Tracheotomy and Airway

A Practical Guide

Eckart Klemm
Andreas Nowak
Editors

Springer

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Preface

The articles in this book follow the—frequently—long journey from indicating and executing a tracheotomy up to eventually decannulating and closing the stoma that is so much desired by patients, physicians and speech therapists alike. Some tracheotomies have been carried out so improperly that the actual concern of rehabilitation can no longer be in the foreground after a serious underlying disease.

Extensive literature, which often enough is hardly comprehensible for the beginner, repeatedly suggests that tracheotomy and tracheostomy were fast, easy and innocuous procedures. However, numerous and—often enough—severest complications up to a fatal outcome at different points in time are described.

Their prevention and competent treatment through indispensable interdisciplinary management is the central concern of this book. Practical anatomy, surgical and endoscopic therapy options of diseases and complications and special problems of anaesthesia for respiratory management round off its scope of topics.

The history of tracheotomy and tracheostomy is very old and, therefore, problems permanently deserve being questioned and re-examined.

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Contents

Abbreviations

CBF	Cerebral blood flow
CCT	Craniocerebral trauma
CO_2	Carbon dioxide
COPD	Chronic obstructive pulmonary disease
CPP	Cerebral perfusion pressure
CVP	Central venous pressure
CVR	Cerebrovascular resistance
ETT	Endotracheal tube
E_TCO_2	End-tidal carbon dioxide concentration
FEES	Flexible endoscopic evaluation of swallowing
f_{HF}	Jet frequency at the high-frequency nozzle
F_iO_2	Inspiratory oxygen concentration
$F_{jet}O_2$	Oxygen concentration of the gas exiting the jet nozzle
f_{LF}	Jet frequency at the low-frequency nozzle
FOTT	Facio-oral tract therapy
GWDF	Guide wire dilating forceps
HF	High frequency
HFJV	High-frequency jet ventilation
Hz	Hertz
I:E	Inspiration:expiration
ICP	Intracranial pressure
ICU	Intensive care unit
IPPV	Intermittent positive pressure ventilation
ITN	Intubation narcosis
LF	Low frequency
LTR	Laryngotracheal reconstruction
MAP	Mean arterial pressure
MMP	Matrix metalloproteinases
MRP	Multi-resistant pathogens
NIV	Noninvasive ventilation
O_2	Oxygen
OSAS	Obstructive sleep apnea syndrome
OST	Open surgical tracheotomy
p	Pressure

p_aCO_2	Arterial carbon dioxide partial pressure
p_aO_2	Arterial oxygen partial pressure
p_{AW}	Airway pressure
PCTR	Partial cricotracheal resection
PDT	Percutaneous dilatational tracheotomy
PEEP	Positive end-expiratory pressure
p_{HF}	Working pressure at the high-frequency nozzle
p_{LF}	Working pressure at the low-frequency nozzle
SHFJV	Superimposed high-frequency jet ventilation
S_pO_2	Oxygen saturation of peripheral blood
TAF	Tracheoarterial fistula
TED	Tracheotomy endoscope for dilatational tracheotomies
TIF	Tracheoinnominate fistula
TTHFJV	Transtracheal high-frequency jet ventilation
V	Volume
VFSS	Videofluoroscopic swallow study
V_t	Tidal volume

Tracheotomy When and Where?

1

Eckart Klemm and Andreas Nowak

1.1 Tracheotomy When?

In a meta-analysis, Griffiths et al. [1] found that out of 15,950 reports on tracheotomies only five studies were useful to answer the question of the optimal time for a tracheotomy. They recommended an early tracheotomy within the first 7 days, whereby the total duration of ventilation can be reduced.

Gründling and Quintel [2] recommend performing a tracheotomy as early as possible if the expected duration of ventilation is more than 21 days; long-term intubation is preferred if the expected duration of ventilation is up to 10 days. Koscielny and Guntinas-Lichius [3] also vote for a tracheotomy if the ventilation duration is expected to take between 10 and 21 days.

Under the aspect of ventilator-related pneumonia and after a randomized controlled multicenter study, Terragni et al. [4] concluded that early tracheotomy after 6–8 days has no significant advantages compared to late tracheotomy after 13–15 days, whereas one third of patients suffered from PDT (percutaneous dilatational tracheotomy) complications, which is why fewer tracheotomies than necessary were found in later indications.

Reviews and statements bearing high-level evidence by ANZICS [5], Cheung et al. [6], Andriolo et al. [7] and Hosokawa et al. [8] indicate tendencies towards positive effects for some clinical pictures in connection with early tracheotomies up to the 10th day of ventilation. However, the general statement as to whether an early

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tracheotomy is superior to a later tracheotomy is not possible after detailed research by Raimondi et al. [9]. A tracheotomy should not be performed if the patient is dying or active treatment is being withdrawn or in case of refusal by the patient and/or guardian [10].

As the adjuvant intervention "tracheotomy" is also subject to discussion under medical law, the following applies according to current scientific findings:

The timing of an elective tracheotomy remains an individual decision, deliberating the risks and prospects of success. The current data situation does not permit a uniform recommendation for an optimal time of performing a tracheotomy in long-term ventilated patients.

In the consensus statement of the ANZICS [5], it was formulated:

"*The timing of tracheostomy is the prerogative of the intensivist, dictated by the patient's clinical status.*"

1.2 Tracheotomy Where?: The Anatomical Relevance

Earlier textbooks differentiated between high, medium and low tracheotomies. This classification with respect to the location of the thyroid gland is obsolete, as is the earlier general recommendation to tracheotomize 1 cm below the cricoid cartilage (Chap. 3 "Anatomy and topography in relation to tracheotomy").

Too high tracheotomies lead to later tracheal stenoses, too low tracheotomies are a risk for lethal bleeding according to Klemm and Nowak [11] (Chap. 10 "Complications of tracheotomy and strategies to avoid them").

The safest place for tracheotomy is between the second and fourth tracheal braces. The internal anatomy of the trachea and the external anatomy of the neck are of equal importance for correct localization.

1.3 Tracheotomy Where?: Intensive Care Unit (ICU) or Operating Theater

A survey conducted by Kluge et al. [12] in 513 ICUs showed that 86% of PDT are performed in ICUs and 72% of surgical tracheotomies are performed in operating theaters. A further survey by Vargas et al. [13] of ICUs in 59 countries with a total of 17,894 tracheotomies showed that 54% of PDT were performed between the 7th and 15th day, 74% of which were performed by intensivists. Fifty-nine percent of surgical tracheotomies were performed in an ICU and 16% in the operating room.

The question in which location a tracheotomy is to be performed can only be determined on the basis of the individual circumstances of the patient, the organizational possibilities on site and the complication density of methods.

Tracheotomies can be performed both in the operating room and in an ICU, provided that minimum personnel and technical standards are met, also to control complications.

The greater the multimorbidity, the more interdisciplinary the type and location of a tracheotomy should be determined solely on the basis of medical criteria.

1.4 Tracheotomy in Patients with Severe Acute Respiratory Syndrome (SARS) e.g. COVID-19

The indication for tracheostomy in patients with SARS, when and where should be made as an individual decision by the intensive care team and the ENT surgeons involved. When making this decision, the patient's prognosis, previous illnesses, current viral load, possible advantages of tracheostomy and the risk of infection of the medical staff must be considered. The treatment teams also have to adjust the right time for tracheostomy individually to the patient's situation and local conditions. Although in the available literature regarding the high viral load, tracheostomy is favored as late as possible, practical (workload), but also medical aspects favor an early tracheostomy. A general determination of the ideal period of the indication is currently not possible [14–16].

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2 Advantages and Disadvantages of Tracheotomy, Contraindications of Percutaneous Dilatational Tracheotomies

Andreas Nowak and Eckart Klemm

2.1 Disadvantages of Long-Term Intubation

The vocal fold plane is physiologically the narrowest part of the human respiratory tract. The cricoid cartilage is not stretchable due to its closed formation. Friction effects on the laryngeal structures caused by swallowing and cough reflexes, by necessary changes in the position and positioning of intensive care patients and the necessary tube changes themselves can lead to edema, ulcerations, bleeding and mechanical irritation after only a few days, with the formation of granulomas particularly in the arytenoid cartilage area being promoted, including later synechia and the formation of glottic and subglottic tracheal stenoses.

Such complications are rather common and must be detected early.

A carefully performed tracheotomy protects the laryngeal structures from long-term intubation damage. After each prolonged intubation and long-term intubation, the larynx must be inspected endoscopically using flexible endoscopes or rigid angle optics.

2.2 Most Common Causes of Tracheotomy in Intensive Care Patients

- Expected long-term ventilation
- Pulmonary function deterioration

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- Prolonged weaning from mechanical ventilation
- Persistent danger of aspiration
- Safeguarding the airway

2.3 Advantages of Tracheotomy

- Direct access to the lower airways
- Reduction of respiratory resistance and breathwork
- Anatomical reduction of dead space
- Aspiration protection
- Reduced need for analgosedatives
- Easier weaning from mechanical ventilation support
- Prophylaxis of intubation damage (edema, bleeding, ulcers, necroses, vocal cord granulomas, synechia)
- Safeguarded airway in oropharyngeal and laryngeal tumors and severe injuries to the facial skull
- Prophylaxis of sinusitis
- Easier connection of devices
- Facilitation of patient positioning
- Talking over a speech attachment as an advantage over intubation
- Possibility of oral intake of food

2.4 Disadvantages of Tracheotomy

- Failure of physiological mechanisms (dust removal, humidification, heating of the breathing air)
- Switching off the glottis as a pressure and pressurizing valve
- Surgical trauma (tissue defects, bleeding) when opening and later closing the trachea
- Wound infection
- Traumas caused by tubes/needles (ulcerations, bleeding, tracheoesophageal fistulas, pneumothorax, skin emphysema)
- Danger of tracheostomy tube dislocation and obstruction with loss of the airway
- Mental alteration due to loss of olfactory faculty and consecutive reduction of tasting capacity, elimination of warning functions
- Loss of normal voice/speech
- Disability in actively blowing the nose
- Induction of swallowing disorders
- Danger of foreign body aspiration through the open tracheostomy tube

2.5 Contraindications of Percutaneous Dilatational Tracheotomies

- Emergency tracheotomies
- Child tracheotomies
- Patients with primarily difficult airways
- Primarily critical oxygenation parameters without any cardiopulmonary reserves
- Anatomical features (large goiters, cervical spine changes, Bechterew's disease, tracheomalacia, descensus laryngis, high truncus brachiocephalicus, vascular anomalies)
- Instable cervical spine, cervical spine fractures, fixed cervical spine
- Phlegmonous throat inflammations
- Condition after neck dissection and radiotherapy
- Re-tracheotomies with pre-existing endoscopically secured alterations
- Fresh tracheal and bronchial sutures
- Laryngo-tracheal stenoses
- Oropharyngeal malignant tumors due to the risk of vaccination metastases (especially TLT according to Fantoni)
- Severe persistent neurological deficits to be expected, e.g., double-sided recurrence pareses, swallowing disorders, aspiration tendencies
- High degree blood coagulation disorder with spontaneous bleeding
- Obesity permagna (BMI ≥ 40)
- Lack of experience and technical requirements and insufficient human resources for surgery and aftercare
- Indication for a permanent tracheostoma

3 Anatomy and Topography in Relation to Tracheotomy

Friedemann Pabst and Gunter Haroske

3.1 Introduction

Only the anatomical aspects that are relevant for tracheotomies with different methods as open surgical tracheotomies (OST), percutaneous dilatational tracheotomies (PDT) as well as coniotomy, which is considered an emergency procedure to avoid complications, are presented here. An exhaustive anatomical examination of the region is not intended.

3.2 External Anatomical Orientation

The tracheotomy is regularly performed with the head retroflexed. This applies to OST, PDT and coniotomy. There are three advantages to overstretching the head, which may be reinforced by additionally cushioning the shoulder region:

1. This results in an improved visualization and palpation ability of the external landmarks (Incisura thyroidea superior, Cartilago cricoidea, Fossa jugularis with the upper edge of the Manubrium sterni and possibly the Glandula thyroidea).
2. Due to its ligament and muscle-mediated suspension, the larynx is pulled cranially by retroflexion; as a result, the trachea connected to the larynx is also shifted cranially. Consequently, a larger part of the (cervical) trachea is surgically accessible.

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3. In addition, this positioning achieves a ventral displacement of the trachea, which also facilitates the surgical procedure.

A *coniotomy* is performed between the lower edge of the thyroid cartilage and the upper edge of the cricoid cartilage; a *tracheotomy* (OST and PDT) should be performed regularly between the second and fourth tracheal braces.

The head in a retroflexed position facilitates to correctly identify the surgical landmarks.

3.3 Anatomically Slidable Layers: Cervical Fascia

On the neck, there are anatomically slidable layers in the form of the Fascia cervicalis (Fig. 3.1) which are structured into laminae [1]:

1. The superficial lamina of the cervical fascia *(Lamina superficialis)* lies under the skin, subcutis and platysma and extends from the anterior edge of the mandible to the clavicle and to the Manubrium sterni. The sternocleidomastoid muscle and trapezius muscle are sheathed by it.
2. The intermediate lamina *(Lamina praetrachealis*) surrounds the suprahyoidal and infrahyoidal musculature, inserts at the Os hyoideum, extends over the lar-

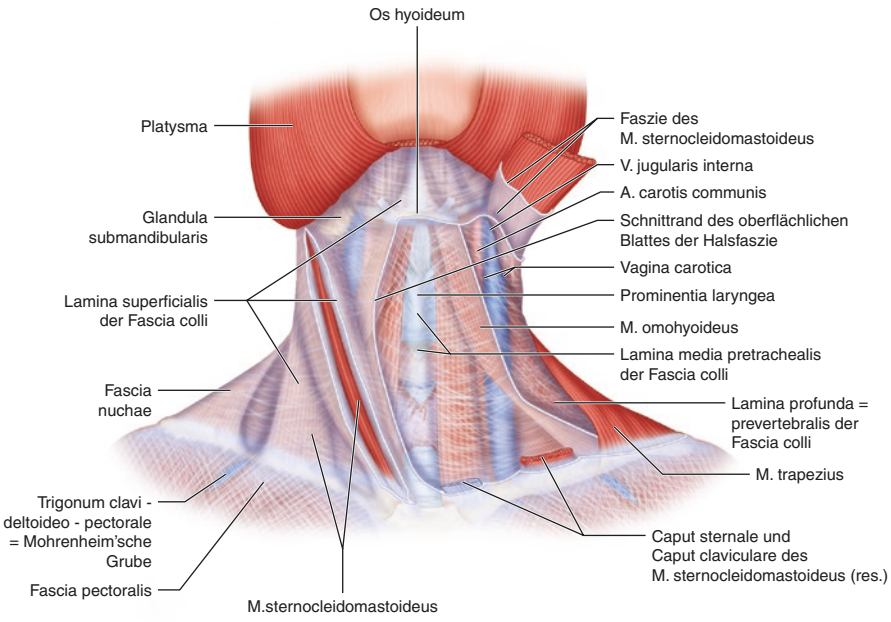

Fig. 3.1 Neck fascias (from Tillmann BN, Atlas der Anatomie, 2nd ed. 2010, p 154, Springer)

ynx, encloses the thyroid gland and continues on the trachea up to the upper edge of the posterior sternum and laterally to the clavicle and scapula. The superficial and middle fascia laminae join at the Prominentia laryngis (median upper edge of the thyroid cartilage). The space between the superficial and intermediate fascia lamina is also called pretracheal space.

3. The deep lamina (*Lamina praevertebralis*) lies between the spine on the one hand and the pharyngeal constrictor muscles, or esophagus, on the other. It surrounds the scalene muscles, the Truncus sympathicus and the phrenic nerve.

The slidable layers described allow movements of the larynx and trachea in the cranio-caudal direction, interacting with the musculature. This is important for physiological processes such as swallowing and speaking, but also for the described cranial displacement of the trachea during positioning for tracheotomy. In a tracheotomy, the fascia laminae are perforated; this can have a negative effect on the physiological mobility of the laryngo-tracheal complex, e.g., as a postoperative swallowing disorder.

The cervical fascia with its laminae facilitates the physiologically important vertical mobility of the laryngo-tracheal complex.

3.4 Cervical Musculature

Of surgical relevance are the sternocleidomastoid muscles, the straight neck muscles (synonyma strap muscles, infrahyoidal muscles) and the cricothyroid muscles (Fig. 3.2). Their physiological function consists in turning the head (sternocleidomastoid muscles), vertical mobility of the laryngo-tracheal complex (straight cervical muscles) and in tensioning the Plica vocalis (cricothyroid muscles).

The sternocleidomastoid muscles originate with their Caput sternale on both sides of the sternum and thus form an upwardly open V-shaped space, the lower part of which is formed by the Fossa jugularis. These muscles limit the surgical site of the tracheotomy laterally. The sternohyoid muscles and the superior venter of the omohyoid muscle form the superficial layer of the straight neck muscles. With the deep layer of the straight neck musculature directly below, which consists of the sternothyroid muscles, they can be shifted laterally during OST. This is done by a vertical incision in the raphe-like midline between the muscles, whose vascular poverty allows largely bleeding-free preparation. In coniotomy, the cricothyroid muscles deserve attention: their Pars recta are directly laterally adjacent to the Ligamentum cricothyroideum to be severed during coniotomy. An injury of this muscle causes the loss of its tension function for the Plica vocalis. This results in a restriction of the phonatory function of the larynx; singing and speaking in elevated vocal pitch may be restricted.

The protection of the straight neck musculature by pushing it aside in OST and by the exact identification of the midline in PDT is intended to rule out postoperative dysfunctions (swallowing disorders).

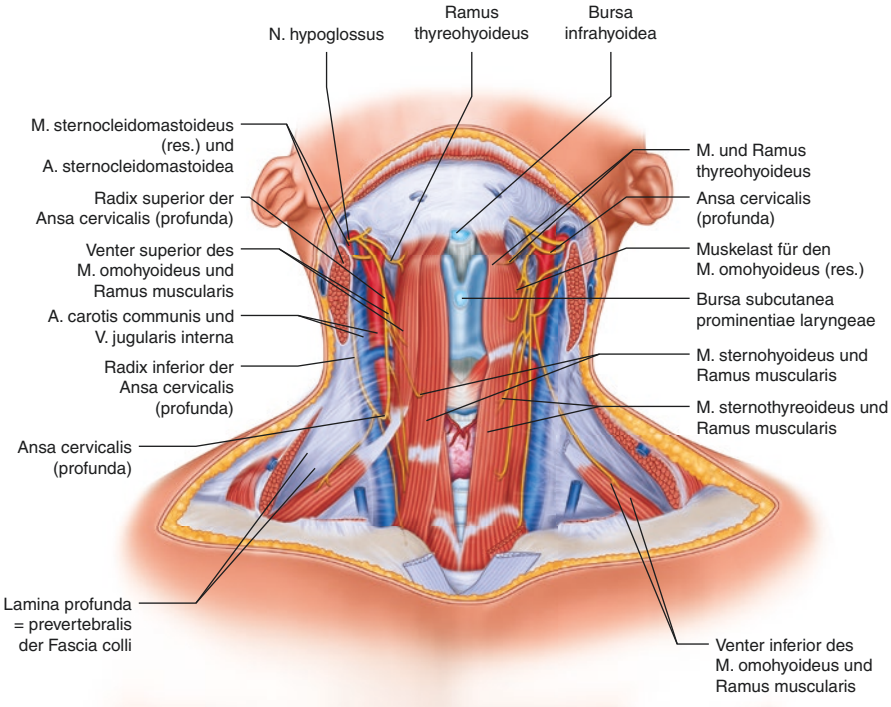

Fig. 3.2 Neck muscles, front view (from Tillmann BN, Atlas der Anatomie, 2nd ed. 2010, p 149, Springer)

3.5 The Thyroid Gland

The thyroid gland is closely related to the larynx and trachea. Its two lateral lobes reach the thyroid cartilage laterally, its middle lobe (isthmus) overlays the anterior tracheal wall at about the level of the second to fourth tracheal braces. Occasionally, a Lobus pyramidalis can be observed as an evolutionary rudiment moving from the isthmus in cranial direction. Thyroid gland pathologies are often accompanied by a partly asymmetrical enlargement of the organ. From an anatomical-topographical point of view, this can result in three peculiarities:

1. The pretracheal thyroid gland part to be severed during tracheotomy can undergo a significant increase in volume.
2. Asymmetrical thyroid gland growth can cause lateral shifts of the trachea, which are particularly relevant for PDT, as a strictly central puncture of the front wall of the trachea is of crucial importance for minimizing the risk of the intervention (Fig. 3.3). Therefore, diaphanoscopy from the endotracheal point of view is rightly a *conditio sine qua non* in PDT. Diaphanoscopy can be performed very

well with flexible optics, and very well with rigid optics and light rods, as with the tracheotomy endoscope for dilatational tracheotomies (TED) according to Klemm [2].

3. Thyroid gland growth can have a compressive effect on the trachea. This can lead to pressure-induced atrophic effects on the tracheal wall with the consequences of tracheal instability (collapse syndrome) and respiration-relevant lumen constriction, the maximum variant of which is known as "sabre-sheath trachea" (Fig. 3.4).

As a highly metabolically active organ, the thyroid gland is highly circulated by blood. Since in loco-typico tracheotomy the isthmus must be severed complying with the rules, the avoidance of bleeding complications from the thyroid gland through proper surgical hemostasis in OST or optimal bleeding prevention in PDT is of great importance (for blood supply to the thyroid gland see below).

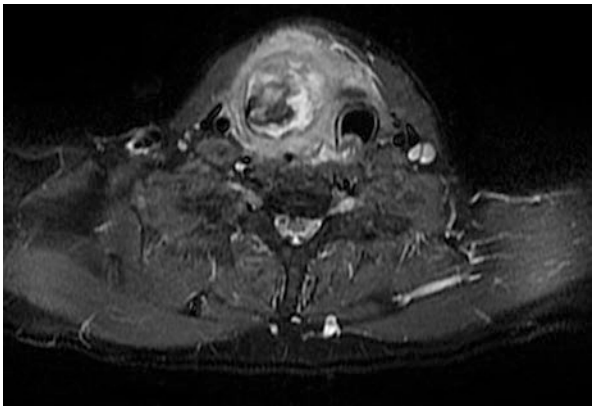

Fig. 3.3 Lateral displacement of the trachea by thyroid gland process in CT sectional view

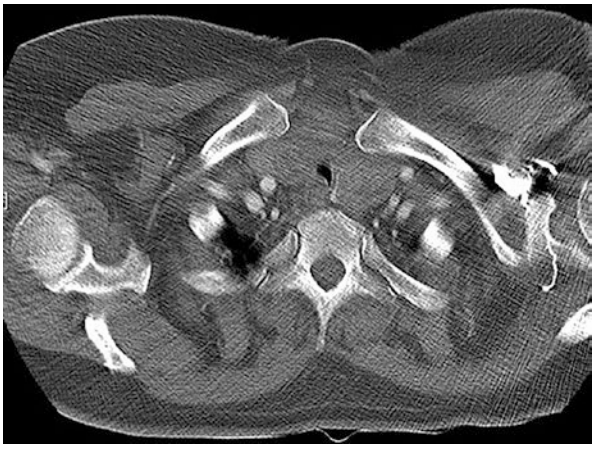

Fig. 3.4 Tracheal compression by thyroid gland enlargement in CT sectional view

The frequent variations of the thyroid gland anatomy in shape and size have a decisive influence on the position and thus the surgical accessibility of the cervical trachea.

3.6 The Trachea

As an unpaired organ, the trachea occupies an exceptional position. In all surgical manipulations it must be borne in mind that only this air-guiding connection exists between the upper and lower airways. The dreaded "loss of the airway" is a possible complication of interventional procedures such as tracheotomy.

The trachea consists of about 16–20 Cartilagines tracheales, usually horseshoe-shaped, hyaline cartilage braces, which form the supporting structure of this airway section. Dorsally, the cartilage braces are connected by the Paries membranaceus. The tracheal muscle is embedded in the dorsal wall. Between adjacent braces of the Paries membranaceus, there are connective tissue planes of collagen and elastic fibers, which are called Ligamenta interanularia. Cranially, the trachea is attached to the cricoid cartilage as connective tissue, the only completely ring-shaped structure of the respiratory tract and thus maximally stable. The caudal end is the Bifurcatio tracheae with its central spur, the Carina tracheae. The inner lining of the trachea, the Tunica mucosa, consists of respiratory epithelium with mixed glands embedded. Descriptively and anatomically, the trachea is divided into a Pars cervicalis and a Pars thoracica. The total length of both parts is approx. 10 cm for women and approx. 12 cm for men [3].

The shape of the tracheal braces is of particular importance for tracheotomy. Figure 3.5 illustrates that the Cartilagines tracheales are often incomplete, fuse with one another or are forked with one or more irregular openings [3]. In addition, the cranial braces are often fused with each other and/or with the cricoid cartilage. Dissection findings showed fusions of the first tracheal braces and cricoid cartilage in 35% of 42 autopsies and between the first and third tracheal braces in 60–100% [4]. Own investigations on tracheotomized patients showed a variety of tissues and possibilities of restructuring processes in the tracheal braces (Chap. 4). The risk of a puncture during PDT of an ossified zone resulting in a tracheal fracture is independent of age. The associated risk of later development of tracheal stenosis can be countered by immediate fracture reduction or removal of the intraluminally dislocated parts of the braces [2].

Asymmetry of the tracheal braces is the norm; ossifications of the cartilage braces can be found across all age groups.

Tracheotomies should be performed between the second and fourth tracheal braces, regardless of whether they are performed as OST or PDT. This recommendation results from two considerations: A more cranial tracheotomy can lead to mechanical involvement of the cricoid cartilage. Inflammatory reactions lead to ossification processes with the consecutive development of suprastomal cricoid cartilage stenoses [5]. More caudally performed tracheotomies increase the

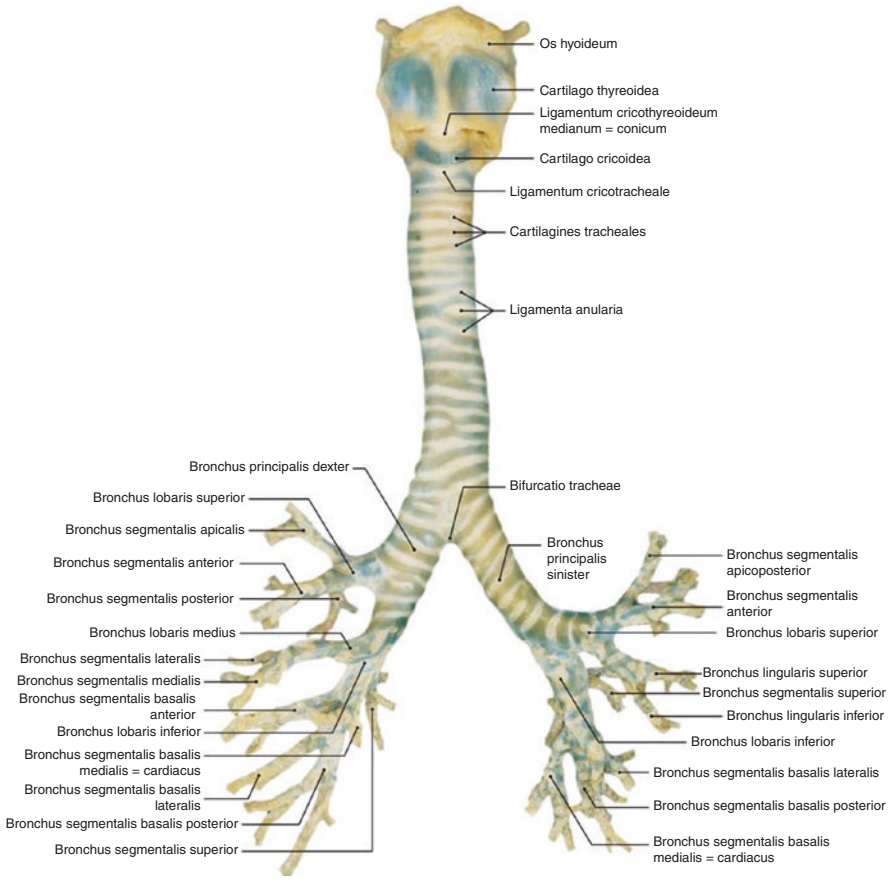

Fig. 3.5 Larynx, trachea and bronchial tree, front view (from Tillmann BN, Atlas der Anatomie, 2nd ed. 2010, p 260, Springer)

risk of complications in the Pars thoracica, such as truncus-arrosion bleeding. The usually palpable cricoid cartilage is the primary external landmark for the position of the second to fourth tracheal braces. In older publications it is recommended to perform the PDT 1 cm below the cricoid cartilage. This is justified by the fact that the second to fourth tracheal braces are located in this region [6]. Own investigations showed in 130 adult autopsies that, when a puncture is performed 1 cm below the cricoid cartilage, the probability of injury for the first and second tracheal brace is 38% (personal communication by Klemm, E., Roitzsch, A., Dürig, E. and Haroske, G., Institute for Pathology "Georg Schmorl" at the Teaching Hospital Dresden-Friedrichstadt, on autopsy findings of the anterior trachea on 130 bodies from 2003 to 2006). Therefore, the recommendation of Dost and Jahnke [7] to perform the PDT 2 cm below the cricoid cartilage must be followed.

The recommendation to perform the tracheotomy between the second and fourth tracheal braces usually means a puncture for the PDT 2 cm in midline below the cricoid cartilage.

3.7 The Tracheotomy-Relevant Vascular Situation

3.7.1 Vascular Situation in General

With regard to the various methods of tracheotomy, knowledge of the vascular situation in situ is important for two reasons:

First, intraoperative bleeding can be minimized by adequate preparation techniques adapted to the vascular situation.

Secondly, postoperative bleeding can be avoided, and wound healing can be improved through knowledge of the special features of cervical blood supply.

The following vascular situations are important for tracheotomy:

1. the arterial and venous supply of the thyroid gland
2. the arterial supply of the trachea
3. the neighborhood relationship with the brachiocephalic trunk

- Ad 1)

Arterial supply is effected via four to five arteries:

– the paired superior thyroid arteries with an end branch to the larynx (A. laryngea superior) from the external carotic arteries,
– the paired inferior thyroid arteries with an end branch to the larynx (A. laryngea inferior) from the thyrocervical trunk,
– the unpaired Arteria thyroidea ima, originating from the aorta or the innominate artery (Truncus brachiocephalicus) and occurring in about 12% [8].

The latter can move directly across the anterior wall of the trachea to the isthmus and thus cause severe bleeding during tracheotomy.

The venous outflows from the thyroid gland, which show considerable variance, are also practically important for bleeding complications [1]. The outflow occurs together with the laryngeal veins via the paired superior thyroid, media thyroid and inferior thyroid veins. At the lower thyroid gland pole, the veins form the Plexus thyroideus impar, which can trigger late postoperative bleeding, for example due to cannula-related arrosion. This danger also exists for the veins which lie more superficially below the Lamina superficialis of the neck fascia in the jugulum and form the Arcus venosus juguli there, a connection between the anterior jugular veins.

- Ad 2)

According to Miura and Grillo [9], the arterial supply of the cervical trachea is ensured by segmentally arranged Rami tracheales from the inferior thyroid and bronchial arteries. These branches enter laterally into the tracheal wall. Too extensive dissection of the trachea into lateral direction may compromise its nutrition and contribute to the development of tracheal stenosis. Perfusion disorders in the tracheal blood supply can also be caused by too high pressures in the cuff of endotracheal tubes or tracheostomy tubes. Possible consequences are necrosis of the Tunica mucosa and the Paries membranaceus with consecutive development of stenoses and tracheoesophageal fistulas.

- Ad 3)

The location of the innominate artery (Truncus brachiocephalicus) in the pretracheal space between the sternum and trachea can lead to bleeding complications due to the formation of an arterio-tracheal fistula [10]. The pathomechanism is most likely to be found in a cuff-pressure-induced laceration of the trachea and vascular walls, as the trunk has no ventral escape due to the fixed abutment of the sternum (Fig. 3.6).

Bleeding is the most common cause of early and late complications in tracheotomies.

3.7.2 Anatomical Variants of Vascular Anatomy

Variants in the vascular courses with relevance for bleeding complications in tracheotomy concern above all —beside the already mentioned A. thyroidea

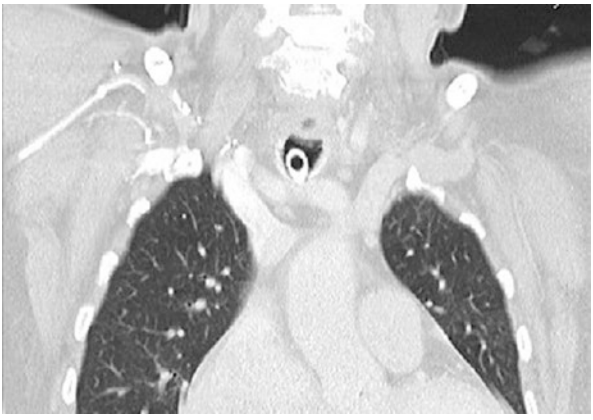

Fig. 3.6 Arrosion bleeding of the brachiocephalic artery caused by the tracheostomy tube, CT angiography

ima—the innominate artery (Truncus brachiocephalicus) and a so-called Truncus bicaroticus. The former can appear as a raised or elongated innominate artery (Truncus brachiocephalicus) in the surgical site. Truncus bicaroticus is a supraaortic vessel from which both carotides originate [11]. The frequency is given as up to 8% [12]. To avoid severe bleeding complications, preoperative sonography is recommended [13].

3.8 Laryngeal Descensus

The so-called Descensus laryngis is both a phylogenetic and an ontogenetic fact. In the course of the tribal evolution of mammals, the larynx sinks in relation to the cervical spine. The physiological consequence is an enlargement of the vocal tract with the possibility of a more differentiated articulation. The higher collapsibility has a negative effect and with it the possibility of developing an obstructive sleep-related respiratory disorder. In the course of individual development, the cartilage of the infant's thyroid cartilage is approximately at the level of the third cervical vertebra; in adults the larynx sinks, and the cartilage of the male thyroid cartilage is projected onto the fifth cervical vertebra (Fig. 3.7). A slightly higher position is typical for women than for men.

The Descensus laryngis is also associated with a Descensus tracheae. Therefore, the larynx of elderly people is often shifted farther caudally into the jugulum. Further peculiarities to be taken into account in senium in the event of tracheotomies are the difficult reclinability of the cervical spine due to degenerative changes and a shift of the trachea into caudal-dorsal direction.

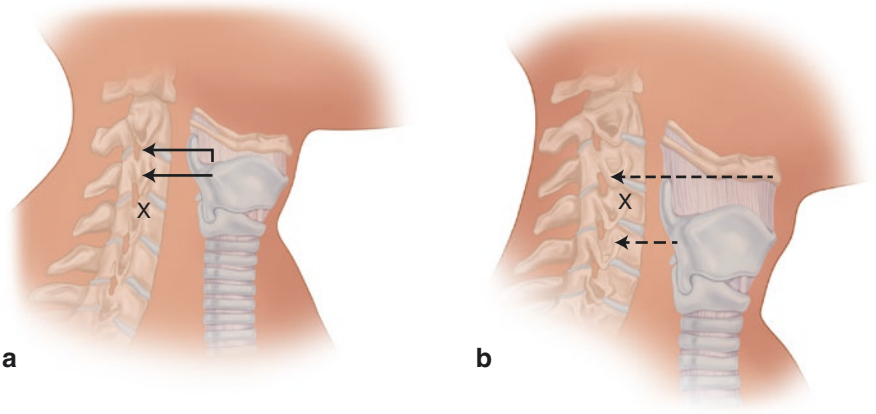

Fig. 3.7 Laryngeal descensus. (**a**) Laryngeal position in a young child. (**b**) Laryngeal descensus in old age (acc. to [14]). **X** 5th cervical vertebra

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Histomorphology of Tracheal Braces of Tracheotomized Patients

4

Gunter Haroske

The hyaline cartilage of tracheal braces is subject to physiological as well as pathological changes, the combination of which we encounter when examining the cartilage tissue of tracheal braces of tracheotomized patients.

The most important physiological changes concern the normal aging process, which takes place in a wide range of variations. Even the normal growth processes, which adapt the cartilage (Fig. 4.1) to higher mechanical loads, can be understood as aging: With an increase of the cartilage braces in volume, the nutritional conditions of the chondrocytes deteriorate with a reduction in the number of cells per unit volume and degeneration of the intercellular substance, visible as so-called mucoid degeneration, as fiber demasking and as fine-grained calcification [1] (Fig. 4.2).

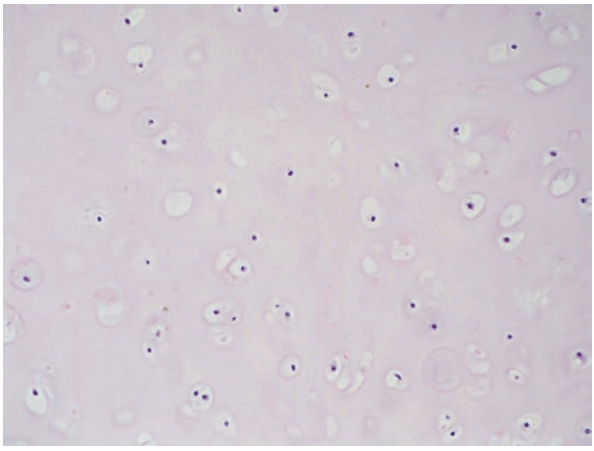

Fig. 4.1 Hyaline cartilage of a tracheal brace without any special peculiarities of a 59-year-old male. Hematoxylin eosin, obj. x 20

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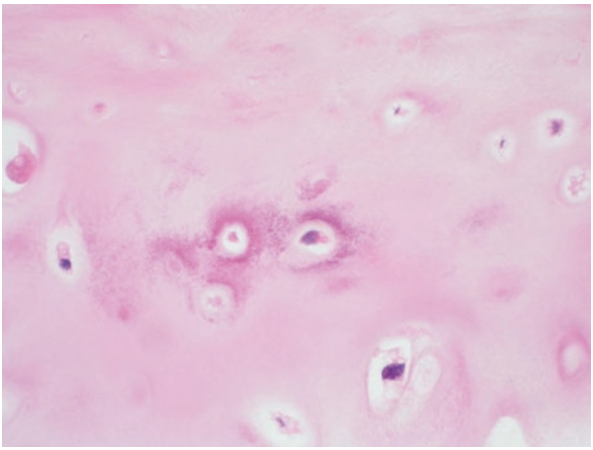

Fig. 4.2 Dystrophic calcifications in the hyaline basic substance. Tracheal brace of an 83-year-old female. Hematoxylin eosin, obj. x 40

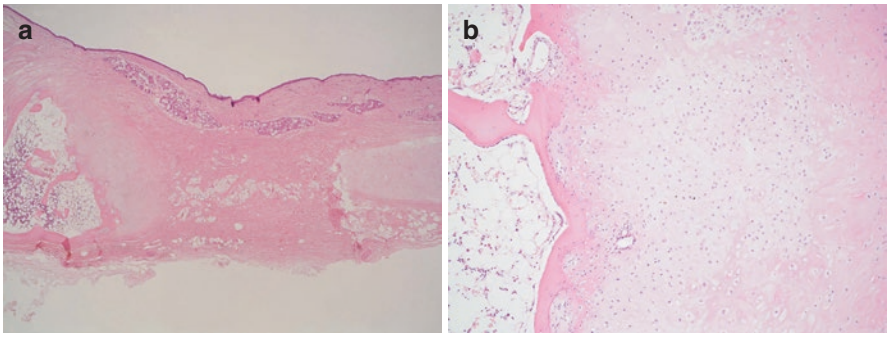

Fig. 4.3 (**a**, **b**) Ossification of hyaline cartilage (right) with formation of hematopoietic bone marrow (left) in a tracheal brace of a 41-year-old female. Hematoxylin eosin, obj. x 4, and obj. x 10, resp

These degenerative processes are apparently an incentive for the increasing ossification of cartilage tissue [2]. In addition, there are altered tensile loads on the collagen fibers in the intercellular substance, which also lead to bone formation when a critical threshold is exceeded [3] (Fig. 4.3). Thus, with increasing age, both mucoid degenerations of the hyaline basic substance and its ossifications are found more frequently and more extensively, roughly following an expansion from caudal to cranial and from peripheral to central [1]. Men are affected much more frequently than women [4]. At an advanced age, regeneration symptoms of cartilage cells in the form of clusters or breeding capsules also occur [5] (Fig. 4.4).

In the case of traumatic or inflammatory events in the tracheal wall, these physiological processes are more or less strongly modulated by pathological stimulus responses.

The possibilities of a tissue's response to stimuli are rather limited: As a rule, we see changes that are subsumed by the terms of degeneration, inflammation and

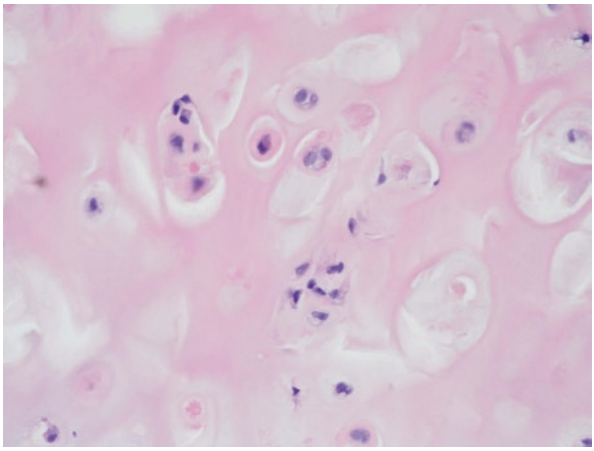

Fig. 4.4 Mucoid degeneration of the basic substance and breeding capsules of chondrocytes in the hyaline cartilage in the tracheal braces of a 49-year-old female. Hematoxylin eosin, obj. x 40

processes of repair. Every response reaction is processual, i.e., it is time-dependent and leads either to *restitutio ad integrum* or to a more or less stable defect condition. Functional disorders are not necessarily reflected in morphologically tangible changes.

Out of 103 patients (aged 18–90, median age 71) in intensive care medicine, the middle pieces of the second or third tracheal brace were histologically examined in a pilot study in the years 2006–2009 when tracheotomies became necessary [6].

These tracheal braces showed only in 26 cases (25%) a normal homogeneous structure of hyaline cartilage. All other cases exhibited different changes in physiological cartilage aging as well as pathological reactive changes to previous traumas and severe concomitant diseases:

- compact and cancellous bone structures, partly with orthologous hematopoietic marrow in 26%
- dystrophic (degenerative) cartilage calcifications in 20%
- proliferation of cartilage tissue (brood capsules) in 13%
- dystrophic to nonvital cartilage zones in 4% (Fig. 4.5)
- osseous metaplasias in connective tissue in 3% (Fig. 4.6)
- cartilage necroses in 2%
- inflammatory reactions in mucous membrane and connective tissue areas in 32% (Fig. 4.7)

No correlations between age and these different histological tissue qualities and reactive changes were evident.

