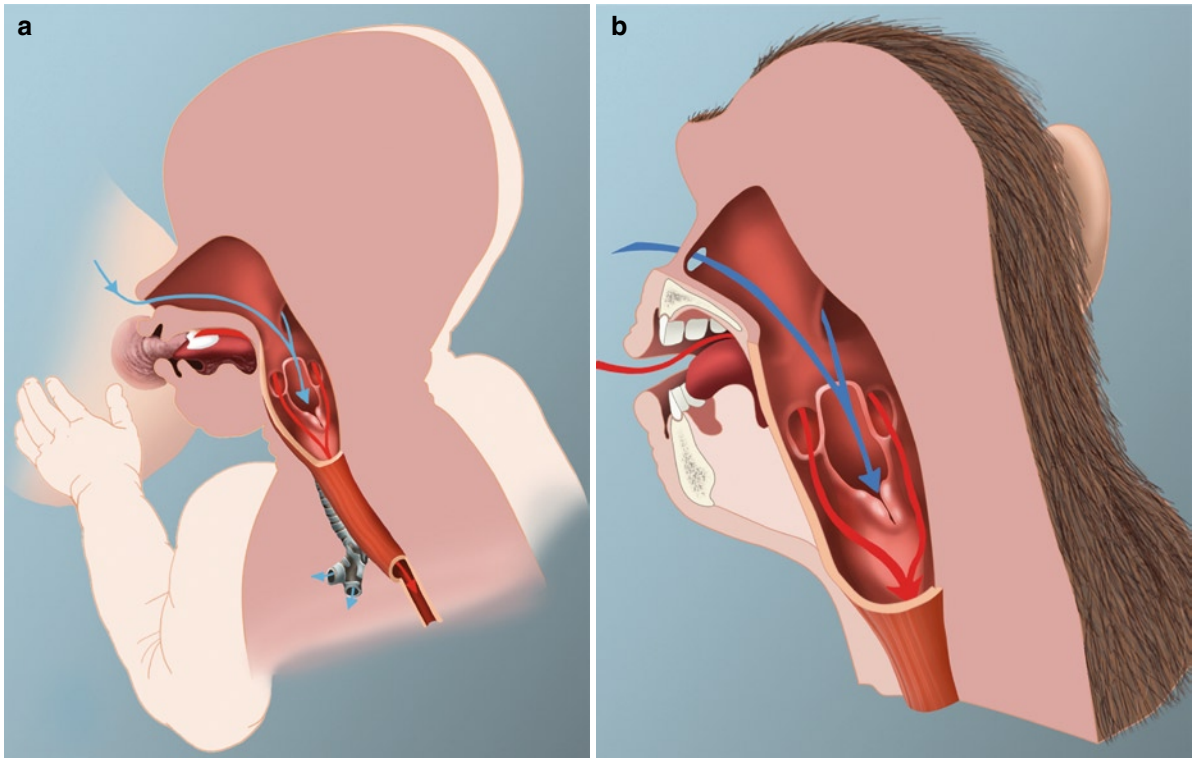
phylogenetic evolution of species, the adult larynx is positioned at C6–C7 level

the preferential nasal breathing and absence of articulated speech (Fig. 2.3). Articulated speech was made possible only by the descent of the larynx at the time of *Homo sapiens*, during the evolution from primates to humans approximately 400,000 years ago. However, recent studies assign this acquisition to direct cortico-laryngeal connections in humans [21, 22].

## 2.2 Laryngotracheal Framework (Fig. 2.4)

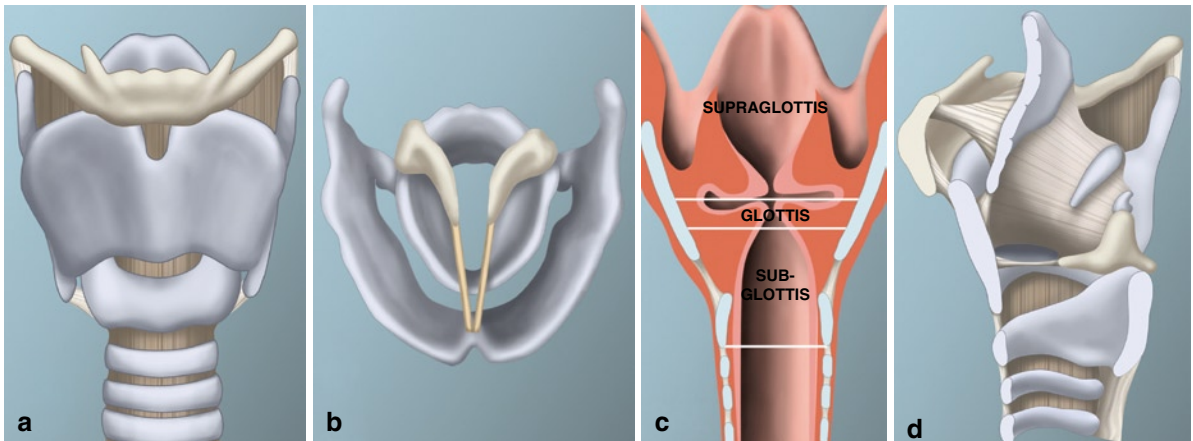
The infant larynx is different from the adult larynx, as summarised below [30]:

- Its size is approximately one-third of the adult larynx.
- The infant thyrohyoid membrane is much shorter, and the thyroid notch is behind the hyoid bone.
- The thyroid cartilage is V-shaped in adults, but more rounded in children (Fig. 2.5a).
- In a full-term newborn baby, the length of the glottis is approximately 7 mm (range 6–8 mm), and the width of the posterior glottis is 3–4 mm.
- Infant arytenoid cartilages are larger and longer, comprising slightly more than 50% of the antero-posterior glottis until 3 years of age. This ratio drops to 20% in adults.
- The interarytenoid distance represents approximately 60% of the inner subglottic diameter in newborns, and more than 70% of this diameter in adults.
- Cuneiform cartilages are proportionally larger in infants than adults; they are not directly connected with the arytenoid cartilages.
- The cephalad half of the infant cricoid is V-shaped and becomes rounded at its lower level (Fig. 2.5b and c).
- The cartilages of the infant larynx are softer and more pliable than in adults.
- The mucosae of the supraglottis and subglottis are lax in infants and hence more prone to oedema when inflamed or injured.



**Fig. 2.3** Similarities of the newborn (a) and primate (b) larynges: The tip of the epiglottis rests behind the uvula of the soft palate in both species due to the high position of the larynx in

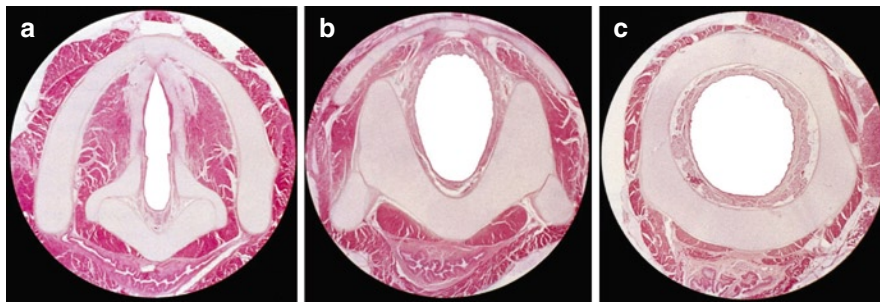
the neck. While simultaneous breathing and suckling are possible, articulated speech is not. (Reproduced from Laitman [35]. With permission)



**Fig. 2.4** Frontal, axial, coronal and sagittal views of the infant larynx: (a) The thyroid cartilage is partially concealed behind the hyoid bone (frontal view). (b) The thyroid cartilage has a blunt, round-shaped curvature at the level of the anterior commissure (axial view). (c) The subglottis is larger than the glottis,

giving an inverted funnel shape to the subglottis in this section (coronal view). (d) The antero-posterior distance at the glottic level is much greater than the diameter of the subglottis at the cricoid level (sagittal view). The size of the arytenoid occupies approximately one-half of the glottic length





**Fig. 2.5** Horizontal histological sections of the infant larynx. (Reproduced from Holinger, Chicago [32]. With permission.) (a) The thyroid cartilage is round and not V-shaped as in adults; the arytenoids are long, contributing to one-half of the glottic length; the cricoid plate is slightly V-shaped (section at the

glottic level). (b) Due to the V-shaped configuration of the upper cricoid, the subglottic lumen is elliptical (section at the mid-portion of the cricoid cartilage). (c) At the lower level of the cricoid cartilage, the lumen is round-shaped

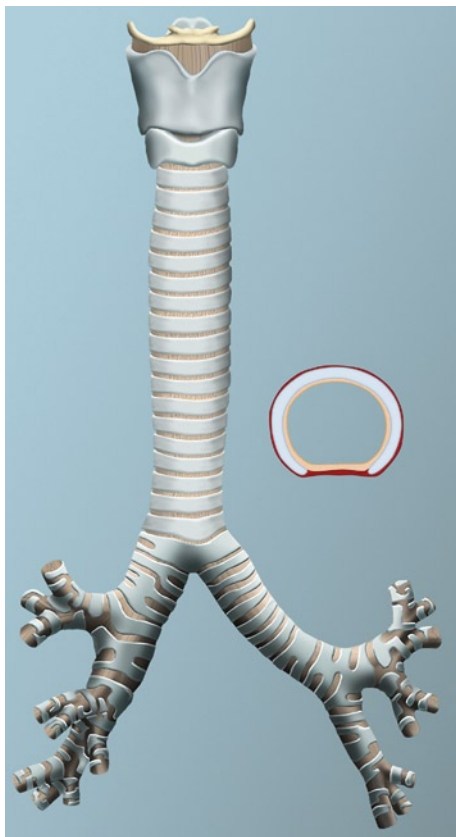
A thorough knowledge of the infant and child larynx calls for the following medical and surgical decisions:

- When performing a full laryngofissure or a partial cricotracheal resection (PCTR), the thyrohyoid membrane must often be sectioned along the thyroid cartilage's upper rim to release the thyroid cartilage from its cranial attachment and move it into the operative field.
- Performance of a precise vertical midline thyrotomy through the larynx's anterior commissure can be difficult in a round-shaped anterior thyroid cartilage. This necessitates a vertical incision through the epiglottis at the level of the thyroid notch, which allows airway division under visual control without damaging the anterior commissure; this is especially relevant when the vocal cords are fused by a laryngeal web or synechia.
- Owing to longer arytenoids, a shorter interarytenoid distance and a V-shaped cephalad cricoid, endotracheal intubation may damage the medial aspect of the arytenoids and postero-lateral portion of the cricoid ring (see Sect. 14.1, Chap. 14) [4].
- When performing a CO<sub>2</sub>-laser supraglottoplasty for laryngomalacia, part of the cuneiform cartilages must be vaporised to obtain a less bulky aryepiglottic fold and induce submucosal fibrosis.
- The pliability of the thyroid cartilage allows the surgeon to increase the subglottic lumen during PCTR by performing an inferior midline thyrotomy; this permits a better adaptation of the larger tracheal ring used for the thyrotracheal anastomosis (see Sect. 20.3, Chap. 20).
- A postoperative mucosal oedema of the glottis and subglottis is more prominent in infants and children than adults. Therefore, there is a greater need for temporary postoperative intubation after single-stage PCTR in the paediatric age group.

The infant and child trachea has the same overall configuration as the normal adult trachea, except for its size [26]. From birth to late adolescence, the trachea more than doubles in length, triples in diameter and increases by sixfold in cross-sectional area, while maintaining the same architecture of 16–20 horseshoe-shaped tracheal rings [60]. The posterior membranous trachea is flexible and consists of fibro-elastic and muscular tissue layers (Fig. 2.6).

### 2.3 The Larynx's Intrinsic Musculature (Fig. 2.7)

Of the intrinsic laryngeal muscles, the posterior cricoarytenoid muscle is the only abductor of the vocal cords. All other muscles are either adductors (paired lateral cricoarytenoid, unpaired interarytenoid) or tensors of the vocal cords (paired thyroarytenoid, including the vocalis muscle). It is worth noting that the function of each muscle changes slightly depending on the position of the vocal cords. During phonation, for example, the posterior cricoarytenoid muscle counteracts the thyroarytenoid muscle's tensor function in order to stabilise the arytenoid cartilage. This type of interaction between agonist and antagonist muscles is essential for balanced

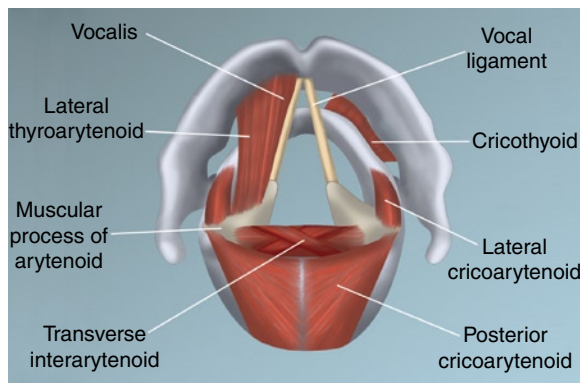


**Fig. 2.6** Infant trachea: The general configuration is similar to that of the adult with 16–20 horseshoe tracheal rings and a pars membranacea. Its size is only 50% in length, 36% in diameter and 15% in cross-sectional area, as compared to the adult's

laryngeal function. Two other slip muscles, the thyroepiglotticus and the aryepiglotticus (not shown in Fig. 2.7), play minor additional roles: The former improves the sphincteric effect of the laryngeal vestibule and the latter shortens the vocal ligament, producing a low-pitched voice [57]. The cricothyroid, an extrinsic muscle of the larynx, also acts as a tensor of the vocal cords, and helps raise the voice's pitch (Fig. 2.8).

Therapeutic surgical or endoscopic interventions may enhance previous trauma (vocal cord palsy, cicatricial stenosis, etc.) and further damage the functions of these delicate muscles:

- Laryngotracheal reconstruction (LTR) with anterior costal cartilage graft and PCTR both abolish the cricothyroid muscle's function (see Chaps. 19 and 20).
- During PCTR, the lateral cricoarytenoid muscle must be preserved in order to maintain stability of the arytenoid cartilage and prevent arytenoid



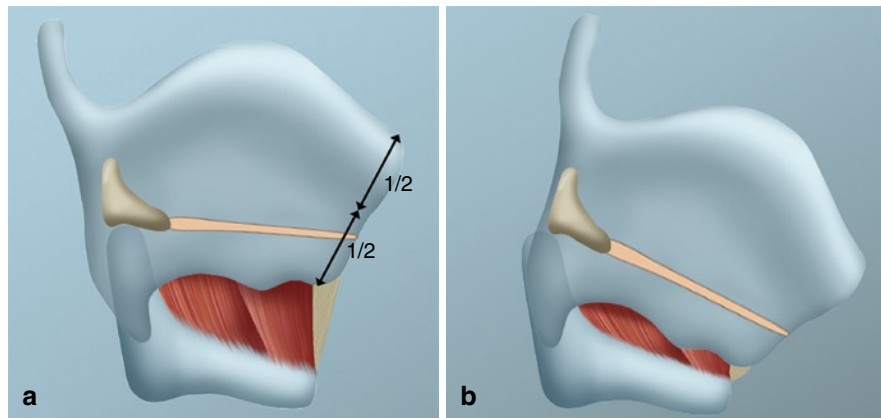
**Fig. 2.7** Intrinsic muscles of the larynx (posterior to anterior superior view): In the infant, location and function of all intrinsic muscles are identical to those of the adult

prolapse during phonation in the postoperative period. This is even more essential if a subglottic stenosis is combined with a posterior glottic stenosis (PGS). The procedure usually requires complete transection of the interarytenoid muscle to enlarge the larynx's posterior commissure; this may eventually destabilise the arytenoids. Extended PCTR with intussusception of the thyrotracheal anastomosis preserves the lateral cricoarytenoid muscle's function and helps prevent arytenoid prolapse (see Sect. 20.5, Chap. 20).

## 2.4 Innervations of the Larynx (Fig. 2.9)

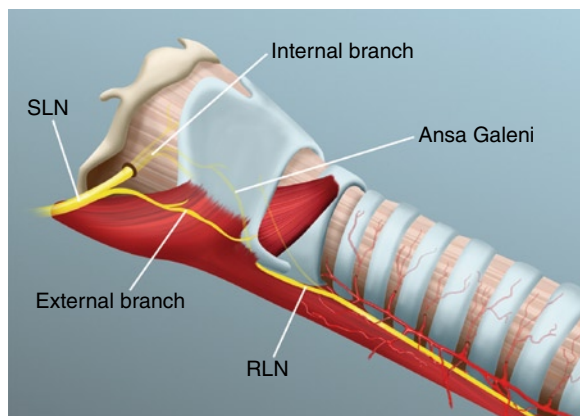
The sensory and motor nerve supply of the larynx originates bilaterally from the vagus nerve. Although the recurrent laryngeal nerve (RLN) provides the sensory supply to the infraglottis, its main function is to provide the motor supply to the intrinsic laryngeal muscles. The superior laryngeal nerve (SLN) predominantly provides the sensory supply to the supraglottis and glottis, but its external branch also provides the motor supply to the cricothyroid muscle. The ansa Galeni, an anastomosis between the SLN's internal branch and one of the RLN's branches, provides the accessory motor and predominant sensory supply to endolaryngeal structures.

To preserve the larynx's function, it is absolutely necessary that the laryngotracheal surgeon has detailed knowledge of the SLN's and RLN's courses in the laryngeal region.



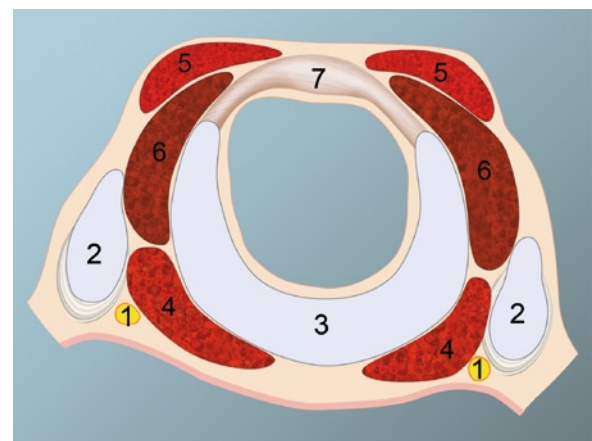
**Fig. 2.8** Function of the cricothyroid muscle: (a) Resting position of the cricothyroid muscle. In infants, the anterior commissure of the larynx is positioned slightly below the mid-distance point between the thyroid notch and the inferior border of the

thyroid cartilage. (b) Contracting position of the cricothyroid muscle: During contraction, the cricothyroid distance is shortened, and the vocal ligament is stretched, raising the voice pitch. This function is lost in LTR and PCTR



**Fig. 2.9** Innervations of the larynx: SLN: The internal branch provides sensory function to the supraglottis and glottis. The external branch provides motor function to the cricothyroid muscle. RLN: Provides motor function to all intrinsic muscles. Provides sensory function to the infraglottis. Ansa Galeni: Provides weak motor and strong sensory functions to the endolaryngeal structures

The RLN originates from the vagus nerve. On the left, in the thorax, the RLN separates from the vagus nerve, passes around the aortic arch, then travels back cranially in the tracheo-oesophageal groove, and eventually reaches the larynx just posterior to the cricothyroid joint. On the right, the RLN passes under the subclavian artery, runs cranially in the tracheo-oesophageal groove, as it does on the opposite side, and enters the larynx just behind the cricothyroid joint [58]. Due to their considerable length, both RLNs are at risk of injury during intra-thoracic surgery on the left side,



**Fig. 2.10** Relationship of the RLNs with the cricothyroid joint: horizontal section at the level of the cricothyroid membrane (diagram): (1) RLN, (2) cricothyroid joint, (3) cricoid plate, (4) posterior cricoarytenoid muscle, (5) cricothyroid muscle, (6) lateral cricoarytenoid muscle and (7) cricothyroid membrane. The RLNs are located immediately behind the cricothyroid joints

and laryngotracheal, pharyngo-esophageal and thyroid surgeries on both sides of the neck.

The entry point of the RLN into the larynx is just behind and below the cricothyroid joint. At this level, it is protected by the inferior constrictor muscle and the cricothyroid muscle (Fig. 2.10). In about 90% of cases, the RLN divides into two to three branches just a few millimetres before entering the larynx underneath the inferior constrictor muscle [53]. The posterior branch runs just behind the mucosa of the posterior cricoarytenoid muscle, where it lies in close contact

with the cricoid plate's lower edge. During a thyrotracheal anastomosis, the surgeon must be aware of potential nerve damage while placing stitches through the cricoid plate.

The SLN leaves the vagus nerve trunk at the level of the nodose ganglion. It runs transversally behind the carotid artery, approaches the larynx with the superior laryngeal branch of the superior thyroid artery, then penetrates the thyrohyoid membrane anterior to the lateral thyrohyoid ligament and at mid-distance between the upper thyroid rim and the hyoid bone [13]. Before entering the larynx, the SLN provides a smaller external motor branch for the cricothyroid muscle that runs on the constrictor muscle's outer surface, where it is at risk of injury during surgery [9].