Necroses, perichondral inflammations and osseous metaplasias in the perichondral connective tissue are an indication of previous or, at the time of the tracheotomy, still existing pathological processes of a stronger degree, which obviously result from the circumstances leading to tracheotomy (e.g., severe shock, sepsis, ARDS). They negatively influence both the mechanical stability of the tracheal

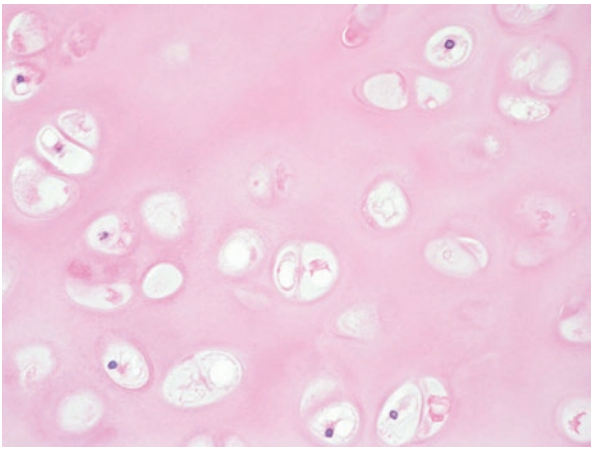

Fig. 4.5 Nonvital chondrocytes and mucoid degeneration in tracheal cartilage of an 85-year-old male. Hematoxylin eosin, obj. x 40

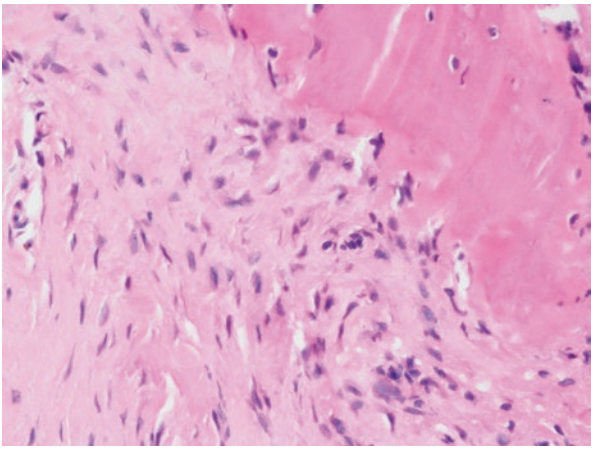

Fig. 4.6 Chronically persistent perichondritis with metaplastic bone formation after 8 weeks of PDT in an 18-year-old male. Hematoxylin eosin, obj. 40

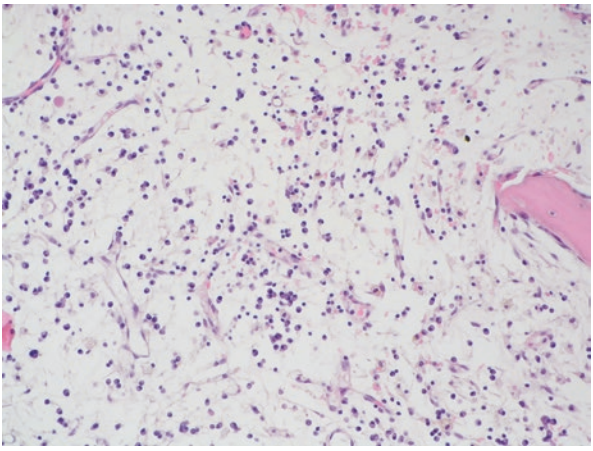

Fig. 4.7 Mildly florid, granulating inflammation in perichondral connective tissue in an 81-year-old male. Low grade metaplastic bone formation. Hematoxylin eosin, obj. x 20

cartilage skeleton and the elasticity of the individual cartilage braces. A quarter of the cases showed an advanced ossification reaching the central parts of the tracheal braces, which practically eliminates the elasticity of the tracheal braces. It is the most important disposition for fractures of braces in PDT.

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Methods of Percutaneous Dilatational Tracheotomy

5

Markus Jungehülsing

5.1 Introduction

The increase in long-term intubated intensive care patients in recent decades and the realization that long-term laryngeal and tracheal damage can be avoided if patients are tracheotomized early has led to a sharp rise in the number of tracheotomies [1].

In search of a fast, reliable method for tracheotomy, Shelden et al. were the first to publish a method in 1955 which, according to their own statements, was safe to perform and which, above all, did not require dissection of the neck with laying open the trachea. Toy and Weinstein [2] presented a procedure for percutaneous dilatation tracheotomy for the first time. However, this procedure did not prevail, probably because of the difficult and, compared to conventional surgical tracheostomy, not very safe technique. It took another 16 years before Pasquale Ciaglia resumed the technique and published his method of percutaneous dilatation tracheotomy (PDT) in 1985.

The Ciaglia technique and later modifications then began a triumphal march in intensive medicine. It is interesting to note that none of the procedures described was first published by an ENT physician or in an ENT journal and that the ENT community initially reacted with considerable mistrust. Like every new surgical procedure, the different PDT procedures showed a learning curve. Today, more than 9/10 of necessary tracheotomies are performed as PDT worldwide [3]. A worldwide survey by Vargas et al. [4] showed that the most commonly used PDT method is the single-step technique according to Ciaglia.

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5.2 The Procedure

5.2.1 Prerequisites

The functioning of the trachea as a singular respiratory organ is a prerequisite for life, or in other words, a prolonged relocation of the trachea is not compatible with life. In principle, any surgical intervention on the trachea can lead to its displacement; this applies both to conventional tracheotomy in dissection technique and to percutaneous dilatation tracheotomy. However, while surgical tracheotomy plays an important role as an operation in the surgical training of the surgical assistant and the technique is always learned under the guidance of an experienced medical specialist, the descriptions of PDT as a supposedly simple, elegant, fast and inexpensive procedure may have led to an underestimation of associated risks and thus to occasional fatal outcomes [5].

In principle, the same demands must be made for PDT as for open surgical tracheotomy: the team carrying out the procedure must always be able to adequately treat acute complications, in individual cases with the possibility of interdisciplinary cooperation.

Before performing percutaneous dilatational tracheotomy, the beginner should

- *learn about surgical tracheostomy,*
- *respect contraindications,*
- *perform a sonography of the neck,*
- *examine the larynx and trachea endoscopically.*

5.2.2 The Principle

The basic principle of PDT has not changed since the description by Ciaglia in [6]: Between the second and fourth tracheal braces, the trachea is sharply punctured using a cannula.

Through the access, a Seldinger wire is inserted into the trachea for guidance. The Seldinger wire is used to dilate the soft tissue mantle of the neck and the anterior tracheal wall using various procedures. Finally, a tube is placed in the trachea through the dilated soft tissues and the tracheal anterior wall.

The PDT principle

1. *Sonography of soft neck tissue*
2. *Endoscopy of the trachea*
3. *Puncture of the trachea*
4. *Insertion of the Seldinger wire into the trachea*
5. *Dilatation*
6. *Insertion of the tracheostomy tube*
7. *Endoscopic control*
8. *Connection of the tracheostomy tube, removal of the endotracheal tube*

The only exception to this procedure is the technique according to Fantoni [7], in which the Seldinger wire is applied transorally and then a dilator is retrogradely guided through the trachea from the inside to the outside. Schachner et al. [8], Griggs et al. [9], and Frova and Quintel [10] as well as Zgoda and Berger [11] have described further modifications of the PDT. Finally, it can be stated today that the procedures according to Schachner and Griggs, but also according to Fantoni, are rarely carried out for various reasons.

On the other hand, the methods according to Ciaglia [12] (Blue Rhino®), Frova (Percu Twist®) and Zgoda (Ciaglia Blue Dolphin®) have prevailed.

Table 5.1 lists the initial describers, methods and their principal features.

5.2.3 Ventilation

Ventilation is provided either conventionally via a tracheal tube or with the aid of high-frequency jet ventilation [13], but present-day applications prefer superimposed high-frequency jet ventilation if rigid tracheoscopy procedures are used (Chaps. 10, 15, and 16).

Table 5.1 Percutaneous tracheotomy methods in chronological order

Specification	Initial describers	Journal	Year	Method
Puncture tracheotomy	Shelden et al.	Journal of Neurosurgery	1955	Puncture, Seldinger wire, scalpel
Puncture tracheotomy	Toy and Weinstein	Surgery	1969	Puncture, Seldinger wire, dilatation with bougie and scalpel, 6.2 mm respiratory trocar
Miniconiotomy	Matthews and Hopkinson	British Journal of Surgery	1984	Puncture, 4 mm respiratory trocar, coniotomy
PDT	Ciaglia et al.	Chest	1985	Puncture, Seldinger wire, dilatation with hollow bougies of increasing diameters
PDT	Schachner et al.	Critical Care Medicine	1989	Puncture, Seldinger wire, retractor
GWDF "guide-wire dilating forceps"	Griggs et al.	Journal of Surgical Gynecology and Obstetrics	1990	Puncture, Seldinger wire, retractor with Seldinger-wire borehole
TLT "translaryngeal tracheostomy"	Fantoni et al.	Minerva Anesthesiologia	1996	Puncture, Seldinger wire transoral, retrograde transtracheal dilatation
Blue Rhino®	Ciaglia	Chest	1999	Puncture, Seldinger wire, tapering hollow bougie
"PercuTwist"	Frova and Quintel	Critical Care Medicine	2002	Puncture, Seldinger wire, dilating hollow screw
"Ciaglia Blue Dolphin"	Zgoda and Berger	Chest	2005	Puncture, Seldinger wire, balloon dilatation

5.2.4 Puncture

A puncture cannula is inserted between the second to fourth tracheal braces through the neck skin and the pretracheal structures into the trachea. If air can be aspirated, the lumen of the trachea is reached (Fig. 5.1).

The trachea should be punctured at about 12 o'clock in order to avoid shearing or tearing in the lateral part of the trachea or injury to structures located laterally to the trachea. A Seldinger wire [14] is now guided caudally through the inserted cannula or, according to TLT-Fantoni, cranially, which remains in the trachea during the entire puncture process to secure access and to guide the dilators (Fig. 5.2).

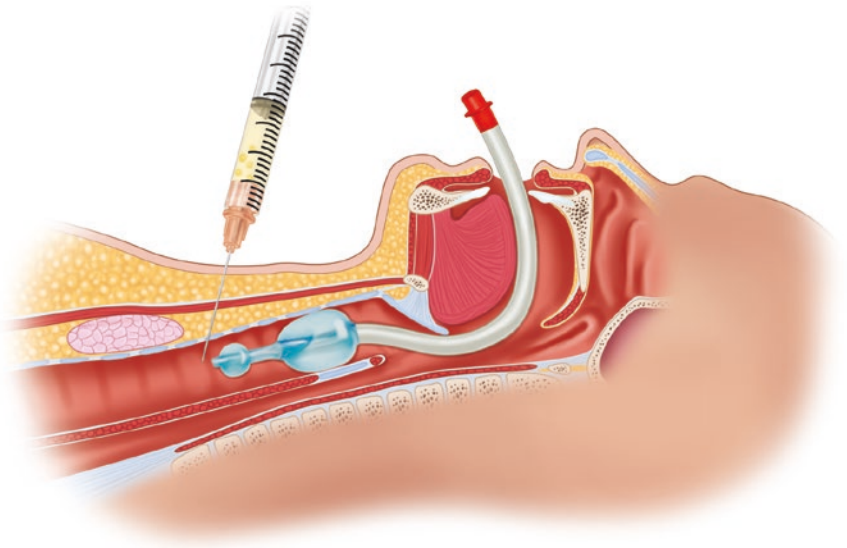
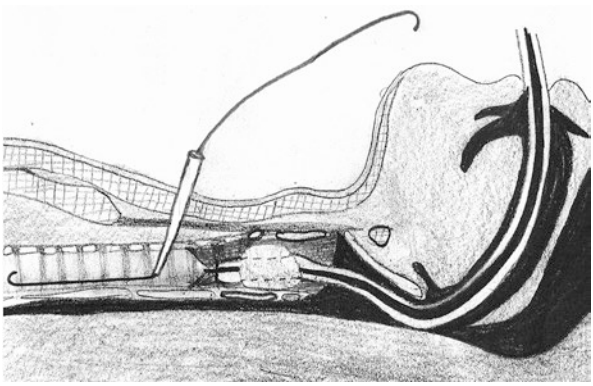


Fig. 5.1 Puncture of the trachea below the second tracheal brace and aspiration of air under endoscopic control

Fig. 5.2 Seldinger wire



The scalpel is then used to open the skin and subcutis to the right and left of the cannula laterally for a few millimeters in order to facilitate the following bouginage.

The puncture can of course result in injuries to the variable structures located in the puncture area.

This is disastrous if it is an innominate artery or the aortic arch (e.g. in patients with a barrel thorax) [15] and not harmless if it is the thyroid isthmus or the internal jugular vein.

Tracheal puncture, typical faults and hazards

1. *Tangential puncture—Tracheal injury, subsequent stenosis*
2. *Posterior wall injury—Via falsa, esophagus perforation, emphysema*
3. *Vessel, thyroid puncture—Hemorrhage*
4. *Paratracheal puncture—Via falsa, pneumothorax*

5.2.5 Endoscopy, Diaphanoscopy, Sonography

Today, either diaphanoscopy [16] or sonography before or during the puncture [17] is recommended as safety for the sharp puncture of the trachea. An endoscopy accompanying PDT is required, which according to analyses by Vargas et al. is also practiced worldwide at 87% in 2015. Today, either diaphanoscopy [16] or sonography before or during the puncture [17] is recommended to be safe for the sharp puncture of the trachea. An endoscopy accompanying PDT is required, which, according to analyses by Vargas et al. in [4], is also practiced worldwide at 87%.

In this regard, either

1. flexible bronchoscopy through the lying tube, or
2. rigid tracheoscopy, e.g., acc. to Klemm [18], or by way of
3. laryngoscopy in the sense of video-supported suspension laryngoscopy [19] can be applied.

While flexible bronchoscopy is performed through the tracheal tube during typical ventilation, jet ventilation is also used for rigid procedures with the tracheoscope or the laryngoscope; positive experiences have been made with the SHFJV® (Chap.16).

The endoscopic control of the puncture of the trachea has the following objectives:

1. Securing the puncture between the second and fourth tracheal braces and protection against ring cartilage injuries by visualization of the internal anatomy,
2. Securing the puncture of the trachea in the area of 12 o'clock, protection against tracheal injuries by tangential puncture,
3. Avoidance of perforating the posterior wall of the trachea and thus the opening of the esophagus,
4. Avoidance of a via falsa with development of a pneumothorax,
5. Early diagnosis of hemorrhage in the trachea,
6. Early detection of a tracheal brace fracture and removal of dislocated cartilage, if necessary.

5.2.6 Dilatation

A skin incision is made before the dilatation.

The procedures now differ in the way in which the soft tissues and the anterior tracheal wall are dilated. While Ciaglia first used a series of hollow bougies with increasing diameter for dilatation in 1985, he himself replaced this procedure with a single, tapered, soft hollow bougie in 1999 (Blue Rhino®). Ciaglia himself reported that the rigid dilators were too dangerous, after he had observed several dissections of the posterior tracheal wall in his own patients.

Schachner and Griggs suggested different clamps for spreading to dilate the soft tissues in front of the trachea. Frova designed a hollow screw, with which dilatation is achieved by slow turning (Percu Twist®). Finally, Zgoda introduced a balloon catheter (Ciaglia Blue Dolphin®) for dilatation of the soft tissue as for coronary dilatation via the Seldinger wire. Only Fantoni proposed retrograde dilatation.

After sufficient dilatation, a suitable tracheostomy tube is inserted into the dilated channel of the trachea. The tracheostomy tube lies against the soft tissues of the neck under pressure resulting from the elasticity of the dilated tissue. This tight closure means that PDT is less prone to local infection than surgical tracheotomy [20].

5.3 Methods in Detail

For the sake of completeness also the hardly or no longer performed puncture tracheotomies shall be described.

5.3.1 Shelden Tracheotomy

Shelden et al. [21] had developed a special instrument in 1955. They blindly punctured the trachea below the cricoid with a cannula that resembled a cavity dowel. After the puncture was performed, a barb was unfolded from the cannula, the trachea was hooked and luxated (Fig. 5.3a) and punctured again 2 cm below with a second gutter-like cannula (Fig. 5.3b). Via the second guide, a scalpel with a button at the front was inserted sharply horizontally into the trachea, severing the soft tissues of the neck and the trachea on its way (Fig. 5.3c). The silver cannula was then inserted through this opening, fixed to the neck and the guide cannula and the upper cannula were removed. Later, Shelden and the staff omitted the first cannula and only punctured the trachea with the hollow gutter-like guide cannula (Fig. 5.3).

5.3.2 Toy Minitracheotomy

Toy and Weinstein [2] were the first to perform a PDT. The trachea was blindly punctured with a longitudinally folding cannula, the position of the cannula secured by aspiration of air. A special dilator was then inserted via the cannula, first with its wire-like end, then the needle was removed. The dilator had a small knife positioned slightly above the edge of the cannula, which created the necessary space by incising the skin of the neck with further insertion. The tracheostomy tube with a cuff

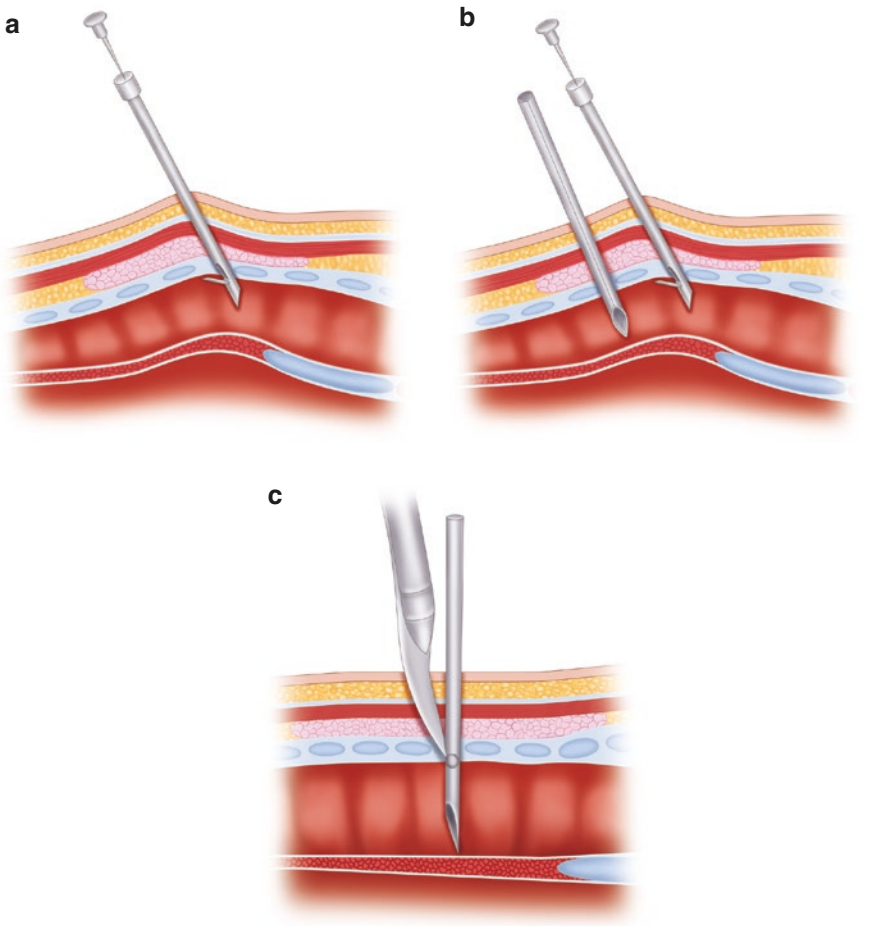


Fig. 5.3 Tracheal puncture during Shelden Tracheotomy: (**a**) After puncture the trachea ist hooked and luxated, (**b**) The trachea ist punctured again 2 cm below, (**c**) A scalpel ist inserted sharply horizontally into the trachea [21]

was attached to the side of the dilator. The procedure took about 30 s and complications occurred in 14% of the 100 cases reported. However, the authors also used the procedure in children, age eight and older, and in emergencies [22].

5.3.3 Matthews Miniconiotomy/Minitracheotomy

In 1984 Matthews and Hopkins described a further development of the Shelden tracheotomy into coniotomy and tracheotomy, which was initially intended as an alternative to conventional surgical tracheotomy. A horizontal incision at the level of the thyroid membrane allows pushing through a front-pointed guide in the Seldinger technique and blindly inserting a 4 mm cannula. The procedure was later used for

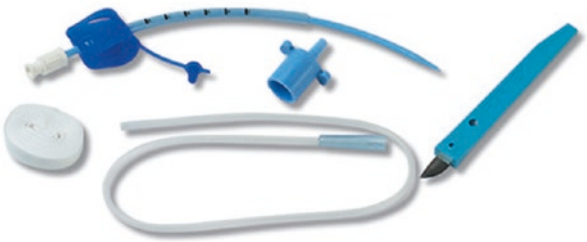


Fig. 5.4 Matthews Portex® Mini-Trach II Kit [24]

bronchial lavage in obstructive supraglottic processes and could be combined with jet ventilation. The dangers were hemorrhage, emphysema, laryngeal injuries and accidental decannulation. The procedure is still used today for special indications: In the case of acutely exacerbated COPD requiring ventilation, "open ventilation", speech and coughing are possible. No secretion basin forms above the cuff, nosocomial pneumonia with problem germs were reported less common [23] (Fig. 5.4).

5.3.4 PDT According to Ciaglia (Multiple Dilators and Blue Rhino®)

Ciaglia et al. introduced the actual percutaneous dilatation tracheotomy via the Seldinger wire in 1985. After puncture and insertion of the Seldinger wire, he extended the access to the trachea with a total of seven rigid hollow plastic bougies. Finally, a tracheostomy tube was inserted via the second thickest bougie. In 1999, Ciaglia himself declared his first procedure obsolete due to catastrophic complications with injuries of the posterior tracheal wall and opening of the esophagus and replaced the rigid bougies with a single curved, soft and tapering hollow bougie. He also called for control endoscopy as a prerequisite for the procedure [12] (Fig. 5.5). The Blue Rhino® method is by far the most frequently performed procedure today. It is easier and faster to perform in one step, inexpensive and seems relatively safe in the hands of the experienced. The main dangers mentioned are tracheal fractures and posterior tracheal wall injuries; hemorrhage and emphysema are very rare [25].

5.3.5 Percutaneous Spread Tracheotomy According to Schachner or Griggs (GWDF)

Schachner et al. [8] and Griggs et al. [9] described a new PDT method. Both carried out the dilatation with the help of a clamp, which is led via the Seldinger wire into the trachea. The clamp is then used to spread the soft tissue and trachea horizontally until the tracheostomy tube can be slid in. The special feature of the Griggs clamp

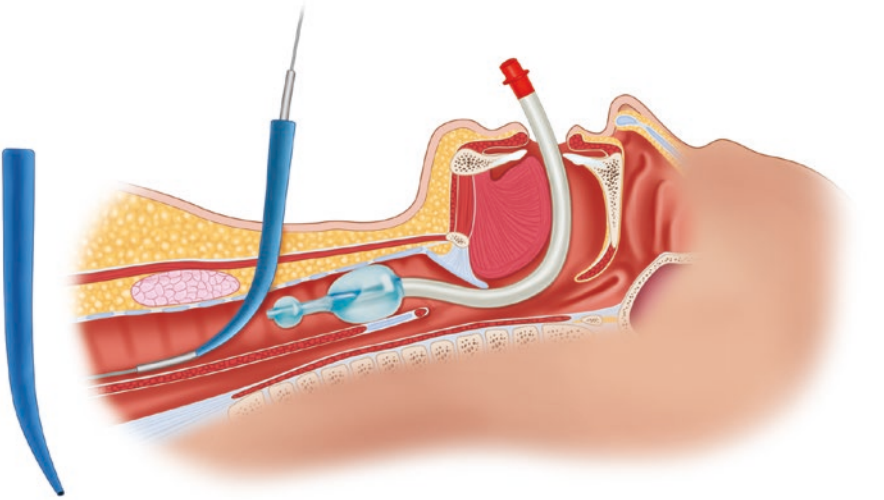


Fig. 5.5 Ciaglia Blue Rhino® [12]

is that it has a hole for the Seldinger wire ("Guide Wire Dilating Forceps", GWDF) through which it can be safely inserted.

The disadvantage of these procedures is the traumatizing spreading, which can cause the structures located in the puncture area to tear and thus, above all, to bleeding that is difficult to control [26].

5.3.6 Translaryngeal Tracheostomy (TLT) According to Fantoni

In the method according to Fantoni et al. [7], after a typical puncture of the trachea, the Seldinger wire is led out of the mouth, a tapering hollow bougie with a subsequent inverted tracheostomy tube is led through the larynx into the trachea and from there outwards through strong pulling and dilatation of the soft tissues. Finally, the tracheostomy tube must be turned by 180° (Fig. 5.6). The advantage of this method is that there are no fractures of the tracheal braces protruding into the lumen of the trachea. The disadvantage is the difficult execution with the risk of accidental extraction of the tube during dilatation and rotation.

In the case of malignant tumors of the upper aerodigestive tract, there is a risk of tumor tissue being carried over into the tracheostoma, resulting in vaccination metastases [27] Chap. 10.

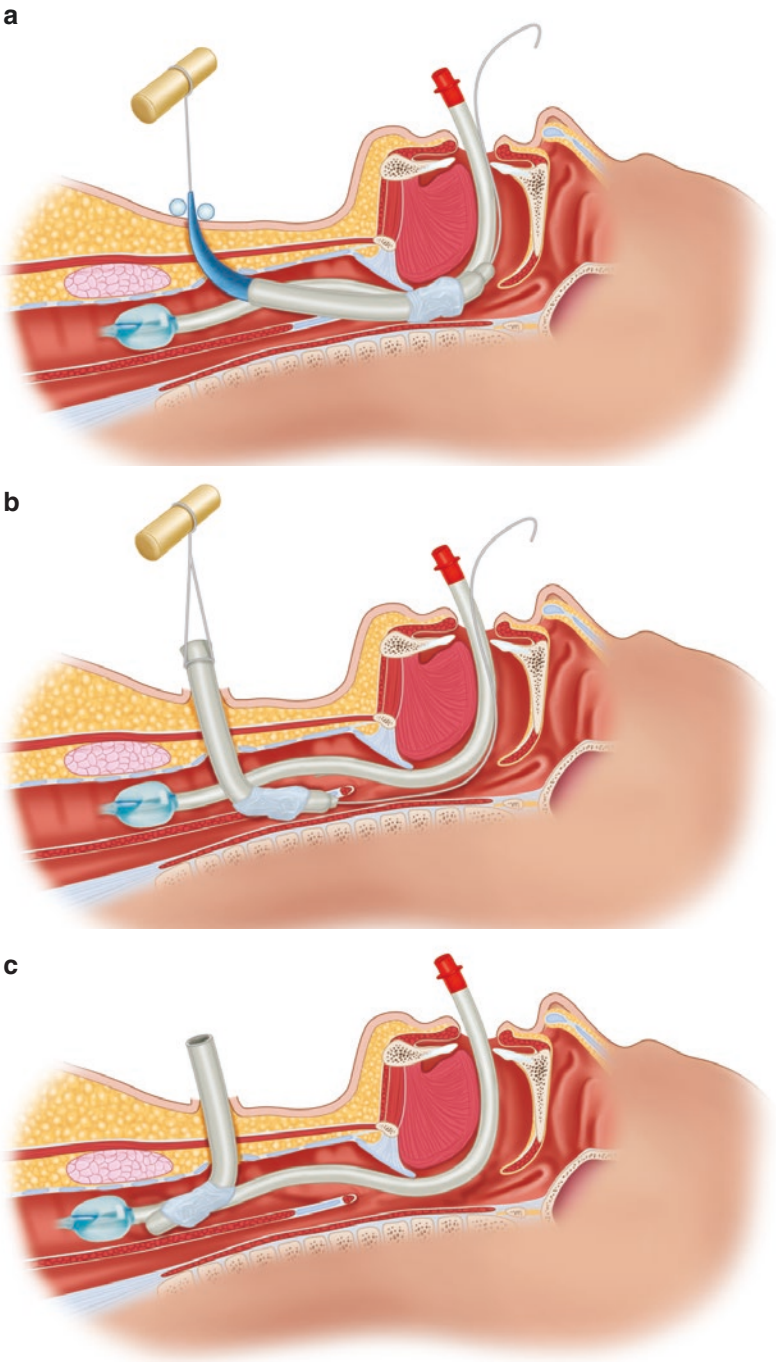


Fig. 5.6 (**a**–**c**) TLT according to Fantoni [7]

Fig. 5.7 Percu-Twist® [10]

5.3.7 PDT According to Frova and Quintel (Percu-Twist®)

Frova and Quintel [10] developed a hollow screw for dilatation, which is inserted via the Seldinger wire and produces the required dilatation while slowly turning it to the right (Fig. 5.7). Along with the Ciaglia Blue Rhino® technique, the Frova method is the most widely used PDT method today. According to the Voltaire's bon mot » le mieux est l'ennemi du bien « (Voltaire, Dictionnaire Philosophique 1764), the method has been able to establish itself widely as the dorsal and caudal force vector causing dilatation, which can lead to tracheal injuries in the Ciaglia methods, is omitted and as ruptures of the structures located in front of the trachea occur less frequently than in the Schachner and Griggs methods [26]. The prerequisite is that the screw is not "drilled" into the depth of the trachea, but that after the thread has gripped the tissue, the screw is pulled moderately when turning.

5.3.8 Ciaglia Blue Dolphin® According to Zgoda and Berger

The modification of Zgoda and Berger [11] is the most recent and, in the author's opinion, the most elegant PDT method. After puncture and Seldinger wire insertion, a set is inserted into the trachea that carries a balloon for dilatation in the front and the tracheostomy tube behind. After filling the balloon with NaCl 0.9% to a pressure of 11 bar for 10 s with a pump known from coronary angioplasty, the liquid is drained again after dilatation (Fig. 5.8). The bougie is advanced further until the tracheostomy tube lies endoscopically controlled and securely in the trachea and the bougie can be pulled out with the deflated balloon. The method requires only one dilating tool, a change between dilator and tracheal tube-bearing guidance is no longer necessary. There is no dorsal-caudal force vector, therefore injuries of the posterior tracheal wall have not been described so far and tracheal fractures seem to be less frequent than with the other procedures. The forces acting on the soft tissues are blunt, so that so far no bleeding incidents have been described in the literature [28, 29]. However, experience to date is still limited; the reason for this may be the cost factor.

5.4 Summary

The introduction of PDT as a new method for tracheotomy from 1985 to the present has led to bitter discussions about the advantages and disadvantages of conventional surgical tracheotomy compared to PDT. This is certainly due to two main reasons:

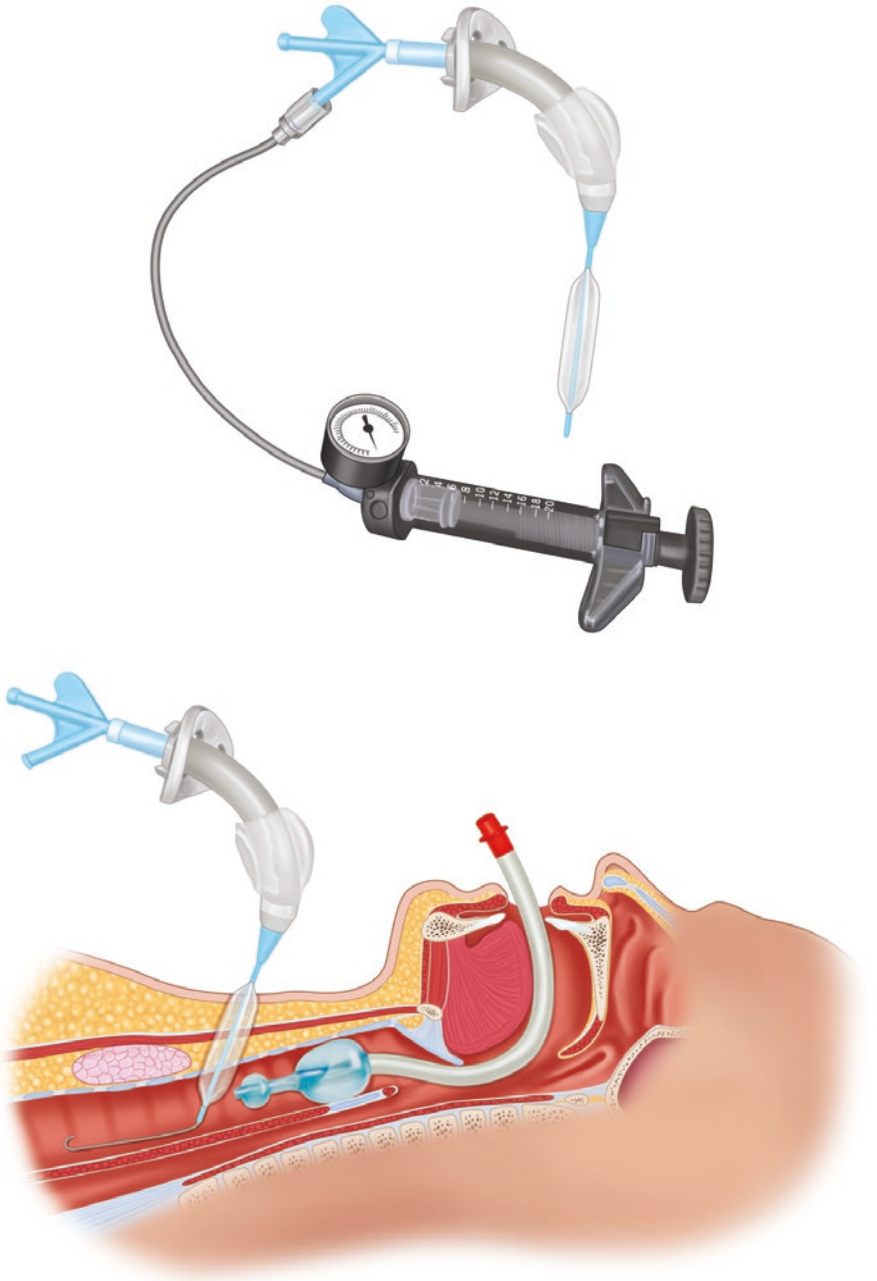


Fig. 5.8 Ciaglia Blue Dolphin® [11]

Some of the users overestimated the new methods and proceeded according to Maslow's statement "I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail." [35]. Another part of the medical profession wanted to maintain the tracheotomy in dissection technique according to the motto: "Never change a winning team" (A. Ramsey, BBC-Reporter during the 1970 soccer world championship).

In recent years, a whole series of meta-analyses have compared the different methods with each other in terms of parameters, such as

- speed of performance,
- perioperative morbidity and mortality,
- costs,
- spontaneous closure rate,
- cosmetic aspects.

Since these meta-analyses compare at least four different percutaneous dilatation tracheotomy methods with at least three different surgical tracheotomy procedures, the statements of such meta-analyses are correspondingly general and occasionally not really convincing [20, 30–32]. Comparisons between PDT and surgical tracheotomies in a Cochrane review by Brass et al. [33] were not able to reveal convincing inferiority or superiority for either approach in key questions.

Today, the following can be ascertained:

PDT is no longer a competing procedure, but a complementary procedure to conventional open surgery tracheostomy. The question as to which method is to be used for which patient must be decided individually and is based on the following factors

- *the anatomical conditions,*
- *the planned duration of ventilation,*
- *the outcome for the patient,*
- *the experience of the practitioners*
- *and the available resources.*

Necessary prerequisites for PDT are endoscopy (flexible or rigid) during the intervention and diaphanoscopy or sonography of the soft tissues of the neck before or during the performance. As tracheotomy, the procedure does not involve epithelization of the trachea opening and thus the creation of a self-supporting tracheostoma. Patients with only a short intensive care ventilation period are able to benefit from PDT because

- the intervention is to be performed faster than the surgical tracheotomy,
- the intervention can be carried out at the intensive care unit,
- the tracheostoma spontaneously closes after removal within a short time without additional intervention, and
- the long-term esthetic results are superior to those of surgical tracheotomy.

An investigation in nursing homes revealed that nearly 66% of the patients were treated with PDT. The complication rates of PDT were significantly higher for all complication types compared to patients receiving ST care. Eighty percent of patients with PDT required readmission to a clinic for tracheostoma revision, versus 23% in ST care [34].

Patients who are expected to undergo long-term intubation should have a surgical, epithelialized tracheostoma to reduce the risks of

– accidental decannulation at peripheral wards, and
– frustrating attempts to recannulation with the risk of a
– via falsa,
– mediastinal emphysema, and ultimately
– the patient's asphyxia resulting in death.

In addition, the non-epithelialized dilatation tracheostoma more frequently shows

– shrinkage tendencies and
– hyperplastic polyposis of the mucous membrane.

It must never be forgotten during trachea surgery that this is a singular and absolutely vital organ, and that complications can lead directly to the death of the patient (Chap. 10 "Tracheotomy-related deaths"). Therefore, as with every medical procedure, PDT must be required to have practitioners in place who are capable of managing complications and to have the infrastructure available to solve problems.

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Methods of Surgical Tracheotomy/ Tracheostomy

6

Sven Koscielny

Tracheotomies have been among the oldest surgical procedures since antiquity. Today, surgical tracheotomies appear as "routine interventions" in clinical everyday life and for the less familiar as a supposedly simple and hasslefree method. The experienced surgeon knows about the problems of a tracheotomy in difficult anatomical situations, with extensive tumor diseases, postoperative and radiotherapeutic changes or considerable obesity. The experienced tracheal surgeon will repeatedly encounter situations that have arisen as a result from serious, costly therapy-related damage to the patient's health caused by disregarding the principles of this seemingly "banal" procedure.

6.1 Definition: Tracheotomy or Tracheostomy

In Anglo-American literature, "tracheostomy" and "tracheotomy" generally refer to the same surgical procedure. According to the Greek roots, we differentiate, as far as possible, between **"tracheostomy = performance of an epithelialized tracheostoma"** and **"tracheotomy = performance of an incision in the trachea (windpipe)"**. Strictly speaking, tracheostomy is a subtype of tracheotomy [1, 2].

6.2 The Objective of the Surgical Operation

The aim is to secure the singular airway by eliminating the upper airway and/or to improve the bronchial toilet.

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6.3 Indications and Contraindications

Indications for surgical tracheotomies are as follows:

1. Any relocation of the upper respiratory tract (pharynx, larynx).
   These include the tumors of the upper aerodigestive tract as well as severe midface traumas and malformations. Patients with a double-sided recurrence paresis benefit from a tracheotomy after the event. However, a glottis enlargement and a tracheostoma closure should be planned after approx. 12 months if both nerves do not recover.
2. Patients with acute nasal or pharyngeal bleeding
3. Acute swelling (insect bite, angioneurotic edema)
   Here the tracheotomy is the *ultimate ratio* to secure the airway.
4. In Patients with chronic aspiration
   the tracheostoma with the blocked tracheostomy tube represents an important aspect for the aspiration protection of the lower respiratory tract. Patients with an expected chronic aspiration (e.g., after neurosurgical interventions, cerebral hemorrhages, apoplexy, chronic neurological diseases) should be discussed interdisciplinarily in the intensive care unit, as they benefit from a surgical tracheotomy compared to a puncture tracheotomy.
5. Tracheotomies in children and adolescents
   Due to the small dimensions of the child's airway and the softness of the cartilage structures, these patients should be tracheotomized by open surgery. This is an absolute contraindication for puncture tracheotomy.
6. Optimization of the bronchial toilet
   Patients with impaired coughing function usually require long-term treatment with a tracheostoma, which is why they should be tracheotomized surgically.
7. Pronounce disorders of blood coagulation
   Due to better possibilities for surgical hemostasis and better control of larger bleedings, tracheotomy should be performed surgically in this situation.
8. Difficult anatomical situation
   For patients with a large goiter, non-palpable laryngeal structures, a lack of anatomical overview from the outside or cervical tumor processes, surgical tracheotomy is the safer procedure due to the step-by-step imaging of the concealed anatomy. Surgical tracheotomy is also indicated for patients with a lack of extensibility of the cervical spine after an accident or operation.
9. Intensive care indications
   Patients with severe gas exchange disorders during intensive care should be tracheotomized surgically for a more stable respiratory situation. This also applies to patients in whom the possibility of oral re-intubation is impossible or difficult. Early tracheotomy with ventilation terms of more than 7 days may lead to the reduction of laryngeal complications and also to the reduction of salivation, of respiratory resistance by reducing the dead space and to better tolerance of ventilation with a reduced need for medication in intensive care patients [3].

10. Long-term necessity of the tracheostoma
    This issue should always be discussed with colleagues in intensive care medicine. Patients who require tracheostomy for a longer period of time (e.g., after apoplexy, neurosurgical interventions or severe neurological diseases) and who need to be cared for by a rehabilitation or nursing facility in the future will benefit from a surgical tracheotomy. The safe tracheostoma with mucocutaneous anastomosis facilitates tracheostomy tube change and care and increases patient safety.

Surgical tracheotomy has no absolute contraindications. *Relative contraindications* are as follows:

1. Lack of consent of the patient or their legal representative in the case of elective indication
2. Imbalanced coagulative situation in plannable tracheotomy
3. Exposure of the patient to vital risk by the operation with plannable tracheotomy (e.g., danger of brain pressure increase)

Surgical tracheotomy can always be performed on almost any patient anywhere under general or local anesthesia.

6.4 Site for Performing the Tracheotomy: Operating Theater or Intensive Care Unit?

Surgical tracheotomy as a classical surgical procedure is anchored in the surgeon's wealth of experience when performed in the operating theater. However, the majority of patients today are seriously ill and require intensive therapy. For this group of patients, the necessary transport to and from the operating theater can pose an additional considerable vital risk. A further aspect in times of scarce material and human resources is the considerable expenditure for transporting an intensive care patient.

In addition, the tracheotomy is not a sterile operation due to the opening of the respiratory tract, which is per se inhabited by respiratory germs.

In the discussion with intensive care physicians, who often prefer the apparently simpler and self-performing puncture methods, patient safety and best practice take precedence over the respective underlying disease. Tracheotomy is only a supporting measure.

Wang et al. [4] reported over 200 bedside tracheotomies without major complications. The cost analysis showed US$ 233 for the bedside surgical tracheotomy, US$ 1000 for the dilatational tracheotomy and US$ 3000 for the surgical tracheotomy in the operating room. You et al. [5] reported 163 bedside tracheotomies compared to the same number in the operating room. They found no difference in complications, a cost reduction of US$ 4600 per bedside tracheotomy and sooner weaning as the tracheotomy was performed earlier.

Each ENT surgeon should work with their intensive care physicians to develop a solution to perform the majority of surgical tracheotomies on the bed side, applying appropriate safety standards. Exceptions can be patients with a BMI ≥ 40 and patients with coagulation disorders difficult to correct, as the technical conditions in the operating room are significantly better.

6.5 Performing the Intervention

Ideally, the operation should take place in the operating theater under optimal technical and staffing conditions. Alternatively, tracheotomy on the bedside is possible under similar conditions. The procedure can be performed under intubation anesthesia or local anesthesia with or without anesthesiological stand-by.

The surgical site of the neck is shaved. As a rule, the patient with an overstretched neck should be positioned on the back, e.g., by placing a roll under their shoulders. This is not always possible with local anesthesia, as salivary aspiration with cough irritation may occur, worsening latent respiratory insufficiency. In such a case, the operation must be performed with the upper body elevated. A tracheotomy under local anesthesia should always be performed by an experienced surgeon due to the required speed and difficulties caused by other positioning.

After skin disinfection and sterile covering, the procedure is performed step by step:

- *Identification of landmarks for anatomical orientation*

Palpation of the shield and ring cartilage as well as the jugulum is always necessary. If the larynx cannot be palpated, the midline is identified by the jugulum and chin apex and the skin incision is made in the craniocaudal axis at the transition from the lower to the middle third (Fig. 6.1)

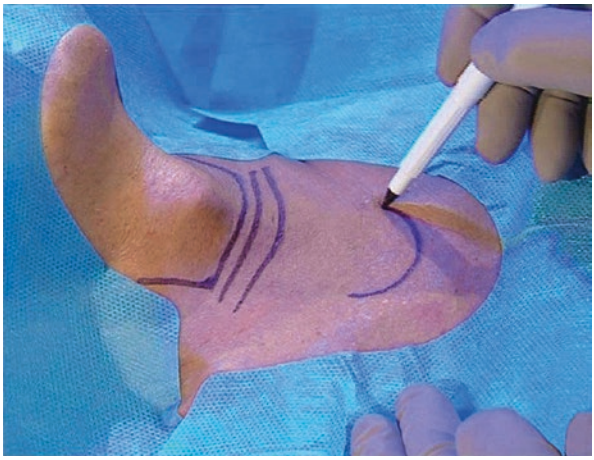

Fig. 6.1 Marking the anatomical landmarks

- *Infiltration with local anesthetic*

To reduce blood loss and local trauma, fan-shaped infiltration with lidocaine 0.5–1.0% with adrenaline 1:100,000 is recommended.

If the intervention is performed under local anesthesia, the deeper layers should also be infiltrated. In this case, some local anesthetic should be applied to the tracheal lumen before opening the trachea in order to mitigate cough irritation when opening the trachea.The maximum permissible doses of lidocaine must be observed (3 mg/kg bw/day without adrenaline; 5 mg/kg bw/day with adrenaline addition) (Fig. 6.2).

- *Skin incision*

The incision should always be made along the skin tension lines "Relaxed Skin Tension Lines" (RSTL) transverse to the trachea. This is the only way to achieve good esthetic results. For these reasons, the previously customary longitudinal incision should be avoided.

- *Severing the platysma*, ligation of straight neck veins
- *Separation of the straight neck muscles in the Linea alba*

The severing should be done strictly in the midline of the alba line to avoid bleeding and to facilitate orientation in the situs (Fig. 6.3).

- *Severing the thyroid isthmus*

After severing the straight neck muscles, one comes across the thyroid gland, which can represent itself in anatomical variants. Careful extracapsular preparation is necessary to avoid heavy bleeding from the thyroid veins. First, the ring cartilage

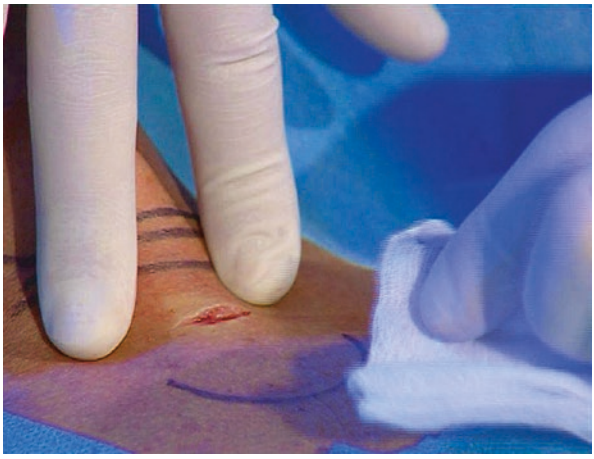

Fig. 6.2 Skin incision

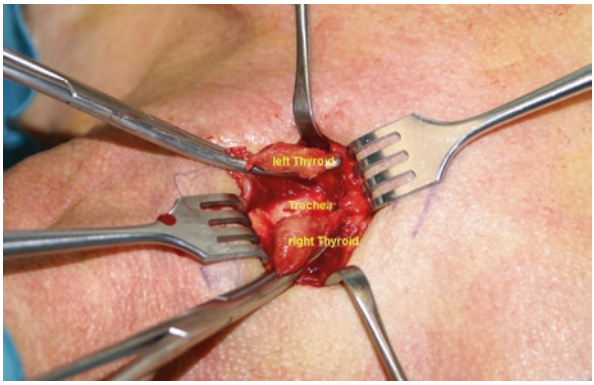

Fig. 6.3 Severing and intercepting the thyroid isthmus

is identified from the cranial side (as an important guiding structure to be protected during the subsequent formation of the stoma) and the thyroid isthmus is lifted from the trachea by a transverse incision of the fascia. Now the thyroid isthmus can be passed under with a clamp or closed scissors with their tips pointing towards the trachea and further detached from the trachea. The thyroid isthmus is then clamped out with two large curved clamps and severed with a scalpel. It is important that the tips of the clamps cross closely caudally to avoid bleeding from undetected thyroid gland parts. After severing, the two ends are serged extracapsularly with a resorbable strong suture. Should severing the entire isthmus at once prove impossible, all the procedure is repeated. The cervical trachea is then completely laid bare. Excessive lateral exposure of the trachea should be avoided in order not to endanger the laterally inward pulling nutritive vessels of the trachea and the deeper lying recurrent nerve.

- *Creating the tracheostoma*

The surgeon should reliably identify the ring cartilage and tracheal braces and then perform the incision. Ideally, the trachea should be opened between the second and third or third and fourth tracheal braces in order to maintain a sufficient distance between the tracheostoma and the ring cartilage. The actual incision of the trachea takes place transversely in the intercartilaginous cleft (Fig. 6.4).

There are two ways to create a stoma:

- *The visor tracheotomy:* The transverse incision itself becomes a tracheostoma, and the caudal and cranial braces are connected to the skin by looping sutures. The advantage of this procedure is a slight trauma to the tracheal cartilage without loss of substance. This type of tracheostoma is to be preferred for temporary, short-term tracheotomies [6, 7].
- *Creating a tracheostoma with the Björk flap* [8]*:* The caudal tracheal braces are incised vertically on the right and left so that the anterior part can be sutured to the skin as a caudally stalked flap. This procedure has the advantage

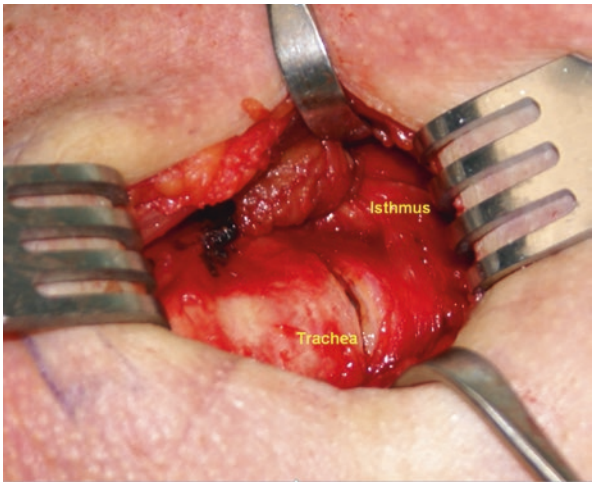

Fig. 6.4 Incision of the trachea

that in thicker necks, the increasing distance between the trachea and the skin anatomically given to the jugulum can be bridged under less tension. The disadvantage is greater cartilage damage to the trachea. The desired repositioning of the cartilaginous flap during tracheostomy is, however, only rarely possible because the flap in its original form can no longer be found due to resorption.

In all tracheostomy incisions, care must be taken to ensure that the lateral parts of the tracheal brace used are affected as little as possible in order to obtain a sufficiently stable and large tracheal diameter for the later tracheostoma closure.

All other methods described in the literature, e.g., cutting out a cartilage window [9, 10] or the longitudinal incision of the trachea over several braces should no longer be used due to the larger substance defects of tracheal cartilage with the risk of later tracheal stenosis and a significantly increased expenditure on plastic reconstruction during closure (Figs. 6.5 and 6.6).

- *Creating the mucocutaneous anastomosis*

First, caudally and cranially, approx. three resorbable sutures are placed with an atraumatic needle in order to fix the skin without tension to the cranial and caudal tracheal braces, including the caudal Björk flap, and then all sutures are knotted. It is important that the assistant approaches the skin with two surgical forceps so close to the trachea that tension-free sutures result. Skin wrinkles and pocket formation ("dog ears") should be avoided. The lateral sutures are also decisive for achieving a circular mucocutaneous anastomosis, which significantly reduces the risk of infection of the tracheostoma.

First the skin of the caudal or cranial flap is pierced, then the lateral tracheal wall and then the skin of the other flap from the underside. When knotting all sutures,

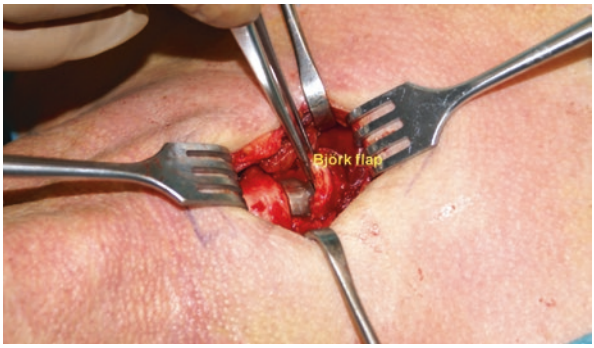

Fig. 6.5 Creating the Björk flap

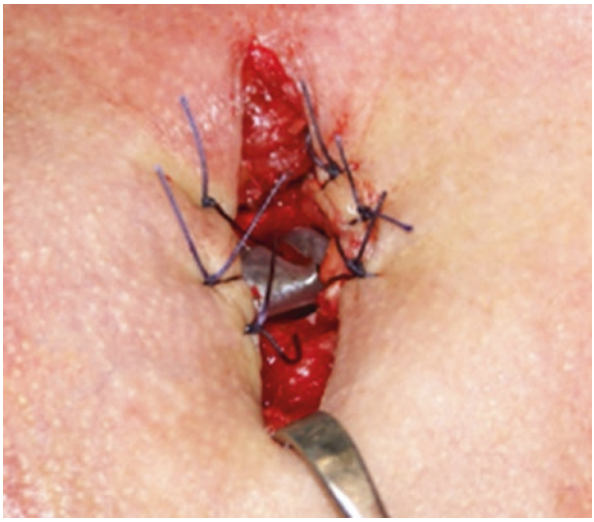

Fig. 6.6 Mucocutaneous anastomosis

make sure that the ever so often delicate tracheal braces do not tear (Fig. 6.7). The tendency to fracture the braces results from their histological quality (Chap. 4).

If this is done on both sides of the tracheostoma, a safely circularly epithelialized tracheostoma results. In order to achieve low tension, a circumscribed subcutaneous fat reduction must occasionally be carried out, which can be reversed when the tracheostoma is closed later. When applying the peristomal sutures, the cuff of the tracheal tube must be instrumentally protected to ensure safe ventilation. In consultation with the anesthetist, a caudal tube displacement can be helpful (Fig. 6.8).

- *Inserting the tracheostomy tube*

After completion of the operation, the tracheostomy tube is inserted, the integrity of which must be checked beforehand. The anesthetist unblocks the oro-tracheal tube and withdraws it. At the same time, the tracheostomy tube is carefully inserted.

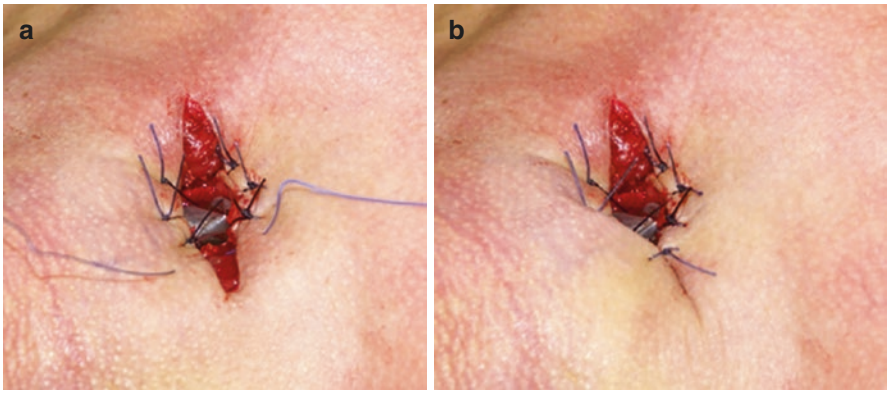

Fig. 6.7 (**a**) Lateral sutures, suture tracking. (**b**) Lateral sutures knotted

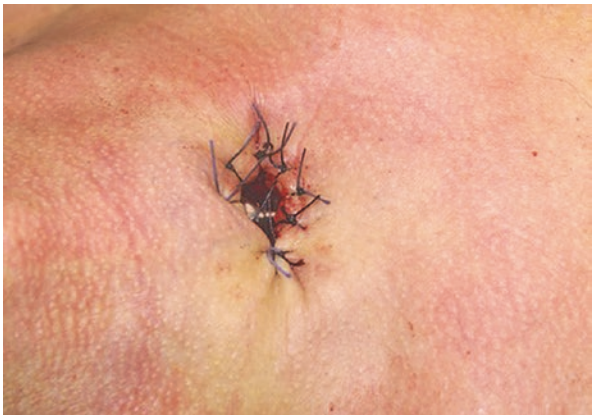

Fig. 6.8 Completed tracheostoma

A nasal speculum with long branches (Killian speculum) is recommended as an aid for gently keeping the tracheostoma open. Size and type of the tracheostomy tube are decided individually.

6.6 Surgical Tracheotomy of the Fat Neck

Patients with a BMI of 30 kg/m^2 or more are considered risk patients. Surgical tracheotomy should be performed on them under general anesthesia in an operating room. For overstretched positioning, a stretch bandage is recommended under the chin for tightening the surgical site by cranial retraction and subsequent marking of the guiding structures. Uncomplicated aftercare is facilitated by systematic fat reduction at the neck, "defatting tracheotomy" [11, 12]. The systematic fat reduction should be carried out for further reasons: significantly better anatomical

overview, reduction of the depth of the stoma canal, reduction of tension in the circular stoma shaft and avoidance of the dreaded scenery phenomenon when changing the tracheostomy tube. The tracheostomy tube should be secured with thick sutures on the cervical skin, as accidental decannulation can have fatal consequences in this risk group. In obese patients, a tracheostomy should always be performed, not a tracheotomy.

6.7 Mediastinal Tracheostomy

Anterior mediastinal tracheostomy is performed in rare indications and only in isolated cases of radical and reconstructive thoracic surgery [13].

6.8 Care Following Tracheostomy

The main postoperative functional problem is the loss of nasal functions (filtering, moistening, warming up, smelling), combined with a tendency of the trachea and the tracheostomy tube to become corked. Due to the lack of nasal functions in tracheostomy respiration, intensive inhalation therapy is required to moisten the breathing air. The tracheal secretion should be sucked off regularly with a flexible suction device with controllable suction (so-called finger tip). To avoid accumulation of secretion in the larynx and upper trachea with blocked tracheostomy tubes, tracheostomy tubes with a separate suction channel are available (Examples Fig. 6.9 and Chap. 19 Fig. 19.3).

For microclimate control it is advantageous if the tracheotomized patient carries a so-called "artificial nose" on his tracheostomy tube. This is a foam filter which, in addition to coarsely filtering the breathing air, retains the moisture in the exhaled air and thus humidifies the inhaled air. This reduces the considerable loss of liquid by the tracheotomy patient via the breathing air.

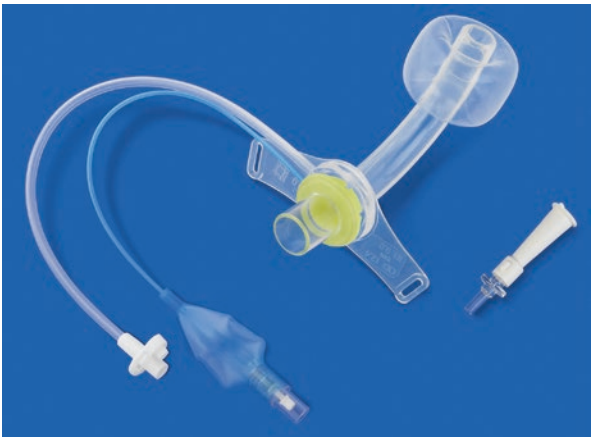

Fig. 6.9 Suction tracheostomy tube PRIMA-DYS® (of the type HEIMOMED, made by Atos Medical GmbH Troisdorf, Germany)

The first scheduled tracheostomy tube change after surgical tracheotomy usually takes place on the second postoperative day in order to achieve a certain resting phase for wound healing. The tracheostomy tube change should always be carried out under good illumination and with a suction system at the ready. After removal of the old tracheostomy tube, the tracheostoma is cleaned, disinfected and the new tracheostomy tube inserted. In anatomically difficult situations (thick neck, deeply located tracheostoma) the change via a stylet (e.g., suction catheter) and with the help of a nasal speculum has proven successful.

In problematic situations with tracheostomy tube displacement and shortness of breath, the tracheostomy tube can be changed at any time due to the epithelialized tracheostoma.

In the further course, mobile patients who are to be discharged with the tracheostoma on schedule or their relatives must learn how to change their tracheostomy tube independently and how to care for the tracheostoma. Furthermore, for this group of patients, care must be provided via a medical aid prescription with a so-called initial equipment kit, which includes a suction and an inhalation device as well as medical aids for tracheostomy tube care (example Fig. 6.10).

The cooperation with an experienced aid company and a social service in the field of tracheostomy care has always proven successful (Fig. 6.11).

Fig. 6.10 Initial equipment kit (HEIMOMED, Atos Medical GmbH Troisdorf, Germany)

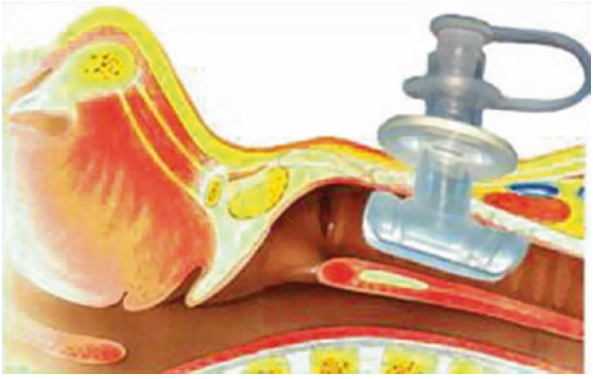

Fig. 6.11 Stoma button in situ

6.9 Stoma Buttons

If a tracheostoma closure is unsafe due to the underlying disease and the breathing work to be performed, the possibility of inserting a placeholder button in the stoma should always be considered in order to avoid retracheotomy. With this decision, a patient can easily be transferred to rehabilitation (Chap. 17).

For special instructions regarding stoma care, please refer to Chaps. 18 and 19.

6.10 Complications in Surgical Tracheotomy

Typical complications are postoperative bleeding. In the case of minor seepage bleeding, a strip tamponade can be placed in the tracheostoma around the tracheostomy tube and fixed to the tracheostomy tube. Major bleeding requires surgical revision, which may require coagulation substitution.

In the literature there are numerous publications with retrospective comparisons of surgical and dilatational tracheotomy [2, 14]. An increased rate of wound infections after surgical tracheotomy is listed there. Meininger et al. [15] described wound infection rates of 4.8% in dilatational tracheotomy and 12.4% in surgical tracheotomies. Oliver et al. [16] found similar results in a metanalysis. Straetmans et al. [17] reported 10.9% wound infections and 4.2% postoperative bleeding in 303 surgical tracheotomies. However, the type of epithelialization of the tracheostoma is never described in any of the studies, which results in publication bias. With the circular epithelialization mentioned above, we have seen very few postoperative wound infections in recent years. Nor are there any prospectively randomized studies to compare surgical and dilatational tracheotomies.

While early complications are relatively well investigated, there are only cursory reports on *late complications* in the literature without any evidence-based studies. These reports repeatedly describe individual cases of severe *tracheal stenoses* without valid data on incidence being available [2]. Therefore, a reliable statement regarding late complications is currently not permissible and will be left to future prospectively randomized trials. The same applies to cartilage-protecting procedures. Unfortunately, apart from the work by [6], there are no follow-up examinations on the long-term postoperative course after closure of a surgical tracheostoma. In a recent systematic review, no significant difference between open surgical and percutaneous dilated tracheotomies could be found with regard to mortality and intraoperative and postoperative bleeding complications [14]. Important for surgical tracheotomy to avoid complications is the exact anatomical orientation and presentation of the guiding structures. What is of importance to avoiding complications in surgical tracheotomy is the exact anatomical orientation and presentation of the guiding structures. The absolutely worst case is a tracheotomy through the ring cartilage (Fig. 6.12) due to incorrect anatomical orientation, as we had to diagnose in a patient presented to us.

Very *rare complications* are the postoperative *recurrent paresis*, *pneumothorax*, *tracheoesophageal fistula* and subcutaneous or mediastinal *emphysema*. Postoperative recurrent paresis is one of the rarities of complications but is possible

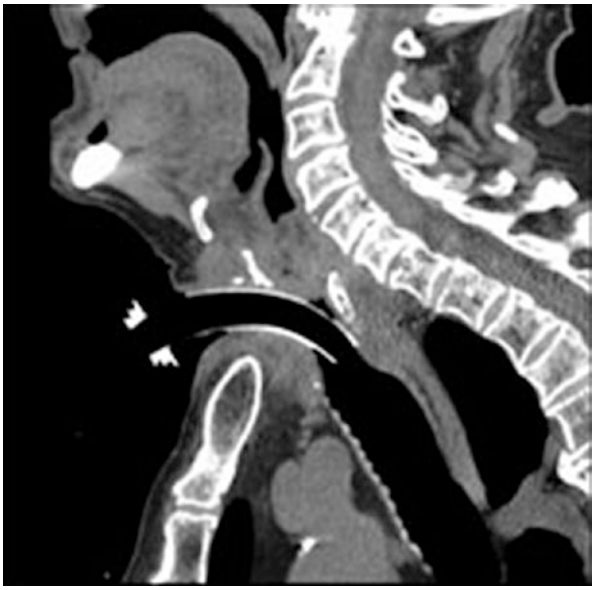

Fig. 6.12 Tracheotomy through the ring cartilage

if the preparation is too far lateral. Emphysema may occur when the patient coughs against the blocked tracheostomy tube. Tracheoesophageal fistulas after proper surgical tracheotomy are very rarely possible. However, it is always difficult to differentiate afterwards whether the fistula was caused by surgery or by trophic disturbances during long-term intubation. In the last 20 years, we have treated two tracheoesophageal fistulas after tracheotomy. Both patients had circulatory disorders and had been intubated for a long time (hemorrhagic shock, pronounced arteriosclerosis).

All in all, surgical tracheotomy is a safe and low-complication intervention if the surgical principles are observed.

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Pediatric Tracheotomy

7

Dietmar Thurnher

7.1 Introduction

The indications for surgical airway safety in the pediatric population have changed significantly in recent years. In the past, pediatric tracheotomies were mostly performed as emergency measures in acute airway obstructions, such as acute epiglottitis. Vaccination programs, rational antibiotic therapy and advances in pediatric intensive care and anesthesia have led to the fact that tracheotomies in infants and toddlers being carried out selectively for cardiopulmonary diseases, neurologic disorders, congenital and acquired craniofacial disorders with upper airway obstructions and airway stenoses including acute airway infections [1]. Therefore, any necessity for long-term mechanical ventilation is an indication for pediatric tracheotomy [2], whereby in the case of burns, for example, the extent of the affected body surface determines the subsequent duration of the tracheostomy [3].

Fifty to Seventy percent of tracheotomized children today are under age one [4, 5]. A national database of 24,354 pediatric tracheostomies in the United States showed permanent tracheostomies in 13% and temporary tracheostomies in 87% [6].

Typical indications for pediatric tracheotomy are:

1. Long-term intubation due to pulmonary malformations and/or infections, bronchodysplasia or neuromuscular diseases;
2. Airway obstructions due to subglottic stenosis, bilateral vocal fold paresis, laryngeal atresia or a rare head and neck malignancy in the pediatric population.

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7.2 Preliminary Anatomical Remarks

7.2.1 Anatomical Differences in the Upper Respiratory Tract of Infants and Adults

Infants and young children have a very large occiput in relation to the body, a relatively short neck and a soft ribcage. Therefore, infants or toddlers lying on their backs may already suffer from respiratory obstruction due to neck flexion caused by the back of the head. Therefore, a shoulder roll must be placed before any surgical intervention begins [7].

The larynx of infants and toddlers is much more funnel-shaped than that of adults and is also much higher in the neck. In infants and toddlers, the epiglottis is located at the level of the cervical vertebrae C2-3/C3-4, whereas in adults it is located at the level of the cervical vertebrae C4-5. This results in a more acute angle between the base of the tongue and the glottis in infants than in adults. According to clinical-anatomical [8] and new radiological measurements [9], the narrowest point of the child's airway is the subglottic area and not, as originally assumed, the cricoid alone [10]; in adults, it is the glottis plane. The trachea is very short in the toddler with approx. 5 cm and has a diameter of 4–5 mm. Even small injuries in the narrow airway can lead to edema with high airway resistance.

7.2.2 Anatomical Peculiarities of Infants and Toddlers for Emergency Airway Management [7]

1. The relatively larger tongue of the infant or toddler which is close to the hard palate, which can make intubation much more difficult;
2. A relatively larger and stiffer epiglottis, which, at approx. 45° to the vertical plane, is tilted backwards over the glottis much further than in adults.
3. The size of the cricothyroid ligament (Ligamentum conicum), because here in adults in the case of a "can't intubate, can't ventilate" situation, a cricothyroidotomy = coniotomy is performed. In the infant, the Ligamentum conicum has an area of approx. 3 × 3 mm and the trachea a diameter of approx. 4–5 mm.
4. Moreover, in infants and toddlers, the lung tips are positioned cranially across the clavicle, which significantly increases the risk of pneumothorax and emphysema.
5. The very large occiput in relation to the body in infants and young children requires a different positioning of the patient than in adults, since flexion of the head leads more quickly to a collapse of the respiratory tract.
6. Due to the small anatomical dimensions of the laryngeal skeleton, no "classical" coniotomy may be performed on infants and small children, i.e., under 5 years of age, and no percutaneous dilatational tracheotomy may be performed on adolescents under 15 years of age.

Pediatric tracheotomy is not an emergency procedure, but usually an elective surgical intervention.

In emergency airway management for infants and young children, the following measures are available for the reasons described above:

1. Endotracheal intubation
2. Establishment of an extraglottic airway using a laryngeal mask. If oxygenation and ventilation is possible in an emergency situation with a laryngeal mask, a tracheotomy can also be performed immediately.
3. Ventilation via face mask
4. The needle coniotomy/needle tracheotomy as an emergency measure in a "can't intubate, can't ventilate" situation (on how to carry it out Chap. 8.).

If the child is to be oxygenated to some extent with non-invasive measures, preclinical trials of an invasive airway safety device should definitely be avoided. Such attempts only appear to be indicated if this is the only way to preserve life [11].

7.3 Patient Positioning and Anatomical Landmarks

7.3.1 Positioning

In order to compensate for the very large occiput of the infant or toddler in relation to the body, it is absolutely necessary to place a correspondingly large shoulder roll even in an emergency situation and, at the same time, to recline the chin of the infant or toddler. For this purpose, an assistant holds the child's chin back while the surgeon glues a wide and long strip of plaster from the chin to the rear edge of the operating table on both sides of the head [12]. If these two procedures are not carried out carefully even under time pressure, the further measures described below may be compromised.

7.3.2 Anatomical Landmarks

After appropriate positioning, the easiest landmark to feel in an infant is the jugulum. The most prominent landmark of the laryngeal skeleton is the ring cartilage, the shield cartilage at this age is usually located behind the hyoid bone. There is still a lot of subcutaneous fat in the anterior neck of the infant, which may make it difficult to feel the landmarks. The jugulum and the position of the cricoid are marked with a marker pen (Fig. 7.1).

7.4 Performing the Pediatric Tracheotomy

7.4.1 General Preliminary Notes

In contrast to tracheotomy in adults, the operation cannot be performed under local anesthesia, but only under general anesthesia. Both surgical methods for children

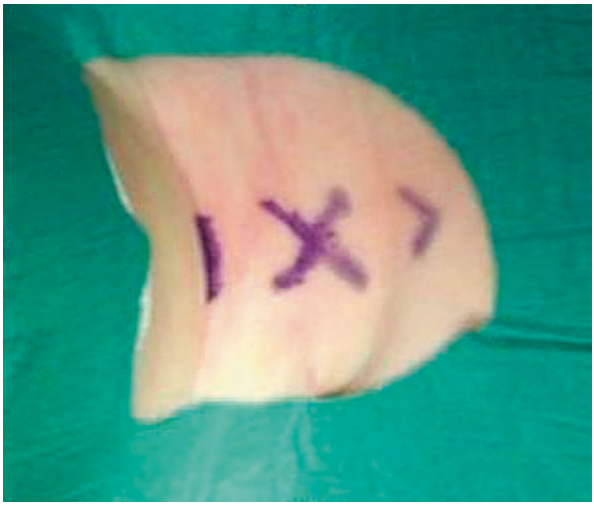

Fig. 7.1 Marking the jugulum, cricoid and surgical site

presented here relate to very small surgical areas with a trachea of a few millimeters in diameter. The use of surgical magnifying glasses and the assistance of two assistant doctors is recommended. Due to the dimensions of the anatomical structures and due to possibly lifelong consequences of errors resulting from the operation, it should be in the hands of experienced airway surgeons.

7.4.2 Conventional Surgical Tracheotomy [12]

Method

Overstretching of the head (see Sect. 7.3.1)

Marking the landmarks (see Sect. 7.3.2)

Infiltration of the surgical area with local anesthetic

Infants and toddlers have an operation area of a few square centimeters, in the case of Starplasty even with only one cross-shaped skin mark of about 1 × 1 cm in the center. This area is injected with, e.g., Xylonest 0.5% with adrenaline 1:250,000 (dose to be adapted to body weight and body condition, from 6 months of age).

Horizontal skin incision and skin flap preparation

While the primary vertical skin incision used to be common in the midline of child tracheotomies [13], this approach has become rare today and has been abandoned for a horizontal incision [12].

Before the incision, an appropriate horizontal marker is placed. The horizontal skin incision is made in the middle between the jugulum and the cricoid, whereby the length of the incision also depends on the age of the child (approx. 1.5–2.5 cm). Subsequently, an upper and lower superficial skin flap are prepared. There is always plenty of subcutaneous fat in infants and toddlers. This must be carefully removed with cold or hot instruments, e.g., with a monopolar needle, so that the fascia of the infrahyoid musculature is visible. However, the fat should not be confused with the

thymus gland, which is still large at this age and which is characterized by a slightly darker color.

Splitting the infrahyoid muscles and severing the thyroid isthmus

The surgeon and his assistant grip the infrahyoid muscles on both sides of the Linea alba, and the surgeon opens the same. The musculature is dissected from the isthmus of the thyroid gland or the anterior wall of the trachea, respectively. The isthmus of the thyroid gland is laid open and can easily be severed in infants and toddlers with an electrical instrument, e.g., a monopolar needle. In this case, ligation of the isthmus stumps can usually be waived.

Note: When using electrical instruments on or in the respiratory tract, strict care must be taken to early reduce the oxygen concentration in the air to below 30% by volume, otherwise there is a risk of airway fire. This should be discussed in advance with the anesthetist. Subsequently, the anterior tracheal wall is exposed with delicate sliding movements with a swab.

Vertical incision of the trachea and creation of a tracheostoma

The anesthesiological team should be informed of opening of the airway before doing so. The anterior tracheal wall is vertically incised at the height of the tracheal braces 3 and 4 in the midline. The tracheal rims are now fixed to the skin with four sutures so that the stoma remains open during accidental decannulation. To facilitate tracheostomy tube replacement, these skin sutures can be left long so that the stoma can be enlarged by pulling them on both sides.

In infants and young children, a single horizontal incision of the trachea, common in adults, should be avoided as this may promote the development of suprastomal subglottic stenosis [14].

Tracheostomy tube insertion

Now the anesthetist retracts the endotracheal tube until the tip is just visible at the upper edge of the stoma. Now a correspondingly large tracheostomy tube can be inserted and secured at the edge of the stoma or around the neck with a tracheostomy tube strap.

7.4.3 Starplasty [15]

The procedure is the same at the beginning as for the standard method.

Overstretching of the head

Marking the landmarks

Drawing in the cut marker

In starplasty, a square of a side length of one centimeter is drawn with its corner points between the markings for the cricoid and the jugulum at half height. The corner points are now connected to form a cross tilted by 45°, which corresponds to the cutting lines of the skin incision (Fig. 7.6). This area is injected with 1ml Xylonest 0.5% with adrenaline 1:250,000.

Skin incision and lifting of the skin flaps

The skin incision is made with a small blade (No. 15) (Fig. 7.2). The small skin triangles are undermined beyond their borders with scissors (Fig. 7.3). The edges of

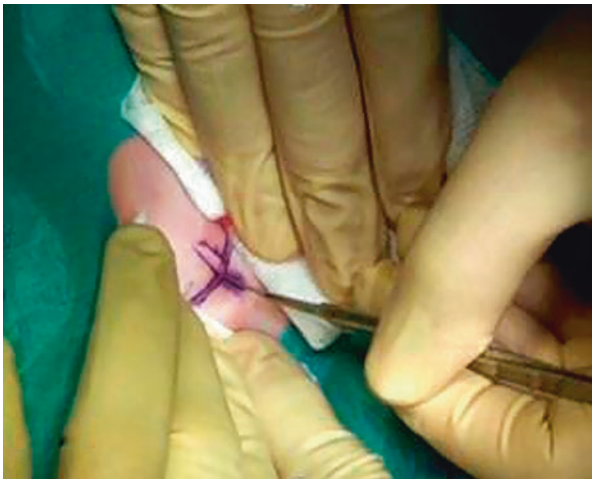

Fig. 7.2 Skin incision

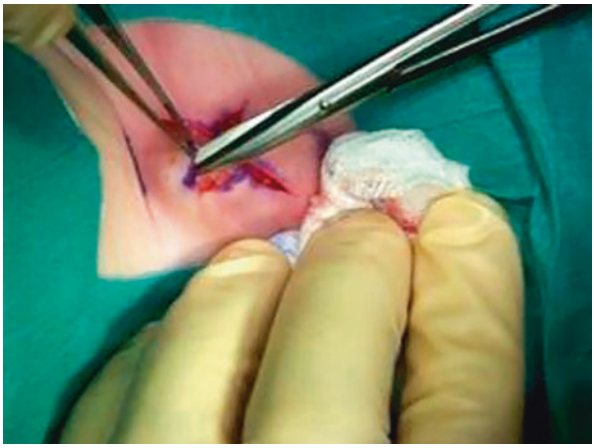

Fig. 7.3 Undermining the skin flaps

the skin are now held by the assistant, e.g., with fine bone hooks. In the small operation area, the abundant subcutaneous fat becomes visible. In the next step, the subcutaneous fat is sharply removed in the surgical area up to the fascia of the infrahyoid musculature with cold or hot instruments (Fig. 7.4).

Splitting the infrahyoid muscles and severing the thyroid isthmus

The next step is performed in analogy to the standard method: The surgeon and assistant grip the infrahyoid musculature on both sides of the alba line, which is sharply severed (Fig. 7.5). The muscles are then removed from the isthmus of the thyroid gland or the anterior wall of the trachea, respectively, and retracted laterally. The isthmus of the thyroid gland is exposed and can easily be severed in infants and toddlers, e.g., with a monopolar needle (Fig. 7.6). Alternatively, the isthmus can also be conventionally ligated and severed. The paratracheal fascia is then severed and the tracheal anterior wall is displayed (Fig. 7.7).

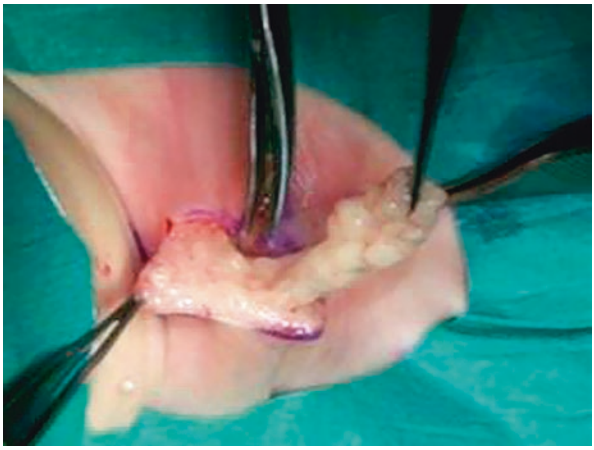

Fig. 7.4 Resecting the subcutaneous fat tissue

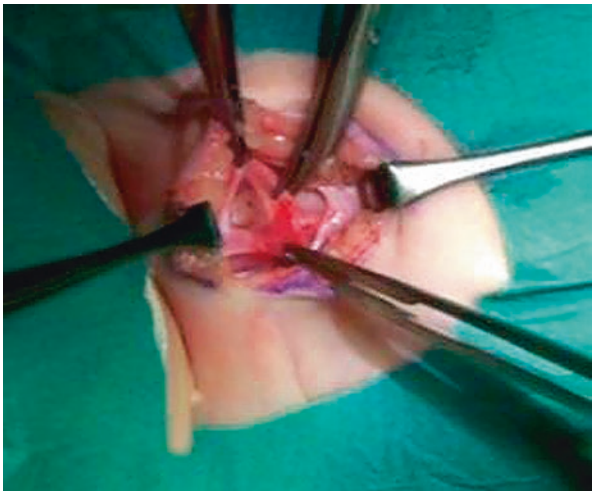

Fig. 7.5 Severing the Linea alba

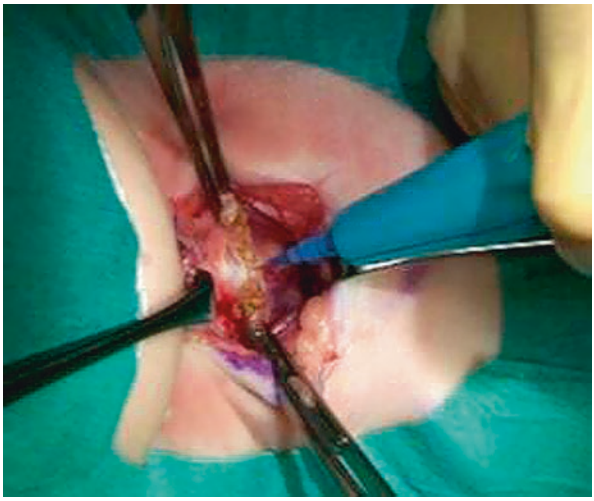

Fig. 7.6 Severing the thyroid isthmus

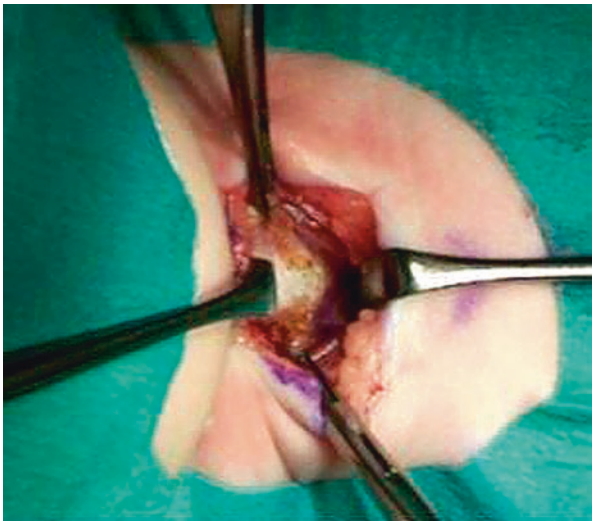

Fig. 7.7 Anterior tracheal wall

Cross-shaped incision of the trachea and creating a tracheostoma

In starplasty, a "plus" or "cross" incision is cut into the trachea. The horizontal incision is made between two tracheal braces. Then, one to two tracheal braces above and below the horizontal incision are cut vertically in the median (Figs. 7.8a, b and 7.9. Depending on the size of the infant or toddler, a resorbable suture is used, e.g., Vicryl® 4-0 or 5-0, whereby a vertical backstitch suture is set here so that it lies outside the tracheostoma (Fig. 7.10). The final result of the starplasty is a small circular tracheostoma, which is stable due to tissue tension and does not collapse even with accidental decannulation (Fig. 7.11a, b).

Tracheostomy tube insertion

Now the anesthetist retracts the endotracheal tube until the tip is just visible at the upper edge of the stoma. Now a correspondingly large tracheostomy tube can be inserted (Fig. 7.12) and sutured to the skin around the tracheostoma or with a tracheostomy tube strap.

Intraoperative hazards

In infants and toddlers, the pleural tips are positioned more cranial over the clavicles than in adults. In both surgical procedures of tracheotomy, preparation far laterally should be avoided.

The innominate artery is significantly higher in infants or small children than in adults and crosses the trachea in the neck area at variable height. After median splitting of the infrahyoidal musculature, the surgeon should palpate the area of the jugulum and the area of the jugulum in order to early detect a possible innominate artery "ride-up".

Fig. 7.8 (**a**) Incision scheme (Drawing by C. Gerstenberger). (**b**) Cross-shaped opening of the trachea

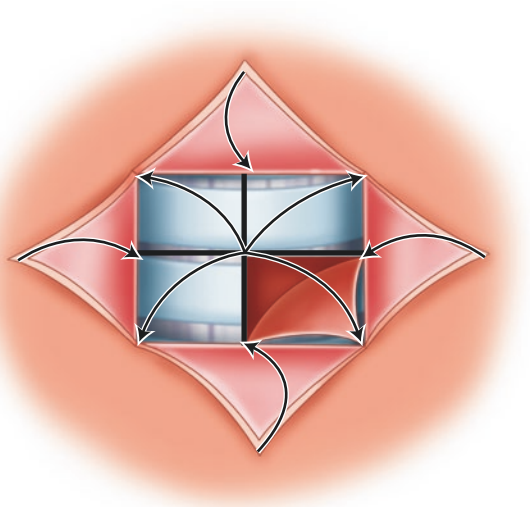

Fig. 7.9 Fixing the retracted skin and cartilage tips by sutures (Drawing by C. Gerstenberger)

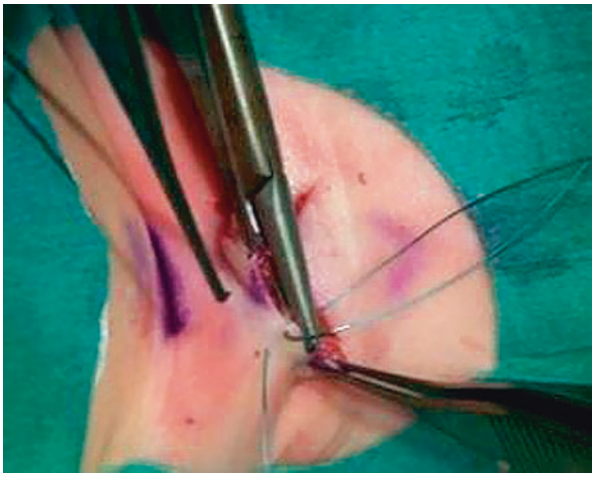

Fig. 7.10 Making backstitch sutures for suturing the stomas

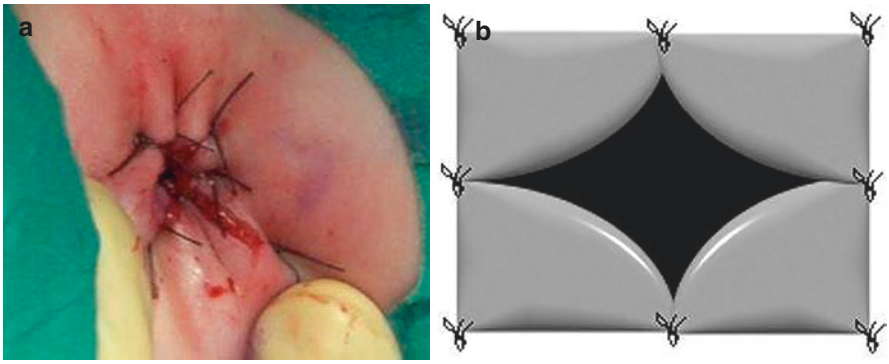

Fig. 7.11 (**a**) Stoma completed. (**b**) Schematic image of the sutured tracheostoma in starplasty (Drawing by C. Gerstenberger)

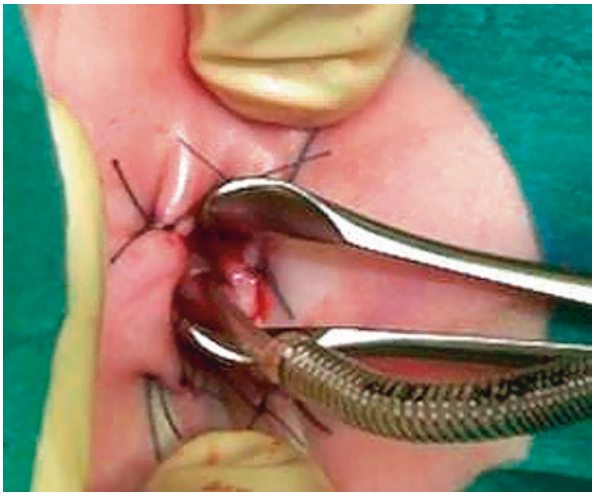

Fig. 7.12 Inserting the tracheostomy tube

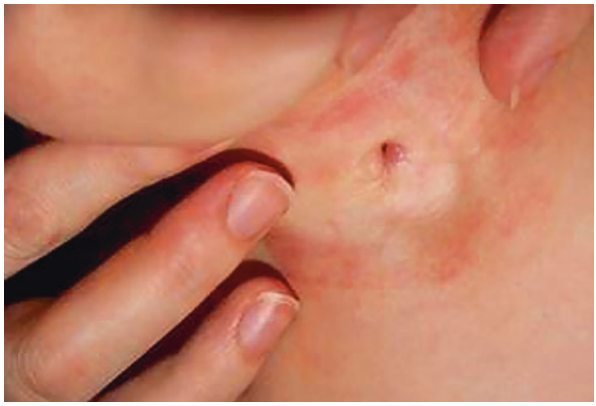

Fig. 7.13 Persistent tracheocutaneous fistula after starplasty. Courtesy of Prof D.M. Denk-Linnert, Medical University of Vienna, Austria

7.4.4 Comparison of the Conventional Surgical Method with Starplasty

The advantage of starplasty compared to the standard method is a small and stable tracheostoma which is sutured in a circular way.

In the literature, early complications after starplasty are very rare [16]. Even with accidental decannulation, there is no stoma collapse and a possibly resulting lethal complication. Another advantage of starplasty is a lower rate of wound infections and a reduced risk of emphysema and pneumothorax [17]. The disadvantage is a longer duration of the operation. It can be assumed that in most cases a persistent tracheocutaneous fistula will remain after decannulation, which must be closed secondarily [18] (Fig. 7.13). However, the rate of tracheocutaneous fistulas after standard tracheotomy is reported to be up to 31% [19].

Clinical note: Starplasty should always be considered in childhood patients with chronic diseases, especially neurological ones with little hope of a decannulation [20].