The surgeon must know these precise anatomical landmarks in order to avoid potential irreversible sensory or motor damage to the larynx:

- Laryngotracheal reconstruction with cartilage expansion is carried out with a vertical midline laryngofissure. This explains its popularity among paediatric otolaryngologists, who are wary of injuring the RLNs and SLNs during more complex surgical procedures, such as airway resection and anastomosis.
- During PCTR, lateral reflection of the cricothyroid muscle, from the midline over the cricothyroid joint, protects the RLN and the inferior laryngeal artery (see Sect. 20.3, Chap. 20).
- While performing the thyrotracheal anastomosis during PCTR, the posterior and postero-lateral stitches must always emerge in a subperichondrial plane on the cricoid plate's outer surface to avoid injury to the RLNs (see Sect. 20.3, Chap. 20).
- A laryngeal release procedure is best performed by sectioning the thyrohyoid muscles on the thyroid cartilage, and by incising the thyrohyoid membrane along the upper edge of the thyroid cartilage to reach the upper lateral cornu on both sides. The upper cornu can be sectioned at this level without risking damage to the SLN's neurovascular bundle.

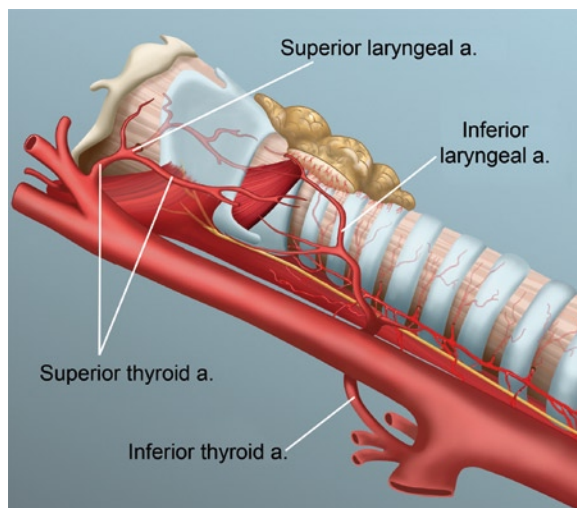
## 2.5 Vascular Supply of the Larynx and the Trachea

The larynx is supplied by vascular branches of the superior and inferior thyroid arteries. The superior laryngeal artery, a branch of the superior thyroid artery,

penetrates the thyrohyoid membrane, together with the SLN, just anterior to the lateral thyrohyoid ligament, providing the blood supply to the supraglottis and glottis [56, 57]. The inferior laryngeal artery, a branch of the inferior thyroid artery, reaches the larynx at the level of the cricothyroid joint and provides the blood supply to the cricothyroid and inferior constrictor muscles, as well as the subglottis and glottis, where it anastomoses with capillaries of the superior laryngeal artery. During PCTR, lateral reflection of the cricothyroid muscle over the cricothyroid joint protects not only the RLN but also the inferior laryngeal artery, thereby preserving the subglottic vascular supply (see Sect. 20.3, Chap. 20).

Although the superior thyroid artery gives no direct branches to the cervical trachea, it anastomoses with the inferior thyroid artery in and around the thyroid gland, and indirectly supplies the adjacent upper tracheal wall with small feeder vessels, originating from the thyroid gland capsule (Fig. 2.11).

In its cervical segment, the trachea receives its blood supply from the inferior thyroid artery [40], and in its thoracic segment from the innominate-subclavian

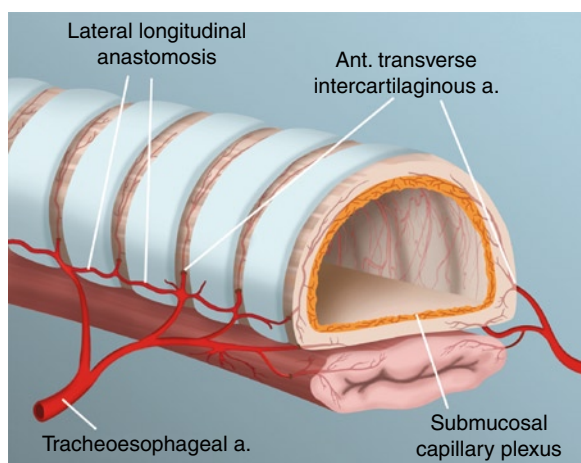


**Fig. 2.11** Vascular supply of the larynx and cervical trachea: The superior and inferior laryngeal arteries, originating from the thyroid arteries, supply blood to the larynx, with anastomoses in and around the thyroid gland. The inferior thyroid artery supplies blood to the cervical trachea and gives rise to the tracheal arteries. Their segmental distribution throughout the entire length of the trachea, with lateral longitudinal anastomoses and transverse intercartilaginous feeder vessels to the inner submucosal plexus, dictates the basic surgical principles for PCTR, as well as those for tracheal resection and anastomosis. (Adapted from Salassa [51]. Copyrighted and used with permission of Mayo Foundation for Medical Education and Research)



system and bronchial arteries [51]. Avoid ischemic complications after airway resection and anastomosis, precise knowledge of the arteries' segmental distribution throughout the trachea is more relevant than that of the supply vessels' origin. The inferior thyroid artery passes posterior to the carotid sheath on both sides and often gives rise to three branches that reach the tracheo-oesophageal groove laterally, travelling anterior or posterior to the RLN. Two tracheo-oesophageal branches, at times even one single vessel, supply the upper cervical trachea [51]. These vessels then divide into tracheal and oesophageal branches. The tracheal branches connect with one another over three to four interspaces, creating a complete longitudinal tracheal anastomosis. Each tracheal branch penetrates the trachea in the intercartilaginous soft tissue space then moves into the submucosa, where it provides a rich interanastomotic capillary bed to the endoluminal surface of the tracheal cartilages. This blood supply is independent from that of the posterior membranous trachea. The tracheal cartilages receive their blood supply on the inner, mucosal side. There is no capillary network on the outer surface of the tracheal cartilages (Fig. 2.12). Therefore, circumferential intraluminal compression of the tracheal mucosa may lead to ischemic necrosis of the tracheal cartilages.

The segmental distribution of the feeder vessels to the thoracic trachea is similar to the cervical trachea's segmental distribution. The bronchial arteries provide



**Fig. 2.12** Schematic view of the tracheal microscopical blood supply: The rich vascular network beneath the endotracheal mucosa originates from the transverse intercartilaginous arteries derived from the lateral longitudinal anastomosis. (Adapted from Salassa [51]. Copyrighted and used with permission of Mayo Foundation for Medical Education and Research)

continual blood supply to the distal trachea and carina [8, 51]. The rest of the blood supply to the upper thoracic trachea is provided by numerous arteries of the innominate-subclavian system, namely, the supreme intercostal artery, the subclavian artery, the mammary artery and the innominate artery, with significant individual variations. The segmental supply from the tracheo-oesophageal grooves is similar to what has been described for the cervical trachea.

Because of this segmental vascularisation of the trachea, the airway surgeon must adhere to the following principles during laryngotracheal surgery:

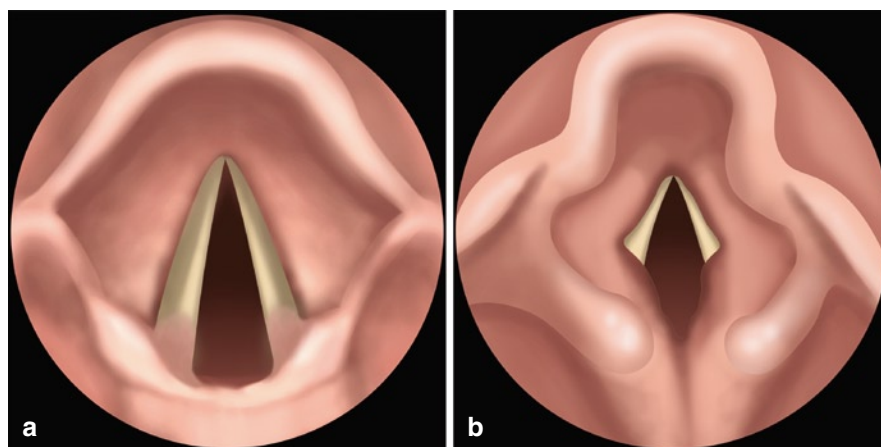
- Preservation of the trachea's lateral blood supply, except for the segment that needs to be resected
- Outer anterolateral dissection of the cervical trachea in close contact with the cartilaginous rings, without compromising the blood supply passing through the tracheo-oesophageal groove
- Minimal tracheo-oesophageal separation, consisting of a few millimetres, cranially and caudally from the resected tracheal segment
- Preservation of the thyroid gland in contact with the trachea while the surgeon resects a tracheal stenosis below the thyroid isthmus
- Sectioning of the thyrohyoid membrane along the thyroid cartilage's upper rim for a laryngeal release procedure
- Lateral reflection of the cricothyroid muscle over the cricothyroid joint in order to protect the RLN and inferior laryngeal artery during PCTR

For a more comprehensive description of the trachea's blood supply, the reader is referred to the work of Salassa et al. that has continued to be a valuable reference for over 30 years [51].

## 2.6 Endoscopic Anatomy (Fig. 2.13)

The infant larynx differs from the adult larynx as follows [30]:

- The epiglottis is omega-shaped and projects posteriorly above the glottis at a 45° angle.
- The lateral edge of the epiglottis is positioned slightly medial to the pharyngo-epiglottic fold.
- The aryepiglottic folds are shorter.
- The tubercle of the cuneiform cartilage is more prominent.



**Fig. 2.13** Schematic endoscopic aspect of the adult and infant larynx: **(a)** Adult larynx: The ligamentous glottis represents approximately 80% of the entire glottic length; the aryepiglottic folds are long; the epiglottis is unfolded and projects vertically;

the subglottis is round-shaped. **(b)** Infant larynx: The entire glottic length is 50% ligamentous and 50% cartilaginous; the aryepiglottic folds are short; the epiglottis is somewhat tubular, omega-shaped; the subglottis is elliptical proximally

- The increased ratio of the cartilaginous to the ligamentous glottis accentuates the pentagonal shape of the glottis during inspiration.
- The immediate subglottic lumen is elliptical, due to the V-shaped upper half of the cricoid cartilage.

during the first 6 years of life, in subjects who are asleep or resting quietly [27, 28]. These data have been correlated with recommended uncuffed ETT sizes for intubation [59] and with rigid bronchoscopes routinely used for diagnostic and therapeutic endoscopies.

## 2.7 Morphometric Measurements of the Larynx and Trachea

Benign stenoses of the larynx and trachea most commonly arise from iatrogenic complications following endotracheal intubation [54].

An improved understanding of airway dimensions at different developmental ages would allow the surgeon and anaesthetist to choose the correct endotracheal tube size, thus avoiding inadvertent damage to the larynx and trachea. Therefore, surgeons, anaesthetists, intensivists and neonatologists must be familiar with the paediatric larynx's morphometric measurements. Iatrogenic complications from the use of oversized endotracheal tubes (ETT) for resuscitation and mechanical ventilation in the paediatric intensive care unit (PICU) could be largely prevented, but only a few studies are currently available in the medical literature [20, 52, 56].

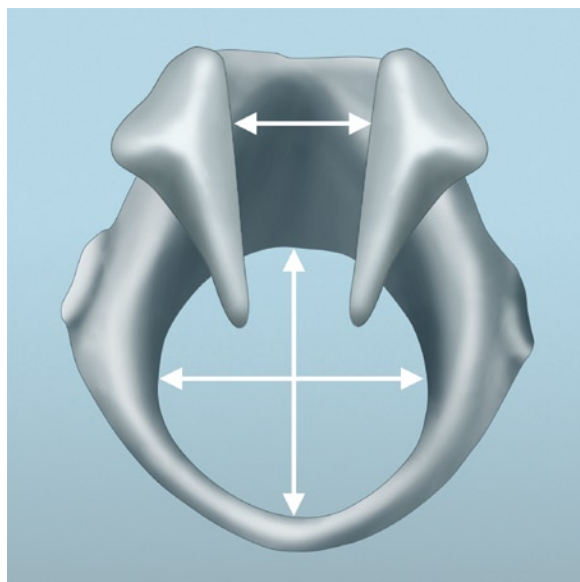
The data in the following section come from studies on whole organ serial sections of the paediatric larynx during the first 5 years of life [14, 15], as well as CT-scan measurements of the paediatric trachea,

### 2.7.1 Larynx Morphometry

#### 2.7.1.1 Subglottic Luminal Diameter and Recommended ET-Tube Sizes

Eckel et al. [14, 15] published cross-sectional area measurements of the cartilaginous subglottis (cricoid ring) and subglottic airway (cricoid ring with mucosa) in 43 infant ( $n=24$ ) and child ( $n=19$ ) larynges. Cross-sectional surfaces were converted into diameters for this work, in order to compare them with ETT sizes (Fig. 2.14). Anaesthetists only refer to the ETT's internal diameters, which are relevant for ventilating the patient. However, the ETT's outer diameters can differ depending on the manufacturer. These differences in outer diameter are significant when we consider the size of the corresponding airway (Table 2.1).

Since a majority of medical professionals prefer the soft Portex blue line tube for prolonged endotracheal intubation in the PICU, we have used this device for comparison in the following tables. Only the median and minimal diameters of the subglottic airway are



**Fig. 2.14** Cricoid ring and arytenoids: The diameters of the subglottis and interarytenoid space are pertinent for assessing the potential risks linked to ETT sizes during intubation

**Table 2.1** Diameters (mm) of endotracheal tubes (ETTs)

Tube n°	Malinkrodt (Lanz and Rae)	Portex	Rüsch
ID	OD	OD	OD
2	3	2.9	2.9
2.5	3.6	3.6	3.8
3	4.3	4.4	4.4
3.5	4.9	5.0	5.3
4	5.6	5.4	5.9
4.5	6.2	6.6	6.7
5	6.9	7.2	7.3
5.5	7.6	8.0	8.0
6	8.2	8.8	8.7
6.5	8.8	9.5	9.3

reported in Table 2.2. Maximum diameters were omitted, since they can readily accommodate recommended uncuffed ETT sizes.

We can draw the following conclusions from these morphometric measurements:

- The outer diameter of the recommended ETTs slightly exceeds the median luminal diameter of the subglottis.

**Table 2.2** Subglottic luminal diameters compared to recommended endotracheal tube (ETT) sizes

Age (years)	Subglottic lumen (mm)*		Recommended ett (mm)**	
	Median	Minimal	Outer $\phi$	Inner $\phi$
0–1	4.6	3.7	4.4–5.1	3.0–3.5
1–2	5.5	4.9	5.9–6.6	4.0–4.5
2–3	6.7	6.2	6.6	4.5
3–4	6.8	5.8	6.6–7.3	4.5–5.0
4–5	7.0	6.2	7.3–8.0	5.0–5.5

\*From Eckel et al. [14]

\*\*From Weyckemans [59]

- The ETTs may be oversized at all ages.
- If the larger recommended ETT is used, it will induce significant intubation trauma at all ages.

Therefore, any slight trauma to the subglottic mucosa during intubation can induce severe dyspnoea in the infant (Fig. 2.15).

According to Holinger [30], the width of the posterior glottis (i.e., the interarytenoid distance) corresponds to approximately 80% of the subglottic lumen. If the median interarytenoid distance is calculated at 80% of the subglottic lumen's median diameter, then all recommended ETTs are oversized and cannot fit the posterior glottis without excessive pressure on the mucosa (Table 2.3). In order to avoid iatrogenic complications of intubation, anaesthetists and intensivists must be aware of these discrepancies between ETTs and paediatric airway sizes.

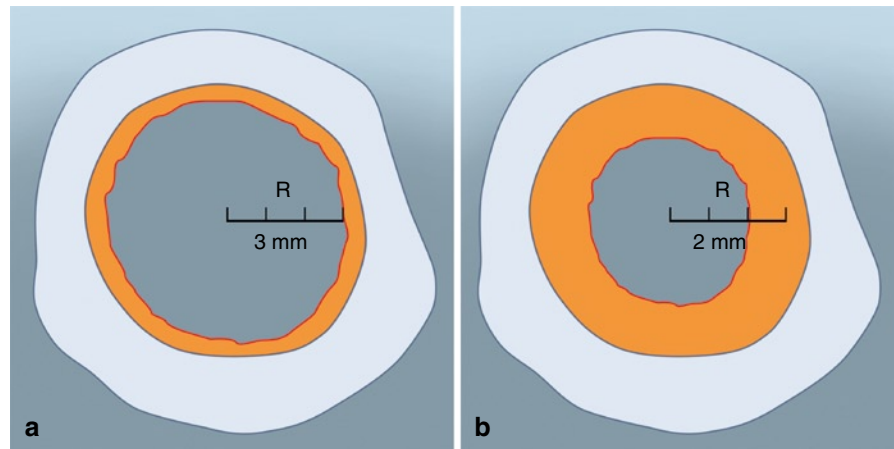
The following principles should be respected:

- At the slightest resistance met when introducing the ETT into the larynx, we recommend changing the ETT to a smaller size.
- In the PICU, the smallest tube that will provide adequate ventilation for infant and child should always be chosen over the largest.

### 2.7.1.2 Cricoid Cartilage Diameter Compared to Recommended Sizes of Rigid Bronchoscopes

For a short procedure like rigid bronchoscopy, the diameter of the cricoid cartilage is acceptable as a reference

**Fig. 2.15** Infant subglottis and risk of dyspnea: The size of the infant subglottis has a maximum diameter of 5–6 mm and a cross-sectional area of 28 mm<sup>2</sup>. One millimetre of mucosal oedema reduces the diameter by 2 mm and the cross-sectional area (12.6 mm<sup>2</sup>) by nearly 50% (Reproduced with permission of Holinger, Chicago [31])



**Table 2.3** Median interarytenoid distance compared to recommended ETT sizes

Age (years)	Median interarytenoid distance (mm)*	Recommended ETT (mm)**	
		Outer ø	Inner ø
0–1	3.7	4.4–5.1	3.0–3.5
1–2	4.4	5.9–6.6	4.0–4.5
2–3	5.3	6.6	4.5
3–4	5.5	6.6–7.3	4.5–5.0
4–5	5.6	7.3–8.0	5.0–5.5

\*From Eckel [14]

\*\*From Weyckemans [59]

**Table 2.4** Cricoid cartilage diameters compared to recommended sizes of rigid bronchoscopes

Age (years)	Cricoid cartilage diameter (mm)*		Recommended rigid bronchoscopes	
	Median	Minimal	Outer ø	Storz ø
0–1	6.3	4.8	4.2–5.7	2.5–3.5
1–2	7.7	7.1	6.4	3.7
2–3	8.1	7.7	6.7–7.3	4.0–4.5
3–4	7.9	7.5	7.3–7.8	4.5–5.0
4–5	9.0	8.6	8.2	6.0

\*From Eckel [14]

since a temporary compression of the subglottic mucosa is tolerated. However, the presence of a pre-existing pathology that diminishes the subglottic lumen's size should first be ruled out (Table 2.4). The outer diameter of the rigid bronchoscope's recommended dimensions

is always smaller than that of the median cricoid cartilage diameter. The risk of trauma to a normal-sized subglottis is minimal during rigid bronchoscopy. Furthermore, a smaller size of endoscope can always be used if a slight resistance is met during the bronchoscope's insertion into the larynx.

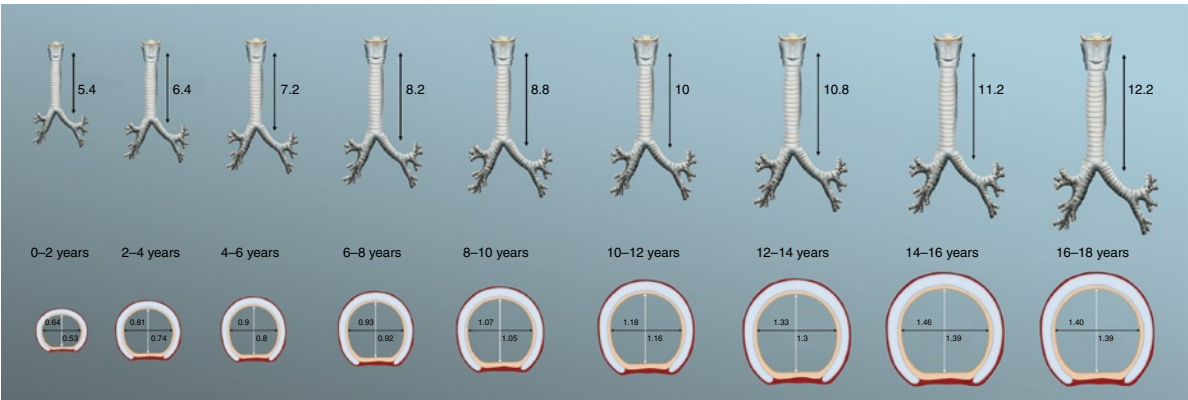
### 2.7.2 Trachea Morphometry

The length and size of the trachea vary considerably depending on the artefacts induced by ex vivo (autopsy specimens) versus in vivo (CT-scan) measurements. The CT-scan studies of Griscom et al. [27, 28] on 130 infants and children are displayed in Fig. 2.16. The measured parameters (length, diameter, cross-sectional area, volume) correlated with body height, but in small children the correlation was higher with body weight. Until the age of 6 years, the antero-posterior diameter of the trachea is smaller than the lateral diameter. Later in life, the cross section of the trachea becomes rounder, taking on comparable antero-posterior and lateral diameters. The recommended uncuffed cannula for the child's age usually fits the tracheal lumen (Table 2.5).

Precise knowledge of airway dimensions or direct access to a chart with all relevant information is necessary to avoid major complications of endotracheal intubation:

- Recommended ETT sizes are usually at the upper limit of the age-corresponding airway diameter (subglottic lumen, interarytenoid distance) or larger. Oversized tubes primarily induce pressure necrosis on the medial aspect of the arytenoids.