7.5 Aftercare

The main dangers in aftercare are accidental decannulation and the obstruction of tracheostomy tubes by obstructions. Due to the small airways, the small diameters of the tracheostomy tubes and the inability of infants to make themselves felt, both situations can quickly become life-threatening. In follow-up care, infants should therefore be visited more often than is usual for adults. Stoma care, tracheostomy tube replacement and humidification of the respiratory air are carried out according to the same criteria as for adults. However, an intervention, e.g., a tracheostomy tube change, should only be carried out in the presence of trained personnel. In addition to assistance with the actual tracheostomy tube change, a second specialist is required to hold the child. Since one of the most frequent lethal complications is the obstruction of tracheostomy tubes with crusts or plugs, they must be regularly cared for and changed.

7.6 Complications

Pediatric tracheotomy is a surgical procedure of high morbidity and mortality, which are 2–3 times higher than in adults [21]. In Corbett et al. [21, 22], mortality in children after tracheotomy was approximately 20%. The rate of tracheotomy-related deaths is stated in the literature to be 0.5–3.6% [23, 24], the risk of accidental decannulation was described as 6.3% [25]. In a retrospective cohort study with a total of 18,806 tracheotomized children and adolescents, Berry et al. [26] showed that there is a significant correlation between increased mortality and tracheotomy in children with congenital heart defects, under-1-year-olds and preterm births.

The literature generally distinguishes between early complications up to 7 days after surgery and late complications more than 7 days after surgery. A review showed early complications in 5.6–22.6% and late complications in up to 85.4% [27].

Stoma infections were observed in 8% [25].

A very frequent occurrence are granulation formations on the stoma, which usually have no consequences for the further course of the disease and are often not regarded as real complications in the literature.

7.6.1 Early Complications

Emphysema
- Pneumomediastinum
- Pneumothorax

Hemorrhage due to wound granulation

Tracheostomy tube obstructed by crusting

Accidental decannulation

Common early complications include emphysema, pneumomediastinum and pneumothorax [28].

Displaced or obstructed tracheostomy tubes and accidental dislocations are potentially life-threatening. Adequate air humidification, stoma care and regular tracheostomy tube changes should be strictly observed.

Accidental tracheostomy tube dislocations or complete decannulation are indicated in the literature at 1–18% [25, 29], whereby this occurs more frequently with small children than with infants, since these are motorically more active.

7.6.2 Late Complications

Suprastomal narrowness
Collapse
Subglottic stenosis
Tracheomalacia
Tracheocutaneous fistula

In an assessment including 44 children having a tracheostomy tube, 70% presented problems in the oral and/or the pharyngeal phase of swallowing, 43% aspirated [30].

Subglottic stenoses as a long-term consequence of pediatric tracheotomy are relatively rare in the literature and are reported at a rate of 3–6% [24]. Stenoses have far-reaching consequences (Chap. 12).

7.7 Decannulation

In a review by Mahedevan et al. (2007), the successful decannulation rate of pediatric tracheotomy patients was 75%, in a Japanese database it was 39% in the median time of 12 month [31]. Due to diverse underlying diseases, the decannulation rates are different and very low in patients with chronic neuromuscular diseases.

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Coniotomy, a Life-Saving Emergency Measure

8

Dietmar Thurnher

8.1 Definition

Coniotomy = cricothyroidotomy describes the surgical severing of the Ligamentum conicum = cricothyroid ligament, which stretches between the shield cartilage and the ring cartilage of the larynx. Since, in this area, the respiratory tract comes closest to the skin, it can be opened and secured very quickly, safely and without complications by cutting this ligament. This can be done surgically or with needle catheter systems based on the Seldinger technique as "needle coniotomy" or with trocar systems.

8.2 Introduction

The coniotomy is a potentially life-saving measure in a "can't intubate, can't ventilate" situation. If securing the airway fails on the first three levels (level 1: spontaneous breathing, assisted ventilation or controlled ventilation with a face mask; level 2: extraglottic airway support; level 3: endotracheal tube), oxygenation via a translaryngeal or transtracheal access should be performed in case of impending asphyxia. Under no circumstances must the invasiveness of this measure or its dubious success in individual cases be interpreted to mean that an indicated coniotomy should be omitted for alleged safety reasons, as this would have fatal consequences (cerebral hypoxia, death) [1].

The need to perform a coniotomy is a rare event. In a retrospective review, coniotomies in the difficult airway management of the prehospital phase in trauma patients were reported as 0.6% [2], for the hospital phase as 0.06% [3]. In recent

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years, new methods have been introduced to secure the airway (intubation aids, video laryngoscopy, laryngeal masks, etc.) and training in the subject of the difficult airway has been improved (simulation training).

Coniotomies of all procedures can be practiced on cadavers or models, whereby even untrained persons were successful after a few attempts, depending on the study, after approx. 40–70 s. The competence achieved on the model for performing a surgical coniotomy can be directly transferred to the execution on the cadaver [4]. In some studies, non-surgical coniotomy is slightly superior in time [5–7]. In the study by Chrisman et al. [8], surgical coniotomy—performed by experienced anesthetists on a pig model—took the shortest time, followed by the VBM Surgicric II Surgical coniotomy set; the coniotomy performed with the Melker® set took the longest [8]. In a systematic review, no significant differences were found regarding the method or Seldinger-based sets used for coniotomy [9]. In addition to the time factor, the success rates of the various methods are, of course, of importance. In a randomized study by Helm et al. [10] with young anesthetists inexperienced in coniotomy, carried out on fresh corpses with subsequent immediate autopsy, a significantly higher success rate of 100% was found for the surgical technique compared to the puncture technique of 67%. For the puncture procedure with transtracheal jet ventilation, a failure rate of 42% was found in a systematic review [11].

In the guidelines of the Difficult Airway Society (UK), surgical coniotomy is given preference in a "can't intubate, can't oxygenate" situation [12].

Braun et al. [13] demonstrated that laypersons without or with only minimal anatomical knowledge were able to perform a coniotomy successfully in 80% of cases with two household appliances (pocketknife and ballpoint pen), but not always in an adequate time. In a recent statement, however, Mohr et al. [14] stated, "In order to make a clear evidence-based recommendation in favor of a puncture technique or a surgical preparation technique in the context of emergency cricothyroidotomy, the data situation is not sufficient at the moment."

8.3 Surgical Anatomy

The knowledge and rapid identification of the "surgical landmarks" by palpation form the basis for performing a coniotomy, regardless of the method used [15–17]. In comparison with neck sonography for the correct detection of the Ligamentum conicum, palpation by an experienced clinician is of equal value [18]. State-of-the-art ultrasound techniques enable us to identify sonoanatomy of thyroid cartilage, epiglottis, cricoid cartilage, cricothyroid membrane, tracheal cartilages and esophagus for decision-making before coniotomy [19].

8.3.1 Surface Anatomy

At first, the upper edge of the shield cartilage (Incisura superior of the thyroid cartilage) is palpated with index finger and thumb. This is particularly easy for men

with the comparatively prominent "Adam's apple". With the index finder, the front edge of the shield cartilage is now traced caudally until one slides into a depression. This is the point where the Ligamentum cricothyroideum = Ligamentum conicum stretches between the cartilage of the shield and the cartilage of the ring (cricoid cartilage). In persons with a very slender neck, the retraction of the skin can be seen at this point. If the index finger now slides out of this depression further caudally, it feels the relatively prominent ring cartilage, which is followed further caudally by the tracheal rings.

Below the ring-cartilage, the variably large thyroid gland lies before the trachea, which makes direct palpation of the tracheal rings impossible, except in persons with a very slim neck. Another surface landmark is the upper thoracic aperture, the jugulum, which can be palpated cranially of the sternum.

8.3.2 Ligamentum Conicum

The Ligamentum conicum stretches between shield cartilage and ring cartilage and anatomically represents the anteromedial part of the Conus elasticus. The blood supply to this fibrous ligament is relatively poor. There is no clinically relevant vessel or nerve in this area. The only exceptions are the variably occurring cricothyroid artery and vein; the artery is a branch of the laryngeal superior artery. These vessels run horizontally from both sides in the upper part of the ligament, i.e., at the lower edge of the thyroid cartilage. Furthermore, a variable Processus pyramidalis of the thyroid gland may run over the Ligamentum conicum, but mostly on the left side. In the anatomical study by [20], the authors therefore defined the lower right quadrant as the best puncture site for a needle coniotomy.

At the Ligamentum conicum, the airway comes closest to the skin of the neck, which is why in an emergency only this point is suitable to reach the airway quickly and with little complication from the outside.

8.4 Indication

- "can't intubate – can't ventilate" or "can't intubate – can't oxygenate" (CiCo)

The final stage of the algorithms for the management of the difficult airway is the "can't intubate – can't ventilate" scenario. For many years, an invasive procedure in the form of a coniotomy has been uniformly recommended in all guidelines [21]. "Emergency tracheotomy", repeatedly mentioned and propagated in the past and in the English literature also known as "slash tracheotomy", is too protracted and likely to inflict complications in the real emergency situation by the necessary ligature of the thyroid isthmus before opening the trachea. In contrast, coniotomy is a surgically simple procedure, which, after a few instructions on the cadaver or simulation model, can usually be performed in a short time even by beginners.

- Trauma patients with cervical spine injuries

- Severe midface fractures
- Severe bleeding from the upper aerodigestive tract
- Severe edema in the area of the upper aerodigestive tract
- Trismus/lockjaw
- Foreign object obstruction

8.5 Contraindications

8.5.1 Absolute Contraindications

The possibility of hassle-free intubation is, of course, a contraindication to coniotomy. The heaviest laryngeal traumas or tearing off of the trachea with retraction into the thorax make a coniotomy impossible.

8.5.2 Relative Contraindications

Infants and young children under the age of 5 have a very small Ligamentum conicum, which makes surgical coniotomy very difficult or even impossible [22]. In infants, for example, the ligament has a size of 3 × 3 mm. In this case, even an attempt at surgical intervention should be omitted and a "needle coniotomy" performed immediately.

8.6 Methods of Coniotomy

In addition to the surgical "classical" coniotomy, a so-called "needle coniotomy" with subsequent possible jet ventilation can be performed as an alternative method, especially for infants and small children. This ventilation method is used in the inpatient environment.

8.6.1 Method of Surgical Coniotomy [23]

1. Overstretching/retracting the head

The head should be reclined as far as possible. Time and situation permitting, a shoulder roll should be put under.

2. Identifying the surgical landmarks

Once the depression between the ring cartilage and the shield cartilage, i.e., the Ligamentum conicum, has been identified, the surgeon fixes the larynx with his non-dominant hand and no longer changes this position.

3. Vertical incision of 2–3 cm above the Ligamentum conicum

A vertical skin incision actually runs against the relaxed skin tension lines but has the advantage that the equally vertical Vv. jugulares anterior are not opened. Heavy bleeding from these often larger veins could make it difficult to carry out the emergency measure. If the craniocaudal extension of the Ligamentum conicum was wrongly assessed in an initial horizontal incision, a second horizontal incision would have to be performed. For this reason, a vertical incision is recommended, except in the case of ENT practitioners who are experienced in ear, nose and throat surgery [24].

4. Horizontal section of the Ligamentum conicum

With regard to the cricothyroid artery, the incision through the ligament should be made at the upper edge of the cricoid and not at the lower edge of the thyroid. The tip of the blade should be tilted slightly caudally to avoid injury to the vocal cords directly above it (Fig. 8.1). Furthermore, the blade must not be inserted too deeply to avoid injury to the dorsal subglottic region.

5. Keeping the coniotomy site open

After the ligament has been cut horizontally, a distance between thyroid and cricoid must be kept open until a tube can be inserted.

If available, a cricoid hook can be used for this purpose. Alternatively, the already inserted blade can be "put upright on edge". The caudal pull by the hand that still fixes the larynx also leads to a greater distance between the shield cartilage and the ring cartilage.

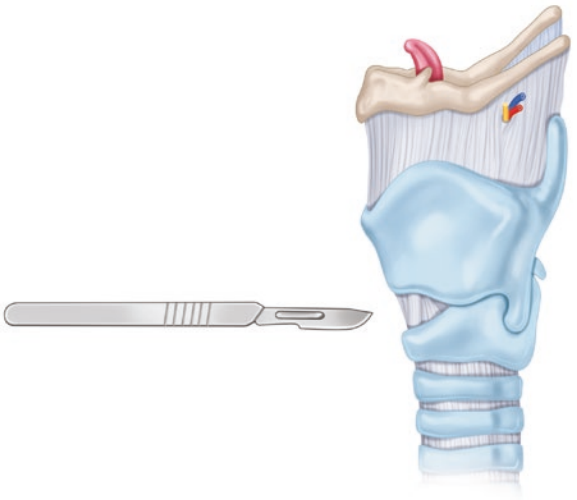

Fig. 8.1 Coniotomie: The ligamentum conicum is divided between cricoid and thyroid cartilage (image by Piero Lercher, courtesy of [25])

6. Inserting a tube

The patient can only be ventilated temporarily via a coniotomy. After the patient has been stabilized, the coniotomy must be converted into a tracheotomy within 72 h, otherwise there is a risk of subglottic stenosis. However, a meta-analysis showed that only little less than 2% of coniotomized patients developed a subglottic stenosis later [26].

An alternative to the surgical procedure described above is the simplified Rapid Four-Step Technique (RFST) as palpation-incision-traction intubation [27]. Here, after palpation of the Ligamentum conicum, the skin and the ligament are opened with a single horizontal puncture incision. The procedure is comfortable [28].

As an alternative to surgical coniotomy, an industrially manufactured system can also be used, whereby a beveled trocar is used for puncturing the skin and the Ligamentum conicum, via which a tube is inserted directly into the coniotomy site (Figs. 8.2 and 8.3).

8.6.2 **Needle Coniotomy Method** (Fig. 8.3)

1. Reclining the head

Fig. 8.2 Trocar cannula system Qicktrach II (Courtesy of VBM Medizintechnik GmbH Sulz, Germany)

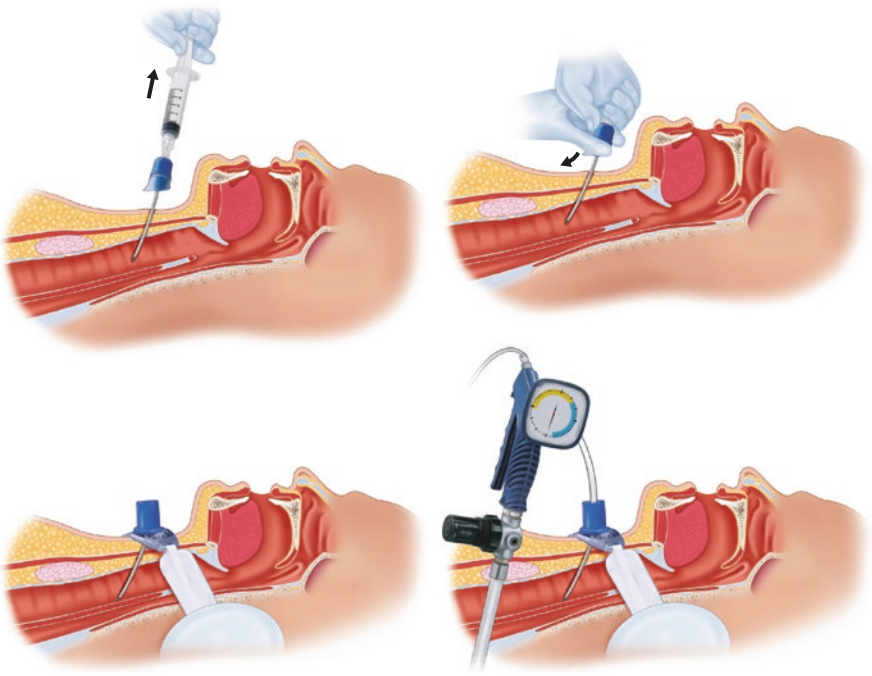

Fig. 8.3 Needle coniotomy using a jet ventilation catheter (Courtesy of VBM Medizintechnik GmbH Sulz, Germany)

The head should be reclined as far as possible. Time and situation permitting, a shoulder roll should be put under.

2. Identifying the surgical landmarks
3. Puncturing the Ligamentum conicum with a needle catheter

The ligament is punctured with a needle-supported plastic catheter (13–14 G for adults, 14 G for children, 16 G for infants) (Fig. 8.4), on which a 10 ml syringe is placed, half of which is filled with physiological saline solution. The tip of the catheter is guided, as in surgical coniotomy, slightly caudally in order to avoid injuries to endolaryngeal structures. After the ligament has been punctured, aspiration is performed using the syringe. As soon as there are air bubbles in the saline solution, the tip of the catheter is intralaryngeal and the needle can be removed from the catheter.

4. The catheter is now connected to a manually controllable high-pressure ventilation device, which delivers a pressure of up to 4 bar, and the patient is ventilated by it (Fig. 8.5).

Fig. 8.4 Jet-Ventilationskatheter nach Ravussin (Courtesy of VBM Medizintechnik GmbH Sulz, Germany)

8.7 Summary

Coniotomy is a fast and safe method of securing the airways when a "can't intubate, can't ventilate" situation cannot be controlled by any other measure. A coniotomy can be practiced on a cadaver or simulation model with a fast learning curve. In infants and young children, a needle coniotomy should be performed instead of a surgical coniotomy. Possible complications do in no way whatsoever compensate for death by suffocation if this method is waived.

Fig. 8.5 Manual jet device MANUJET (Courtesy of VBM Medizintechnik GmbH Sulz, Germany)

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Closing a Tracheostomy: Step-by-Step Dissection, Pearls and Pitfalls and Complications

9

Matthaeus Ch. Grasl and Boban M. Erovic

9.1 Introduction

Complications related to tracheotomies have been significantly reduced since suturing skin to the tracheal window and subsequently creating an epithelialized tracheocutaneous fistula are performed. An open, non-sutured canal between skin and open trachea should always be avoided. Decannulation of patients with a tracheostoma depends on the primary indication for surgery. If the underlying disease has improved and it is considered that the tracheostoma is no longer necessary, steps for decannulation can be initiated. Decannulation and tracheostoma closure are always done during hospitalization because of the possibility of serious complications [1] and airway impairment [2].

Requirements for a tracheostoma closure:

- the closed defect should resist reopening by coughing
- closing should not be a risk for tracheal stenosis
- should end up in a satisfactory aesthetic result

The success of a tracheostomal closure essentially depends how the tracheostomy was performed since the rule "the smaller the stoma, the greater the success with the closure" is key. Therefore, a tracheostomy must be planned and carried out with the greatest possible care to subsequently avoid intra- and postoperative

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complications. Patients who have a long-term stoma, local hygiene measures are of particular importance and have a significant impact on outcome of tracheostoma closures [3].

9.1.1 Indications

Patients with a tracheostoma often suffer from dysphagia and recurrent upper and lower respiratory infections. The stoma itself poses a risk of contamination. Particular hygiene measures for cleaning the stoma and the tracheostomy tube are of utmost importance. Further disadvantages of a tracheostoma are the considerably challenging communication and the impairment of patients' aesthetic appearance with subsequent changes of their social interactions. A secure airway is an absolute must for abandoning a tracheostoma but before suggesting to close the tracheostoma patients should be cancer-free, able to swallow their saliva easily and have an appropriate cough reflex.

9.1.2 Contraindications

The closure of the tracheostoma must be postponed or even rejected when (i) the respiratory tract is not adequately secured, (ii) there is an uncertain prognosis of the underlying disease or (iii) there are significant inflammatory peristomal skin changes. In addition, tracheostoma occlusion is impossible if the tracheal sidewalls are too low, or a tracheal stenosis, or tracheomalacia are present.

Pearls and pitfalls:

- it is necessary to reintroduce the tracheostomy tube postoperatively if a stridor occurs either due to a tracheal collapse or a stricture caused by a scar
- to reintroduce the tracheostomy tube, use a Killian speculum. This speculum allows spreading of the tissue and eases gentle insertion
- the stoma can also be reopened or expanded with the help of bougies
- if there are any doubts regarding a successful decannulation, a placeholder can be inserted and further test for decannulation can be planned
- re-tracheotomy may be necessary if a longlasting attempt of decannulation has been unsuccessful

9.1.3 Planning

Endoscopy can be used to predict whether a patient can be successfully decannulated or not. In children particular parameters of polysomnography are predictors for successful decannulation [4]. Therefore, a meticulous clinical and endoscopic examination of the airway, the larynx and in particular the supraglottic space, trachea, oropharynx and hypopharynx, must be performed through the oral/nasal cavity and retrograde through the stoma.

The localization of the primary disease should be meticulously assessed as well as any new problems that may be caused by the tracheostoma. All granulations localized within the tracheostomal area and in the trachea must be removed. The functionality of the vocal folds has to be assessed and any suprastomal/subglottic stenosis that occur particularly in children, often require complex reconstructive measures. The height of the lateral tracheal wall of the tracheastoma on both sides is of crucial importance to prevent stenosis after closure [5]. Depending on the size of the persisting stoma, interventions to close the tracheostoma can be carried out under local or general anesthesia. In addition to the continuous recording of vital signs, continuous monitoring of CO_2 is mandatory. When operating under general anesthesia, it should be taken into consideration not to place the blocking sleeve of the endotracheal tube at the level of the stoma, as by manipulations at the stoma level the balloon can be damaged.

9.2 Decannulation and Self-Closing of the Tracheostoma

The step-by-step reduction of the diameter of the tracheostomy tube leads to a paraventilation that subsequently helps the patient to get used to the increasing airway resistance. If this maneuver is well tolerated, the tracheostomy tube is blocked for a few hours a day. As a second step, the tracheostomy tube blockage is kept for 24–48 h—even at night—with oxygen monitoring (Chap. 17) overnight.

If there are no signs of a stridor, the tracheostomy tube is removed and the tracheostoma is closed with a cotton swab and a light self-adhesive pressure bandage.

Decannulation should be done in the morning to better manage any challenging or unpredictable situations caused by the new situation.

Daily dressing changes are mandatory and allow inspection and cleaning of the wound area. The patient is asked to hold its fingers on the tracheostoma when speaking, coughing and pressing so that no air can pass through the former stoma and through the bandage. This maneuver helps to get the stoma closed with any surgical intervention.

After decannulation the tracheostoma usually starts to shrink within 24–72 h. If this process without any reasons stops surgical closure under local or general anesthesia is indicated. Interestingly, percutaneous dilatation tracheotomies are almost closed within 3–5 days in almost 100% of all cases. Supportive measures to help ‘self-closing’ of the stoma are using a curette and/or silver nitrate etching at the skin edges.

Specific complications during or after self-closure of the stoma:

- persistent tracheocutaneous fistula
- tracheal granulation
- tracheal stenosis [5]
- tracheomalacia
- non-esthetic appearance of the closed stoma [6]

9.3 Surgical Closing of the Tracheostoma

Depending on the surgical technique and the time period of existence of the tracheostoma, spontaneous closure of the stoma is possible but in some cases tracheocutaneous fistula remains. These fistulas can only be closed surgically by reconstructing the anterior wall of the trachea and simultaneously to avoid any contractions of the skin. Various surgical closure techniques have been published ranging from simple local dissection and primary skin closure [7, 8] to complex surgical procedures [9, 10]. Some surgeons prefer application of fibrin glue to secure the sutures and support wound healing, but also as a prophylaxis of postoperative neck emphysema in patients who suffer from significant cough irritation. Patient information encompasses all of the specific complications of surgical tracheostoma closure, although life-threatening complications rarely occur [1].

- bleeding with tracheal compression
- mucosal injuries
- tracheitis
- local skin inflammation caused by saliva leakage
- wound dehiscence
- skin emphysema
- narrowing of the trachea
- a need for re-cannulating the patient
- hoarseness or loss of voice
- laryngeal nerve paralysis
- dysphagia
- perichondritis
- mediastinitis
- unsatisfactory cosmetic result (hypertrophic scar, keloid)

9.4 Adults

9.4.1 Surgical Closure of an Epithelialized Residual Tracheostoma [11]

Key steps:

- resection of the tracheostoma canal
- mobilization of the lateral muscles
- skin sutures are placed within the skin tension lines

Step-by-step dissection:

- start with circular dissection of the tracheal mucosa and elevate a small flap
- mobilize skin within and around the stoma
- excise the epithelialized duct

- release lateral muscles
- close the stoma by suturing first the tracheal mucosa followed by the second muscle layer with an inverted resorbable sutures (Vicryl 3–0)
- excise two 'Burrows-like' triangles around the stoma. This maneuver enables creation of a horizontal, elliptical defect that easily can be closed within skin tension lines

Pearl: use continuous subcutaneous sutures.
Specific complication:

- skin emphysema (Fig. 9.1)

Modification:

In the case of inflammation and/or damaged skin after radiation within and around the tracheostoma, skin should be resected and covered with a local, rotation flap. The skin flap is harvested over the clavicle or jugulum and rotated towards the stoma. The pivot point of the flap is right on the lower/mid third of the sternocleidomastoid muscle. The donor side can easily be reconstructed by primary closure.

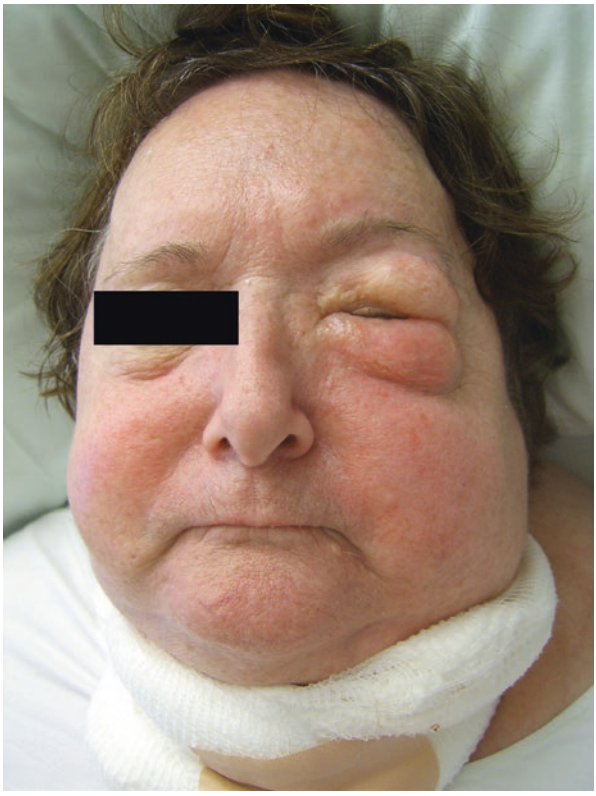

Fig. 9.1 Emphysema of the neck and eyelids

9.4.2 Closure of the Tracheostoma with Reconstruction of the Anterior Tracheal Wall Using Peristomal Skin

Key steps:

- reconstruction of the anterior tracheal wall with skin
- outer and inner sutures are set in a non-corresponding way to provide more stability
- skin incision and primary skin sutures are set in a horizontal fashion

Pearls and pitfalls:

Vertical incisions are not recommended due esthetic reasons and therefore only horizontal closure along the skin tension lines are performed. In case a patient has a vertical skin incision the scar should be resected and reconstructed with a Z-plasty [12, 13].

Step-by-step dissection:

- skin incision is marked with a pen and a horizontal-elliptoid resection of the skin is carried out. Any "dog- ears" can be resected.
- mobilize and invert the skin around the tracheostoma (Fig. 9.2a)
- mobilized outer skin layer is sutured as a second layer over the first sutured inner tracheal epithelialized mucosa layer (Fig. 9.2b)
- do not use the same suture canal for the inner and outer layer (Fig. 9.2c)

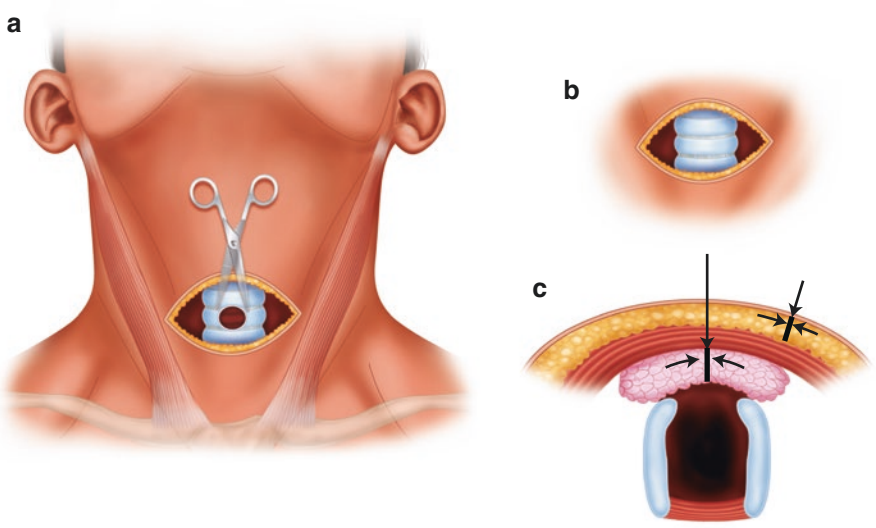

Fig. 9.2 (**a–c**) Closure of an epithelialized tracheostoma with inverted skin

Specific complications:

- recurrent tracheocutaneous fistula
- stenosis
- hair and epithelial deposits in the trachea
- cosmetically unsatisfactory result with a vertical skin incision

9.4.3 Tracheostoma Closure with a Parastomal Flap [14]

Key steps:

- reconstruction of the anterior tracheal wall with a parastomal skin flap
- avoid skin retraction over the jugulum by using muscle sutures
- place the skin sutures parallel to the skin tension lines

Step-by-step dissection:

- circumcise the skin in a U-shape manner (Fig.9.3a),
  - Pearl: the U-shaped flap should be at least 20% bigger than the stoma due to a significant shrinkage of the skin flap!
- harvest the flap and flip it 180° to cover the stoma (Fig. 9.3b)
- suture the flap with resorbable backstitches (Fig. 9.3c) into the defect. As a second layer suture both bellies of the sternocleidomastoid muscle over the flap

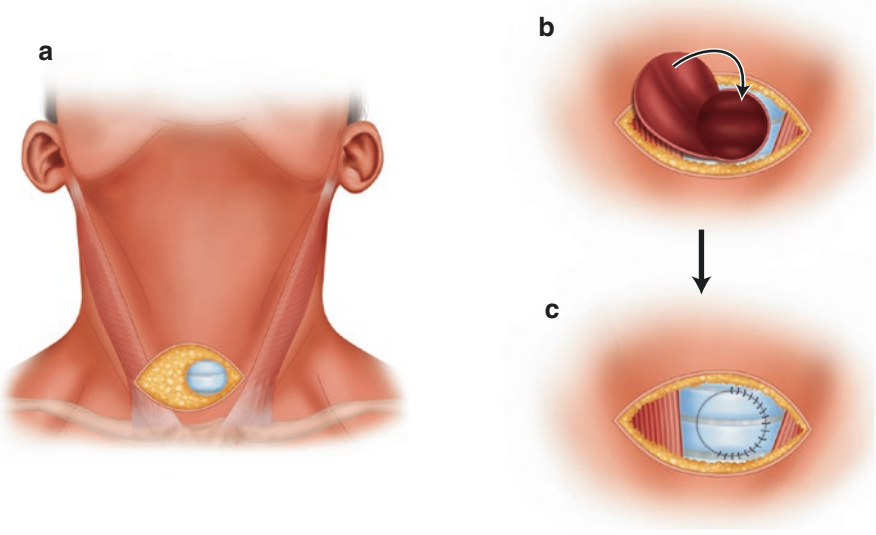

Fig. 9.3 (**a**–**c**) Closure of an epithelialized tracheostoma with a rotation flap

  - Pearl: this maneuver prevents retraction of the overlying skin that may result in an unsatisfactory esthetic appearance
- skin closure and the scar should lie exactly on the skin tension lines

Specific complications:

- insufficient blood supply of the flap
- retraction of a long flap
- in some patients cartilage from the auricle can be used to provide more stability to the flap
- dysphagia due to scarring of the skin that lies over the trachea
  - can be corrected by inserting subcutaneous adipose tissue that acts as a 'mobile' layer

9.4.4 Closure of a Stoma with a Björk Flap [15], [11, 16]

Key steps:
if the Björk flap is still present it can be mobilized and flipped anteriorly to recreate the anterior tracheal wall.

Step-by-step dissection:

- horizontal skin incision is carried out
- excision of the epithelized tracheostoma canal
- mobilize the Björk flap and flip it anteriorly
- Björk-flap is sutured laterally and superiorly to recreate the anterior tracheal wall
- infrahyoid muscles are sutured over the new created tracheal wall as a second layer
- as a third layer skin is mobilized and closed with a horizontal suture
- use a Penrose or Redon drain

Specific complications:

- narrowing of the trachea when the Björk flap is sutured back into the anterior tracheal wall
- Björk flap can significantly lose volume
- Björk-flap necrosis due to local infections

9.4.5 Closure of Long-Term Tracheostoma with Local Flaps [17]

Key steps:
combination of a fatty connective tissue harvest with an advanced skin flap.

Step-by-step dissection:

- semicircular vertical skin incision
- undermine lateral skin
- harvest the skin flap with fat or muscle to gain a bulky flap
- rotate the pedicled skin flap over the remnant stoma
- put single sutures to closed the stoma
- mobilization of the lateral skin for primary vertical skin closure

Specific complications:
In the publication by Eliashar [17] no complications were reported in 37 patients.

9.4.6 Tracheostoma Closure with a Rotational Flap According to Bootz [18]

Key steps:

- removal of skin and scar tissue
- harvest of a subcutaneous flap
- rotation flap

Step-by-step dissection:

- vertical-elliptical skin incision
- scar and skin should be excision completely
- undermining subcutaneous tissue laterally of the trachea and harvesting a kind of subcutaneous flap
- U-shaped incision of the subcutaneous flap
- the subcutaneous flap is door-swing like flipped and turned to the middle and sutured with inverted stiches
- rotation flap based either over the clavicle or sternocleidomastoid flap is harvested
- defect is closed by two layers

Specific complications:

- flap dehiscence

9.4.7 Tracheostoma Closure with Skin Replacement by Bridge Flaps According to Berghaus [9]

Key steps:

- assuming that a tracheostomy with a Björk-flap was performed
- a cosmetically favorable bridge flap is used

Step-by-step dissection:

- a horizontal skin incision, approximately 2 cm below the initial skin incision is carried out
- the U-shaped flap is flipped superiorly
- after refreshing the cranial tracheostoma margin the flap is turned in and sutured to the cranial tracheal margin
- thus a new tracheal anterior wall is reconstructed
- dissection of the skin laterally and the pre-tracheal muscles
- reimplantation of the Björk flap to stabilize the flap for anterior tracheal wall reconstruction
- the muscle are mobilized and sutured in the middle of the defect as a second layer
- cranially the neck skin is elevated and brought inferiorly to close the flap harvest defect
- the skin flap is sutured inferiorly preventing that the sutures are lying directly over the former stoma
- finally subcutaneous and skin sutures
- if the skin cannot be closed without tension, V-shaped incisions submentally can be made to increase skin mobility

Specific complications:

- If the neck is radiated, there is high risk of wound dehiscence and flap failure

Case Report

A 67-year-old woman was diagnosed with moderate-differentiated squamous cell carcinoma of the base of the tongue with cervical lymph node metastases (T3 N2b M0). Combined radio-chemotherapy was used as primary therapy and due to increasing shortness of breath approximately 3 weeks after the beginning of therapy she got a tracheotomy with a Björk flap. Approximately 6 weeks after the end of therapy laryngeal edema has decreased significantly and the patient was clinically and radiologically cancer free. Therefore, patient was scheduled for decannulation and the remaining tracheocutaneous fistula was resected under local anesthesia. The Björk flap was used for recreating the anterior tracheal wall and a three-layer wound closure, including the infrahyoid muscles, was carried out. Despite significant cervical bandage and additional pressure on the wound during speaking, a re-fistulation occurred after 3 days. Since a local flap was not an option due to the significant radiation damage of the skin, it was decided to close the tracheostoma with a pectoralis major flap (Fig. 9.4). First, the radiation-damaged skin of the neck was resected and the tracheostoma

dissected (Fig. 9.5). At the same time, the myocutaneous pectoral major flap was harvested and flipped cranially. The flap covered the neck and the stoma (Fig. 9.6). The postoperative course was uneventful and function and, in particular, cosmetic results were satisfactory.

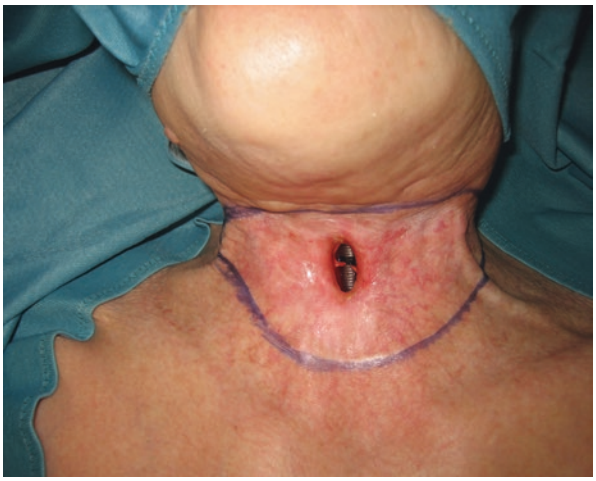

Fig. 9.4 Preoperatively the skin of the neck is severely damaged after radiotherapy

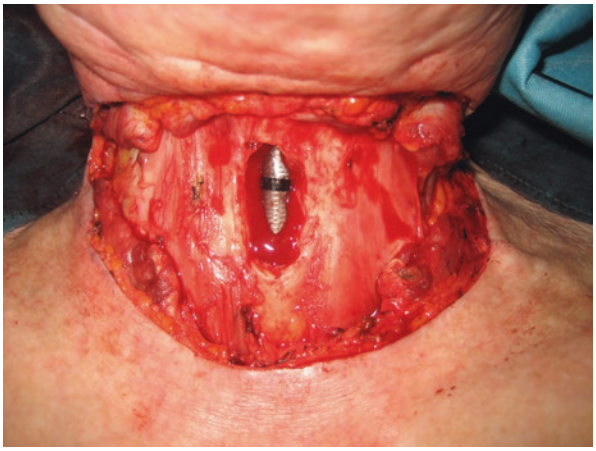

Fig. 9.5 Resection of the skin of the neck

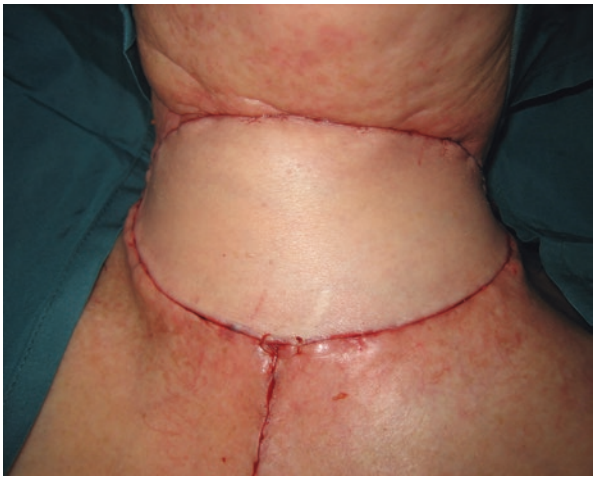

Fig. 9.6 Postoperatively the tracheostoma is closed with myocutaneous pectoralis major flap

9.5 Closure of Tracheostoma in Children

Tracheostoma in children can be linked to following major side effects:

- dysphagia, aspiration and hygiene issues [19]
- successful decannulation depends on the indication for tracheotomy
- sutured-in tracheostomata reduce serious complications such as pneumothorax, sudden decannulation and 'via-falsa' re-cannulation
- increased incidence of tracheostoma fistulas after decannulation compared to adults [20–23]
- Decannulation in children is always a huge challenge particularly in children who had a tracheotomy for a long period of time. Therefore, a decannulation and treatment in case of persistent stoma after decannulation requires a multidisciplinary team, time and patience. Preoperatively, granulation tissue or a collapse of the anterior tracheal wall has to be excluded [24]. A careful postoperative monitoring is of tracheostomatas importance. Basically, there are three techniques for closuring tracheostomata in children [24–28]:
- closure with layers
- resection of the tracheocutaneous fistula and closure with three layers
- resection of the tracheocutaneous fistula and secondary healing

9.5.1 Closing a Tracheostoma After Vertical Incision of the Anterior Tracheal Wall

Key steps:

- horizontal skin incision
- resection of the tracheocutaneous fistula
- closing the tracheal defect while avoiding tracheal stenosis
- three layers are dissected, including the infrahyoid muscles, subcutaneous tissue and skin, to close the stoma
- no cartilage resection

Step-by-step dissection:

- horizontal elliptical skin incision
- resection of the tracheocutaneous fistula
- vertical closure of the anterior tracheal wall without narrowing the tracheal lumen
- suturing of the infrahyoid muscles and closing the defect
- second and third layer by suturing subcutaneous tissue and skin

Specific complication:

- skin emphysema

9.5.2 Tracheostoma Closure After "Star Plasty" [29]

Key steps:

- resection of the tracheocutaneous fistula
- three-layer closure of the tracheostoma
- no need for drains

Step-by-steps dissection:

- horizontal-elliptical skin incision around the star-shaped tracheocutaneous fistula (Fig. 9.7a)
- dissection of tracheocutaneous fistula to the tracheal anterior wall (Fig. 9.7b)
- keep a small cuff of the fistula close to the tracheal lumen and put a suture to close it

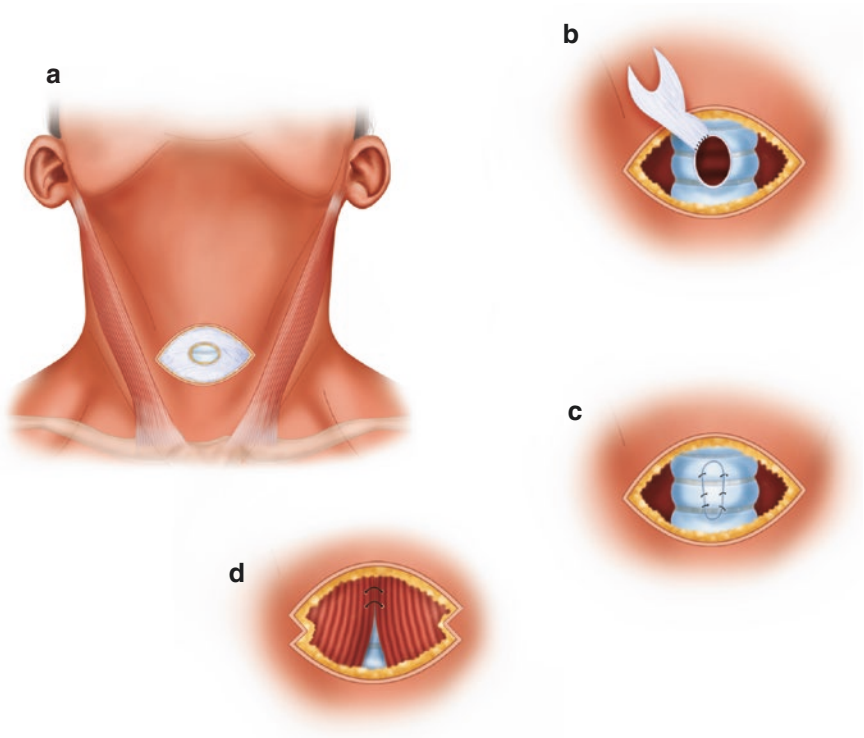

Fig. 9.7 (**a–d**) Tracheostoma closure after a "star plasty"

- close the defect with three layers including the infrahyoid muscles (Fig. 9.7c, d)
- wound closure with subcutaneous and skin closure

Specific complications:

- suture abscess
- endotracheal granulomas

9.6 The Oversized Tracheostoma

The size, shape and location of tracheostoma are a significant predictor for good breathing and satisfying voice production. An oversized tracheostoma is in particular good for providing a sufficient airway, but it can be a huge challenge for the patient in regards to controlling the position of the tracheostomy tube. A tracheostomy tube that is moving within the stoma leads (Fig. 9.8a, b) to irritation of the tracheal mucosa and the skin of the neck. Moreover, patients who have an air

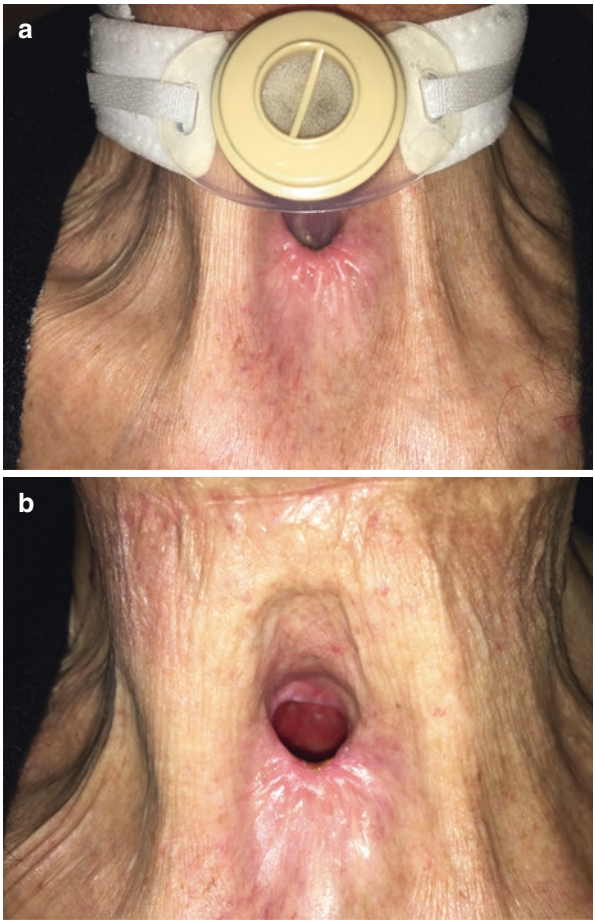

Fig. 9.8 (**a**) Patient after laryngectomy with cranially and ventrally displaced tracheostomy tube. (**b**) Tracheostoma without tracheostmy tube. Due to the depth of the stoma and the prominent sternocleidomastoid muscles the diameter of the stoma is significantly enlarged

leakage have a worse voice reproduction, shorter speaking periods and more background noises compared to those who have a well-sealed tracheostoma. The diameter of the stoma is to its depth and the prominent sternocleidomastoid muscles significantly enlarged.

There are three main techniques to correct an oversized tracheostoma:

1. tracheostoma plaster
2. epithesis for the tracheostoma
3. surgical reduction of the diameter of the tracheostoma

9.6.1 Tracheostoma Plasters

Patches are made of skin-friendly materials and of different thickness. Patients can easily glue the plaster on the cleaned stoma for an airtight seal. Moreover, these plasters have a central positioned ring that acts as a plug in for temperature and moisture exchangers and as a shower protection. The disadvantage of these plasters is the need for daily renewal, costs and they require a considerable degree of skilled patients to change their plaster.

9.6.2 Epithesis for Tracheostoma

Silicone prostheses for oversized or irregularly shaped tracheostomas are custom made and have a centrally localized hole for breathing that easily can be blocked with a fingertip when needed for speaking. A significant longer phonation time can be achieved without impairing breathing but epitheses are linked to slight local skin reactions [30, 31].

9.6.3 Surgical Reduction of the Diameter of the Tracheostoma

The surgical correction of an oversized stoma is a huge challenge for the patient and its physician. There are two local rotational flaps, derived from the sternocleidomastoid or the supraclavicular area that can be used to reduce the diameter of the tracheostoma.

The sternocleidomastoid muscle can be rotated into the tracheal defect based on the inferior perforators of the transcervical artery or branches of the external carotid artery. If there is a need for tracheal reconstruction, this flap can also be harvested as a costomyogeneous flap including bone of the clavicle. This flap is very reliable, easy and fast to harvest. The supraclavicular flap is a fasciocutaneous flap and is supplied by the supraclavicular artery. This flap is also very easy and fast to harvest but in patients, who underwent neck dissection as part of a previous tumor treatment, the vascular supply of the flap may be compromised or even cut [32].

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Complications of Tracheotomy and Strategies to Avoid Them

10

Eckart Klemm and Andreas Nowak

10.1 Introduction

Complications in tracheotomies are defined very differently in literature according to type and severity, which makes comparability difficult and prompted Fantoni [1] to recommend internationally comparable criteria and the assignment of events and complications in PDT to the three phases of puncture, dilatation or insertion of the tracheostomy tube. This requirement is still valid today. In the present chapter, only studies that show a minimum of comparable operations and defined study criteria have been included.

Percutaneous dilatational tracheotomy is repeatedly evaluated as a simple, quick and cost-effective intervention in literature. It should be emphasized that both surgical tracheotomy and percutaneous dilatational tracheotomy require a learning curve under the supervision of trained personnel. The problem was described by Páez et al. [2] when PDT was introduced in 38 patients: The procedure was described in 60% as easy, in 30% as moderate and in 10% as difficult, accompanied by 26% bleeding requiring therapy, 29% tube punctures and two deaths due to bleeding and pneumothorax. A new analysis of tracheotomy-associated deaths also warns of misjudgments [3].

The complication density of the various tracheotomy methods is shown in the following overviews.

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Table 10.1 Frequency of hemorrhage requiring therapy in tracheotomies

Authors	Number / Method	Definition	Frequency (n)	Frequency (%)
Fantoni and Ripamonti [4] prospective study	109 F	"Bleeding without transfusion"	3	2.7
Muhammad et al. [5] retrospective study	497 C^2	"Different medical interventions"	24	4.8
Klemm et al. [6] retrospective study	148 C^2	">20 ml"	3	2.0
	142 OST		4	2.8
Dongelmans et al. [7] prospective study	128 B	">20 ml"	5	3.9
Kost [8] review	1385 C^1	"Intermediate 200 ml, intervention"	56	4.0
	852 C^2		11	1.3
	337 OST		57	16.9
prospective study	500 BC^2		12	2.4
Delaney et al. [9] meta-analysis	436 PDT	"Clinically relevant"	22	5.0
	425 OST		27	6.3
Diaz-Reganon et al. [10] prospective study	800 G	"25–100 ml"	14	1.7
Straetmans et al. [11] evaluation	303 OST	"Surgical exploration"	11	3.6
Fattahi et al. [12] retrospective analysis	171 OST	"Surgical exploration"	2	1.2
Halum et al. [13] survey	870 OST	"Operative note as complication"	17	1.9
	178 PDT		13	7.3
Hashemian and Digaleh [14] prospective double-blind study	160 BC^1	"Moderate 2–5 cc, severe > 5 cc"	11	6.9
Fiorini et al. [15] retrospective study	304 OST	"Event, unfavorable"	12	3.9
Decker et al. [16] prospective study	289 BC^2	"Moderate, severe"	27	9.3
Pilarczyk et al. [17] retrospective study	1001 BC^2	"Moderate 5–20 ml, severe 20–50 ml, major >50 ml"	88	8.8
Nowak et al. [18] prospective study	179 BC^2	">10 ml and treatment required"	10	5.5
Janik et al. [19] retrospective study	1143 OST	"Surgical exploration"	31	2.7

B PDT acc. to Ciaglia Blue Rhino, *OST* open surgical tracheotomy, *G* PDT acc. to Griggs, C^1 PDT acc. to Ciaglia with endoscopy, C^2 PDT acc. to Ciaglia without endoscopy, *F* TLT acc. to Fantoni

10.2 Intraoperative and Perioperative Hemorrhage

The professional definitions of bleeding are very inconsistent worldwide, both with regard to the quantities and the frequently used classifications of minor and major complications, which leads to a complication bias. Table 10.1 shows the complication density regarding hemorrhages requiring therapy under definition of the individual authors.

Under the clarification that there is bleeding during every operation, there is no uniform definition for the "complication of hemorrhage", which must be observed when comparing the data.

Fig. 10.1 Massive hemorrhage after injury of a thyroid ima artery with impending asphyxia during PDT with flexible endoscopy: A large coagulum in the trachea and main bronchi could only be removed in a 20-year-old patient by rigid endoscopy and powerful suction in a life-saving manner

According to Shlugman et al. [20], bleeding hazards occur when the midline is missed, which can be observed with every fifth intervention. The risk of fatal bleeding complications increases especially with punctures below the fourth tracheal ring [21]. Unknown variants in vascular courses, a thyroid ima artery and a high standing brachiocephalic trunk are of predisposing importance for severe and fatal incidents [3]. Due to possible vascular variations (Chap. 3), ultrasound examinations and endoscopies of the trachea are recommended prior to PDT. Deitmer and Delank [22], Klemm et al. [23] and Nowak et al. [18] agree that a rigid endoscopy with powerful suction must always be at hand for every method of tracheotomy (Fig. 10.1).

It is not the amount of bleeding that is decisive for the respiratory tract, but the risk of acute impairment of gas exchange.

Preoperative clinical examination, neck sonography and endoscopy with light-intense diaphanoscopy contribute to the early detection of atypical vascular routes.

10.3 Pneumothorax

A detailed description for the causes of intraoperative pneumothorax in PDT is provided by Fikkers et al. [24] and, after literature searches, mention posterior tracheal wall injuries nine times, via falsa in punctures and dilatations eight times, a barotrauma twice and tracheostomy tube dislocations four times as well as unexplained causes seven times. Norwood et al. [25] describe the case of a pneumothorax with fatal lung over-inflation as a result of a valve mechanism using a flexible endoscope in a 7.5 mm inner diameter ventilator tube Fig. 10.2 (Table 10.2). In literature searches, Oeken et al. [32] found 40 severe posterior tracheal wall injuries with 28 cases of pneumothorax. Koitschev et al. [33] determined eight pneumothorax cases in surveys. Ten tracheotomy-related deaths from pneumothorax were reported by Klemm and Nowak [3].

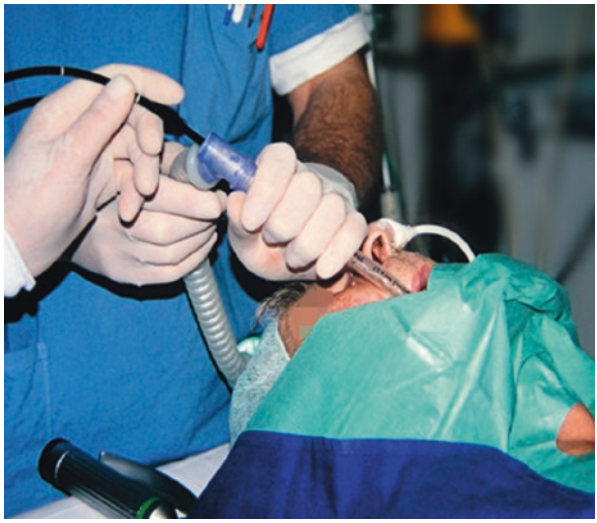

Fig. 10.2 High risk of pneumothorax risk due to pulmonary over-inflation as a result of hindered expiration when using flexible endoscopes in small ventilator tubes

Table 10.2 Pneumothorax through PDT and OST

Authors	Method	Frequency	
		(n)	(%)
Fantoni and Ripamonti [4] prospective study	109 (F)	1	0.9
Norwood et al. [25] prospective study	420 (C^2)	2	0.5 (1 death)
Escarment et al. [26] prospective study	162 (G)	5	3 (2 deaths)
Fikkers et al. [24] review 1986–2003	3012 PDT	31	0.8 (1 death)
Kost [8] review 1988–2003	1385 (C^1)	9	0.6
	852 (C^2)	5	0.6
	337(OST)	7	2.0
Straetmans et al. [11] evaluation 1996–2005	303 (OST)	1	0.3
Trouillet et al. [27] randomized controlled trial	109 (BC^2)	2	1.8
Oreadi and Carlson [28] prospective study	192 (OST)	0	
Hashemian and Digaleh [14] prospective double-blind study	160 (BC^1)	3	1.9
Nowak et al. [18] prospective study	179 (BC^2)	0	
Ulkumen et al. [29] retrospective study	233 (OST)	2	0.9
Cohen et al. [30] retrospective study	256 (C^1)	2	0.8
Tamir et al. [31] retrospective study	311 (OST)	3	1

B PDT acc.to Ciaglia Blue Rhino, *G* GWDF acc. to Griggs, *OST* open surgical tracheotomy, *F* TLT acc. to Fantoni, C^1 PDT acc. to Ciaglia without endoscopy, C^2 PDT acc.to Ciaglia with endoscopy

Beiderlinden et al. [34] see dangers of posterior tracheal wall injuries with the consequences of pneumothorax, pneumomediastinum or pneumopericardium especially in young patients with a yet soft trachea and its impressions due to bougienage processes during PDT.

An intraoperative pneumothorax in PDT is not so rare and potentially fatal. Early detection through auscultation, percussion, sonography, thorax X-ray and immediate therapy are lifesaving.

Table 10.3 Posterior tracheal wall injuries in PDT and OST

Authors	Method	Frequency (n)	Frequency (%)
Norwood et al. [25] prospective study	420 (C^2)	4	0.9
Kost [8]	1385 (C^1)	3	0.2
review 1988–2003	852 (C^2)	2	0.7
	337 (OST)	0	
prospective study	500 (BC^2)	3	0.6
Remacle et al. [35] prospective study	166 (BC^2)	2	1.2
	24 (FR)	3	12.5
Straetmans et al. [11] evaluation 1996–2005	303 (OST)	1	0.3
Trouillet et al. [27] randomized controlled trial	109 (BC^2)	1	0.9
Oggiano et al. [36] retrospective study	209 (C^2)	11	5.3
	169 (OST)	0	
Nowak et al. [18] prospective study	179 (BC^2)	2	1.1

B PDT acc. to Ciaglia Blue Rhino, C^1 PDT acc. to Ciaglia without endoscopy, *OST* open surgical tracheotomy, *FR* PDT acc. to Frova, C^2 PDT acc. to Ciaglia with endoscopy

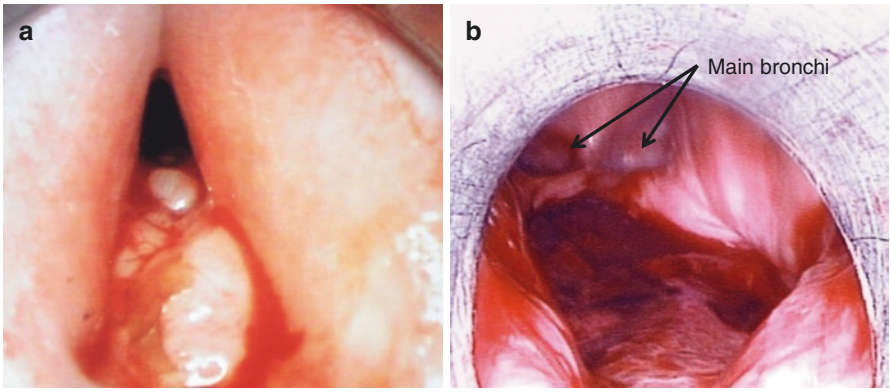

Fig. 10.3 (**a, b**) Posterior tracheal wall injuries levels I and II**,** as a result of PDT despite flexible endoscopic control

10.4 Posterior Tracheal Wall Injuries

Posterior tracheal wall injuries occur in both percutaneous dilatational tracheotomies and surgical tracheotomies (Table 10.3) and may occur harmlessly as superficial mucous membrane injuries and severely in the form of ruptures resulting in tracheoesophageal fistulas Fig. 10.3.

Therefore, Ciaglia warned in [37] against the use of rigid single dilators for PDT remarking that "The day of the rigid dilator... is over".

In Table 10.3 Six authors did not report any severity levels Chap. 11.

In a Rapitrac PDT, Kedjanyi and Gupta [38] describe a rupture of the trachea in 75% of the circumference and Gomez-Caro et al. [39] defects of the trachea of

2–4 cm in length in the cervical and thoracic trachea by PDT, also with fatal outcome. In the result of a survey, Dost and Koeser [40] reported six posterior tracheal wall injuries and seven tracheoesophageal fistulas, Delank et al. [41] reported five severe tracheal lesions requiring surgery after PDT. For diagnostic and therapeutic options, please refer to Chap. 11.

Only an endoscopy with a clear overview and the control of the surgeon by the endoscopist, the use of suitable PDT sets as well as endoscopic control of the upper and lower trachea can prevent posterior tracheal wall injuries or detect them early.

10.5 Intraoperative Loss of the Airway

In all methods of percutaneous dilatational tracheotomy, the ventilation tube must be retracted into the laryngeal plane for the purpose of PDT. Regarding this situation, Rieger [42] formulated as follows, "It is recommended that the cuff of the endotracheal tube is unblocked, and the tube is withdrawn under direct laryngoscopic control until the cuff lies above the vocal cords. The cuff shall now be blocked again above the vocal folds. Here at the latest, the safe control of the airway with the endotracheal tube is abandoned. In this position, there is a danger of dislocation with the risk of loss of the airway and the danger of aspiration. The endotracheal tube must be held in this position by an assistant while the transtracheal puncture is performed." (Fig. 10.4a, b, Table. 10.4).

The intraoperative loss of the airway is methodically possible when PDT is performed with flexible endoscopes, regardless of the type of PDT performed. A ready-to-use and fast possibility for reintubation is required.

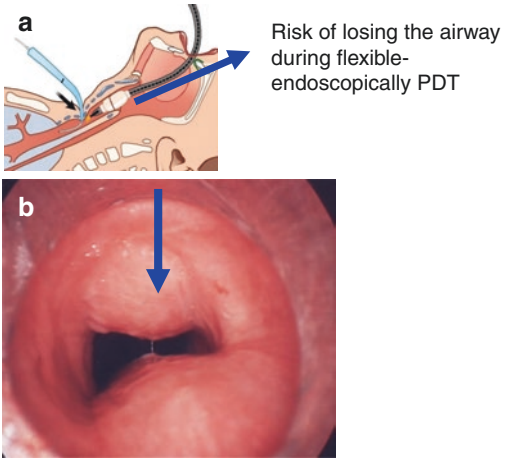

Fig. 10.4 (**a**, **b**) Danger of loss of the airway during flexible endoscopic controlled PDT

Table 10.4 Intraoperative loss of the airway during PDT

Authors	Method	Frequency (n)	Frequency (%)
Fantoni and Ripamonti [4] prospective study	109 (F)	3	2.7
Escarment et al. [26] prospective study	162 (G)	12	7.4
Norwood et al. [25] prospective study	420 (C^2)	3	0.7
Gambale et al. [43] prospective study	181 (C^2)	3	1.7
Kost [8] prospective study	500 (C^2)	3	0.6
Altmann et al. [44] prospective study	214 (G)	6	2.8
Terragni et al. [45] randomized controlled trial	419 (G+FR)	5	1.2
Hashemian and Digaleh [14] prospective double-blind study	160 (BC^1)	3	1.9
Hazelton et al. [46] prospective study	184 (C^2)	2	1.1
Nowak et al. [18] prospective study	179 (BC^2)	0	
Cohen et al. [30] retrospective study	256 (C^1)	2	0.8

C PDT acc. to Ciaglia, *F* TLT acc. to Fantoni, C^1 PDT acc. to Caglia without endoscopy, *FR* PDT acc. to Frova, *B* PDT acc. to Ciaglia Blue Rhino, *G* GWDF acc. to Griggs, *FR* PDT acc. to Frova, C^2 PDT acc. to Ciaglia with endoscopy

Table 10.5 Loss of the airway during tracheostomy tube exchange/decannulation

Authors	Method	Frequency (n)	Frequency (%)
Massick et al. [47] prospectively randomized trial	50 (C^2)	4	8 (1 death)
	50 (OST)	0	
Kost [8] review	2541 (C^1 C^2)	26	1.0
	337 (OST)	6	1.8
Fattahi et al. [12] retrospective study	171 (OST)	2	1.2
Fiorini et al. [15] retrospective study	304 (OST)	6	1.9
Cohen et al. [30] retrospective study	256 (C^1)	20	7.8
Tamir et al. [31] retrospective study	311 (OST)	20	6
Ulkumen et al. [29] retrospective study	233 (OST)	7	3
Liao et al. [48] retrospective study	1000 (OST)	40	4

C^1 PDT acc. to Caglia without endoscopy, C^2 PDT acc. to Caglia with endoscopy, *OST* open surgical tracheotomy

10.6 Perioperative and Postoperative Loss of Airway

Further latent dangers consist in the loss of the airway during tracheostomy tube change due to a "shifting-closure-phenomenon", through accidental decannulation or closure of tracheostomy tube by blood clots and mucus plugs. The term "shifting-closure-phenomenon" refers to the displacement of pretracheal tissue layers, in which parts of fat, thyroid gland, muscles and fascia can immediately lay over the stoma after decannulation, making recannulation more difficult or impossible. The risk is greatest in the early postoperative period (Table 10.5).

No tracheostomy tube change after PDT without a light source (headlamp), guide catheter, speculum (Killian Nasal-Struycken Speculum® with long blades or

Tracheal Dilator Trousseau®) as well as the possibility of re-intubation in stand-by. The same requirements also apply to stomata according to OST.

10.7 Tracheal Ring Fractures

There are different views on the significance of tracheal ring fractures between the fields of intensive care medicine and laryngology. This is due to the fact that the incidence of tracheal ring fractures after surgical tracheotomy plays a minor role in a retrospective literature analysis by Straetmans et al. [11] and Fiorini et al. [15] at 0.9% and 0.6%, respectively, while tracheal ring fractures are a frequent event in both autopsy findings and endoscopic findings after PDT if they are systematically searched for by Nowak et al. [18] and Byhahn et al. [49]. The current type of flexible endoscopically controlled PDT does not reveal an obligatory search, as numerous clinical studies show. Dislocated tracheal rings do not usually lead to tracheal stenosis until 5–12 weeks after epithelization and scar formation [50]. These are periods of time after which patients have long disappeared from the intensive care medicine, and when diagnostics and therapy of tracheal stenoses are assigned to the specialties of laryngology, thoracic surgery or pneumology (Chap. 12). The tracheal braces with their different anatomical variants and histological tissue formations (Chap. 4) tend to fracture during powerful compression during bouginage in PDT, independent of the method described. Van Heurn et al. [51] described necrosis and ossification processes on injured tracheal braces, especially from the 3rd week after PDT.

Walz and Schmidt [52] describe a particular tendency to vertical tracheal ring fractures of 1 to 2 adjacent braces in autopsy findings. There are currently no systematic studies available on when and under what circumstances tracheal fractures lead to tracheal stenoses requiring treatment [53] (Fig. 10.5a, b, Table 10.6).

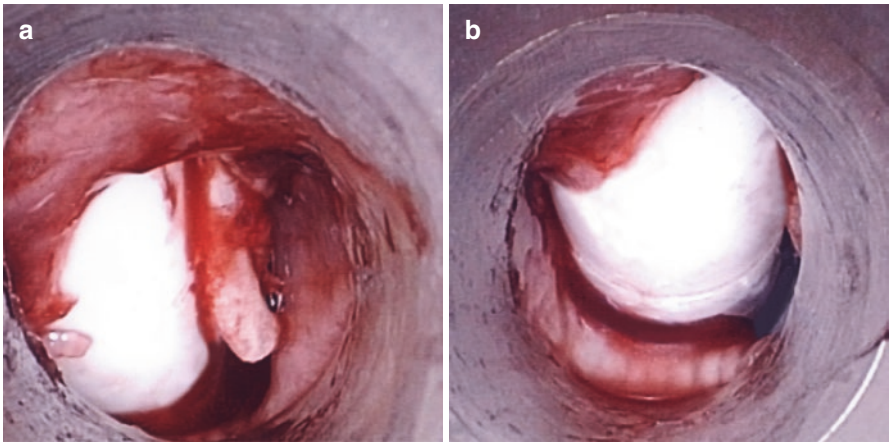

Fig. 10.5 (**a, b**) Tracheal ring fracture during PDT. Immediate endoscopic therapy by TED for the necessary prophylaxis of tracheal stenosis

Table 10.6 Tracheal ring fractures in various methods of tracheotomy

Authors	Method	Frequency (n)	Frequency (%)
Walz and Schmidt [52] clinical-pathological study	42 (C), post mortem autopsy findings trachea	12	28.6
Dollner et al. [54] retrospective study	19 (G) by way of postoperative endoscopy after 17 months, cricoid lesions	7	32
Frova and Quintel [55] prospective study	50 (FR) intraoperative endoscopy	4	8
Higgins et al. [56] prospective study	132 (FR)	12	9.1
	75 (B)	4	5.3
Straetmans et al. [11] Evaluation	303 OST	3	0.9
Dempsey et al. [57] prospective study	576 (B)	56	9.7
McCague et al. [58] retrospective study	426 (BC^2)	63	14.8
Fiorini et al. [15] retrospective study	304 OST	2	0.6
Ferraro et al. [59] retrospective study	219 (B/FR/D)	21	9.6
Decker et al. [16] prospective study	289 (BC^2)	18	6.2
Nowak et al. [18] prospective study	179 (BC^2)	30	17.1

B PDT acc. to Ciaglia Blue Rhino, *C* PDT acc. to Ciaglia, C^2 PDT acc. to Ciaglia with endoscopy, *FR* PDT acc. to Frova, *OST* open surgical tracheotomy, *G* GWDF acc. to Griggs, *D* PDT Ciaglia Blue Dolphin

The high number of fractures detected by Nowak et al. [18] is the result of a targeted search by study protocol in a multi-center interdisciplinary study.

Dislocated tracheal ring fractures must be expected with every percutaneous dilatational tracheotomy. Cartilage and bone splinters must be subjected to immediate endoscopic therapy to prevent later tracheal stenosis. If this is not successful, early surgical intervention is indicated.

10.8 Tracheal Stenoses

The late complication of the development of tracheal stenosis requiring therapy, usually lumen constriction from 60 to 70% up to total occlusion (grade III and IV according to Myer and Cotton), is a feared event. This circumstance is very unfortunate for the patient, as all the effort of the original rehabilitation is lost and the patient is again hospitalized with surgical and rehabilitative measures, including conditions of shortness of breath and anxiety (Table 10.7).

The widely differing definitions make comparability of the follow-up examinations difficult. The classification of degrees of severity of tracheal stenosis [70] was ignored.

Table 10.7 Tracheal stenoses after PDT and OST

Authors	Number	Method	(Stenoses definitions) Stenosis n	(%)	Time of control	Type of control
van Heurn et al. [51] retrospective study	p 123	PDT (C)	*(Stenosis 25–50%)*		5–53 months	CT neck, check voice function
	f 80		2	2.5%		
			(Stenosis 50–75%)			
			1	0.8%		
Hill et al. [60] prospective study	p 353	PDT(C)	*(Symptomatic stenosis)*		10 months	Telephone interview, clinical doctor's visit
	f 214		8	3.7%		
Law et al. [61] prospective study	p 109	PDT (C)	*(Stenosis >40%)*		6 months	Questionnaire, telephone interview, spirometry, endoscopy
	f 41		1	2.4%		
Rosenbower et al. [62] prospective study	p 95	PDT (C)	*(Subglottic stenosis)*		12 months	Endoscopy ENT doctor, telephone interview
	f 55		2	2%		
Walz et al. [63] prospective study	p 337	PDT (C)	*(Stenosis > 50%)*		6 months	Clinical doctor's visit, X-ray check
	f 106		4	3.7%		
Norwood et al. [25] prospective study	p 422	PDT (C)	*(Stenosis > 50%)*		26 months	Telephone interview, endoscopy, CT neck
	f 100		3	3%		
Escarment et al. [26] prospective study	p 162	GWDF (G)	*(Stenosis with surgery)*		3 months	Clinical visit, endoscopy, telephone interview
	f 81		4	4.9%		
Kearney et al. [64] prospective study	p 824	PDT (C)	*(Stenosis with surgery)*		12 months	Type of control, not specified
	f 548		9	1.6%		
Dollner et al. [54] retrospective study	p 60	GWDF (G)	*(Stenosis > 25–50%)*			Telephone interview
	f 19		2	3.3%		
			(Stenosis > 50%)		17 months	Doctor interview, endoscopy
			1	1.6%		
Jung et al. [65] retrospective study	p 419	OST visor tracheotomies	*(Stenosis > 25–50%)*		6 months	ENT examination, endoscopy
	f 93		3	3.2%		

Young et al. [66] prospective study	p 120	PDT (B)	*(Stenoses > 46%)*		3 months	Questionnaire, MRT, spirometry
	f 50		5	4%		
Lopez-Pastorini et al. [67] retrospective study	p 401	OST *(degree of stenosis unspecified)*	92 surgical stoma occlusion		3 months	Clinical visit, endoscopy
	f 155		3	3.3%		
			63 spontaneous occlusions			
			14	22.2%		
Dempsey et al. [68] review, pooled estimate % (95%CI)		418 OST	11	2.8%	Not specified	Type of control + degree of stenosis, not specified
		1831 PDT(G)	10	0.9%		
		1546 PDT(C)	15	1.0%		
		1474 PDT(B)	7	0.6%		
		124 TLT(F)	1	1.5%		
Araujo et al. [69] prospective study	p 114	PDT (D)	*(Stenosis > 50%)*		7 months	CT, endoscopy
	f 52		*2*	3.7%		
Janik et al. [19] retrospective study	p 1143	OST	*Surgical Intervention*		8 weeks	Clinical visit, endoscopy, MRT/CT
	f 435		6	1.4%		

B PDT acc. to Ciaglia Blue Rhino, *C* PDT acc. to Ciaglia, *G* GWDF acc. to Griggs, *Fr* PDT acc. to Frova, *D* PDT Ciaglia Blue Dolphin, *p* number of primary PDT, *OST* open surgical tracheotomy, *f* number of follow-up examinations, *F*: TLT Fantoni

The causes of tracheal stenoses are complex and usually based on a combination of tracheal trauma, inflammation and foreign body irritation with tissue formation (granulation) at predisposed sites above, next to and below the stoma with loss of the original tracheal tissue layer by fibrosis.

The ring cartilage reacts particularly sensitively to traumas and injuries with the development of recurrent tracheal stenoses, caused by excessive regeneration processes with osteoid expression of the osteoblasts and mineralization in an acidic environment. According to Nicolli et al. [71], independent of the tracheotomy method, overweight, diabetes and reflux with chronic inflammatory reactions are risk factors for the development of subglottic stenoses. Gadkaree et al. [72] extend the disposition to laryngotracheal stenoses by the co-morbidities COPD, nicotine abuse, OSAS as well as hypertension and microcirculation disorders after an analysis of 262 stenoses patients.

Between 1996 and 2016, a total of 102 patients with tracheal stenoses requiring therapy (aged 17–89, average age 60 years) were observed in the hospital's own patients of the University Teaching Hospital Dresden-Friedrichstadt. These were patients from 20 clinics who became conspicuous during rehabilitation several weeks after tracheotomies with shortness of breath. The occurrence of this stenosis was recurrent in 75 PDT but also in 27 OST with too high tracheostomata with injuries of the ring cartilage and/or associated with dislocated cartilage fractures left behind. One hundred and fourty-eight follow-up operations with therapy costs of Euro 1,174,850 were necessary (Fig. 10.6).

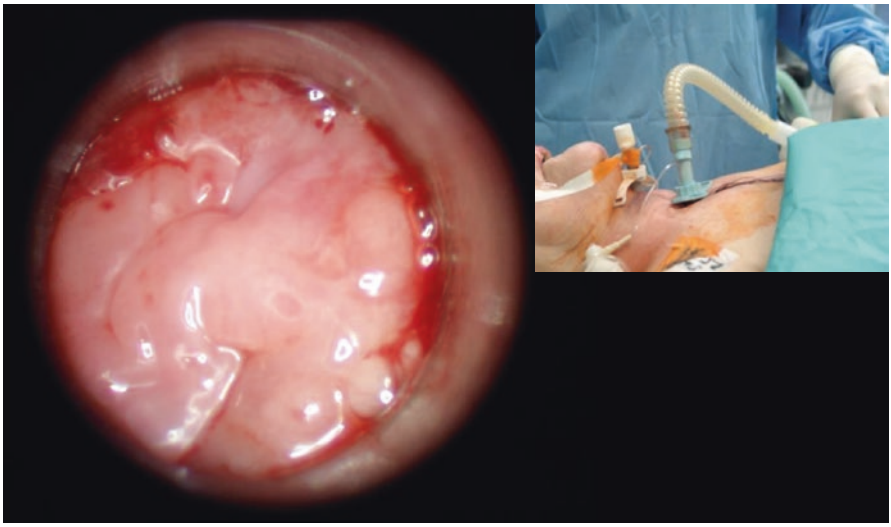

Fig. 10.6 Total laryngeal atresia by via falsa in PDT: puncture, dilatation and insertion of the tracheostomy tube over the hyoid bone with subsequent total destruction and firm adhesions of the laryngeal internal structures, additionally upper tracheal stenosis Myer-Cotton IV. The patient did not survive the underlying brain tumor disease

For whatever reason, there is no indication for a tracheotomy that is supposedly "necessarily" too high, as is occasionally published in the literature. The safest prevention for later tracheal stenoses is a gentle atraumatic procedure at the right place between the 2nd and 4th tracheal braces in the midline, use of atraumatic ready sets for PDT and tissue-friendly, adapted tracheostomy tubes, therapy of infections and granulations, regular tracheostomy tube and skin care, therapy with existing reflux and continued controls with remaining tracheostoma.

10.9 Stoma Infections

There is a general opinion that surgical tracheotomies have a higher postoperative infection rate than PDT. There are no scientifically based studies on the causes. Wound infections in the stoma area are not defined in the literature (Table 10.8).

For the therapy of wound infections, please refer to Chap. 18.

10.10 Stoma Metastases

According to a study by Knipping et al. [73] using 58 PDT after Ciaglia and 17 PDT after Fantoni for malignant tumors in the mouth, larynx and throat, two cases of stomametastases with fatal outcome occurred according to the TLT Fantoni method, which is why this combination is strongly discouraged.

Table 10.8 Wound infections [8][a], [68][b]

Method	Number of tracheotomies		Infektionen	
			n	%
OST[a]	337		43	12.7
PDT (C^1)[a]	1547		21	1.3
PDT (C^2)[a]	994		16	1.6
OST[b]	418		36	8.5
PDT (G)[b]	1666		16	1.5
PDT(C)[b]	1355		11	1.0
PDT (B)[b]	554		6	1.7
TLT (F)[b]	124		4	3.9
Tamir et al. [31]	311	OST	11	3.5
Ulkumen et al. [29]	223	OST	8	3.6
Cohen et al. [30]	256	C^1	17	6.6

OST open surgical tracheotomy, *PDT (B)* PDT acc. to Ciaglia Blue Rhino, C^I PDT acc. to Caglia without endoscopy, *PDT(G)* PDT acc. to Griggs, *PDT(C)* PDT acc. to Ciaglia, *TLT(F)* TLT acc. to Fantoni, C^2 PDT acc. to Ciaglia with endoscopy

[a]Review

[b]29 studies, evaluated via "pooled estimate (95-%-CI)"

10.11 Tracheotomy-Related Deaths

While publications on tracheotomies have increased in recent years under various scientific aspects, communications on tracheotomy-related deaths have been published only sporadically, which is why Klemm and Nowak [3] conducted a systematic review for PDT and OST for the period 1990–2015.

In 109 publications from 21 countries with a total of 25,056 tracheotomies, including 16,827 PDT, 7,934 OST and 295 tracheotomies with no descriptions of the method, 352 tracheotomy-related deaths were found, corresponding to a total frequency of 1.4%, for PDT 0.67% (95-%-CI: 0.56; 0.81), for OST 0.62% (95-%-CI: 0.47; 0.82).

The main causes for death were bleeding (PDT 0.26%, OST 0.26%), loss of the airway (PDT 0.20%, OST 0.21%) and via falsa (PDT 0.20%, OST 0.11%). Disposing factors for deaths were variations of large blood vessels and variations of the anatomy, missing or insufficient overview in flexible endoscopy, loss of the respiratory tract, via falsa resulting in bleeding, pneumothorax and tracheoesophageal defects, sometimes in combination. Other causes for death were inadequate strategies to control complications, such as severe bleeding and pneumothorax. Too caudal tracheotomies are a high-risk factor for tracheoinominate fistula (TIF) or, synonymously, tracheaoarterial fistula (TAF). A review of the last 15 years showed a fatal outcome 77%, despite emergency intervention [74]. In addition, other risk factors are inexperience of the actors and insufficient knowledge of respiratory physiological peculiarities in tracheotomized patients and accessories in the clinic and outpatient area.

Caution! Danger of pneumothorax and death! The application of a speaking valve demands prior complete cuff-deflation whenever a cuffed tracheal tube is used [75].

Tracheotomy-related deaths are underreported worldwide [76].

Conclusions for practice

- *The frequency of tracheotomy-related deaths is similar for PDT and OST.*
- *Deaths are caused by complications, the avoidance and control of which must be taken into account both during planning and aftercare, also from the point of view of medical law.*
- *The use of a checklist makes sense.*
- *The formation of a stoma lower than the fourth tracheal brace should be omitted; dangerous areas of the vascular anatomy can be reached.*
- *Heavy bleeding to the outside must be treated surgically. For internal bleeding, securing the airways has absolute priority. Rigid endoscopy with powerful suction must be readily available.*
- *Despite methodological weaknesses via falsa and flexible endoscopy are not mutually exclusive.*
- *Early detection of pneumothorax can save lives.*
- *Tracheotomies, regardless of the PDT or OST method, are not beginner operations and must be learned under the guidance of experienced physicians.*
- *Tracheostomy tube management requires special knowledge and experience.*

10.12 Avoidance and Reduction of Complications by the Rigid Tracheotomy Endoscope for Dilatational Tracheotomies (TED)

Whereas rigid tracheobronchoscopy was a common aid in the hands of the anesthetists and intensive care therapists decades ago, this management has almost been lost with the development of flexible endoscopes.

The design of the rigid tracheotomy endoscope has been adapted to the modern requirements of respiratory medicine and combines the advantages of rigid endoscopy with the aim of better controlling and reducing known and severe complications in percutaneous dilatational tracheotomies. Any current method of PDT can be performed with the endoscope in a controlled manner. The method is easy to learn.

This technique has been introduced into the endoscopy of ENT medicine by Klemm [77, 82] and adopted by Nowak et al. [78, 79] into the practice of anesthesia/intensive care.[1]

10.12.1 Percutaneous Dilatational Tracheotomy with the Tracheotomy Endoscope, Practical Execution in Seven Steps

Step 1 Endoscope Insertion
Preoperative control on the basis of the "Surgical Safety Checklist" of the WHO and determination of the external landmarks, the disinfection of the neck and cleaning of the mouth and throat is carried out with the installation of a silicone dental protector in the upper jaw. The rigid endoscope is carefully inserted into the larynx entrance along the lying tube via the right corner of the mouth under sight (Fig. 10.7).

The patient's endotracheal tube is the guidance when the endoscope is inserted.

Step 2 Extubation/Intubation
With recognition of the laryngeal structures, the lying tube is unblocked by an anesthesia nurse. The endoscopist removes the endotracheal tube step by step with his left hand and simultaneously inserts the rigid endoscope into the larynx and trachea with his right hand under direct vision. Then the endoscope is connected to the ventilator (IPPV or JET). The connection of a monitor system with image transmission and respiratory gas monitoring is possible (Fig. 10.8).

[1] *Tracheotomy endoscope for dilatational tracheotomies (TED acc. to KLEMM): Manufactured by Karl Storz GmbH Tuttlingen, Germany, patented Nov 30, 2006, USA Pub. No. US2006/0270907A1 by Karl Storz GmbH Tuttlingen.*

EC Declaration of Conformity: Karl Storz GmbH Tuttlingen, Oct 16, 2008, Endoscopes E, F, G.

Tracheoscope acc. to ALOY-KLEMM: Manufactured by Carl Reiner GmbH Wien, Austria, adapted to TwinStream™ Multi Mode Respirator made by Carl Reiner GmbH, Declaration of Product Compatibility, Vienna, Jan 28, 2008.

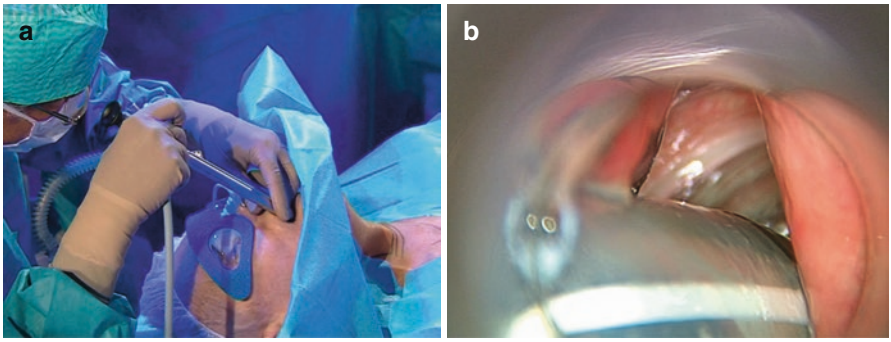

Fig. 10.7 (**a, b**) Rigid endoscope insertion under sight. The endotracheal tube is the guidance!

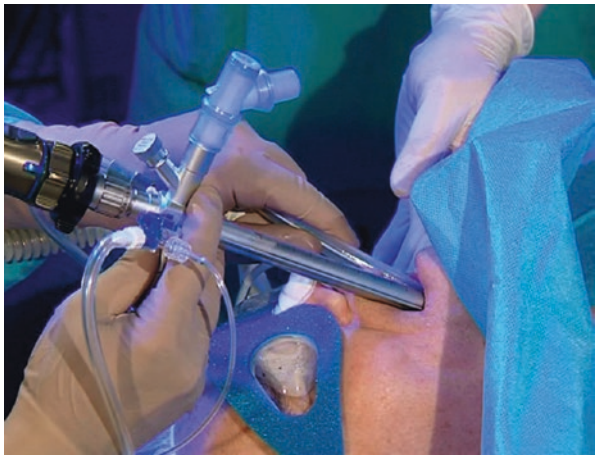

Fig. 10.8 The endotracheal tube is removed by the endoscopist simultaneously with the insertion of the rigid endoscope into the larynx under direct vision

With IPPV via a rigid endoscope, the leakage can be reduced using a tamponade around the endoscope with a narrow gauze bandage. However, in the case of jet ventilation, the leakage around the rigid endoscope must be maintained to exhaust respiratory gases. A tamponade around the endoscope is prohibited in jet ventilation due to the risk of air trapped with a subsequent pneumothorax.

The processes of extubation (endotracheal tube) and intubation (rigid tracheotomy endoscope) must not be separated in time.

Step 3 Clarification of the Internal Anatomy/Topography

If necessary, the trachea is cleaned by suction from secretion to the main bronchi. The trachea is then optically inspected with exact determination of the clearly visible tracheal braces 1 to 4 with deliberate identification of the ring cartilage not to be affected during tracheotomy, with possible displacement of the trachea (goiter) and possible pulsating protrusion of the brachiocephalic trunk (Arteria anonyma) (Fig. 10.9).

The internal anatomy is of equal obligatory importance as the external anatomy of the neck. The higher the body mass index, the more the topography of the inner trachea gains in importance.

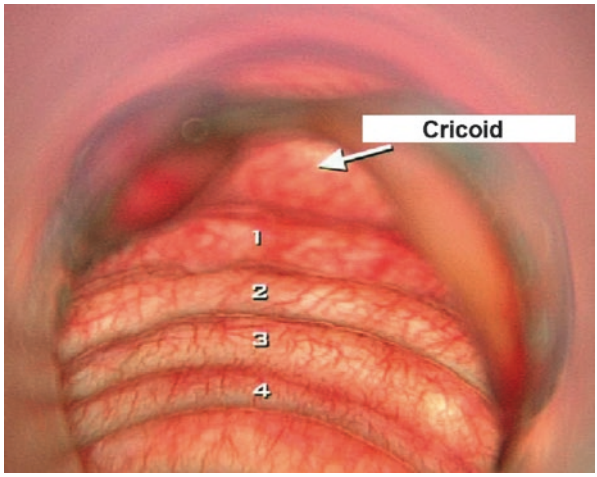

Fig. 10.9 The correct place for tracheotomy is between the second and fourth tracheal braces

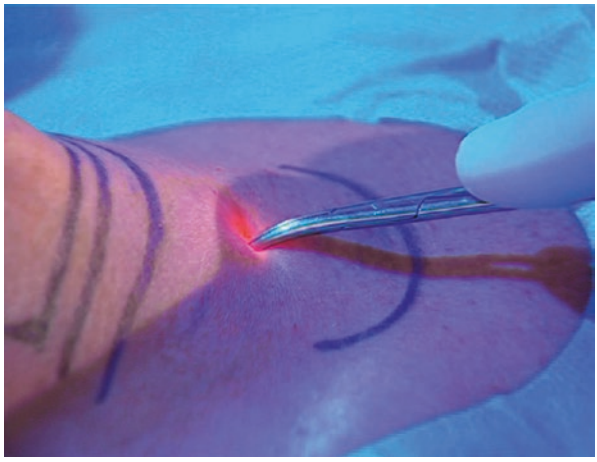

Fig. 10.10 Bright diaphanoscopy provides security in orientation

Step 4 Diaphanoscopy and Puncture

A rigid diaphanoscopy rod, which is specially bent at the front and brightly shining, has been developed for the endoscope (Karl Storz GmbH Tuttlingen Germany), which enables brightly lit diaphanoscopy and, in individual cases, the detection of large vessels in the intended tracheotomy area. The puncture of the trachea takes place in the center of the light cone in harmonious consultation between endoscopist and surgeon between the second and fourth tracheal braces. The endoscopist always controls the surgeon. If the puncture needle is placed on a tracheal brace, it must be corrected by a few millimeters downwards or upwards with only a slight retraction of the needle to reach the space between two tracheal braces in the midline. The Seldinger wire is inserted through the puncture needle. There is a sufficiently large skin incision horizontally next to the needle, possible is also a blunt spreading (Figs. 10.10 and 10.11).