**Fig. 2.16** Tracheal lengths and diameters [27, 28]: From birth to adolescence, the length of the trachea doubles, its diameter triples and its cross-sectional area increases sixfold

**Table 2.5** Tracheal diameters compared to recommended Shiley paediatric cannula sizes

Age (years)	Tracheal diameter (mm)*		Cannula size (mm)	
	Median	Minimal	Outer ø	Inner ø
0–1	4.6	4.1	4.5	3.0
1–2	5.3	4.1	5.2	3.5
2–3	6.7	6.4	5.9–6.5	4.0–4.5
3–4	7.4	5.8	7.1	5
4–5	7.8	7.5	7.7	5.5

\*From Griscom [28]

- Medical personnel involved in intubation and ETT management in the PICU should know the tube outer diameter corresponding to the patient's age or be able to refer to a chart containing this information.
- Although considerable progress has been made and incidences of postintubation laryngotracheal stenoses have dropped to less than 1–3%, this complication can be devastating for the individual patient and family.

## 2.8 Laryngeal Stents

Because of the significance of the inner laryngeal contours for an adequate indwelling stent, this section has been included in the chapter on airway anatomy.

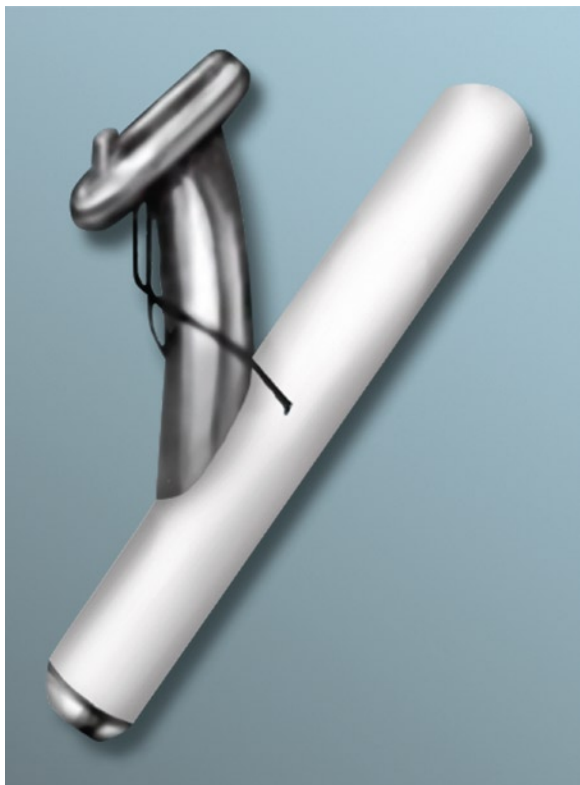
Laryngotracheal stents are temporarily used to keep the airway expanded after surgical reconstruction (LTR or extended PCTR) for complex glotto-subglottic stenoses. Although they support and immobilise tracheal grafts during the healing process,

they also act as foreign bodies in the reconstructed airway. If stents do not conform to the inner laryngeal contours or if their consistency is hard, mucosal injuries, granulation tissue formation and subsequent stenosis may occur. Ideally, a stent should conform to the airway contours and exert less than 30 mmHg mucosal pressure. Additionally, a stent should resist compressive forces, sustain airway anatomy, move with the larynx during respiration and deglutition, and be biocompatible [50].

Several laryngeal stents are currently available on the market. The basic devices, such as the finger cot and the rolled silastic sheet, are customised [19]. Over time, these devices have been largely replaced by the Aboulker stent [2], the Montgomery T-tube [43], the Healy-Montgomery paediatric T-tube and the Montgomery [46] or the Eliachar laryngotracheal stents [16]. However, these stents do not truly meet the aforementioned requirements for safe use without potential damage to the reconstructed airway. Although stenting is still necessary after complex airway reconstructions involving the glottis, the shape of current stents has remained suboptimal considering the complexity of the inner laryngeal contours. For the management of complex airway stenoses in infants and children, these stents must be used with caution to achieve superior results following LTR or extended PCTR.

### 2.8.1 Aboulker Stent (Fig. 2.17)

This cigar-shaped prosthesis, introduced in the early 1960s by the French otolaryngologist Aboulker, is



**Fig. 2.17** Aboulker stent: Cigar-shaped, hard-Teflon prosthesis, unsuitable for stenting glotto-subglottic stenoses

made of very hard Teflon and is available in a variety of outer diameters. Originally used in adults, the Aboulker stent is now primarily used in children to splint the airway after LTR. In the late 1960s, Aboulker reported a decannulation in three out of five children having undergone airway reconstruction [1]. After 1970, Grahne [25], Cotton [11] and Crysdale [12] began using this stent for stabilising the post-LTR airway in children, reporting favourable results. Subsequently, other surgeons also started using this prosthesis for stenting airway reconstructions [3, 47, 62]. Although the highly polished Teflon of the Aboulker stent is well tolerated by tissues, this prosthesis is too hard and does not conform to the complex inner contours of the larynx. In 1992, Zalzal [63, 64] reviewed the complications with the Aboulker stent. These complications included granulation tissue formation occurring at the inferior or superior end of the stent, in addition to infection, stent migration, broken stents and pressure necrosis at the base of the epiglottis and on the medial aspect of the arytenoids. Furthermore, in cases of cicatricial fusion of the vocal

cords, this cigar-shaped stent cannot restore a sharp anterior laryngeal commissure, which has a negative impact on voice quality.

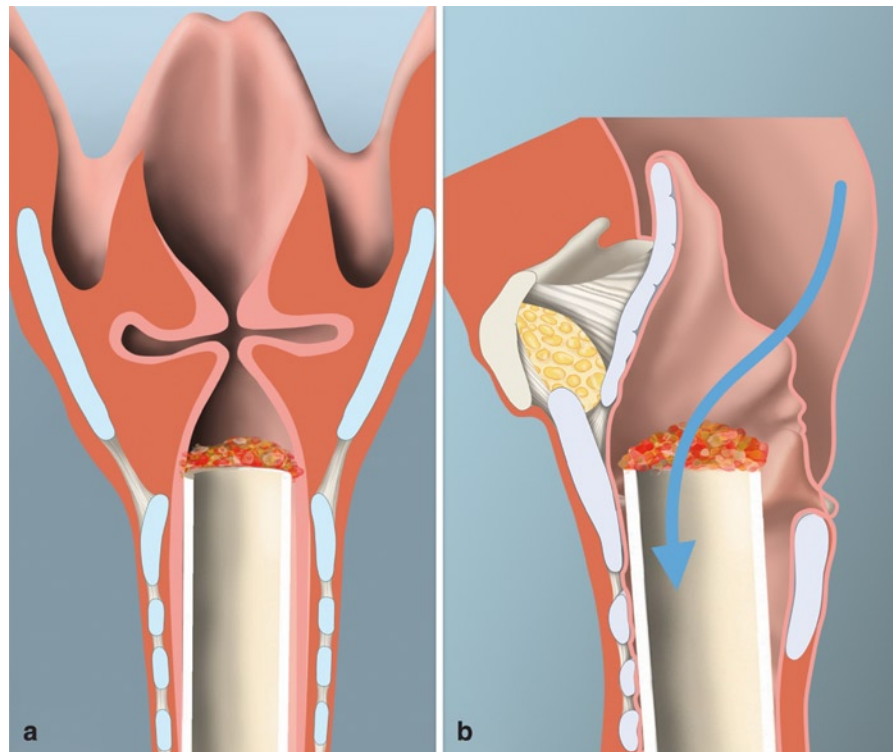
### 2.8.2 Montgomery T-Tube (Fig. 2.18)

The Montgomery T-tube is a simple open silicone tube with a smaller lumen projecting from the side of the stent at a 90° angle. It is soft and pliable, allowing easy insertion through the tracheostoma [45]. Although the Montgomery T-tube is well tolerated by the underlying mucosa, its extremities are sharp with cut edges, promoting granulation tissue formation at the site of the shearing forces between the stent and the airway mucosa. This occurs primarily in the conic-shaped subglottis if the upper end of the stent is positioned below the vocal cords. Because of this, the upper end of the stent must be placed slightly higher than the level of the false vocal cords. Nonetheless, this position may also



**Fig. 2.18** Montgomery T-tube: Simple open silicone T-tube suitable for tracheal stenting but not for glotto-subglottic airway reconstructions

**Fig. 2.19** Complications induced by the Montgomery T-tube: (a) In the subglottis, the upper cut edge of the prosthesis gets impacted into the conus elasticus during coughing, inducing ulcerations, granulation tissue formation and restenosis. (b) In the supraglottis, the opened proximal extremity of the prosthesis must be closed to avoid aspiration problems, although it may still induce ulcerations, granulation tissue formation and scarring



lead to the production of granulation tissue on the laryngeal aspect of the epiglottis and on the ventricular bands (Fig. 2.19). To protect the airway from aspiration, the stent's upper extremity must be closed by sutures, a silicone glue plug or a cap. Although the Montgomery T-tube is an effective device for stenting simple tracheal stenoses, it is not always suitable for stenting airway reconstructions of the glottis and subglottis [10]. Similar to the Aboulker stent, its round-shaped configuration does not restore a sharp anterior commissure of the glottis. In children, the safety of the stent must be considered when sizes less than 8 mm in outer diameter are used. The prosthesis can become plugged with dried secretions that may be lethal, requiring prompt removal of the T-tube [7, 55]. Reported complications in children include self-removal of the T-tube by the child, expulsion of the tube due to upward migration, formation of granulation tissue and plugging [23].

### 2.8.3 Healy Paediatric T-Tube (Fig. 2.20)

To overcome the Montgomery T-tube's risk of clogging in children, Healy designed a paediatric T-tube with a 70° connecting angle, allowing the introduction



**Fig. 2.20** Healy paediatric T-tube: This prosthesis comprises an inner cannula that can quickly be removed and changed in case of clogging by dried secretions. This inner cannula further diminishes the inner size of the prosthesis required for the passage of air

of a flexible inner cannula. Although this paediatric T-tube permits quick removal of plugged secretions in the inner cannula, it further diminishes the airway size in an already small T-tube. This paediatric counterpart of the adult tracheal stent shares all of the aforementioned drawbacks of the Montgomery T-tube when used in older children and adults.

#### 2.8.4 Montgomery LT-Stent (Fig. 2.21)

Designed for the treatment of glotto-subglottic stenosis, this prosthesis is made of plain silicone and is quite hard; it was obtained by moulding cadaver larynges. However, its posterior interarytenoid distance is narrow, reproducing the cadaveric paramedian position of the vocal cords. Therefore, this prosthesis is not entirely appropriate for stenting airway reconstructions for subglottic stenosis combined with posterior glottic stenosis. In addition, the Montgomery LT-stent

only exists in two different sizes, which is largely insufficient when applied to the full spectrum of laryngo-tracheal stenoses in the paediatric age group. Currently, this stent is seldom used in paediatric airway reconstructions [44].