Bright diaphanoscopy facilitates the view on prescribed ways. The surgeon must follow the instructions of the endoscopist.

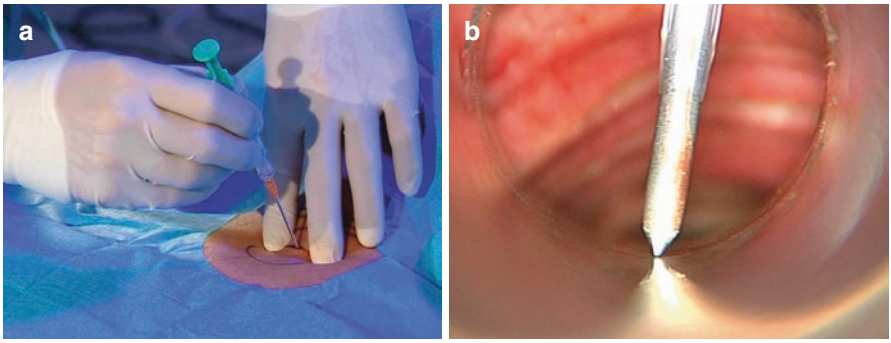

Fig. 10.11 (**a, b**) Puncture of the trachea. The extended rear tube lip of the TED protects the posterior tracheal wall from injury

Fig. 10.12 Bougienage of the trachea under sight with a conical single dilator

Step 5 Bougienage

Bougienization takes place from the outside under continuous ventilation, whereby any commercially available ready set is suitable for PDT. The rigid endoscope stabilizes the trachea from the inside and protects the posterior tracheal wall (Fig. 10.12).

Bougienage must be carried out with "gentle force"" adapted to the vulnerable trachea under continuous visual control by the endoscopist.

Step 6 Insertion of the Tracheostomy Tube

Taking age, gender and body height into consideration, the appropriate—stepless, if possible—tracheostomy tube is inserted into the trachea and blocked under endoscopic vision. Ventilation is transferred from the endoscope to the fixed tracheostomy tube. Auscultation is used to check lateral equidistant ventilation and monitoring of the E_TCO_2 is used to verify the endotracheal position of the tracheostomy tube. In case of ambiguities, the position of the tracheostomy tube is checked flexibly endoscopically, also with regard to the distance to the bifurcation (Fig. 10.13).

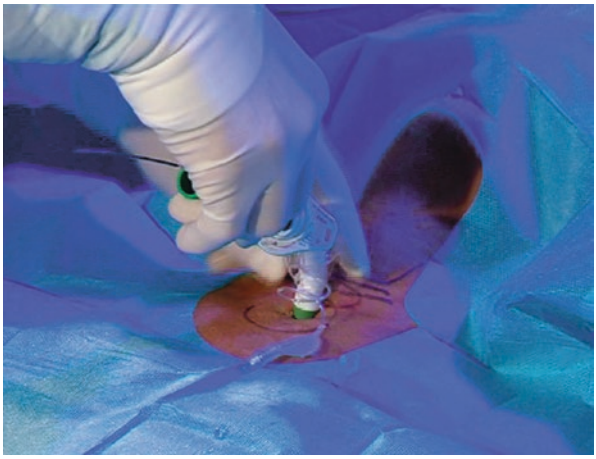

Fig. 10.13 Controlled insertion of the tracheostomy tube

Step 7 Check of Upper Trachea, Larynx and Dental Status
After determining optimal equidistant ventilation via the tracheostomy tube, the rigid endoscope is slowly withdrawn into the laryngeal plane with inspection regarding possible pathological changes of the trachea (dislocated fragments of tracheal braces) and regarding long-term intubation damage of the larynx. It is necessary to check the dental status. Tooth damage can be expected in 0.15% of cases with rigid tracheobronchoscopy [80]. Do not forget to remove foreign objects, e.g. tooth protection, tamponade.

Immediate therapy of possible pathological changes (granuloma formation, tracheal fractures) is possible and recommended without delay through the rigid endoscope.

Every elective tracheotomy requires preoperative clarification and postoperative documentation (surgical report).

10.12.2 What Are the Advantages for Avoiding and Reducing Complications in Percutaneous Dilatational Tracheotomies Using the Rigid Tracheotomy Endoscope (TED)?

- Optimum ventilation of the intensive care patient is possible during the entire tracheotomy process. Superimposed High-frequency Jet Ventilation SHFJV® has proven to be particularly effective, Chap. 16.
- No loss of airway during PDT. The rigid tracheotomy endoscope secures the airway during all individual steps. Loss of the airway is practically impossible.
- Optimum protection of the posterior tracheal wall. The tracheotomy endoscope is designed in such a way that an extended rear tube lip deliberately protects the posterior tracheal wall from injury right from the start during puncture, dilatation and tracheostomy tube insertion. Severe tracheal posterior wall injury with tracheoesophageal fistula is avoided.

- The rigid tracheotomy endoscope forms an abutment when bougienage and tracheostomy tube insertion into the trachea are necessary and prevents tracheal lumen loss and lateral compression.
- The excellent overview through a rigid endoscope with bright illumination of the entire trachea up to the bifurcation allows optimal execution of the tracheotomy with early detection of malfunctions and via falsa with the danger of a pneumothorax or a tracheoesophageal fistula.
- In the event of unforeseen significant bleeding, blood suction via a rigid endoscope with metal suction cups is much more effective than suction via flexible endoscopes, which can save lives. According to own experimental studies, the better capacities of blood suction with a correspondingly long metal suction cup differ from those of flexible endoscopes by 70%. Light bleeding can be stopped endotracheally with a curved special coagulation suction device.
- In the case of massive bleeding, immediate reintubation through the endoscope is possible with a cuff that can be placed under sight at or under the bleeding source to secure the airway.
- Dislocated tracheal braces and fragments as well as granulomas in the larynx can be treated endoscopically immediately to prevent later stenosis.
- Continuous breathing gas monitoring is possible [18, 81].
- The possibility of stent implantation exists.
- The entire tracheotomy process can be demonstrated via image monitoring for teaching purposes and documented by images for the patient file.
- All parts of the endoscope are easily accessible for cleaning and can be sterilized.
- The use of the rigid endoscope complies with the 2015 German guidelines for tracheobronchoscopy [83].

Note: From 2006 to 2010, the rigid Tracheotomy Endoscope (TED) was used in a multicenter study under the positive vote of the Ethics Committee of the Saxon Medical Association (EK-MPG-09/06-1) in 180 patients of intensive care medicine and ENT medicine on the basis of a study protocol based on Fantoni [1]*, published by Nowak et al.* [18].

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Iatrogenic Tracheal Injuries: Therapeutic Options

11

A. Rolle

11.1 Introduction

In spite of the constantly increasing number of inpatient, surgical, interventional and intensive care treatments for patients, iatrogenic tracheobronchial injuries have remained a rare complication of medical practice to this day, although—once occurred—they do involve the risk of high morbidity and mortality. With regard to causes and circumstances, the literature references are unambiguous: Emergency intubation leads by a clear margin, followed by intubation with double lumen and single lumen tubes [1]. It is far more difficult to obtain objective figures about the frequency, since most of the data come from individual regional centers or clinics, which must not be interpreted as generally valid. The most cited frequency of tracheal injuries in orotracheal intubations is 1/20,000 (0.005%) and 0.05–0.19% for double lumen tube intubations. In the total frequency, tracheobronchial injuries as a result of percutaneous dilatational tracheotomies (PDT) follow at 0.2 to 0.7% [2–4]. In a survey by Schneider et al. [5] in 182 clinics in Germany with an evaluation of the German Diagnosis Related Groups (G-DRG), tracheobronchial injuries occurred in 0.17% of 22,449 PDT. Current studies show a similar order of magnitude Chap. 10, Table 10.3.

Other important causes include endoscopic examinations and interventions in addition to blunt transhiatal esophagectomy.

With regard to the patients at risk, clear information can again be found in the literature. Strikingly, in all larger studies small and obese women of a height of 160 cm and an average age of 60 years are 80% affected [6–8]. It is discussed that in these women the anatomical small size of the tracheobronchial system is underestimated, and too large, unsuitable endotracheal tubes have been used.

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11.2 Diagnostics

If the intubating physician did not notice the tracheal injury, a slowly increasing mediastinal and skin emphysema occurs after the extubation in the following hours until the first day, which can be recognized as a leading symptom at the upper thoracic aperture and at the neck in almost 90% of the patients. Patients often complain of coughing, sore throat and increasing dysphonia. In about 30% of cases hemoptysis occurs, which can be interpreted as an alarming symptom. Further progression leads to dyspnea and possibly to pneumothorax. The leading symptom of mediastinal and skin emphysema should lead to a suspected diagnosis of tracheal injury following elective or emergency intubation or tracheotomy [1]. The two most important examination techniques are:

1. A multislice neck and thorax CT, which shows the injury and the extent of concomitant diseases even without contrast medium and provides information about the mediastinum and the lungs.
2. Bronchoscopy, where flexible bronchoscopy under local anesthesia is the simplest form. This examination technique was sufficient to classify the patient's injury in Fig. 11.1 and to initiate conservative therapy.

In hemoptysis or increasing dyspnea and respiratory insufficiency, rigid tracheobronchoscopy alone or in combination with flexible bronchoscopy with the possibility of ventilating the patient, or jet ventilation is recommended. With this ventilation technique, not only diagnostics but also smaller procedures can be performed much more comfortably and safely, including hemostasis. Depending on the patient's condition and the availability of experienced bronchoscopists and thoracic surgeons, a decision should be made as to whether the patient should be transferred to a specialist center at an early stage when the condition is stable. If the personnel resources are available in the clinic, the thoracic surgeon should already be involved

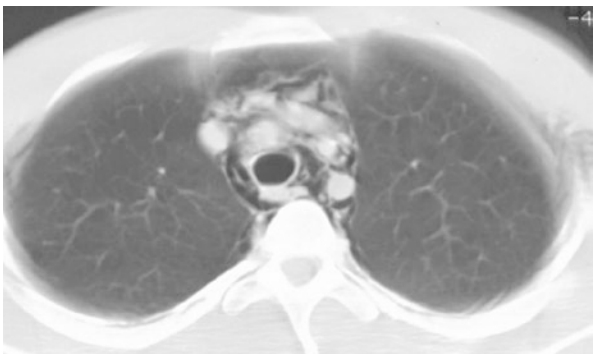

Fig. 11.1 Mediastinal emphysema in a 40-year-old female patient 1 day after elective goiter surgery with spontaneous breathing. Grade II injury bronchoscopically confirmed with complication-free healing after 1 week of conservative therapy

in the first tracheobronchoscopy, since the extent of the injury and the overall situation of the patient can already help determine the further therapy at this point. The classification of iatrogenic tracheal injuries into four different grades proposed by [1] and slightly modified according to our clinical experience should be carried out (Table 11.1).

The bronchoscopic findings first describe the height at which the injury begins and the depth to which it extends in the direction of the bifurcation. Grading follows, whereas Grade I injuries are limited to the mucous membrane and the submucosa. A Grade II injury is most frequently observed at almost 80% and is characterized by the fact that the muscle layer of the Paries membranaceus (posterior tracheal wall) is also injured (Fig. 11.2a). In addition, there is a mediastinal and skin emphysema, but mediastinitis or esophageal injury can be ruled out.

In a grade III injury of the trachea, the entire wall is torn and allows a view of the esophagus or the mediastinal soft tissue, which can also herniate into the injury under spontaneous breathing. By definition, no florid mediastinitis exists at this degree of injury and the esophagus is not injured either.

Only in Grade IV is the all-layer injury of the trachea combined with an esophageal perforation and then obligatory with mediastinitis. If the mediastinal pleura is

Table 11.1 Morphological tracheobronchoscopic classification of isolated and combined tracheal injuries (modified acc. to Cardillo et al. 2010 [1])

Grade I	*Tracheal injury restricted to mucosa and submucosa without esophageal involvement and emphysema*
Grade II	*Tracheal injury with destruction of the muscle layer of the Paries membranaceus (posterior tracheal wall) with mediastinal and skin emphysema without esophageal involvement and mediastinitis*
Grade III	*Complete rupture of the Paries membranaceus (posterior tracheal wall) with a view to an uninjured esophagus or mediastinal tissue without florid mediastinitis*
Grade IV	*Tracheal injury with esophageal injury and/or rupture of the mediastinal pleura with mediastinitis or also older injury with empyema*

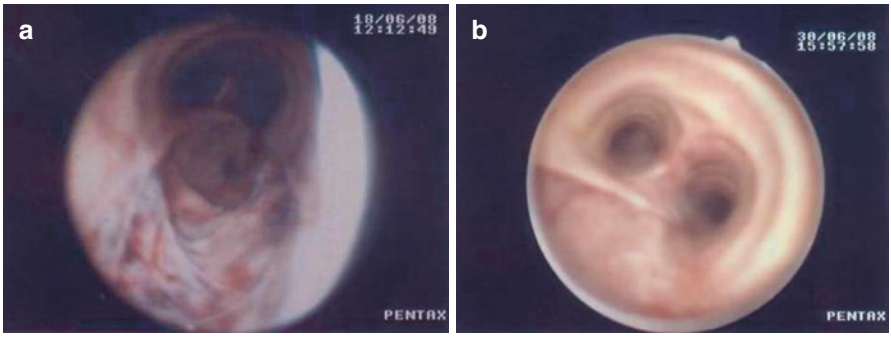

Fig. 11.2 (**a**) Grade II injury with rupture of the muscle layer of the Paries membranaceus (posterior tracheal wall) to above the bifurcation in a 67-year-old female patient with mechanical ventilation due to pneumonia, condition after emergency intubation in a foreign hospital. (**b**) Healing after conservative treatment with bridging by microcuff tube, 12 days later at the time of extubation

also ruptured in the mediastinal direction by this injury, there is inevitably a connection to the pleural space, which immediately leads to a pneumothorax with free pleural leaves and very quickly to a tension pneumothorax with ventilation, which must be relieved with thoracic emergency drainage. Grade IV also includes the rare, but all the more threatening cases in which the injuries are only discovered days later if they have already led to a severe mediastinal empyema (Fig. 11.4 a and b) with sepsis or even later if large defects have already occurred in the trachea and esophagus (Fig. 11.5 a, b, c).

11.3 Therapeutic Options

While, until the end of the 1990s, emergency surgical treatment of every tracheal injury via a posterolateral right-sided thoracotomy was demanded as the gold standard, reports and studies increasingly showed at the beginning of the new millennium that iatrogenic tracheal injuries can be healed conservatively in at least 50% of cases [2, 9–11]. Based on clinical studies and own experiences, a therapy algorithm can be presented (Fig. 11.3), which also provides a guideline for colleagues who are not often confronted with this problem [10, 12].

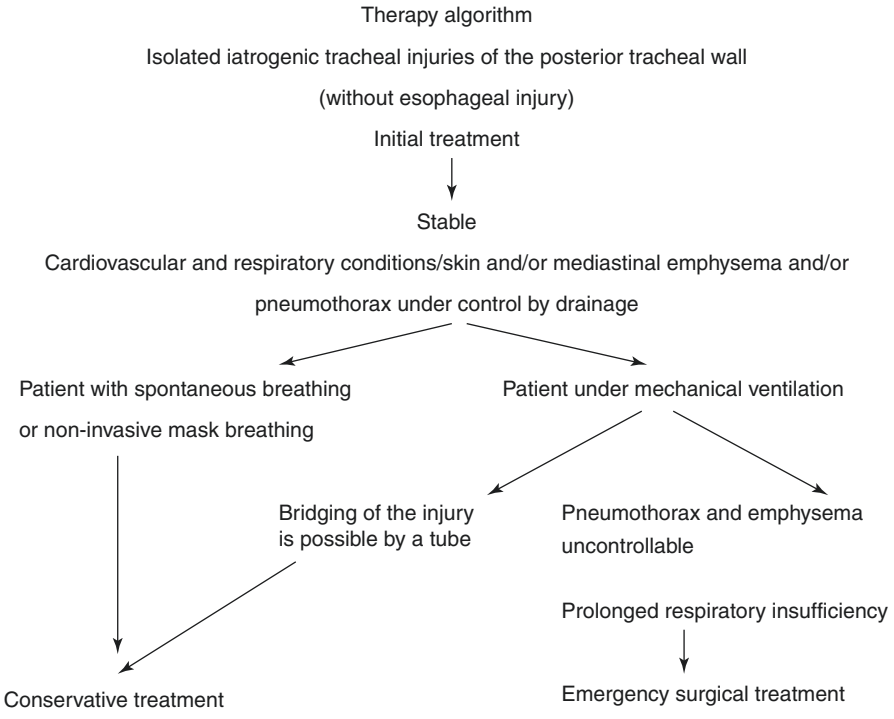

Fig. 11.3 Tracheal injury therapy algorithm

Of course, the initial care of the patient according to the overall situation that led to the iatrogenic tracheal injury is the first priority. Once stable cardiovascular and respiratory conditions have been achieved despite mediastinal and skin emphysema and if any concomitant pneumothorax is controlled by adequate thoracic drainage, two different clinical scenarios can be developed.

In the first case, the patient is stable, e.g., after an elective procedure with spontaneous breathing or after an emergency intubation due to a heart attack with non-invasive mask ventilation and the bronchoscopy has shown a tracheal injury Grade I to Grade III. In this scenario, the injury can be treated conservatively with an initially calculated antibiotic regime under intensive care observation. In more than 90% of cases, the mediastinal and skin emphysema slowly subsides under spontaneous breathing. Under the initially calculated antibiotic administration no mediastinitis develops and the defect is usually closed after 7 days.

In the second case, mechanical ventilation was already necessary before a Grade I to Grade III injury or it becomes necessary in the further course due to the development of respiratory insufficiency, e.g., on the grounds of pre-existing lung diseases. In this scenario, a specialist center can still try to bridge the injury with an adapted tube or tracheostomy tube and continue conservative therapy. If this bridging is successful over a period of 1 week, a high percentage of the defect will be closed under antibiotic therapy and further healing will take place without strictures or stenoses (Fig. 11.2a, b).

Only the failure of this bridging intubation with progressive skin emphysema or massive fistulation via a pneumothorax then makes surgical treatment mandatory with definitive closure of the injury.

Finally, there are Grade IV injuries with involvement of the esophagus and/or primary rupture of the mediastinal pleura, for which surgical emergency care is still recommended. It is still carried out today, especially when the esophagus is involved, via a right-sided thoracotomy, but increasingly as an anterolateral thoracotomy with preservation of the latissimus dorsi muscle, the most important donor muscle of the thoracic wall. Alternative surgical procedures with transcervical or endoluminal approaches are limited to injuries without esophageal involvement and are reserved for special clinics and studies [13–16].

Only in individual cases and exclusively in clinics in which operative therapy is guaranteed at all times and without delay can interventional measures, such as esophageal and/or tracheal stenting be tried in high-risk patients. The aim is then to avoid the high-risk emergency operation or at least to postpone it for several days until respiratory insufficiency and general condition have improved through therapeutic measures.

After all, the extreme cases, which are discovered very late after injury and are already treated as a full-blown sepsis (Fig. 11.4) or a defect of the trachea and esophagus that has already occurred (Fig. 11.5), must also be mentioned.

Figure 11.4 a and b show CT images of a 45-year-old woman five days after an elective plastic surgery, which resulted in an unverified Grade IV injury of the trachea with esophageal involvement. After extubation, a severe mediastinal empyema with fulminant sepsis developed within a few days under spontaneous respiration.

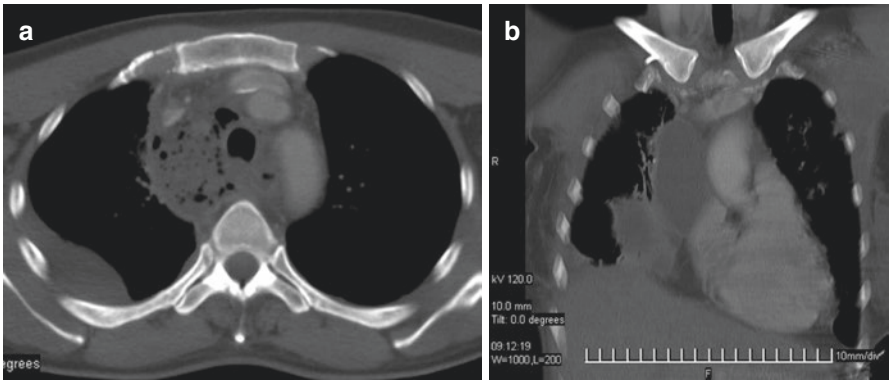

Fig. 11.4 (**a**) Extended mediastinal empyema after late Grade IV injury with esophageal involvement and severe sepsis. (**b**) The empyema has already spread throughout the upper and lower mediastinum. Indication for emergency surgery with treatment of the injury and drainage of the mediastinum

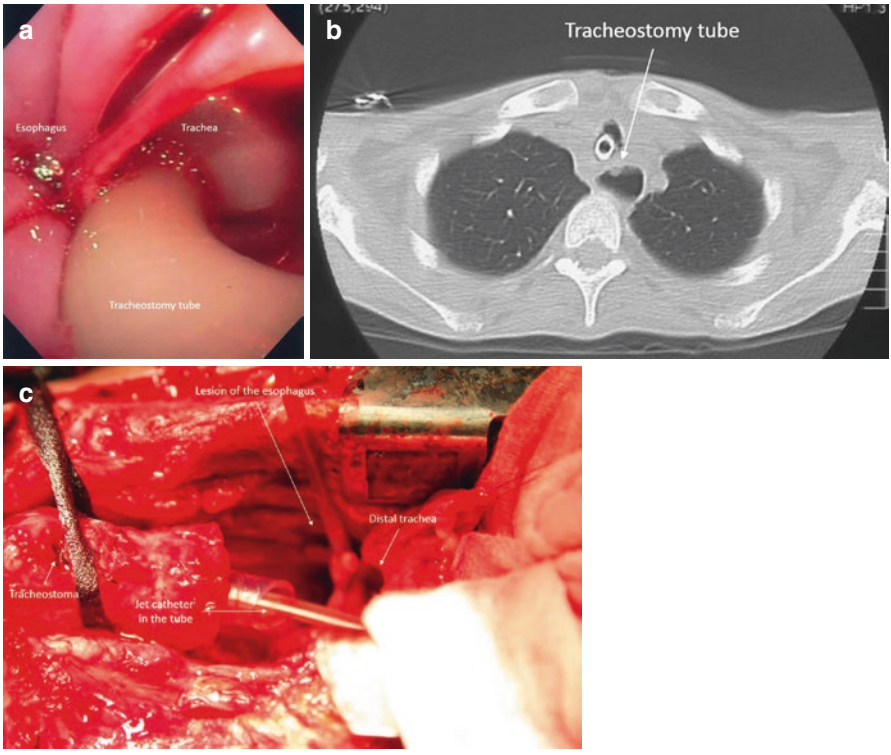

Fig. 11.5 (**a**) Several weeks old, delayed Grade IV injury after emergency intubation and percutaneous dilatational tracheotomy in a 30-year-old man. The image shows a view of the tracheal cannula in the esophagus, which reaches the trachea distally via a dorsal defect. (**b**) Tracheal cannula in the significantly extended esophagus; (**c**) Intraoperative site with 6.5-cm-long defect of the trachea and esophagus. Reconstruction with tracheal segment resection, esophagus additionally covered with muscle flap plastic, healing after 3 weeks

After emergency treatment of the injury via an anterolateral right-sided thoracotomy and drainage of the mediastinum, healing without late sequelae occurred after 2 weeks.

Figure 11.5 a–c shows a 6.5-cm-long defect of the trachea and esophagus in a 30-year-old man, which had developed after emergency intubation during resuscitation and percutaneous dilatational tracheotomy with long-term ventilation and several difficult tracheal cannula changes. The transfer to our specialist center was due to uncontrollable recurrent lower lobe pneumonia due to constant aspiration resulting from the large defect.

11.4 Conclusion

While 20 years ago, the operative therapy of iatrogenic tracheal injuries was mainly propagated, a clear turn to conservative therapy has taken place. It was shown that under certain conditions, such as spontaneous breathing and stable cardiovascular and respiratory conditions, good healing results could be achieved with purely conservative therapy [2, 9, 10, 17]. Thereby, it is important to make a morphological classification of the injuries and to differentiate between tracheal injuries with and without esophageal involvement. The length of the defect, which has so far been propagated as the most important prognostic factor, takes a back seat. Using this therapy algorithm and the classification, it was shown that Grade I to Grade III injuries occur most frequently at 80% and thus explain the rapidly increasing share of conservative therapy.

Thus, the much rarer grade IV injuries with esophageal involvement or rupture of the mediastinal pleura and the even rarer obsolete injuries in which severe infections have already developed remain for surgical treatment. This reduces the proportion of surgical therapy but represents a clear negative selection of patients and explains the high postoperative mortality rate of 20–60%.

Care should be taken to ensure that difficult elective and emergency intubations are documented, and controls initiated. Every patient with difficult intubation and suspected tracheal injury must be examined for possible injury. After percutaneous dilatational tracheotomy, the trachea should be checked for possible injury immediately after insertion of the tracheal cannula. With this simple management, early detection of injuries can be improved, and the success rate of conservative treatments can be optimized.

For PDT, good endoscopic vision is the best prophylaxis for severe iatrogenic tracheal injury (Chap. 10).

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Laryngotracheal Reconstruction

12

Ch. Sittel

12.1 Etiology

Stenoses of the laryngotracheal transition are always acquired in adulthood, whereby basically four cause complexes are to be distinguished:

1. Intubation

   In adulthood, the development of a tracheal stenosis by intubation is a rare event. In addition to the length of the tube retention period, a possible intubation trauma is of particular importance, especially in emergency situations. The underlying pathomechanism has not been conclusively clarified, but a multifactorial situation is suspected. Additional risk factors are an individual disposition as well as an esophageal-laryngeal reflux. The differentiation from idiopathic subglottic stenosis in particular can be difficult. The basic rule is that if there is a period of more than two years between intubation and the first appearance of symptoms, a correlation must be considered unlikely. Typically, intubation-related stenosis manifests itself at the level of the ring cartilage and is short-distance. Endoscopic therapy can be successful in the early stage of stenosis formation, before complete scarring has been completed.
2. Idiopathic progressive subglottic stenosis (IPSS)

   The IPSS concerns almost exclusively women of childbearing age. The symptoms of the inspiratory stridor usually develop over years, but accelerated courses are possible [1]. A triggering event must be excluded by careful anamnesis, an intubation more than 2 years ago can be considered etiologically insignificant. Particular attention should be paid to the exclusion of a systemic disease, in par-

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ticular polyangiitis with granulomatosis (Wegener's disease). Accelerated disease progression is typical during pregnancy. In combination with the clear sex disposition, this has always been interpreted as an indication of a possible connection with the metabolism of female sex hormones. The study situation is contradictory so far, but recently there have been indications that a dysbalance between different types of estrogen and progesterone receptors may be etiologically significant, whose importance for wound healing has been documented elsewhere. The endoscopic appearance is uneven, but always shows an inconspicuous epithelial surface, mostly with submucosal corkscrew-like scar strands. The proliferation of submucosal tissue is almost pathognomonic, especially in the area of the ring cartilage plate, which is not nosologically attributable. Numerous etiological models are discussed in the literature, ranging from esophagotracheal reflux to microtrauma due to coughing attacks and chronic mycoplasma infections [1–4]. However, none of these interpretational models can plausibly explain the clinical appearance, the course of the disease and, in particular, the gender distribution. The proposals for therapy are accordingly inconsistent. Some authors interpret IPSS as a fibrosating inflammation in the sense of a limited or localized systemic disease, which leads to the conclusion that surgical treatment is inadequate for pathophysiological processes. However, the application of endoscopic procedures, usually consisting of laser surgery, possibly in combination with high pressure balloon dilatation and intralesional injections of corticosteroids, shows in many series rather disappointing results with especially high treatment frequency at only short symptom-free intervals [5, 6].

Open surgical reconstruction aims to remove the pathology zones as completely as possible. The procedure of choice is cricotracheal resection (CTR), corresponding data in the literature show predominantly good to very good results [7, 8]. On the other hand, however, there is a higher expenditure and a complication risk not to be underestimated in this patient group, which differs from other forms of stenosis by a higher tendency to re-stenosis.

3. Tracheotomy

   The most common form of tracheotomy-related tracheal stenosis is A-frame deformation. This is caused by a loss of the anterior tracheal wall, which develops iatrogenically as a result of a too generous resection and especially in the case of a necrotized Björk flap or after perioperative infection with subsequent necrosis. The lack of anterior wall stability leads to instability of the tracheal side walls, which then medialize in the shape of the letter **"A"**. The appropriate term for this condition is pseudoglottic stenosis. Another important risk factor is the injury of the cricoid during tracheotomy, which leads to chronic perichondritis with subsequent stenosis. Depending on the individual situation, other patterns of damage can also be found. The initially suspected higher frequency of laryngotracheal stenoses after dilated puncture tracheotomy can neither be verified statistically nor by own observation. In critically ill patients, early tracheotomies ($\leq$ 7d) do not significantly reduce the risk of developing tracheal stenoses compared to later tracheostomies, regardless of the method [9].

4. Systemic diseases

   In the majority of cases, systemic diseases can be confirmed by a detailed anamnesis or by the presence of further manifestations. In particular, polyangi-

itis with granulomatosis can lead to a larviated initial finding in the area of the subglottic larynx [10]. The endoscopic diagnosis shows a typical picture in most cases, but biopsies as well as serological parameters cannot always provide clarity, especially in the early phase. With a typical anamnesis and symptom constellation as well as a clear clinical picture, the habitual determination of numerous serological parameters should be omitted. In particular for the clarification of idiopathic subglottic stenosis, which can be difficult to distinguish from hidden systemic diseases, a complete diagnosis in the sense of an exclusion procedure is obligatory.

12.2 Basic Diagnostics

Flexible transnasal laryngoscopy, preferably in HD technology, is the most important basic diagnostic measure in cases of suspected respiratory stenosis. Supraglottic and glottic stenoses can be reliably detected, subglottic and tracheal stenoses only in individual cases. In small children with significant stridor, flexible transnasal endoscopy "on the mother's arm" should be performed with great restraint and intubation readiness, as emergency situations may quickly occur.

Computer tomography is the dominant imaging technique, especially for stenoses of the laryngotracheal transition. Particular attention is paid to changes in the ring cartilage and the ring cartilage plate. In progressive idiopathic subglottic stenosis, magnetic resonance imaging is often able to visualize the almost pathognomonic submucosal soft tissue thickening. In childhood and especially infancy, imaging procedures are of limited importance due to the weak contrast between cartilage structures and surrounding soft tissues. Three-dimensional reconstructions can make it easier to quickly determine the topography of the stenosis. However, since such reconstructions are represented by data reductions, there is no gain in information.

Overall, lung function tests are of secondary importance; they are generally not possible for tracheotomized patients. However, pulmonary concomitant diseases are particularly important preoperatively.

By far the most important diagnostic measure is the endoscopic examination under short anesthesia using rigid optics. Only in this way can all details be comprehensively recognized and taken into account. Preoperative diagnostic endoscopy is the most important measure for correct diagnosis and selection of the correct reconstruction procedure. Its importance and the importance of precise, accurate and reproducible execution can therefore hardly be overestimated.

12.2.1 Diagnostic Endoscopy

Anesthesia and endoscopy of the patient with stridor and dyspnea are often cause for anxiety to both the ENT physician and the anesthesiologist. However, if both the necessary equipment and the institutional, interdisciplinary competence are available to deal with them, high-risk patients can also be treated in a stress-free atmosphere.

The basic rule is that a patient who has entered the operating theatre with sufficient spontaneous breathing practically never has to undergo an emergency tracheotomy as part of an endoscopic diagnosis.

Preparation

Before administering anesthesia, the team must discuss what measures are planned and what requirements are to be met by the anesthetist. The anesthesia procedure to be chosen and, if necessary, the initial maintenance of spontaneous breathing depend on this.

The most simple and often sufficient technique is the short inspection in apnea. For more complex situations or simultaneous interventions, catheter-based jet ventilation should be preferred as a simple and inexpensive procedure. Alternatively, intermittent intubation with a thin tube is possible, but care should be taken to perform a primary endoscopy prior to the first intubation to avoid tube-related changes that may compromise accurate diagnosis. If airway stenoses are examined at regular intervals, ventilation procedures should be available that can safely handle even very complex ventilation situations. These include the tube-less Superimposed High-frequency Jet Ventilation (SHFJV®), apneic oxygenation with high-flow oxygen and the Ventrain® system.

Patient Positioning

The positioning of the patient corresponds to the procedure in microlaryngoscopy, the head is extended, the neck is flexed (sniffing position, Jackson position). The often observed simultaneous extension of the neck as well as the support of the shoulder area with a positioning cushion are to be avoided, as they complicate the exposure of the larynx.

Procedure

The larynx is adjusted with the anesthetist's McIntosh laryngoscope spatula; visualization is performed with a 0° optics of 30 cm in length, correspondingly shorter for children. Routine video projection and recording is highly recommended. It allows all parties involved to be simultaneously informed about the current examination and thus about any risk situations. The interdisciplinary discussion of the case on the recorded video is extremely helpful for exact diagnosis and therapy planning.

After optimizing the image parameters and exhausting secretions, a slow camera movement from supraglottic space to the carina and back is performed. The topographic relation of the pathology can be reliably determined by markings on the endoscope via a fixed point (row of teeth).

The assessment of respiratory stenosis should follow a structured and reproducible procedure. Thereby, the most important parameters are the degree of stenosis, the length of stenosis, involvement of ring cartilage and the vocal fold level, consistency and degree of activity. A recent consensus paper of the European Laryngological Society (ELS) provides good guidance for the assessment of respiratory stenosis [11].

12.3 Tracheal Segment Resection

12.3.1 Indication

Tracheal segment resection is the procedure of choice for stenoses of the cervical and thoracic trachea without involvement of the cricoid. With correct technical execution and especially correct indication, the results are excellent. If, however, stenoses involving the cricoid are operated on as tracheal segment resections, re-stenosis is almost obligatory. Since isolated tracheal stenoses without involvement of the ring cartilage are comparatively rare, but tracheal segment resection as "transverse resection" is often used as a synonym for tracheal surgery, it can be assumed that the indication is often too uncritical. This is probably the reason why tracheal segment resection has an unjustified reputation as a less successful procedure.

12.3.2 Procedure

The access path is almost exclusively transcervical, even for stenoses just above the bifurcation. The optimal exposure of the stenotic area with circumferential preparation of the entire tracheal circumference is of essential importance. Separation between esophagus and Paries membranaceus is obligatory. Sufficient mobilization of the distal and proximal trachea to ensure a tension-free anastomosis must be strictly observed, depending on the resectate length. After complete resection of all pathological parts, the anastomosis is performed with resorbable suture material. Postoperative intubation should only be performed in absolutely exceptional cases; chin-breast sutures are obsolete.

12.4 Cricotracheal Resection (CTR)

12.4.1 Indication

CTR is the method of choice for laryngotracheal stenoses involving the ring cartilage but without affection of the glottis plane, almost independent of the underlying etiology and the extent of the pathology. Cricotracheal resection was first described for adult patients almost simultaneously and independently by Pearson et al. [12] and Grillo in 1982 [13], the transfer to the pediatric population was not performed until the late 1980s by Monnier et al. [14].

12.4.2 Procedure

CTR is conceptually and operationally fundamentally different from tracheal segment resection. The basic principle is the complete resection of the laryngotracheal stenosis including the ring cartilage arch with complete exposure of the ring

cartilage plate [15]. After appropriate mobilization maneuvers, the distal trachea is partially adapted to the remaining cricoid, predominantly to the thyroid (thyrotracheal anastomosis). An existing tracheostoma is usually included in the resection, unless 2–3 healthy tracheal braces are left between the caudal stenosis margin and the cranial tracheostomy margin, which are available for anastomosis. As a rule, the procedure is performed at one time, i.e., without performing another tracheostomy (Figs. 12.1, 12.2, 12.3, 12.4, 12.5, 12.6).

Wherever possible, ventilation is initially via a laryngeal mask. Cricoid, thyroid and trachea are meticulously exposed via a cervical approach. Depending on the expected resectate length, a supralaryngeal release is carried out by discontinuing the infrahyoidal muscles. The preparation of the lateral trachea is carried out strictly along the cartilage, whereby damage to the recurrent nerves can be reliably avoided. The use of magnifying glasses is highly recommended for this partial step in particular. Below the stenosis, the trachea is incised and the distal tracheal stump

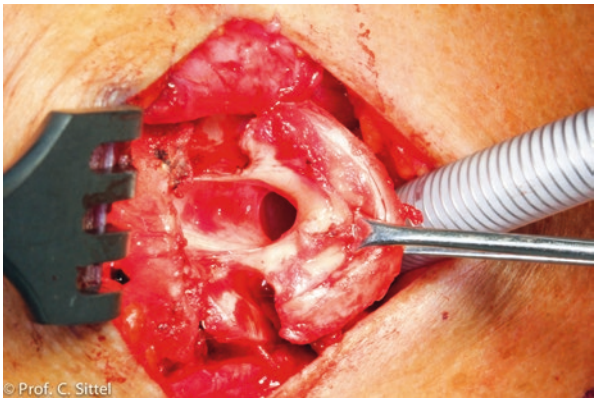

Fig. 12.1 CTR: Ring cartilage arch set off, view of the stenosis

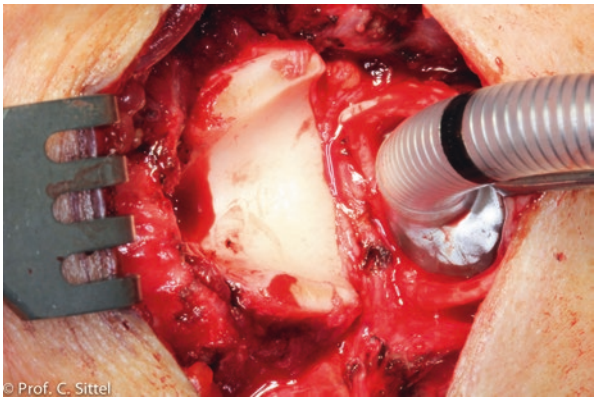

Fig. 12.2 CTR: View of the ring cartilage plate

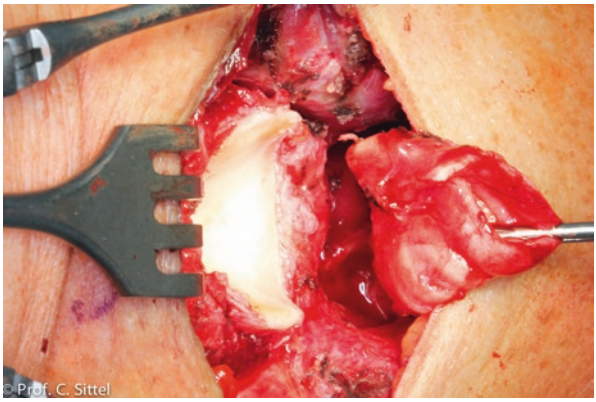

Fig. 12.3 CTR: Circumferentially mobilized trachea

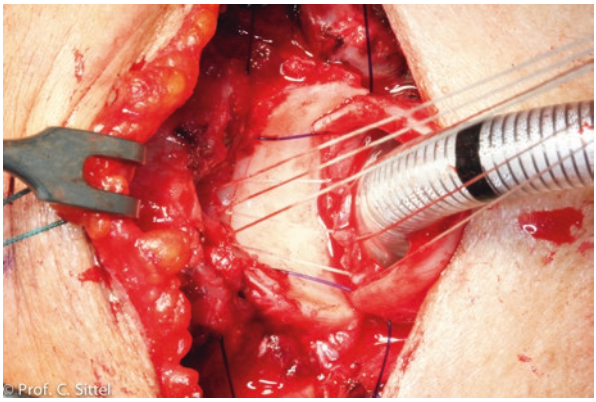

Fig. 12.4 CTR: Preparation of corner and posterior wall sutures

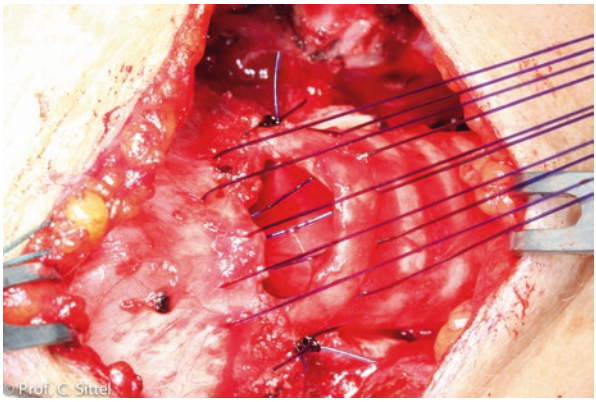

Fig. 12.5 CTR: Completed posterior wall anastomosis, preparation of the anterior wall anastomosis

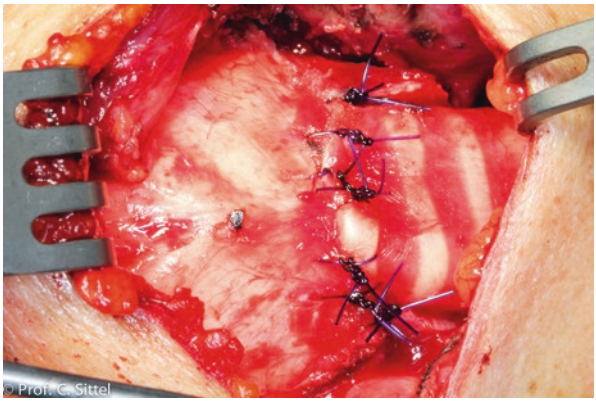

Fig. 12.6 CTR: Finalized site

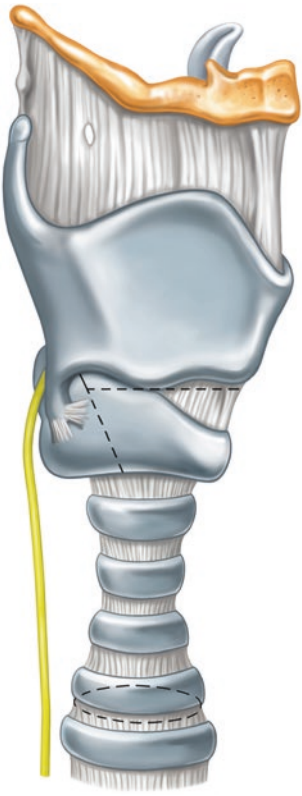

Fig. 12.7 Resection borders of the CTR

intubated. The cranial incision is made in the cricothyroid membrane, the ring cartilage arch is set off obliquely on both sides (Figs. 12.1, 12.7, 12.8), the mucosa on the ring cartilage plate is incised depending on the height of the stenosis. The ring cartilage plate is shown up to its caudal margin, the stenotic segment is separated

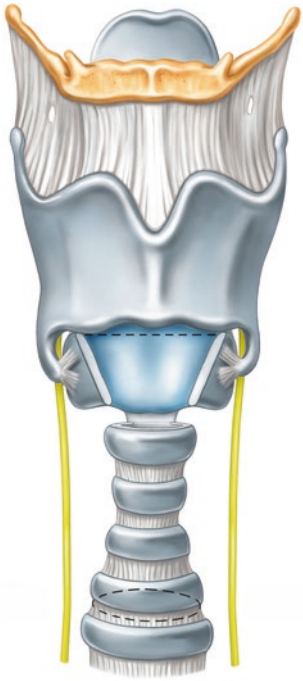

Fig. 12.8 Setting off the ring cartilage arch

from the esophagus and resected *in toto* (Fig. 12.2). The complete resection of the entire pathological part is of great importance, as is the generous mediastinal mobilization of the distal trachea. The ring cartilage plate is thinned out with the diamond drill to remove possible residues of pathological changes and to gain additional space (Fig. 12.3). The distal trachea is now placed tension-free on the ring cartilage plate and anastomosed with resorbable suture material with the lateral parts of the cricoid, the mucosa of the interarytenoid region and the thyroid (Fig. 12.4). This results in a primarily epithelialized anastomosis while avoiding exposed cartilage surfaces (Figs. 12.9 and 12.10). Before the anterior anastomosis wall is finally tied, the ventilation tube is removed from the distal trachea and the still inserted laryngeal mask is reused for ventilation (Figs. 12.5 and 12.6). The main advantage here is the immediate check for possible air leaks, which must be meticulously closed. Apart from a few exceptions, the patient's breathing is spontaneous, and postoperative intubation does not bring any advantages. Chin-breast sutures complicate physiological breathing and do not provide additional safety for anastomosis integrity. They are therefore considered obsolete.