#### 2.8.5 Eliachar LT-Stent (Fig. 2.22)

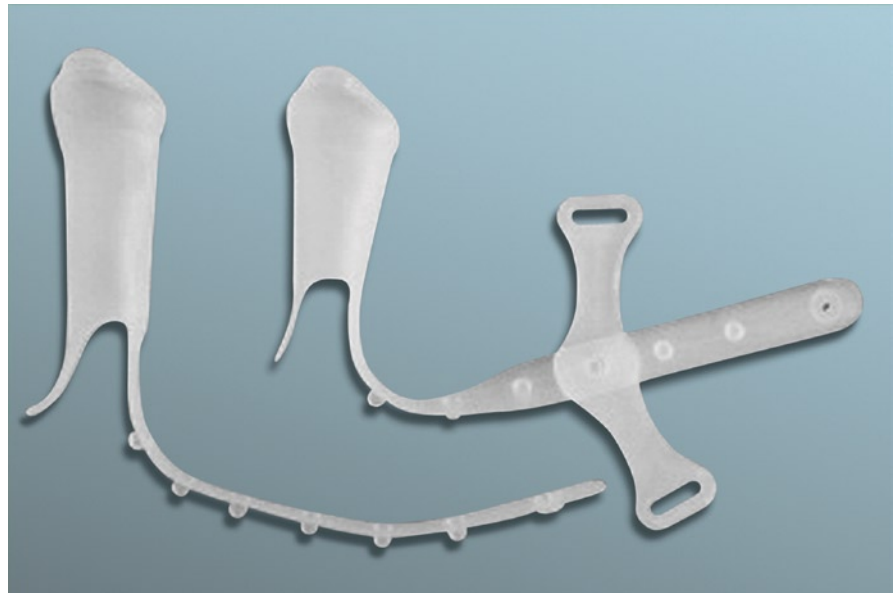
Made of soft silicone, this prosthetic hollow stent is less traumatic to the laryngeal mucosa than the Montgomery LT-stent. It was initially designed for the management of chronic aspiration [16]. Its conformity to the inner laryngeal contours is superior to that of all the previously discussed stents, but its shape is not triangular at the level of the glottis. Although providing internal support to laryngeal airway reconstructions, it does not restore either a large interarytenoid distance or a sharp anterior commissure of the glottis. Moreover, the Eliachar LT-stent cannot be used in infants or



**Fig. 2.21** Montgomery LT-sent: Plain silicone, hard prosthesis for the stenting of posterior glottic stenoses. (a) Posterior view: The interarytenoid distance is too narrow and cannot stent the larynx in the abducted position of the vocal cords. (b) Lateral view: The supraglottic position of the stent is too small



**Fig. 2.22** Eliachar LT-stent: Soft silicone prosthesis designed for chronic aspiration management. Its general shape cannot restore a large interarytenoid distance or a sharp anterior commissure of the larynx



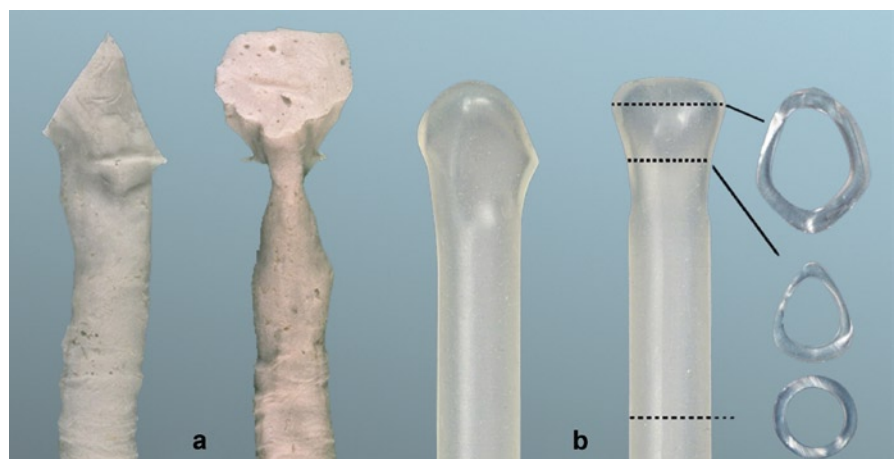
children, and its fixation system with the silicone strap through the tracheostoma may induce granulation tissue formation at the tracheostoma site.

### 2.8.6 Monnier LT-Mold (Fig. 2.23) (Table 2.6)

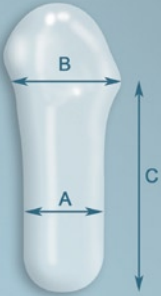
This laryngotracheal prosthesis is made of silicone at a strength of 50 Shores-A. Because of its softness, it avoids pressure necrosis at the medial aspect of the arytenoids. The Monnier LT-Mold design was created after moulding cadaver larynges and increasing the

interarytenoid distance in order to obtain the intralaryngeal contours of a fully abducted larynx. This property is essential when treating a subglottic stenosis combined with a posterior glottic stenosis. After the publication of a pilot study in *The Laryngoscope* in 2003 [41], the LT-Mold was modified with a dedicated silicone cap for each prosthesis size to avoid granulation tissue formation at its distal extremity. The prosthesis exists in 10 different sizes, from 6 to 15 mm in outer diameter, and four different lengths for each size (Fig. 2.24 and 2.25). It can be inserted into the airway during open surgery (intra-operative use) (see Sect. 20.4, Chap. 20) or after endoscopic resection of a laryngotracheal stenosis (see Sect. 14.3.3, Fig. 14.17, Chap. 14).

**Fig. 2.23** Monnier LT-Mold: (a) Moulds of cadaver larynges with narrow interarytenoid distance due to the paramedian cadaveric position of the vocal cords. (b) The LT-Mold is triangular at the glottic level with a large interarytenoid distance. The supraglottic head of the prosthesis is larger than that at the glottic level, preventing accidental shifting into the distal airway



**Table 2.6** LT-Mold dimensions (in mm)

Lt-Mold	A	B	C*
	6	8	10/14/18/23
	7	9.2	12/16/20/25
	8	10.5	13/18/22/28
	9	11.8	15/20/25/30
	10	13.2	17/22/27/33
	11	14.5	18/24/29/35
	12	15.8	20/26/31/38
	13	17	22/28/34/40
	14	18.5	23/30/36/43
	15	19.8	25/32/38/45

\* 4 different lengths for each size

A = external diameter  
B = glottic length  
C = length from glottis to inferior border of LT-Mold

In 1992, reviewing the essential features of an ideal stent, Zalzal [63] identified five major characteristics: (a) availability of different sizes and shapes to fit into the reconstructed areas; (b) placement that avoids any risk of respiratory passage obstruction; (c) absence of foreign body reaction, pressure necrosis or discomfort; (d) adequate voice production and swallowing without aspiration; (e) easy placement and removal.

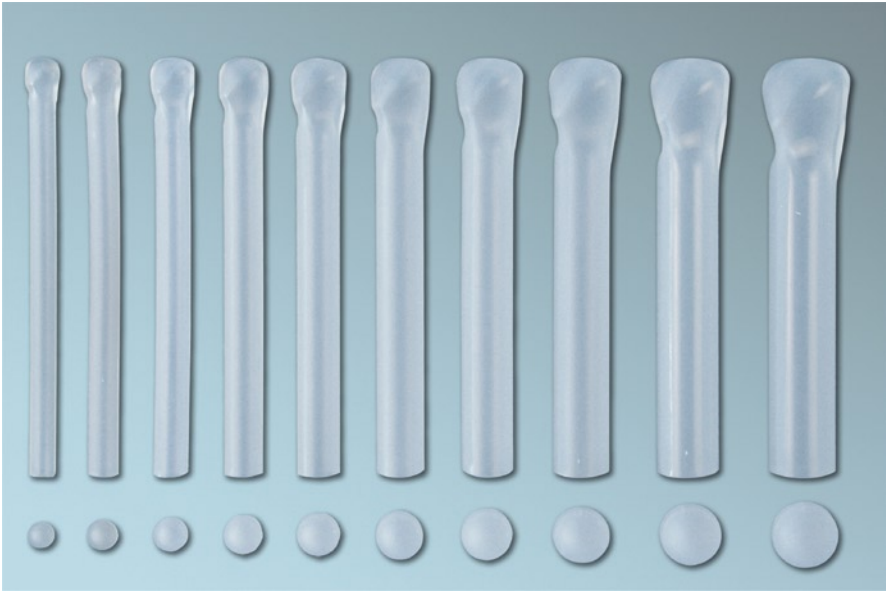
Based on the experience gathered in 30 paediatric patients [42], the LT-Mold almost meets the ideal requirements except for voice production. Given that these patients have already undergone failed surgeries and often present with aphonia, a further delay of several months before successful decannulation and voice production is acceptable.

**Disclosure**  
The author holds a financial relationship with the company whose product is mentioned in the text.

2.9 Tracheal Stents

Benign congenital and acquired tracheal stenoses must be treated surgically. There is almost no justification for using self-expandable metallic airway stents (SEMAS) in the management of benign stenoses of adult and child airways. Numerous reports of severe complications from indwelling SEMAS in the trachea and bronchi [6, 17, 24, 36, 37, 39, 61] are found in the literature. Among long-term complications, granulation tissue formation with subsequent restenosis, mucostasis, stent-migration, stent-fracture, as well as massive and lethal haemorrhage are described. Even though their easy application and

**Fig. 2.24** Monnier LT-Mold: The prosthesis exists in 10 different sizes (6–15 mm in outer diameter) for use in infants, children and adults



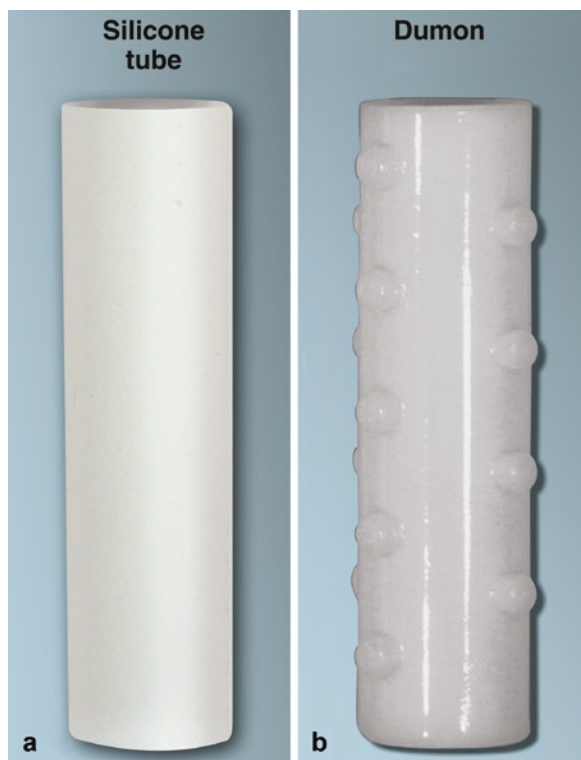


**Fig. 2.25** Monnier LT-Mold: Per size, the prosthesis exists in four different lengths to accommodate different positions of the tracheostomy site

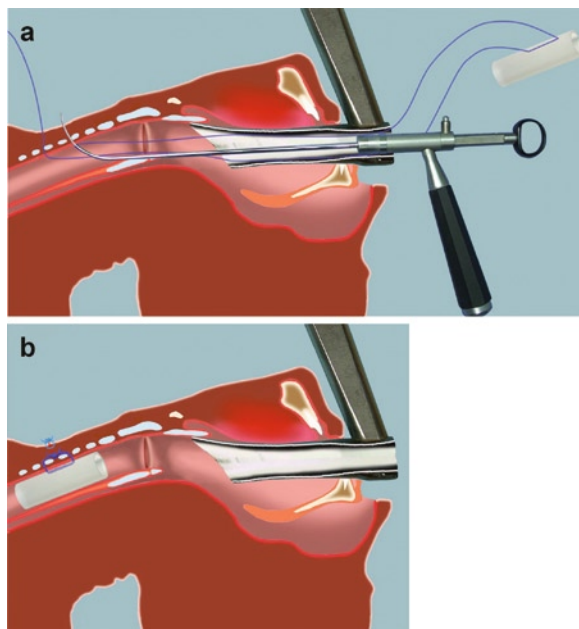
availability in many different sizes seemingly make them ideal prostheses, in only very rare cases is the endoluminal placement of SEMAS in the paediatric age group justified as a life-saving measure [36, 48].

Other options to alleviate benign tracheal obstructions in infants and children include:

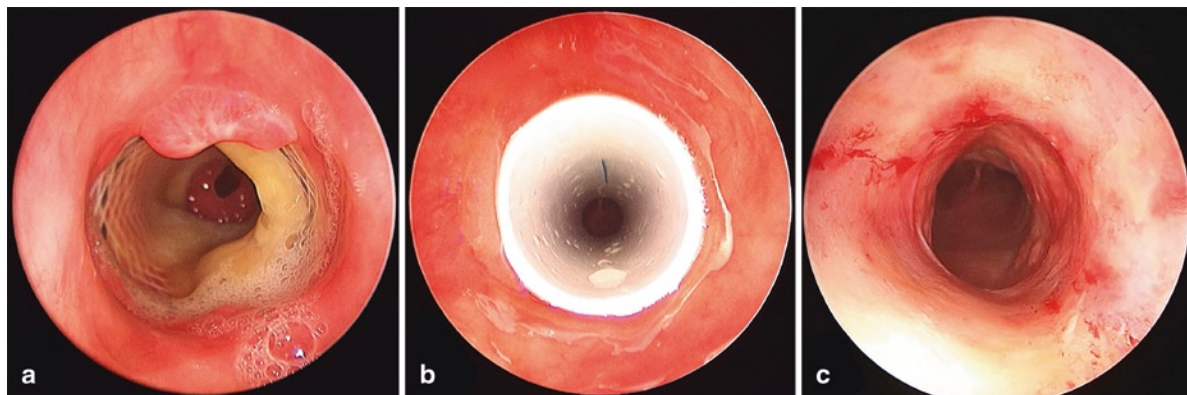
- Non-invasive mask ventilation with continuous positive airway pressure (CPAP) or bi-level positive airway pressure (BiPAP). This is a temporary measure for moderate obstruction, as seen in tracheo-bronchomalacia [18, 33].
- Tracheotomy with tracheal stenting by a long cannula. The tip of the cannula should be positioned just above the carina.
- Tracheostomy with a Montgomery or Healy T-tube. This is the most commonly used technique that allows stenting of the trachea. In children, caution must be exercised when outer diameter size is less than 8 mm, due to the risk of suffocation if the stent becomes clogged with dried secretions. At the time of tracheostomy closure, anterior costal cartilage grafting is often necessary to rigidify a localised segment of malacia at the former stoma site.
- Stenting without tracheotomy. This technique can only be used for recurrent inoperable tracheal stenoses as a last-chance treatment, after resection and anastomosis and subsequent tracheoplasty with costal cartilage grafting have failed. This technique is not appropriate for infants and small children, whose airways are too small to tolerate a small-sized stent. This method of long-term tracheal stenting is appropriate in older children and adolescents when a silicone tube with an outer diameter of at least 8 mm can be inserted into the airway. Perfectly smooth on its outer surface, the silicone tube exerts only minimal pressure on the tracheal wall, thus allowing re-epithelialisation of the stenotic zone (Fig. 2.26a). The prosthesis is fixed to the trachea by a 3.0 Prolene suture (Fig. 2.27). Based on our experience (unpublished data), only the plain smooth silicone tube can be used for long-term tracheal stenting without tracheotomy.
- The Dumon stent, anchored to the tracheal wall by studs on its outer surface, causes constant granulation tissue formation. This prevents complete re-epithelialisation of the stenotic segment around the stent [38] during the management of benign tracheo-bronchial stenoses [49]. Shearing forces occurring at the stent-mucosal interface also generate granulation tissue formation at both extremities of the Dumon stent (Fig. 2.26b).
- The covered SEMAS tends to get impacted into the tracheal wall, also preventing re-epithelialisation of the stenotic zone and promoting granulation tissue formation at both extremities of the stent (Fig. 2.28a).
- By contrast, the plain silicone tube does not generate such complications provided that the chosen size is appropriate for the specific trachea. It is snugly fixed to the trachea by a 3.0 Prolene suture and moves with the trachea during respiration and coughing. This prevents granulation tissue formation at both of its extremities. The pressure on the tracheal wall is less than 30 mmHg, which is favourable for the re-epithelialisation process (Fig. 2.28b and c).



**Fig. 2.26** Plain silicone tube and Dumon stents: **(a)** Plain silicone tube: The smooth outer surface of the plain silicone tube facilitates re-epithelialisation of the trachea around the stent. The prosthesis must be fixed endoscopically to the trachea with a 3.0 prolene suture. **(b)** Dumon stent: The outer surface of the Dumon stent presents several studs which help maintain the prosthesis in place. However, migration is common in benign stenoses, and re-epithelialisation around the stent is compromised by the irregular outer surface of the stent that causes mechanical trauma to the tracheal wall



**Fig. 2.27** Endoscopic placement of a smooth silicone tube in the trachea to calibrate an inoperable benign stenosis: **(a)** A 3.0 (70 cm long) prolene suture is initially passed through the silicone tube: In SML, the prosthesis is fixed to the trachea by endo-extralaryngeal stitches using a Lichtenberger needle-carrier. **(b)** Silicone tube in place and snugly fixed to the tracheal wall: The 3.0 prolene thread is tied under the skin after recapturing the threads through a small horizontal skin incision



**Fig. 2.28** Recurrent tracheal stenosis after several failed resection-anastomoses and tracheoplasties in a 16-year-old adolescent. **(a)** Initial presentation: The self-expandable polyflex tube retains secretions and produces granulation tissue resulting in severe distal airway obstruction. **(b)** Status 1 year after replacement

of the expandable stent by a plain silicone tube fixed with a prolene suture: excellent tolerance of the stent without granulation tissue formation. **(c)** Long-term result 2 years after stent removal: stabilised airway at 70% of its normal size



## 2.10 Appendix 1

Recommended uncuffed ET-tube sizes

Patient age	Tube size (Portex®)	
	ID (mm)	(OD mm)
Premature <1,000 g	2.0	2.9
Premature 1,000–2,000 g	2.5	3.6
Newborn to 6 months	3.0/3.5	4.4/5.0
6 months to 1 year	3.5/4.0	5.0/5.4
1–2 years	4.0/4.5	5.4/6.6
2 years and older	$\frac{Age + 16}{4}$	

## 2.11 Appendix 2

Recommended uncuffed and cuffed ET-tubes for children 2 years and older

Uncuffed ET-tube	$\frac{Age + 16}{4}$
Cuffed ET-tube	$\frac{Age}{4} + 3$
Length of insertion	
Oral (cm)	$3 \times ID \text{ (mm)}$
Nasal (cm)	$3 \times ID \text{ (mm)} + 2$

## 2.12 Appendix 3

Recommended tubes and scopes based on patient age

Patient age	Bronchoscope		Oesophagoscope	Tracheostomy tube ISO	ETT ID
	size	OD (mm)			
Premature	2.5	4.2	4	2.0/2.5	2.5
Term newborn	3.0	5.0	4–5	3.0/3.5	3.0/3.5
6–12 months	3.5	5.7	5–6	3.5/4.0	3.5/4.0
1–2 years	3.7	6.4	6	4.0	4.0/4.5
2–3 years	4.0	6.7	6–7	4.0/4.5	$\left. \begin{array}{c} \\ \\ \end{array} \right\} \frac{Age + 16}{4}$
3–4 years	4.5	7.3	7	5.0	
4–5 years	5.0	7.8	8	5.0/5.5	