12.4.3 Complications

The rate of success of a technically accurate and correctly indicated CTR can be regarded as excellent with well over 90%, which could be reproduced by various

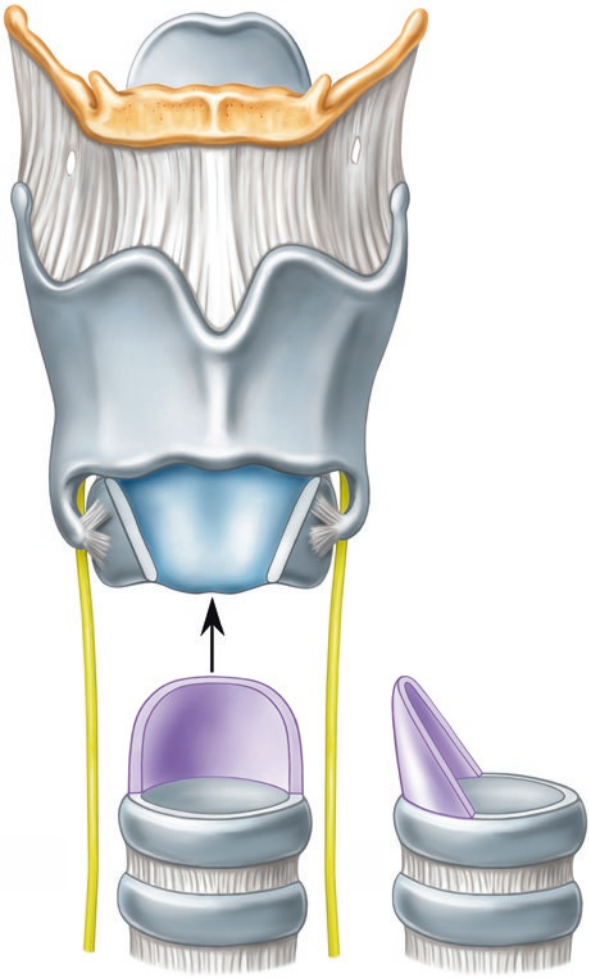

Fig. 12.9 Site after resecting the stenosis

working groups [16–18]. Nevertheless, this is a complex, three-dimensional intervention of considerable difficulty that requires a learning curve that should not be underestimated. Despite excellent final results, complications are not uncommon. Smaller endoscopic corrections, such as removal of fibrin deposits or granulations, are necessary in almost 2/3 of all patients, mostly only once. Severe complications, such as anastomotic insufficiencies or cartilage necrosis, are very rare exceptions. Despite the anatomical proximity, injuries of the recurrent nerves are extremely rare events with accurate and precise surgical techniques.

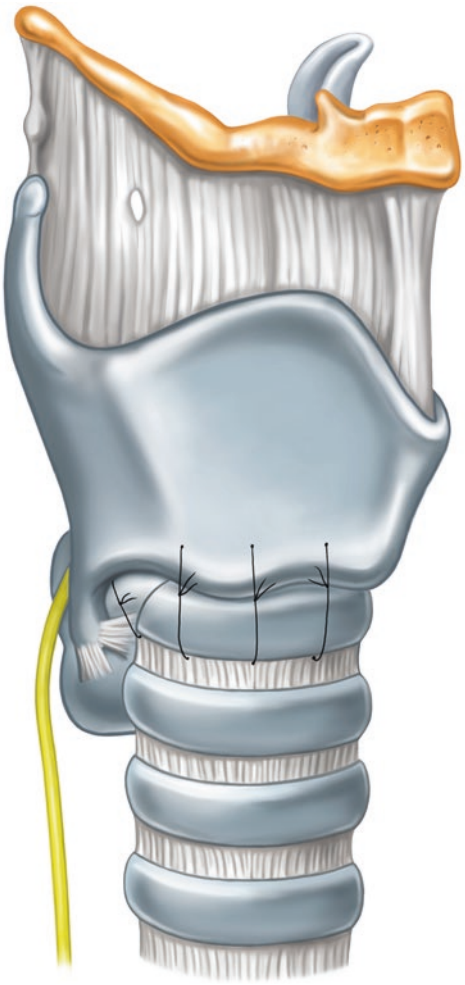

Fig. 12.10 Thyrotracheal anastomosis

12.5 Laryngotracheal Reconstruction (LTR)

12.5.1 History and Indications

More than 100 years ago, in the case of subglottic stenoses caused by diphtheria, which were endemic at the time, an attempt was made to expand the narrowed airway by permanently inserting a placeholder. The name Réthi is historically associated with the technique of additional splitting of the ring cartilage to facilitate splint dilatation [19]. In the 1970s, Cotton first described a technique in which the cleavage of the anterior and posterior ring cartilage was fixed with an autologous

transplant of rib cartilage [20, 21]. Under the term laryngotracheal reconstruction (LTR), this procedure represented the gold standard in the treatment of subglottic and glottic stenoses for the following three decades. The introduction of cricotracheal resection in children has put the importance of this procedure into perspective. However, it remains the procedure of choice for all cases involving the vocal fold level. LTR continues to be the best therapy for higher-grade interarytenoid fibroses that cannot be treated endoscopically.

Compared to cricotracheal resection, LTR is a technically less complex procedure that can be learned much more quickly [22]. The possible complications are no less frequent, but less dramatic. These may also be the most important reasons for the fact that, especially in childhood, the CTR, which is more promising in principle, was only able to assert itself numerically against laryngotracheal reconstruction at particularly specialized centers. Another reason is the increasing number of complex stenoses involving the glottis level.

The autologous transplantation of rib cartilage is possible very reliably in childhood; with increasing age, wound healing disorders with resorption or rejection are increasingly occurring. Nevertheless, LTR can be a useful treatment option until the 4th decade of life if resection procedures are not possible. The autologous transplantation of rib cartilage is possible very reliably in childhood; with increasing age, wound healing disorders with resorption or rejection increasingly occur. Nevertheless, LTR can be a useful treatment option until the 4th decade of life if resection procedures are not possible. In addition, however, the indication must be very strict.

As a rule, the removal of rib cartilage is technically possible after the completion of the 2nd year of life. In the first 18 months of life, a special form of LTR can be performed using autologous thyroid cartilage, which is not described in more detail here [23].

12.5.2 Procedure

For the LTR, there are different modifications depending on the author, therefore only the basic features shall be described here (Fig. 12.11).

The thyroid, cricoid and cranial trachea are exposed by access from the outside at the level of the ring cartilage. In contrast to CTR, circumferential preparation is not necessary, so there is no significant risk for the recurrent nerves. After meticulous exposure of the laryngeal structures, the medial incision of the cricothyroid membrane, the cricoid and the upper 1–3 tracheal braces takes place. Depending on the exact location of the stenosis, a partial or total laryngofissure may also be necessary. For atraumatic exposure, the use of a special laryngofissure barrier is recommended (Fig. 12.12).

After clear exposure of the ring cartilage plate, the incision is made over the entire length until the two halves of the ring cartilage are clearly separated. If necessary, an additionally existing interarytenoid fibrosis must be separated with micro scissors, whereby a cranial mucous membrane limitation should be maintained. The posterior graft is prepared like a podium with the “1st place” facing lumenwards

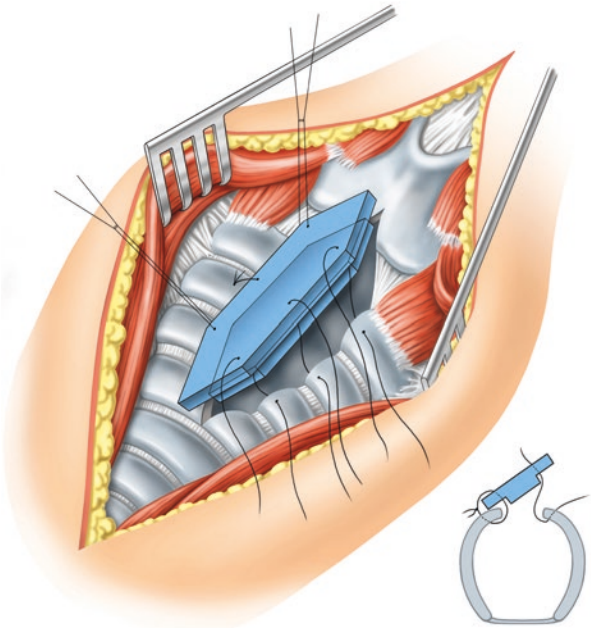

Fig. 12.11 Anterior laryngotracheal reconstruction

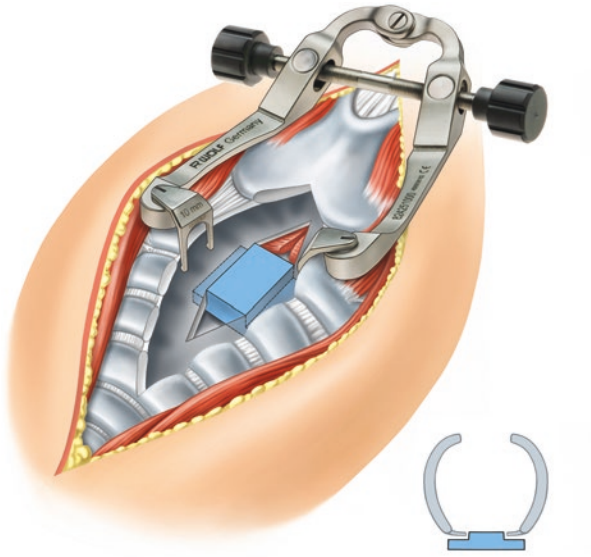

Fig. 12.12 Posterior laryngotracheal reconstruction with a laryngofissure barrier

and covered with rib perichondrium to reduce the tendency to granulation. The posterior perichondrium of the ring cartilage plate is undermined to receive the graft. The graft can then be inserted with considerable pretension; in most cases, additional fixation by suturing is not necessary and does not make sense. The inherent tension of the ring cartilage results in a primarily stable fit of the rib cartilage

(Fig. 12.12). Similarly, a second graft is inserted into the split cricoid, which extends into the cranial trachea or the caudal thyroid depending on the individual situation (Fig. 12.11).

The LTR is a modular procedure that can be used only anteriorly or only posteriorly. The anterior LTR alone does not require stenting and can usually be performed without tracheostoma. The posterior LTR and the combined anterior and posterior LTR, on the other hand, should always be performed in two stages, i.e., with a temporary tracheotomy or preservation of an existing tracheostoma.

Postoperative stenting to splint the reconstruction result is increasingly being used cautiously. The Montgomery T-tube often leads to considerable problems caused by granulation formation and pressure lesions. The LT-mold developed by Monnier represents a considerable improvement in all respects, but is unfortunately still not commercially available. In our hands, the 1-week inlay of a rubber fingerling tamponade has proved sufficient in the majority of cases. Overall, the question of postoperative stenting, especially in childhood, has not yet been solved satisfactorily in many aspects.

12.5.3 Follow Up

Granulation and edema occur relatively regularly on the lumenward graft surfaces. A control endoscopy with the option of granulation ablation should be performed regularly after about 3 weeks. Stubborn granulations can often be influenced very well by the topical application of Mitomycin-C (concentration 2 mg/ml). If a successful reconstruction of the airway is finally confirmed during a control endoscopy, decannulation can be performed step by step. Usually, the tracheotomy tube size is first downsized step by step (downsizing), followed by stopping the tracheotomy tube. In the last step, the tracheostoma is masked before the surgical tracheostoma closure. This process can usually be shortened considerably in adulthood.

12.6 Endoscopic Dilatation Methods

12.6.1 Different Procedures

Especially less pronounced respiratory stenoses, especially at the glottis level, can be treated successfully and reproducibly with endoscopic techniques, which are not the subject of this chapter. For subglottic stenoses in childhood as well as in adulthood, long-term success with endoscopic techniques can only be recorded in rare exceptional cases from severity level III according to Myer and Cotton. The use of the CO_2 laser, especially when used repeatedly, must therefore be regarded as contraindicated and obsolete, especially in infancy. The collateral damage that always occurs leads to a long-term deterioration of the stenotic situation, which in the worst case makes open reconstruction not only more difficult but also impossible.

12.6.2 High-Pressure Balloon Dilatation

High-pressure balloon dilatation represents a good compromise between tissue protection and probability of success [24]. In comparison to all laser-assisted techniques, the procedure can be characterized as much more benign; even with multiple applications, significant concomitant traumatizations are not to be expected. If it is possible to treat the stenosing process with one or more balloon dilatations before it is completed, a permanently normalized lumen can be achieved. If, on the other hand, the treatment only begins after the complete completion of the scarring fixation, this is generally not the case. Nevertheless, high-pressure balloon dilatation can also be a sensible measure for these patients, for example when it comes to avoiding a tracheotomy in the bridging phase up to an open reconstructive procedure.

If the intervals until re-stenosis are not too short, repeated balloon dilatation can also be a sensible concept for long-term therapy of individual patients.

High pressure balloon dilatation is becoming increasingly important as a postoperative adjuvant. The procedure is particularly well suited for the early postoperative phase of edema of the subglottic slope, which is often observed after cricotracheal resection. Imminent, early re-stenosis processes can also often be successfully intercepted. Therefore, if the expectations remain realistic and the limits are respected, high pressure balloon dilatation is a valuable building block in the treatment of laryngotracheal stenoses [25].

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Stenting of the Trachea

13

O. Michel

13.1 Introduction

The trachea can be splinted both from the inside and from the outside to keep it open or to stabilize it-a measure that may become necessary in connection with a tracheotomy or to avoid a tracheotomy. The therapy of keeping the airways clear gains a further option through these procedures. The following chapter will discuss the current possibilities of endoluminal placeholders (stents) with the necessary critical view [1].

13.2 History and Definition

Tubular endoprostheses or placeholders, also known as "stents", are used for internal splinting. They have a long tradition in laryngology. They were marketed as "tracheal bolts", "rubber tubes", "Aboulker prostheses" or "Montgomery tubes" and were generally used to temporarily stabilize the wound conditions within the trachea and larynx. They usually require a tracheotomy because they have either no lumen or insufficient lumen for the breathing air.

The modern term "stent" also refers to an inner splint that has such a large lumen that breathing is possible and tracheotomy can be avoided. The name "stent" is attributed to the English dentist Charles T. Stent (1807–1885). The impression material invented by him was first used in urology and later also in other disciplines for the internal splinting of ducts, vessels and hollow organs [2].

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The further slow development can be followed over the years. Bond wrote in 1891 in Lancet about a divisible T tube with the possibility of endotracheal splinting [3]. In 1929, Schmiegelow described the method of using a placeholder when stenosing the larynx [4]. The introduction of silicone as a material in the 1960s gave the process a real boost. In addition to plastics, special metal alloys such as the "shape memory metal" Nitinol,[1] but also self-expanding steel meshes, have been available for 20 years now, and are becoming increasingly popular due to their stability and easy placement.

The stents initially developed for angioplasty were also used in interventional radiology, anesthesia, bronchopulmology and thoracic surgery. They were further developed for recanalization of the central airways and placed under general anesthesia with a rigid bronchoscope. The latest developments are stents that release drugs [5] or are biodegradable [6].

13.3 Overview of Stents

13.3.1 Preliminary Note

In general, the following minimum conditions are expected from endoprosthetic placeholders (stents):

- small insertion diameter, as they have to pass through the narrowest points, such as the glottis or a stenosis,
- easy and uncomplicated placement, since ventilation must be maintained as far as possible during placement,
- self-stability, so as not to be deformed by coughing with physiological constriction of the trachea or to be compressed by external pressure from scars or tumor growth,
- low or no tendency to mucous incrustation
- biofilm resistance,
- no displacement or migration
- radiopaqueness,
- minimal traumatization of the trachea surface in order not to cause granulation tissue and new constriction,
- good tissue compatibility,
- easy removal,
- durability, no material fatigue.

The following shall briefly introduce common and frequently used stents (overview Table 13.1).

[1] Acronym of "Nickel Titanium Naval Ordnance Laboratory".

Table 13.1 Overview of common endoluminal stents (no claim to completeness)

Types of stent, trademarks	Made by	Structure or design	Size (mm)
Wallstent	Boston Scientific	Woven cobalt/chromium alloy monofilament with silicone sheathing	8 × 20–24 × 60
Ultraflex tracheobronchial stent	Boston Scientific	Woven monofilament of Nitinol covered and uncovered with silicone	8 × 20–20 × 80
Dumon	Novatech	Molded silicone	9 × 20–18 × 70 + Y
Hood stent Y stent Tracheal/bronchus stent	Hood Corp.	Molded silicone with and without reinforcement, external nubs or rings	6 × 13–18 × 90 + Y
Polyflex Airway Stent	Boston Scientific	Polyester mesh encapsulated in silicone	6 × 20–22 × 80
Dynamic (Y) Stent	Boston Scientific	Silicon with U-shaped steel braces that are open at the rear	11 × 110– 15 × 110 + Y
Tracheobronchial Y-stent	Rüsch Teleflex Company	Silicon with U-shaped steel braces that are open at the rear	13, 15, 17 (Trachea) 110

13.3.2 Metal-Based Stents

Self-Expanding Stents of Metal

Gianturco Z Stents

Gianturco Z stents or Cook-Z® stents are self-expanding stainless steel grates that are placed over a stenosis with special insertion instruments into the trachea. A catheter system releases the stents on site. Due to their inherent elasticity, they expand like a claws grid and can thus exert pressure on the tracheal wall. This may be desirable in stenosing processes. To ensure that it is securely fixed and does not slip, the diameter of the stent should be approx. 1/3 larger than the diameter of the trachea to be splinted. The spacing between the metal filaments is relatively large, so that a coarse mesh is formed. This makes it possible to grow through, e.g., during a tumorous process. As a rule, the stent can no longer be removed. Due to passive movements of the trachea, this stent can also drill through the walls and thus get out of place. These stents are available in a diameter of 6–12 mm and a length of 15–90 mm, so that they are no longer suitable for a very wide trachea due to their dimensions.

Wallstents™

Wallstents™ are endoprostheses consisting of a circularly woven, flexible, close-meshed and self-expanding wire mesh (Fig. 13.1). The thickness of the wire filaments is between 0.08 and 0.17 mm. The braids are mounted on a catheter system in the stretched state and are thus inserted. For implantation, fluid is injected under

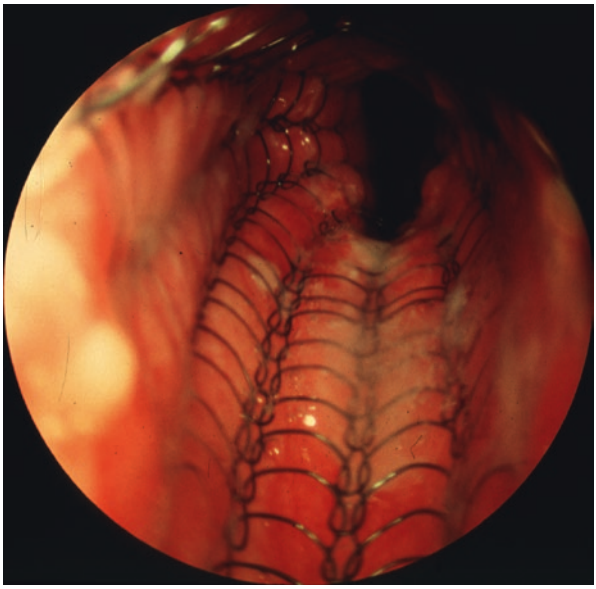

Fig. 13.1 Metal stent (Wallstent™) in the trachea

pressure between the diaphragms of the double membrane enveloping the stent. The stent then expands automatically to the specified width. The system is retracted, and the wall stent remains in place. The ends of the stent are slightly bent outwards. The ends penetrate into the mucous membrane and anchor the stent. Although explantation of the stent is possible in principle, it is very traumatizing for the mucous membrane and time-consuming because the wires have to be removed individually [7] (Fig. 13.2).

Balloon-Expandable Metal Stents

Strecker Stents

Strecker Stents consist of a fine-meshed mesh of tantalum wire of a thickness of 0.15 mm, which is pulled onto a small-diameter balloon catheter (Fig. 13.3). The catheter is inserted into the stenosis. Using an isotonic saline solution, the balloon is inflated at a pressure of approximately 6–7 bar. This expands the stenosis to the desired lumen and brings the stent into its final shape at the same time. Strecker stents are semi-rigid placeholder systems that exert only little pressure on the lumen walls. Due to their flexibility, Strecker stents can contract with the trachea or bronchial section during a cough push, so that secretion from deeper sections can be transported across the stent through the airflow. The close-meshed net also allows mucus secretion into the lumen so that there is no risk of incrustation [8]. Removal of the Strecker stent is usually possible without major problems and without damaging the trachea wall.

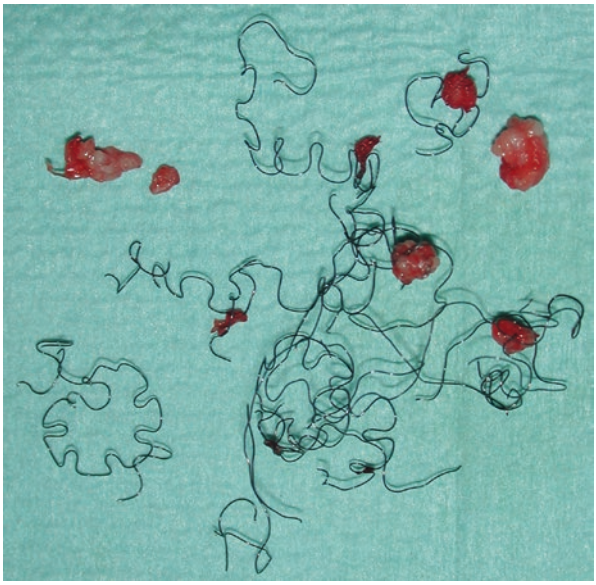

Fig. 13.2 Metal stent removed in pieces

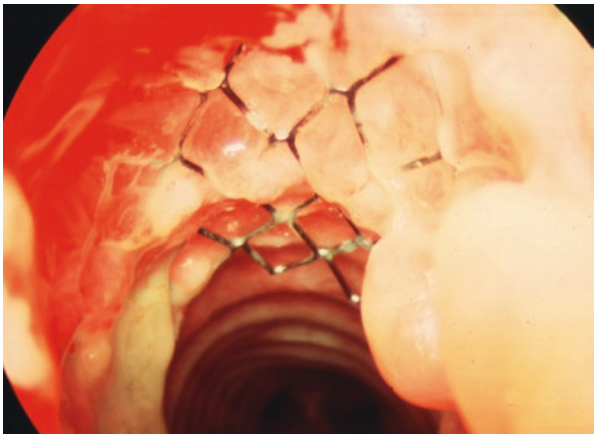

Fig. 13.3 Strecker stent

Palmaz® Stents

Palmaz® stents are grid constructions made of surgical stainless steel, which are mounted on a balloon catheter similar to the Strecker stent and are inserted into the stenotic area with the still small diameter. The expansion of the stent takes place through the balloon, which is inflated by means of a fluid with overpressure (approx. 10 bar). To generate the pressure, a special syringe and a transfer system must be used, which can generate or withstand the enormous pressure. These stents are rigid systems once they have been put into shape. Since they do not have any restoring force, they can be deformed and compressed by external pressure, which has serious

disadvantages in stenosing processes with self-growth. Another disadvantage is the formation of granulation tissue at the ends of the stent where it comes into contact with the tracheal tissue. Palmaz® stents are known to have problems with removal, especially deformation. They are available in diameters from 3 to 16 mm and lengths from 12 to 30 mm. Wall thickness ranges from 0.076 to 0.127 mm.

Y Stents und J Stents

In addition to the classic silicone Y stent, self-expanding metal stents such as the Ottomed stent, Meditech Y stent [9] are now also available on the market. A special form is the J stent for one-sided lung resection.

13.3.3 Silicone-Based Stents

The most commonly used stents are made of silicone, a polymeric organosilicon compound. Due to the fact that the stents are made of pure silicone, the wall thickness is at least 1 mm for reasons of stability, which means that the outer diameter of these stents is considerably larger than the inner diameter. The material can be made radiopaque by additives or incorporated strips so that the position can be determined in X-rays. One of the disadvantages of this material is its easy flammability during laser procedures.

Solid Silicone

Montgomery® Stents

Montgomery® prostheses are T-shaped, relatively rigid placeholder systems that are inserted into the trachea through a tracheostoma [10] (Fig. 13.4). The short leg of the T-tube can be secured by the stoma. The soft silicone material allows both distal and proximal adaptation by shortening. The trachea can be aspirated through the opening of the tracheostoma and the opening of the T-prosthesis. The wide distribution and the possibility to have custom-made prostheses made to measure are advantageous. As a rule, they can be easily removed by pulling the protruding piece. The disadvantage of this system is that it can only be used in conjunction with a tracheostoma, have a strong tendency to internal encrustation and may be difficult to place and special anesthetic precautions must be taken [11].

Dumon-Artemis Stents, Noppen Stents

The principle of inner splinting in malignant respiratory stenoses was widely adopted by a stent specially developed by Dumon for this indication in 1988 [12]. The Dumon-Artemis stent (Endoxane®-stent) is a tubular placeholder made of silicone which has external nubs for fixation within the trachea or bronchi. Position correction and removal are therefore only possible to a limited extent. The Noppen stent remedies this weakness [13]. Due to its smooth inner surface, it can lead to secretion retention and mucous incrustation. These placeholder systems are available in a diameter of 9–16 mm and a length of 20–50 mm, so that actually all tracheal sizes can be well treated.

Fig. 13.4 Montgomery® Safe-T-Tubes™ (© Boston Medical Products, Inc.)

Silicone/Steel, Silicone/Polyester, Silicone-Coated Stents

Orlowski Stents

Orlowski stents consist of closed steel rings that are coated with silicone and connected to each other. The steel rings allow a smaller wall thickness of the stent at yet high stability. Their appearance is somewhat reminiscent of Rügheimer tubes. They are not that easy to place and have a tendency to secretion retention.

Y Stents

The Y stents are related to the Orlowski stents in material and appearance. However, they do not have continuous but reinforcing U-shaped rings that end in a thinner silicone membrane towards the posterior tracheal wall. This allows the stents to deform like the natural trachea in the event of a cough strike and allows self-cleaning due to the resulting reduction in diameter [14].

At one end, two little asymmetrical arms have been attached which are modelled on the main bronchi and do not contain steel rings. In fact, the Y stent is supposed to sit on the carina and is therefore suitable for all processes that take place in one or both main bronchi or close to the carina. As the little arms do not have steel rings, they can easily be shortened and adjusted with scissors. Stents are available in diameters from 8 to 11 mm and lengths from 20 to 40 mm (Fig. 13.5).

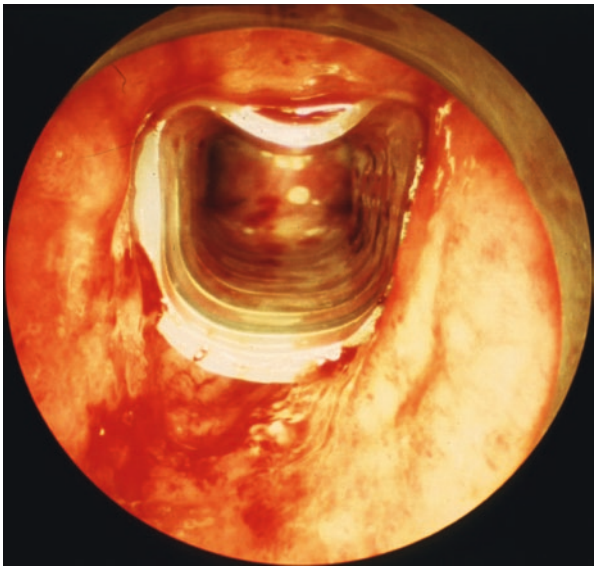

Fig. 13.5 Horizontal Y stent

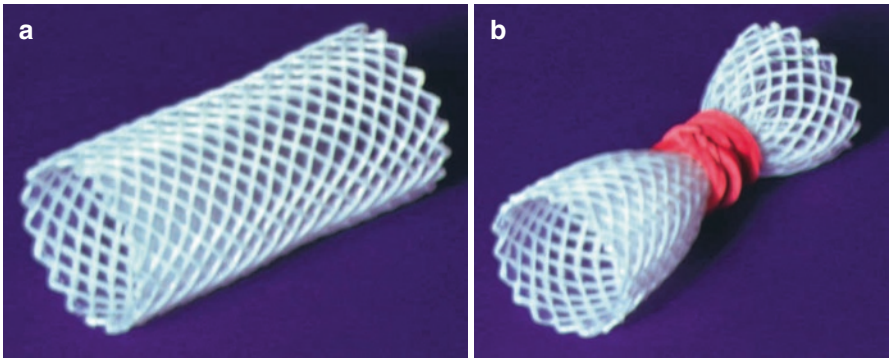

Fig. 13.6 Polyflex™ stent (**a**) unfolded, (**b**) folded

Polyflex™ Stents

The Polyflex™ stent consists mainly of silicone in which diagonally running polyester fibres are embedded. These form a rhomboid pattern which supports the deformation (Fig. 13.6a, b). At the ends, the stents are reinforced, but have rounded edges, so that little granulation tissue can develop at the transition points [14]. They can be easily deformed for insertion but require a special "inserter" from which they are ejected on site. Since they are prolonged during deformation, this fact must be taken into account during placement. They can follow a cough strike so that they show hardly any tendency to incrustation. A major advantage is that their flexibility

and low wall thickness make them suitable for the "stent-in-stent" procedure, so that, as the disease progresses, several stents can be inserted one behind the other, overlapping like roof tiles (Figs. 13.7 and 13.8). Polyflex™ stents can be easily removed and cause hardly any wall damage. In addition, they have an elastic positioning force, so that as the external pressure increases, they also exert more pressure against it.

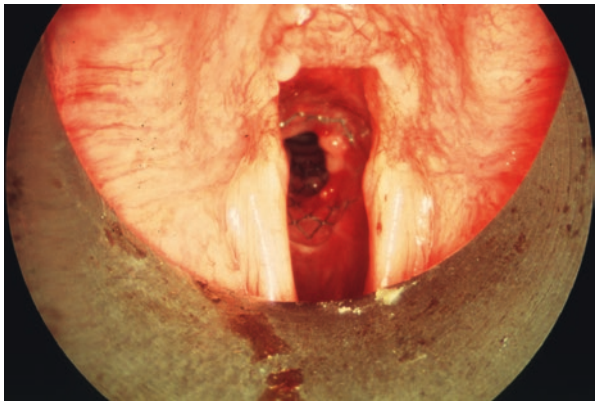

Fig. 13.7 Stent in tumor diseases

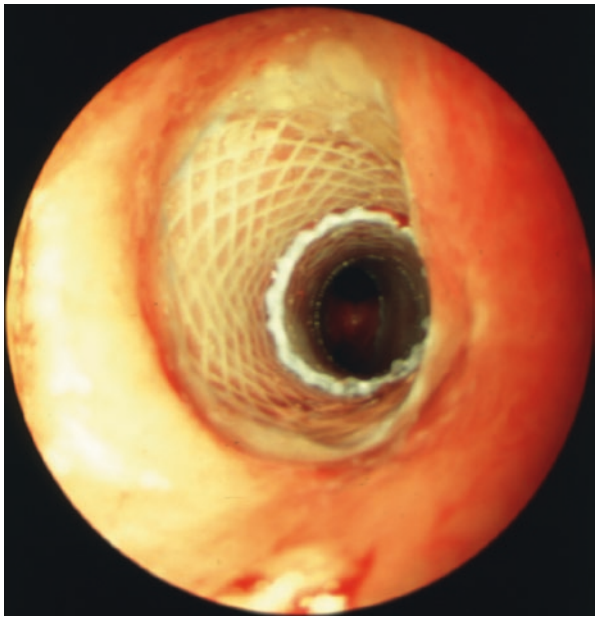

Fig. 13.8 Stent-in-stent in the trachea

13.4 Implantation Technique

As a rule, an internal stent is implanted under general anesthesia and via a rigid bronchoscope or microlaryngoscopy tube. Both ensure a sufficient working diameter [15, 16]. Using a microscope or endoscope, the implantation can be performed under sight. Before that, the same instruments should be used to inspect and, measure the length of the stenosis and its position relative to the carina. After precise topographic documentation of the stenosis, a debulking or excision of scar tissue can also be performed prior to placing a stent in order to produce sufficient tracheal lumen. With balloon-expanded systems, expansion is also possible depending on the consistency of the stenosis.

During stent placement, patients are ventilated preferably in jet ventilation [17], Chaps. 15 and 16.

If a rigid tracheobronchoscope is used, ventilation can also be effected via the tube. This always requires good coordination with the anesthetist before and during the procedure. The endoscopist must inform the anesthetist of any necessary apnea phases of the patient. Good communication is a key to success.

After insertion of any stent, its position must be checked. This can be done with a flexible endoscope or, in the trachea, with a rigid endoscope. A position correction of the passive stents can only be performed during stent deployment by repositioning the catheter. With silicone stents, on the other hand, repositioning is easily possible and, in many cases, also necessary, since the placement of the stent often restricts the patient's view or has to be carried out quickly due to apnea. A stent should also be radiographically visible for position checks.

A second position check of the stents should be performed tracheobronchoscopically (flexible optics) or radiologically within a defined time interval. The physiological improvement of the respiratory flow can be documented and tracked by monitoring.

13.5 Indications and Application

13.5.1 Preliminary Remark

The increasing use of metal and silicone stents for benign and malignant constrictions in the tracheobronchial system requires increased cooperation between pulmonologists and ENT physicians with regard to diagnosis and execution. The implantation of the stents is predominantly carried out by rigid endoscopy, while follow-up checks on the position and condition of the lumen are less stressful and can also be carried out on an out-patient basis by means of flexible tracheobronchoscopy. Photo documentation or the removal of smaller granulations is also possible using flexible endoscopes and can be performed on an out-patient basis with little strain on the patient. Common complications caused by stents have to be considered, as the following overview shows (Table 13.2).

Table 13.2 General drawbacks of stents

Secretion retention, fetor
Stent dislocation
Stent fracture
Hemoptysis
Ulcerations of the trachea
Tracheitis
Granulations

Table 13.3 Method for keeping the trachea open

Procedure without opening the trachea	Procedure with opening the trachea
Diathermy	Tracheal resection with end-to-end anastomosis
Dilatation	Autologous tissue transplantation
Cryotherapy	Open channel
Laser therapy	Foreign-material implantation
Stents	Tracheal transplantation
Steroids	
Mitomycin	

The following are usual indications for stent placement in benign and malignant tumors or respiratory changes:

– anesthesiological risks or poor general condition of the patient that doubt open neck surgery on the trachea
– severe radiation damage to the soft tissues of the neck with expected wound healing disorders
– inoperability of a growing intraluminal or extraluminal tumor
– short life expectancy with unfavorable prognosis within the framework of a palliative concept [1].

Before using stents, it must always be considered whether a surgical recanalization technique is suitable (Table 13.3).

13.5.2 Tracheal Constrictions

Regarding tracheal constrictions, differentiation is made between structural stenoses, such as

- intraluminally growing,
- extraluminally compressing tumors or
- scarred strictures, and functional stenoses (dyskinesia), such as
- malacic wall weakness or
- flaccid posterior wall.

Table 13.4 Non-binding recommendations for selecting from the range of different stent models

Silicone stents	Trachea, main bronchus, lumen >10 mm;
	Bronchus, lower lobe
Metal stents	Intermediate bronchus, lower lobe
	Bronchus, trachea, main bronchus with small remaining lumen only
T stents	Proximal, long-range tracheal stenoses
Y stents, J stents	Bifurcation stenoses, near-carina tumors
Custom-made products	Extremely long-range stenoses

The indications of the various stents must be taken into account (Table 13.4).

13.5.3 Benign Tracheal Changes

Stenoses of the trachea and the main bronchi develop predominantly in the course of non-malignant diseases, such as tracheal injuries (strangulation, accidents, tracheotomy, etc.) or long-term respiration.

Tracheomalacia and short-distance, collarous and carina-far lesions are accessible in principle to endotracheal or extratracheal surgical therapy, Chap. 12. This also includes mechanical forceps removal, electrotherapy and cryotherapy, bouginage and laser desobliterations, autologous tissue replacement and plastic tracheal replacement. The success of these operations, but also of others, such as lung transplants, is reduced in no small part by scarring restenosis and granulation formation [18, 19]. To prevent this, the stents offer an alternative procedure, often complementary to surgery.

The extension of tracheal stenosis with the CO_2 laser has not resulted in a change of the restenosis rate despite the application of different extirpation techniques (star-shaped, segment-shaped, etc.). On the contrary, many surgeons have returned to conventional techniques after disappointments with laser surgery.

The generation of self-expanding stents—which are already used in the treatment of bronchial, esophageal and vascular stenoses—appears to be suitable for preventing restenosis [20].

13.5.4 Malign Tracheal Changes

The symptoms of malignant airway stenoses depend on the localization of the stenosis, the degree of airway constriction and the growth form as well as the nature of the tumor. Proximal stenoses usually manifest themselves as inspiratory (or expiratory) stridor, possibly blood cough, mucous incrustation formation, with an increasing narrowing of the lumen in conjunction with dyspnea, cyanosis and ultimately asphyxia.

Lung function tests do not always allow a functional assessment of the extent of high-grade stenoses. The determination of expiratory peak flux may be more appropriate.

In distal stenoses, poststenotic pneumonia is often an aggravating factor, which should first be treated antibiotically, anti-inflammatory and secretolytically.

Palliative stent placement may be considered if the underlying disease is incurable and the lumen is less than half the normal diameter [18]. The lumen of the trachea or bronchus can be kept open by internal splinting of the airway section affected by a tumor. This can be done in conjunction with debulking [1, 21].

Coarsely meshed wire-mesh stents have proven unsuitable for the often rapid growth of the tumor or deformation of the stent due to insufficient restoring forces.

Closed, tubular stents made of silicone, which can resist compression from the outside and at the same time are not permeable by tumor tissue, are generally better suited to allow long-term airway patency [22].

More frequently than primary tracheal tumors, tumors of surrounding organs (esophagus, thyroid gland, larynx or bronchus) lead to a narrowing of the breathing tube [23]. Malignant processes in the vicinity of the carina provide a special situation, since in the region of the main bronchi the lumen narrows for purely anatomical reasons and will leave the geometry of the trachea through the branch. Adaptable Y-shaped silicone stents have proven worthwhile in such cases.

13.6 Problems and Hazards

13.6.1 Stent and Tracheotomy

Endoluminal tumor growth can often be improved by endoscopic "debulking" of obstructing tumor masses, preferably with the help of the CO_2 laser, which is coupled to an operating microscope. Mechanical desobliteration can also be effected with the rigid endoscope itself in soft, less bleeding tumors. This endoscope then serves both as a bougie and as a tangentially shearing instrument. In addition, various double spoon forceps, suction cups, monopolar coagulation probes and other instruments from the fields of rigid esophagoscopy and microlaryngoscopy are used to remove parts of the tumor and stop any bleeding.

The risk of these measures consists in causing trachea injuries with subsequent mediastinal emphysema, the occurrence of tracheoesophageal fistulas and severe bleeding. Critical indication, manual mastery of airway endoscopy and precautionary measures to be taken, including coordination with neighboring disciplines, are indispensable prerequisites for such measures [1].

If a tracheotomy becomes necessary, if it has not already been performed, the stent lying in the lumen is to be expected. It may be possible to cut an opening in pure silicone stents, but it will usually be better to remove the stent or deploy it so that a tracheotomy is possible. The difficulties of opening a horizontal stent from the outside should not be underestimated. In the case of metal stents, the difficulties can

be insurmountable if one tries to break through the stent from the outside. The rigid stents yield under pressure from the outside and can thus completely displace the lumen. So in these cases it will be better to remove the metal stent before the tracheotomy is performed.

13.6.2 Tracheoesophageal Fistula

Tumor growth from the trachea or vice versa from the esophagus may cause a tracheoesophageal fistula [24]. Since the esophagus can also be seen from the inside, it should be considered from which side the fistula should be bridged [25]. If stents are to be placed both in the esophagus and in the trachea, care must be taken that no additional pressure necrosis occurs between the two. As a rule, it is better to opt for the stent of one organ. As a rule, the trachea will be given preference, as respiration is much more important.

13.6.3 Stent and Intubation

In the case of a laid silicone stent, intubation is usually possible if consideration is given to the diameter of the airway narrowed by the stent. The cuff can lie within the lumen but also outside, depending on the position of the stent. With all metal stents lying down, an intubation using an endotracheal tube with cuff is likely to destroy the cuff due to sharp-edged metal edges, especially if the cuff lies on the edge of the stent.

13.6.4 Stent and Laser

When using a CO_2 laser with a laid stent, the material properties must be taken into account. Stents made of silicone or with silicone sheathing can catch fire especially in oxygen-enriched breathing air if they are hit by the laser beam. This hazard does not exist with metal stents. However, since metal reflects the laser beam, uncontrolled combustion effects can be expected in the trachea.

13.7 Outlook

Despite the development of new technologically advanced stents since 1990 and new approaches, such as resorbable or drug-releasing stents, there are no prospective or randomized studies in the literature other than larger case studies and literature reviews. Recommendations from professional societies are therefore based less on evidence than on empiricism.

As each stent implantation is based on a very individual medical history, an emergency pass should be issued to the patient.

13.8 Case Studies

Case 1
The 32-year-old patient was admitted 2 months after long-term ventilation due to polytrauma with inspiratory and expiratory stridor. Tracheoscopically, about 2 cm subglottic, a double, ring-shaped and predominantly membranous stenosis of a length of 1.5 cm was observed. In the first operation, the stenosis was gradually removed with the CO_2 laser. It was planned to perform a trachea end-to-end anastomosis in a second step. The patient was sceptical about this procedure, which is why conservative methods (long-term cortisone therapy) were used to prevent restenosis. Approximately 2 months later, the patient came to the hospital due to renewed inspiratory and expiratory stridor. As the patient continued to be hostile to an end-to-end anastomosis of the trachea, the implantation of a tracheal stent was offered as an alternative. Tracheoscopically, a ring-shaped, relatively broad-based stenosis, which ran out in a small sail towards the lumen, appeared at the same site of the trachea, approximately 2 cm subglottic. The residual lumen of the trachea was approximately 4 mm. The tracheal stenosis was blown up with the CO_2 laser by an incision-like tissue separation at 8, 11, 2, 5 o'clock. A Palmaz® stent of a diameter of 12 mm was then implanted. Immediately after the operation, the stridor instantly disappeared, and the patient could be discharged four days later after a microscopic laryngoscopic and radiological position check of the stent. Approximately 1 week after discharge, a first control tracheoscopy in jet ventilation was performed, showing that the stent was unchanged in position and continued to provide the desired lumen. Only at the distal end of the stent was a small granulation with a completely smooth surface visible that covered the stent at this location. Four weeks later, a control tracheoscopy showed no more granulation. The mucosa was now completely free of irritation and the stent was unchanged in situ. The radiological position was checked by means of a trachea-ray. The patient remained symptom-free and subjectively had the same quality of life as before his accident.

Case 2
A 28-year-old female patient was presented with stress dyspnea 3 months after tracheotomy and long-term ventilation. During the tracheoscopy a ring-shaped stenosis of about 2 cm subglottic was observed with a closed tracheotomy scar without irritation. The excision of this stenosis was performed with the CO_2 laser in jet ventilation. A Palmaz® stent of a diameter of 14 mm was implanted. The stent implantation was completely unproblematic, and the patient could be discharged into outpatient monitoring after two control tracheoscopies with non-irritant mucosal findings. Immediately after the operation, a tracheal scan was taken for later radiological control. The implantation of the stent increased the peak flow from 70 to 400 liters/minute. The patient was not able to walk more than ten steps without interruption preoperatively. After laser stent therapy, the patient was able to return to her hobby of cycling without any restrictions.