## References

1. Aboulker, B.: Traitement des Sténoses Tracheales. Problèmes Actuels d'oto-rhino-laryngologie, pp. 275–295. Librairie Maloine, Paris, France (1968)
2. Aboulker, P., Sterkers, J.M., Demaldent, E.: Modifications apportées à l'intervention de Rethi. Intérêts dans les sténoses laryngo-trachéales et trachéales. *Ann. Otolaryngol. Chir. Cervicofac.* (Paris) **83**, 98–106 (1966)
3. April, M.M., Marsh, B.R.: Laryngotracheal reconstruction for subglottic stenosis. *Ann. Otol. Rhinol. Laryngol.* **102**, 176–181 (1993)
4. Benjamin, B., Holinger, L.D.: Laryngeal complications of endotracheal intubation. *Ann. Otol. Rhinol. Laryngol.* **117**, 2–20 (2008)
5. Bosma, J.F.: Anatomy of the infant head. Johns Hopkins University Press, Baltimore, MA (1986)
6. Burningham, A.R., Wax, M.K., Andersen, P.E., et al.: Metallic tracheal stents: complications associated with long-term use in the upper airway. *Ann. Otol. Rhinol. Laryngol.* **111**, 285–290 (2002)
7. Calhoun, K.H., Deskin, R.W., Bailey, B.J.: Near-fatal complication of tracheal T-tube use. *Ann. Otol. Rhinol. Laryngol.* **97**, 542–544 (1988)
8. Cauldwell, E.W., Siekert, R.G., Lininger, R.E., et al.: The bronchial arteries: an anatomic study of 105 human cadavers. *Surg. Gynecol. Obstet.* **86**, 395–412 (1948)
9. Cernea, C.R., Ferraz, A.R., Nishio, S., et al.: Surgical anatomy of the external branch of the superior laryngeal nerve. *Head Neck* **14**, 380–383 (1992)
10. Cooper, J.D.: Use of the silicone tracheal T-tube for the management of complex tracheal injuries. *J. Thorac. Cardiovasc. Surg.* **82**, 559–568 (1981)
11. Cotton, R.T., Evans, J.N.: Laryngotracheal reconstruction in children. Five-year follow-up. *Ann. Otol. Rhinol. Laryngol.* **90**, 516–520 (1981)
12. Crysdale, W.S.: Subglottic stenosis in children. A management protocol plus surgical experience in 13 cases. *Int. J. Pediatr. Otorhinolaryngol.* **6**, 23–35 (1983)
13. Durham, C.F., Harrison, T.S.: The Surgical Anatomy of the Superior Laryngeal Nerve. *Surg. Gynecol. Obstet.* **118**, 38–44 (1964)
14. Eckel, H.E., Koebke, J., Sittel, C., et al.: Morphology of the human larynx during the first five years of life studied on whole organ serial sections. *Ann. Otol. Rhinol. Laryngol.* **108**, 232–238 (1999)
15. Eckel, H.E., Sprinzl, G.M., Sittel, C., et al.: Zur Anatomie von Glottis und Subglottis beim kindlichen Kehlkopf. *HNO* **48**, 501–507 (2000)
16. Eliachar, I., Nguyen, D.: Laryngotracheal stent for internal support and control of aspiration without loss of phonation. *Otolaryngol. Head Neck Surg.* **103**, 837–840 (1990)
17. Eller, R.L., Livingston 3rd, W.J., Morgan, C.E., et al.: Expandable tracheal stenting for benign disease: worth the complications? *Ann. Otol. Rhinol. Laryngol.* **115**, 247–252 (2006)
18. Essouri, S., Nicot, F., Clement, A., et al.: Noninvasive positive pressure ventilation in infants with upper airway obstruction: comparison of continuous and bilevel positive pressure. *Intensive Care Med.* **31**, 574–580 (2005)
19. Evans, J.: Laryngotracheoplasty. *Otolaryngol. Clin. North Am.* **10**, 119–123 (1977)
20. Fearon, B., Whalen, J.S.: Tracheal dimensions in the living infant (preliminary report). *Ann. Otol. Rhinol. Laryngol.* **76**, 965–974 (1967)
21. Fitch, T.: A cognitive biologist foresees breakthroughs in understanding vocal learning. *Journal club. Nature* **466**, 163 (2010)
22. Fitch, T., Hauser, M.D.: Computational constraints on syntactic processing in a nonhuman primate. *Science* **303**, 377–380 (2004)
23. Froehlich, P., Truy, E., Stamm, D., et al.: Role of long-term stenting in treatment of pediatric subglottic stenosis. *Int J Pediatr Otorhinolaryngol* **27**, 273–280 (1993)
24. Gaissert, H.A., Grillo, H.C., Wright, C.D., et al.: Complication of benign tracheobronchial strictures by self-expanding metal stents. *J. Thorac. Cardiovasc. Surg.* **126**, 744–747 (2003)
25. Grahne, B.: Operative treatment of severe chronic traumatic laryngeal stenosis in infants up to three years old. *Acta otolaryngologica* **72**, 134–137 (1971)
26. Grillo, H.C.: Anatomy of the trachea. In: Grillo, H.C. (ed.) *Surgery of the trachea and bronchi*, pp. 40–59. BC Decker Inc, Hamilton; London (2004)
27. Griscom, N.T., Wohl, M.E.: Dimensions of the growing trachea related to age and gender. *Am J Roentgenol* **146**, 233–237 (1986)
28. Griscom, N.T., Wohl, E.B., Fenton, T.: Dimensions of the trachea to age 6 years related to height. *Pediatr. Pulmonol.* **5**, 186–190 (1989)
29. Hast, M.: Anatomy of the larynx. *Otolaryngology* **3**, 1–16 (1986)
30. Henick, D.H., Holinger, L.D.: Laryngeal development. In: Holinger, L.D., Lusk, R.P., Green, C.G. (eds.) *Pediatric laryngology and bronchoesophagoscopy*, pp. 1–17. Lippincott-Raven, Philadelphia; New York (1997)
31. Holinger, L.D.: Evaluation of stridor and wheezing. In: Holinger, L.D., Lusk, R.P., Green, C.G. (eds.) *Pediatric laryngology and bronchoesophagology*, p. 42. Lippincott-Raven, Philadelphia; New York (1997)
32. Holinger, L.D., Green, C.G.: Anatomy. In: Holinger, L.D., Lusk, R.P., Green, C.G. (eds.) *Paediatric laryngology and bronchoesophagology*, p. 23. Lippincott-Raven, Philadelphia; New York (1997)
33. Kirk, V., O'Donnell, A.: Continuous positive airway pressure for children: a discussion on how to maximize compliance. *Sleep Med. Rev.* **10**, 119–127 (2006)
34. Laitman, J.T.: The anatomy of human speech. *Natural History* **93**, 20–27 (1984)
35. Laitman, J.T.: L'origine du langage articulé. *Recherche* (Paris, 1970):1164–1173 (1986)
36. Lim, L.H., Cotton, R.T., Azizkhan, R.G., et al.: Complications of metallic stents in the pediatric airway. *Otolaryngol. Head Neck Surg.* **131**, 355–361 (2004)
37. Madden, B.P., Loke, T.K., Sheth, A.C.: Do expandable metallic airway stents have a role in the management of patients with benign tracheobronchial disease? *Ann. Thorac. Surg.* **82**, 274–278 (2006)
38. Martinez-Ballarín, J.I., Diaz-Jimenez, J.P., Castro, M.J., et al.: Silicone stents in the management of benign tracheo-

- bronchial stenoses. Tolerance and early results in 63 patients. *Chest* **109**, 626–629 (1996)
39. Merrot, O., Buiret, G., Gleizal, A., et al.: Management of tracheobronchial stenoses with endoprotheses: experience with 103 patients and 11 models. *Laryngoscope* **118**, 403–407 (2008)
  40. Miura, T., Grillo, H.C.: The contribution of the inferior thyroid artery to the blood supply of the human trachea. *Surg. Gynecol. Obstet.* **123**, 99–102 (1966)
  41. Monnier, P.: A New Stent for the Management of Adult and Pediatric Laryngotracheal Stenosis. *Laryngoscope* **113**, 1418–1422 (2003)
  42. Monnier, P.: Airway stenting with the LT-Mold™: Experience in 30 pediatric cases. *Int. J. Pediatr. Otorhinolaryngol.* **71**, 1351–1359 (2007)
  43. Montgomery, W.W.: T-tube tracheal stent. *Arch. Otolaryngol. Head Neck Surg.* **82**, 320–321 (1965)
  44. Montgomery, W.W.: The surgical management of supraglottic and subglottic stenosis. *Ann. Otol. Rhinol. Laryngol.* **77**, 534–546 (1968)
  45. Montgomery, W.W.: Silicone tracheal T-tube. *Ann. Otol. Rhinol. Laryngol.* **83**, 71–75 (1974)
  46. Montgomery, W.W., Montgomery, S.K.: Manual for use of Montgomery laryngeal, tracheal, and esophageal prostheses: update 1990. *Ann. Otol. Rhinol. Laryngol.* **150**, 2–28 (1990)
  47. Ndiaye, I., Van de Abbeele, T., Francois, M., et al.: Traitement chirurgical des sténoses laryngées de l'enfant. *Ann. Otolaryngol. Chir. Cervicofac.* **116**, 143–148 (1999)
  48. Nicolai, T.: Airway stents in children. *Pediatr. Pulmonol.* **43**, 330–344 (2008)
  49. Puma, F., Ragusa, M., Avenia, N., et al.: The role of silicone stents in the treatment of cicatricial tracheal stenoses. *J. Thorac. Cardiovasc. Surg.* **120**, 1064–1069 (2000)
  50. Richard, L.G., John, B.S.: Long-term stenting in the treatment of subglottic stenosis. *Ann. Otol.* **86**, 795–798 (1977)
  51. Salassa, J.R.: Gross and microscopical blood supply of the trachea. *Ann. Thorac. Surg.* **24**, 100–107 (1977)
  52. Schild, J.A.: Relationship of laryngeal dimensions to body size and gestational age in premature neonates and small infants. *Laryngoscope* **94**, 1284–1292 (1984)
  53. Schweizer, V., Dorfl, J.: The anatomy of the inferior laryngeal nerve. *Clin. Otolaryngol. Allied Sci.* **22**, 362–369 (1997)
  54. Shah, R.K., Lander, L., Choi, S.S., et al.: Resource utilization in the management of subglottic stenosis. *Otolaryngol. Head Neck Surg.* **138**, 233–241 (2008)
  55. Stern, Y., Willging, J.P., Cotton, R.T.: Use of Montgomery T-tube in laryngotracheal reconstruction in children: is it safe? *Ann. Otol. Rhinol. Laryngol.* **107**, 1006–1009 (1998)
  56. Tucker, G.F., Tucker, J.A., Vidic, B.: Anatomy and development of the cricoid: serial-section whole organ study of perinatal larynges. *Ann. Otol. Rhinol. Laryngol.* **86**, 766–769 (1977)
  57. Tucker, H.M.: Anatomy of the larynx. In: Tucker, H.M. (ed.) *The Larynx*, p. 12. Thieme, Stuttgart; New York (1993)
  58. Wang, C.: The use of the inferior cornu of the thyroid cartilage in identifying the recurrent laryngeal nerve. *Surg. Gynecol. Obstet.* **140**, 91–94 (1975)
  59. Weyckemans, F.: Equipement, monitoring, and environmental conditions. In: Bissonnette, B., Dalens, B. (eds.) *Pediatric anesthesia: principles and practice*, pp. 419. McGraw-Hill, Medical Pub. Division (2002)
  60. Williams, P.L., Bannister, L.H.: *Gray's anatomy: the anatomical basis of medicine and surgery*. Churchill Livingstone, New York (1995)
  61. Zakaluzny, S.A., Lane, J.D., Mair, E.A.: Complications of tracheobronchial airway stents. *Otolaryngol. Head Neck Surg.* **128**, 478–488 (2003)
  62. Zalzal, G.H.: Use of stents in laryngotracheal reconstruction in children: indications, technical considerations, and complications. *Laryngoscope* **98**, 849–854 (1988)
  63. Zalzal, G.H.: Stenting for pediatric laryngotracheal stenosis. *Ann. Otol. Rhinol. Laryngol.* **101**, 651–655 (1992)
  64. Zalzal, G.H., Grundfast, K.M.: Broken Aboulker stents in the tracheal lumen. *Int. J. Pediatr. Otorhinolaryngol.* **16**, 125–130 (1988)

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