Case 3

A 36-year-old patient was presented after long-term ventilation due to polytrauma with progressive stress dyspnea and aphonia. Tracheoscopically, a ring-shaped stenosis of a length of 2.5–3 cm and a residual lumen of 30% was seen about 2 cm subglottic. This was followed by tracheocricopexy in a classical manner. It turned out that the tracheal piece to be resected was of a length of 3 cm. The postoperative course was unproblematic in the first ten days. From the 11th day, the patient developed an increasing stridor. Tracheoscopically, the lumen was narrowed by ventrally growing granulation tissue, which was removed in the same session. The patient could be discharged with well-being and conservative therapy. Three weeks later, the patient was admitted to emergency hospital due to severe shortness of breath. Tracheoscopically, a ventral, semicircular scar sail appeared in the resection area, which shifted the tracheal lumen by 50%. An extension after Réthi as well as a tracheostomy and the implantation of an Aboulker prosthesis were performed. In cases of strong granulation tendencies, Aboulker prostheses of increasing diameter were used to achieve lumen enlargement. The peak flow after these measures was 140 liters/minute.

Due to wound healing disorders, the Aboulker spacer prosthesis was removed and the patient was fitted with a Jatho silver cannula. Six months later another tracheoscopy was performed, showing that the trachea 2.4 cm below the glottis plane was almost completely stenosed by granulation polyps and malacic cranially of the tracheostoma. The removal of the granulation polyps was carried out in the usual manner. To splint the trachea, a 4-mm-long extensor stent of a diameter of 8 mm was first implanted. 2 days later, the patient could be discharged for outpatient follow-up. Through the tracheostoma opening, retrograde endoscopy of the trachea section carrying the stent was possible at any time. After 1 month, the patient was tracheoscoped again under intubation anesthesia, showing that the stent was in situ without irritation. However, there was a granulation tissue starting from the tracheostoma and displacing the lumen. After unproblematic removal of the stent with the foreign body grasping forceps, it was determined that the tracheal section where the stent was located was now stabilized. The stenosis was removed with the CO_2 laser. The trachea was now free up to the tracheostoma. Following hemostasis, an extensor stent of a diameter of 10 mm was implanted. After a further 2 weeks, the tracheostoma could be closed under local anesthesia in irritation-free endotracheal mucosal conditions. An increase in peak flow from 160 to 450 liters/minute was recorded after laser stent therapy.

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Tracheotomy in Patients with Increased Intracranial Pressure

14

S.-O. Kuhn and K. Hahnenkamp

14.1 Introduction

Severe neurological deficits with central respiratory disorders, dysphagia or cerebral nerve pareses often necessitate prolonged ventilation or airway protection via a tracheostoma. Safe access to the respiratory tract while protecting the larynx is a priority. In addition, improved patient comfort and easier oral hygiene are decisive factors for an early decision on tracheotomy in clinical routine.

In the acute phase of severe brain damage, disturbed cerebral autoregulation may lead to an increase in secondary brain damage caused by ischemia. Increased cerebral pressure, arterial hypotension and hypoxia can significantly worsen the outcome of brain-injured patients both immediately after the initial damage and later. Absolute priority is therefore given to maintaining optimal cerebral blood flow and avoiding ischemia [1].

Since a tracheotomy is usually performed as an elective procedure, it should be performed under maximum safety conditions and under strict risk-benefit considerations, especially for critically ill patients.

14.2 Physiology and Pathophysiology of Intracranial Pressure

Under physiological conditions, cerebral autoregulation ensures optimal blood circulation in the brain (the so-called Bayliss effect) even in the case of large fluctuations in systemic arterial blood pressure. Between a mean arterial

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pressure (MAP) of 50–150 mmHg there is a largely constant cerebral blood circulation. These limits can be shifted in the case of chronically increased blood pressure. The cerebral blood flow (CBF) is mainly regulated by an adaptation of the vasotonus and thus of the vascular resistance. An increase in $PaCO_2$ leads to cerebrovascular vasodilation, and vice versa a decrease in $PaCO_2$ leads to vasoconstriction. This regulatory mechanism functions in a range between 25 and 60 mmHg. There is a linear relationship between $PaCO_2$ and the increase in CBF: the increase in CO_2 partial pressure by 1 mmHg leads to a 4% increase in cerebral blood flow. Cerebral blood flow, cerebral metabolism and oxygen extraction are closely linked [2]. CBF is also dependent on cerebral perfusion pressure (CPP) and cerebrovascular resistance (CVR). The following relationships exist:

- CBF = CPP/CVR
- CPP = MAP—ICP.

The intracranial pressure (ICP) in healthy individuals is 7–15 mmHg. An ICP above 20 mmHg is expected to cause brain damage and there is an urgent need for therapy; an ICP above 40 mmHg is a life-threatening condition. The prognosis for craniocerebral trauma (CCT) is significantly worse in these cases. If the cerebral blood flow falls below a critical limit of about 15% for a longer period of time or is completely interrupted for several minutes as a result of pathological changes, such as an increase in cerebral pressure, this leads to irreversible brain damage. In particular, brain areas that can in principle still be saved after damage (penumbra in strokes) exhibit disturbed autoregulation. In order to maintain an adequate blood supply to the brain, it is recommended not to fall below a CPP of 70 mmHg. Therefore, in patients with critical cerebral findings, the monitoring of ICP or CPP by means of special monitoring is recommended [3].

In patients with critically elevated intracranial pressure, the following therapy goals apply:

- *securing brain perfusion*
  - *CPP > 70 mmHg*
- *controlled ventilation, mild hyperventilation*
  - *CPPV, $PaCO_2$ = 35–38 mmHg*
- *adequate analgosedation*
- *optimum positioning*
  - *upper body 30°–45° up, neutral position of the head*
- *normothermia to mild hypothermia*
- *reduction of intracranial pressure by medication, if necessary*
  - *osmotherapy*
  - *barbiturates*
- *decompression craniotomy, if necessary*

14.3 Tracheotomy in Severe Brain Damage

Knowledge of the pathophysiology ICP is a prerequisite for responsible therapy decisions.

So far, the Pro-Contra debate on tracheotomy in patients with severe brain damage has not been decided. Apparent advantages, such as improved patient comfort, less dead space and easier weaning from ventilation, are relativized by various publications that could not show any reduction in mortality or ventilator-related pneumonia in tracheotomized patients [4].

Since the prognosis of a successful extubation is difficult, the Glasgow Coma Scale (GCS) is often included in the decision on tracheotomy. However, own observations support data that could not prove a connection between GCS and extubation failure. In our experience, extubation is much better in patients with subarachnoid hemorrhage than in those with hemorrhage or ischemia of the posterior skull fossa or near the brain stem, who suffer more frequently from dysphagia.

If the indication for tracheotomy is given in patients with acute or subacute brain damage, the following points should be considered:

- optimal point in time for the tracheotomy
- risk assessment
- suitable equipment/suitable procedure/experienced surgeons

Current studies show that the various methods of surgical and dilatative tracheotomies can generally be considered safe. However, whether an early tracheotomy up to about the 10th day of treatment can improve the long-term outcome of brain-damaged patients and reduce the duration of ventilation or the ITS stay is not sufficiently proven [5–7]. A clear recommendation for the right time of tracheotomy in acute brain-damaged patients can therefore still not be given. However, intraoperative and postoperative complications are reason enough for a strict indication especially in the acute phase [8]. According to the authors, the procedure should not be performed before the 7th to 10th day in patients with subacute brain damage. Acute patients at risk of intracranial pressure, on the other hand, should not be tracheotomized unless there is an urgent indication, such as injuries to the face and jaw. An individual assessment of risk and benefit remains [9].

14.3.1 Perioperative Hazards

Interventions or surgical measures must be weighed particularly critically in the first few days after brain damage. In detail, the following dangers must be assumed:

- Inadequate anesthesia can lead to relevant circulatory instability with hypotension, an increase in ICP and a decrease in CPP. In almost all corresponding publications, significant increases in ICP and decreases in CPP are described,

especially at the time of placement of the tracheostomy tube. [10–13]. Peak ICP levels are higher during PDT than in OST [14].

- After positioning with the head reclined, the jugular venous discharge may be obstructed by compression of the jugular veins. This leads consecutively to an increase in ICP.
- During the various surgical and puncture tracheotomy procedures, considerable loss of respiratory gas may occur due to leakage as well as the displacement of the endotracheal tube through the endoscope. In addition to hypoxia, hypercapnia appears to be of particular importance due to an increase in ICP due to cerebral vasodilatation. Reilly et al. [15] were early to point out this "occult hypercarbia". In a study of 289 patients, Kuechler et al. [16] found in 33% a temporarily mild hypercapnia and in 15% a severe hypercapnia during PDT in Ciaglia Blue Rhino technique, despite a temporally short flexible endoscopy.

Figure 14.1 shows the typical perioperative course during a dilatational tracheotomy. Significant intraoperative fluctuations of ICP, CPP and MAP are recognizable.

The question arises as to whether all these potential hazards are clinically relevant. The publications of recent years are limited in their significance. Some older studies are no longer comparable with the current situation due to the further development of tracheotomy methods and learning curves. On the other hand, the investigated case numbers are too small for a valid evaluation. Taking the literature into account, all common tracheotomy procedures can be recommended for brain-damaged patients [10, 17]. However, the potential intraoperative and postoperative complications must be explicitly recalled at this point. In addition to bleeding

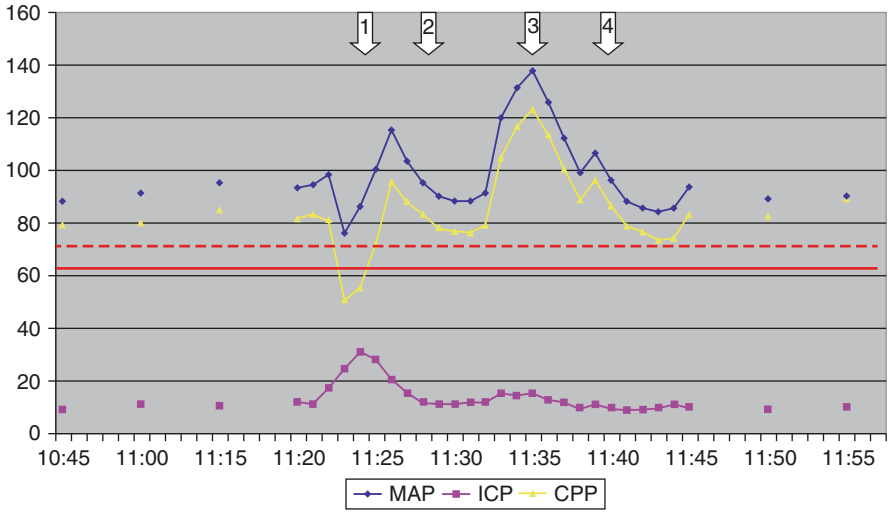

Fig. 14.1 Perioperative course of MAP, ICP and CPP during a dilatational tracheotomy; **1** positioning, **2** reintubation to a larger tube, **3** start of surgery, **4** end of surgery

complications or ventilation problems during surgery, the risk of accidental extubation is potentially life-threatening, especially in the first days after tracheotomy [17, 18]. Sonographically, the anatomical conditions can be easily visualized preoperatively, and any pretracheal vessels can be identified. In order not to endanger patients with acute brain damage or increased intracranial pressure, the avoidance of a tracheotomy may also be a better decision.

14.4 Conclusions for Practice

- An elective tracheotomy in patients with craniocerebral injuries or critically increased intracranial pressure should only be performed after the acute phase has been overcome, i.e., generally after 10 days.
- A preoperative sonography of the neck or the neck vessels is recommended for the evaluation of the situs.
- A large lumen endotracheal tube and a small flexible endoscope should be used to avoid airway obstruction in PDT.
- Patients are optimally positioned with a raised upper body and a slightly reclined head that is aligned with the axis.
- The procedure should be performed by an experienced surgical team.
- Emergency medication should be available to treat circulatory imbalances or intracranial pressure peaks.
- Careful anesthesia control and monitoring of the hemodynamics are obligatory.
- The intervention should take place under extended monitoring, including the ICP and/or $S_{jv}O_2$.
- The choice of a safe surgical method, in the case of a dilatational tracheotomy, e.g., the Ciaglia Blue Rhino technique, is recommended.
- It is useful to have an emergency plan in case of serious complications.

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Jet Ventilation in the Difficult Airway

15

A. Aloy

Since the publication of the "Practice guidelines for management of the difficult airway" of the American Society of Anesthesiologists Task Force on Management of the Difficult Airway [1], there has been a generally accepted definition of the "difficult airway" that exists when a trained anesthesiologist has difficulties with mask ventilation, endotracheal intubation or both. Subsequently, both classifications of the forms of the difficult airway and strategies and algorithms of the possible procedure were developed. On the basis of the American description, specialist societies worldwide have developed national proposals for the approach to the difficult airway, in which indications are also given for jet ventilation [2–4].

According to the clinical situation, the expected difficult airway, the unexpected difficult airway, difficult mask ventilation and the most difficult situation "cannot intubate, cannot ventilate" are distinguished [5, 6].

15.1 The Expected Difficult Airway

The algorithm of the expected difficult airway, in which difficult intubation must be anticipated, aims to find a way to secure the airway and thus the ventilation of the patient. Proposals include fiber-optic intubation, laryngeal masks, other supraglottic airway aids, possibly also coniotomy and tracheotomy.

Difficult intubation can be expected, for example, in the following situations: facial malformations and anomalies of the oral cavity, consequences of accidents, restrictions in cervical spine mobility, reduction in jaw mobility, space-consuming processes in the upper respiratory tract and pathological changes in the larynx and trachea.

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Often the pathological changes can be attributed to the field of ear, nose and throat medicine or oral and maxillofacial surgery: changes in the larynx and trachea, laryngeal stenoses, recurrent pareses on both sides, tracheal stenoses, tracheomalacia, injuries and tumors or jaw and facial anomalies.

The form of the "expected difficult airway", which is often preferred in the fields of ENT medicine and maxillofacial surgery and whose localization lies in the area of the meso-hypopharynx, larynx or subglottic space, is characterized by the fact that it is still possible to find the way to the larynx or glottis. However, it is often impossible to place an endotracheal tube through the highly constricted glottis. Alternatively, a tracheotomy must be considered.

The first and foremost requirement to remedy this situation of the difficult airway is to secure the patient's airway and thus enable continuous ventilation. The second requirement is that the measures that have been introduced should make the surgical procedure possible.

The localization of a pathological process in the glottis area results in a competitive situation for surgery and anesthesia. The desire for sufficient anesthesiological ventilation on the one hand and the necessity to guarantee the surgeon unhindered access to the actual surgical area on the other has therefore contributed significantly to the development of special high-frequency ventilation techniques.

Jet ventilation is an established ventilation technique for surgical laryngeal and tracheal interventions. The advantage of high-frequency ventilation techniques, also known as jet ventilation, is that gas volumes can be applied in compressed form via a thin catheter with a nozzle opening or via a jet nozzle. In the respective jet nozzles, there is high pressure (approx. 1–2 bar), which, however, decreases by around hundredfold with the outlet of the gas from the jet nozzle and then amounts to merely 10–20 mbar.

As part of the surgical procedure in the case of glottis stenoses with the aim of surgically expanding the airway, coniotomies or tracheotomies are still performed in many places and are regarded as the last choice for securing the airway. This shows that jet ventilation is playing an increasingly important role in the planning of anesthesiological strategies for these operations.

While a sudden narrowing of the airways due to a rapidly progressive stenosis caused by trauma or acute inflammation is accompanied by severe clinical symptoms, a slowly progressive narrowing of the laryngeal lumen by up to 80% is clinically better tolerated by patients. However, a further increase in the stenosis, e.g., due to swelling, can cause life-threatening dyspnea. The therapeutic goal is a rapid restoration of the displaced airway in order to ensure sufficient gas exchange and possibly to avoid an invasive procedure (e.g., tracheotomy).

15.1.1 Possible Applications of Jet Ventilation in Obstructive Supraglottic or Glottic or Subglottic Changes

If there is no pathological stenosis of the vocal cord, any form of jet ventilation can be used. The narrower the glottis diameter due to a pathological process, the more attention must be paid to the jet procedure to be selected.

According to the local spread of the pathological event, the following anatomical localizations of an obstruction or stenosis exist:

1. supraglottic space,
2. glottis plane,
3. subglottic space,
4. trachea.

In principle, three options are available for ventilation with jet technology, firstly the possibility of using a needle, secondly a catheter or thirdly a special jet laryngotracheoscope. Depending on the primary location of the jet nozzle, a distinction must be made between infraglottic and supraglottic jet ventilation.

In infraglottic jet ventilation, the jet gas is administered from a nozzle opening below the glottis plane. Either a needle is placed transtracheally or transcricoidally or a catheter transorally or transnasally through the glottis plane.

In supraglottic jet ventilation, on the other hand, the jet gas is emitted above the vocal cord plane via jet nozzles integrated into the operating endoscope (jet laryngoscope, jet tracheoscope).

15.1.2 Infraglottic Jet Ventilation Respiration Techniques

Transtracheal High-Frequency Jet Ventilation (TTHFJV)

Transtracheal or transcricoid Jet ventilation (Fig. 15.1) [7] is a simple and safe technique for ventilation during endoscopic laryngeal surgery as well as laser surgery. The advantages are the endotracheal tube which is not required, the excellent view of the larynx by the surgeon and the associated optimal working conditions. Most patients also have satisfactory oxygenation and ventilation. If this technique is

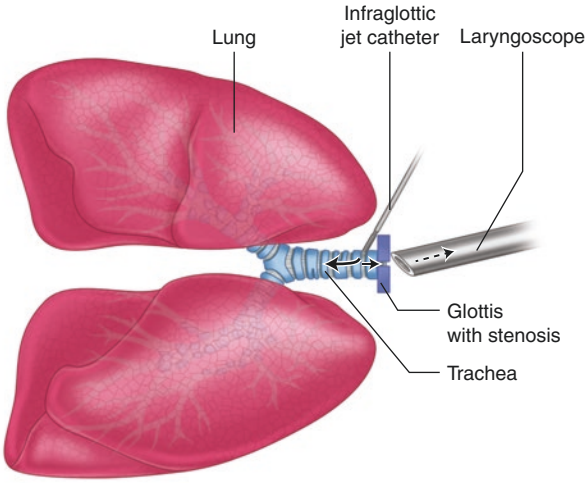

Fig. 15.1 Schematic representation of the transcricoid placement of the jet catheter (e.g., needle acc. to Ravussin) with an existing glottis stenosis

undisputedly excellent for laryngeal interventions with normal glottis width, the question arises whether and to what extent it can also be used for interventions with an increasing narrowing of the airway to varying degrees.

Clinical applications show that transtracheal jet ventilation is another possible ventilation technique in patients with supraglottic or glottal airway obstruction that may be characterized by clinical stridor symptoms. Ravussin et al. [8] already described the successful application of transtracheal jet ventilation in two children aged 4 months and 5 years with laryngeal obstruction. In the 4-month-old child, the transtracheal access pathway was performed between the first and second tracheal ring, and in the 5-year-old child, transcricoidally.

Depieraz et al. [9] later described the successful application of transtracheal jet ventilation in a patient population of 16 children with 28 interventions. All children showed severe stenosing changes in the larynx or upper tracheal area. The authors pointed out that this ventilation technique avoided tracheotomy, which was otherwise necessary at least temporarily. There were three complications: a surgical emphysema, a pneumothorax caused by total gas blockade in the absence of pressure monitoring in the airways and a vagus nerve-induced circulatory reaction. All complications were remedied. Ross-Anderson et al. [10] reported on the application of transtracheal jet ventilation in the difficult airway of 50 patients. The extent of lumen constriction in these patients was more than 70%. The authors only described the occurrence of so-called "minor complications" with an incidence of 20%, this mainly concerned buckling of the jet catheter and low bleeding. Serious complications did not occur.

Advantages Transtracheal jet ventilation offers several advantages in the management of the expected difficult airway, such as securing the airway before general anesthesia, avoiding the need for a tracheostoma, unrestricted view of the larynx during planned surgery.

Implementation of the Puncture Overstretching of the neck, if possible, an infiltration of the puncture site with lidocaine 2% should be carried out before puncture, use of a jet ventilation catheter after Ravussin (Fig. 15.2). The catheter has an internal steel cannula on which a syringe filled with water can be placed. The aspiration of air indicates the tracheal position of the cannula. The internal steel cannula is

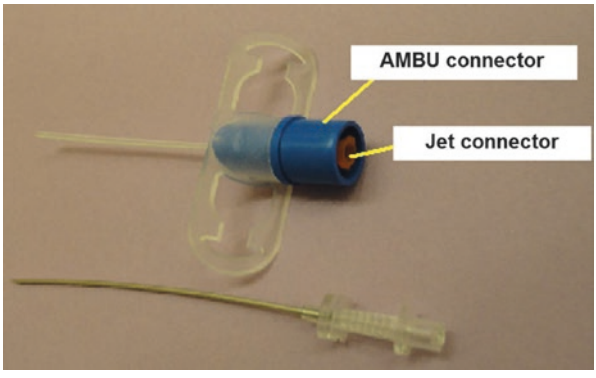

Fig. 15.2 Jet ventilation catheter with internal steel cannula (VBM-Medizintechnik GmbH, Sulz, Germany)

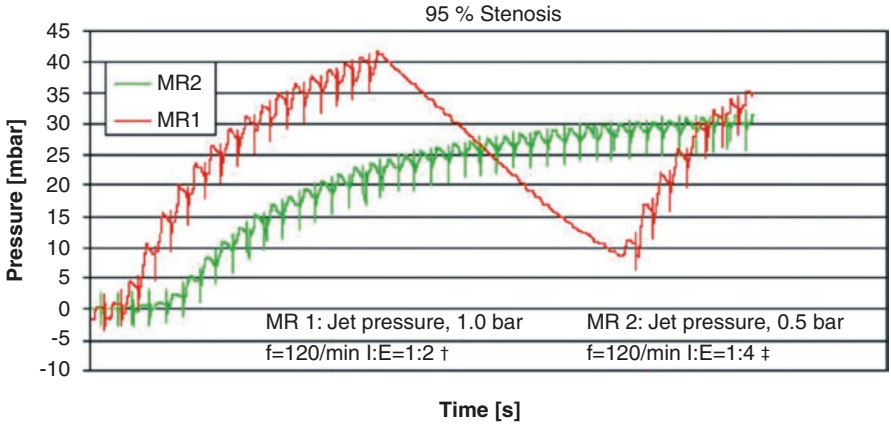

Fig. 15.3 Increasing volume filling of the lung with continuous jet ventilation with a 95% stenosis, which hinders the gas flow out of the lung. As the volume fills up, the intrapulmonary pressure increases. The pressure limitation at the respirator switches ventilation off and there is a pressure drop (red curve)

retracted with the syringe and, if necessary, the catheter can be connected to the capnography for a short time to prove the intratracheal position.

Respiratory Requirements Mechanical ventilation should be performed with an electronic respirator. Modern jet respirators use pause-pressure measurement to monitor ventilation pressure. Between two emitted jet gas pulses, the pressure, known as the pause pressure, is measured in the same pressure line in the phase of the expiratory pause. It is not the pressure between two jet pulses that is measured, but the total pressure in the lungs. This raises the curve. If the expiration of the gas is obstructed, the pause pressure increases (Fig. 15.3). The level of the tolerable pause pressure can be set on the ventilation pressure monitoring. If the set pressure limit is reached, the jet gas pulse is suspended. In this way, over-inflation of the lung and the risk of a barotrauma can be prevented.

As there is a risk of a restriction of the gas flow in higher-grade stenoses and poststenotic application of the jet gas, the risk of a barotrauma is increased in principle. It is therefore advisable to aim for a device setting that enables a safe gas outflow through the existing stenosis. Therefore, the jet frequency should be kept low in this situation. The inspiration time should be short, but the expiration time long. The device jet pressure at which the gas exits the jet nozzle should be kept low (Fig. 15.3).

Ventilation setting for stenosis and transtracheal jet ventilation:	
Respiratory frequency:	**low**
Inspiration time:	**short <1 s at manual jet ventilation**
Expiration time:	**long**
Device jet pressure:	**low**

Transoral and Transnasal Infraglottic Jet Ventilation

In transoral or transnasal infraglottic jet ventilation, a catheter is placed transorally or transnasally through the vocal cord plane sufficiently deep into the trachea (Fig. 15.4). If the Glottis is not constricted in its cross-section, ventilation can be carried out without problems. The applications of a special subglottic catheter, such as the "Jockjet tube" [11] or the "Hunsaker catheter" are described. [12] (Figs. 15.5 and 15.6). Davies et al. [13] reported the successful application of subglottic jet ventilation in 552 patients. The "Hunsaker Mon-Jet Ventilation Tube" (Medtronic Xomed Inc., Jacksonville, FL, USA) introduced in 1994 was used. However, the Hunsaker catheter should be used with a modern automatic jet respirator, as the author emphasizes. In contrast to manually controlled jet ventilation, a modern respirator equipped with a pressure limiter can reduce the risk of a barotrauma. The barotrauma described by Cook and Alexander [14] was associated with a manually operated jet fan.

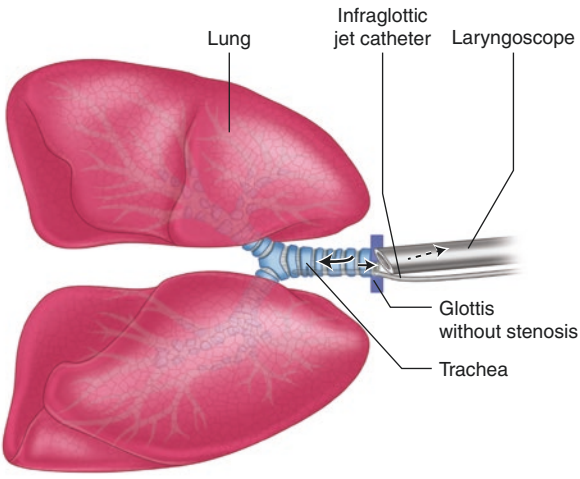

Fig. 15.4 Schematic representation of the positioning of an infraglottic jet catheter

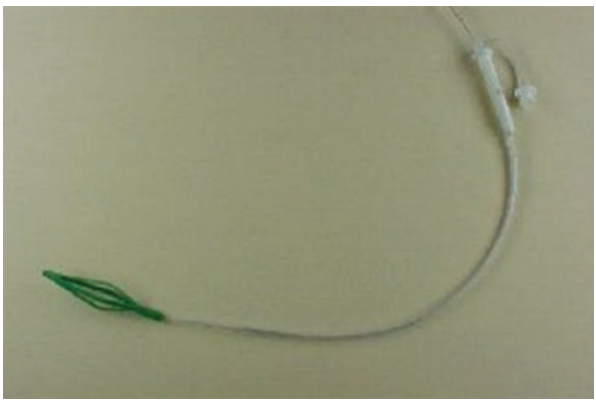

Fig. 15.5 Hunsaker Mon-Jet ventilation tube Ø 5 mm (Medtronic Xomed Inc., Jacksonville, FL, USA)

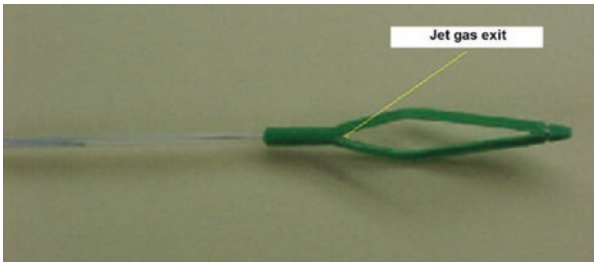

Fig. 15.6 Distal section of the Hunsaker catheter with the basket attached to the tip. It cannot be advanced through the remaining lumen in higher-grade stenoses

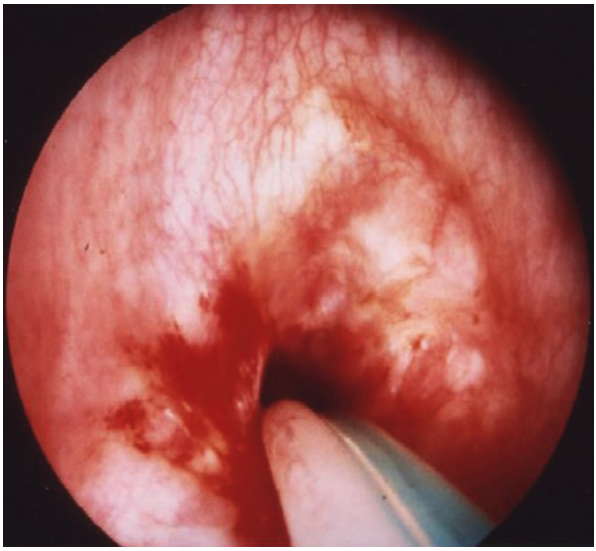

Fig. 15.7 Placement of a Hunsaker catheter through a subglottic stenosis. The remaining space is considered to be very small. In this situation it cannot be estimated with certainty to what extent the gas discharge for expiration is secured

Especially in cases of a stenosis of the respiratory tract, a modern jet respirator with adjustable pressure limitation is an absolute necessity. If a stenosis of the airway is present, transoral subglottic catheter-jet ventilation should only be carried out with slight forms of stenosis. In any case, a remaining open airway cross-section should be clearly visible. Since this technique involves placing a catheter through the glottis, possible obstruction of the gas flow and thus the risk of over-inflation of the lung and barotrauma must be considered (Fig. 15.7). An intraoperative change—and be it even a slight one—in the position of the head and thus also of the neck can lead to a possible occlusion of a too small residual lumen. Due to the size of individual catheters of a diameter of at least 4 mm (Hunsaker catheters and Jockjet catheters), these catheters cannot be placed in pronounced obstructions of these dimensions and can therefore not be used. This is especially true for children. Single-lumen catheters or catheters with a second lumen are available for monitoring. The length of the catheters also allows nasal placement. The catheter material consists of non-combustible laser-resistant material. The catheters offered have an external diameter of 2.6–5.5 mm. Changes are possible due to further developments.

The open basket at the distal end of the Hunsaker catheter ensures that the position of the jet catheter remains stable and cannot be thrown back and forth by pulsations. At the same time, an immediate impact of the jet impulse on the tracheal mucosa is avoided. Thus, there is no damage to the tracheal mucosa.

Complications

Barotrauma, subcutaneous emphysema, pneumomediastinum, hematomas, catheter malpositions.

Bourgain et al. [7] described the following complications in 643 patients: 8.4% subcutaneous emphysema, 2% subcutaneous spread of the emphysema in the face, 2.5% pneumomediastinum and 1% pneumothoraces.

Russel et al. [15] reported a complication rate of 10% and of a jet catheter having caught fire from 90 patients with infraglottic catheter technique; Gilbert [16] reported gastric rupture after misalignment of a jet catheter.

Overall, the incidence of complications in elective procedures is low, but significantly higher in emergency interventions.

Ventilation Requirements for Stenosing Anatomical Situations

The same requirements apply as for transtracheal jet ventilation. The higher the degree of stenosis, the lower the working pressure of the jet fan should be. In order to keep the risk of a barotrauma as low as possible, the following ventilation procedure is indicated:

Ventilation setting with stenosis and transoral infraglottic jet ventilation	
– *Respiration frequency*	low
– *Inspiration time*	short
– *Expiration time*	long
– *Device jet pressure*	low

Infraglottic transoral jet ventilation should be performed with a modern respirator with integrated pressure limitation. The working pressures to be used are usually less than 1 bar, the frequency to be used is 1.6 Hz, the I:E ratio of the jet impulse is 1:2. Necessary individual adaptations depend on the patient's body weight and lung function.

Conclusion

Clinical studies show that both transtracheal and infraglottic transoral jet ventilation are ventilation methods that can also—and especially—be used in difficult airways. However, in these cases an electronic jet respirator with integrated pressure limitation should be used.

15.1.3 Supraglottic Jet Ventilation

Supraglottic jet ventilation is characterized by the fact that the gas is released above the glottis, i.e., above the existing stenosis (Fig. 15.8). This technique has been successfully applied to more than 1500 patients without ventilation complications in various laryngotracheal interventions [17, 18].

Ventilation Technology

The jet laryngoscope (Fig. 15.9) for supraglottic Superimposed High-frequency Jet Ventilation (SHFJV®) has two jet nozzles which are integrated into the laryngoscope. The jet gas is delivered in the proximal endoscope section, but in front of the glottis. The endoscope contains an integrated ventilation pressure measurement which is attached to the tip of the endoscope. The handle of the endoscope has an opening for humidification and heating of the respiratory gas. The two jet nozzles are located on the left side of the jet endoscope (Fig. 15.9).

The superposition (Fig. 15.10) of the high-frequency and low-frequency jet gases shows a lower (PEEP) and an upper (PIP) pressure plateau in accordance with

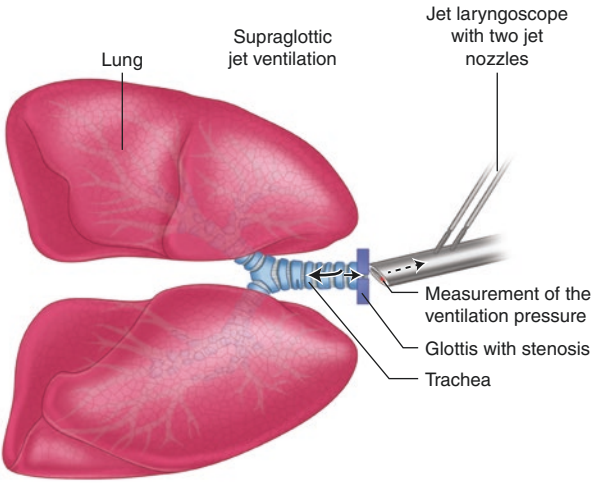

Fig. 15.8 Schematic representation of supraglottic jet ventilation in laryngeal stenosis. The endoscope with integrated jet nozzles is placed in front of the stenosis. The breathing gas is applied above the pathological constriction in the upper respiratory tract

Fig. 15.9 Jet laryngoscope for SHFJV® (Made by Carl Rainer GmbH, Vienna, Austria)

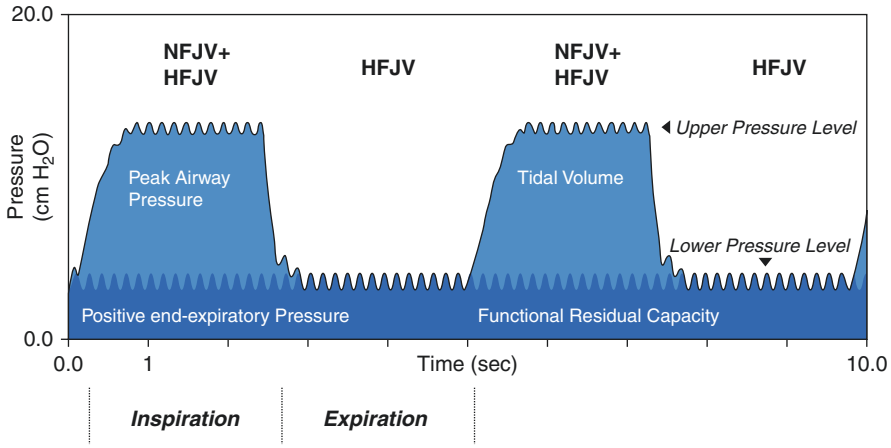

Fig. 15.10 Schematic representation of the ventilation pressures with simultaneous standard-frequency and high-frequency jet ventilation. The standard-frequency jet ventilation generates the upper and the high-frequency jet ventilation the lower pressure plateau. It is a time-controlled pressure-controlled ventilation

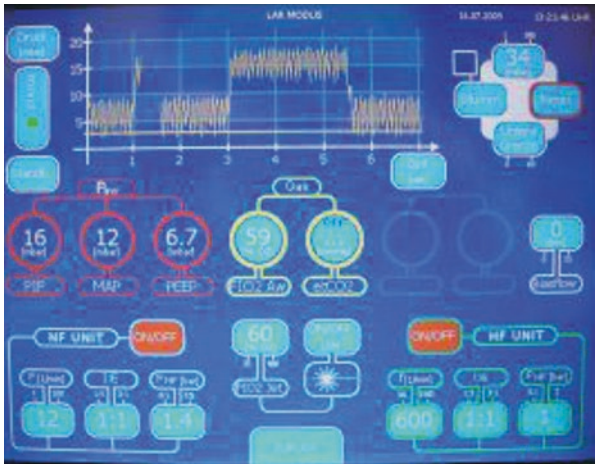

Fig. 15.11 Monitor screen of the multimode jet respirator Twin Stream® (Carl Reiner GmbH, Vienna, Austria). The two pressure plateaus of time-controlled pressure-controlled ventilation are clearly visible

time-and-pressure-controlled respiration with the respective gas flow. State-of-the-art jet ventilators (Twin Stream®) (Fig. 15.11) are equipped with adequate monitoring (peak pressure, mean airway pressure, PEEP, set and actual F_iO_2), furthermore, freely variable pressure limitation and separate control of high-frequency (HF) and low-frequency (LF) jet gases.

Another advantage of supraglottic jet ventilation is its use in children [19, 20]. Due to the limited space available in infants and toddlers, the avoidance of an additional jet catheter creates optimal surgical working conditions. If a stenosis of the respiratory tract is present at the same time, our experience shows that adequate ventilation can be ensured in any case. Concurrently, due to the absence of a catheter, laser surgery can be performed without possible interaction with flammable materials. Therefore, in accordance with Eckel and Remacle [21], this technique is

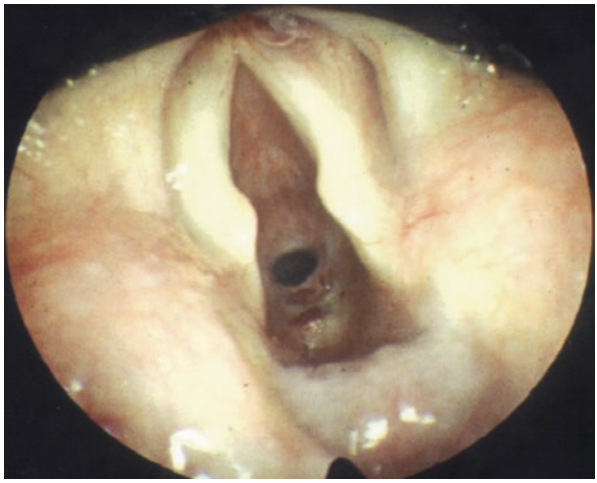

Fig. 15.12 Respiration with supraglottic jet ventilation in the therapy of a pronounced subglottic stenosis. In this case, an infraglottic jet catheter technique would not have been possible, even wrong

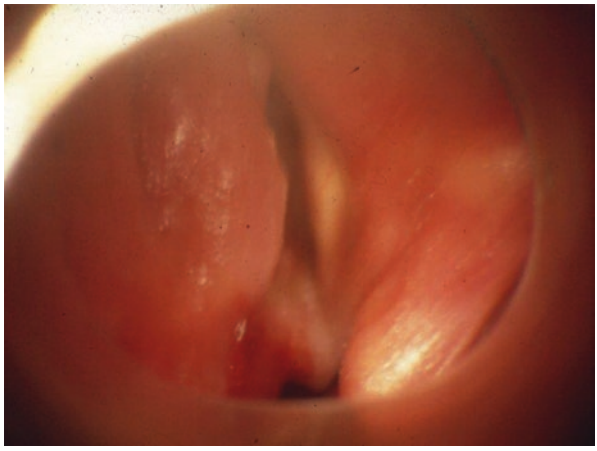

Fig. 15.13 Pronounced tumor-related stenosis. In the area of the posterior commissure, there is a residual lumen through which the spontaneous breathing of the patient was just possible. The patient is ventilated via the residual lumen using supraglottic jet ventilation. An infraglottic catheter jet ventilation would not have been feasible or wrong

suitable for those forms of expected difficult airways caused by upper airway stenosis (Figs. 15.12 and 15.13). The prerequisite, however, is that the jet laryngoscope can be placed in front of the expected constriction.

Of these, 139 patients (9.2%) with laryngeal or tracheal stenoses, which were associated with an expected difficult airway, were ventilated by supraglottic jet ventilation. While its use was initially still reserved in the case of stenosing upper respiratory tract diseases, its advantages soon became apparent, especially in the case of pronounced stenoses of the respiratory tract [22–24].

An explanation for applying SHFJV® with stenoses in particular is supplied by experimental results [25]. The pressure occurring before the stenosis plays an important role in the flow of the gas through a stenosis. The pressure gradually rises (Fig. 15.14) at the front end of the jet up to the stenosis, but the velocity (Fig. 15.15) shows reversed behavior. The pressure caused by the stenosis is also responsible for a stronger local backflow and a lower entrainment. In the stenotic area there is a decrease in pressure, with a simultaneous increase in velocity according to the

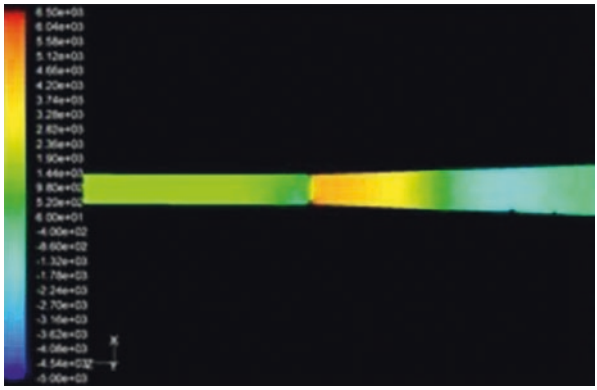

Fig. 15.14 CFD (Computational Fluid Dynamics) analysis to determine the flow in the jet laryngoscope shows that the pressure behind the stenosis is lower than before it. One can see the dynamic pressure in front of the stenosis

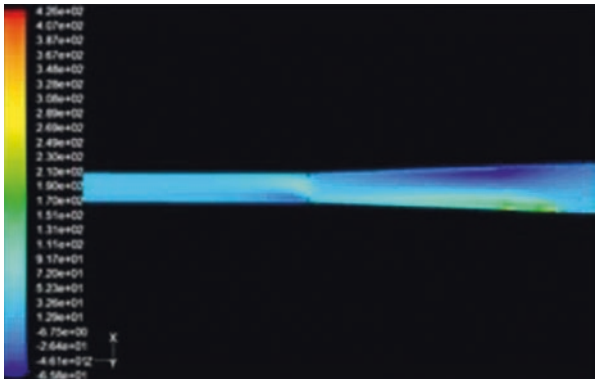

Fig. 15.15 Representation of the flow conditions (velocity distribution m/sec) in the jet laryngoscope, in the stenosis area and behind the stenosis in the fictitious tracheal area at a lung pressure of 15 cm H_2O

Bernouilli equation, which is pronounced after the stenosis and continues in the post-stenotic area to a limited extend. From a fluidic point of view, it is not surprising that the pressure before the stenosis is high and lower in the stenosis area and behind the stenosis. This confirms that, in the presence of a stenosis, the airway pressure building up behind the stenosis cannot be higher than the ventilation pressure measured at the tip of the laryngoscope before constriction.

Obstruction of the Respiratory Tract by Introducing of Instruments into the Jet Laryngoscope with Supraglottic Jet Ventilation

It is almost always necessary to insert surgical instruments into the jet laryngoscope in order to ensure therapy. As we have shown (Fig. 15.16), it is also possible to perform adequate ventilation with an additional instrumental constriction [23, 24]. The following question results: How large may the narrowing of the ventilation cross-section be when using the jet laryngoscope? Jet ventilation can be performed if the following algorithm is observed:

1. Measurement and registration of the airway pressure in the jet laryngoscope before the introduction of any instruments.

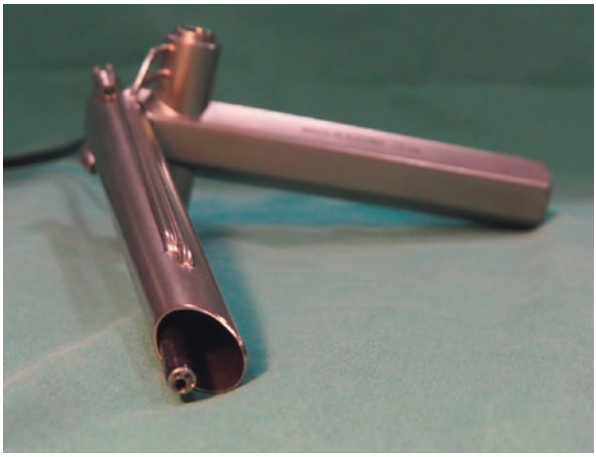

Fig. 15.16 High-grade cross-sectional reduction of the jet laryngoscope by a flexible endoscope

2. Installing the instruments that may cause gas discharge obstruction. In the event of an **increase in airway pressure**,
3. **Jet discharge pressure** must be **reduced** until the increased airway pressure corresponds to the ventilation pressure that existed before the instruments were inserted. If the procedure described above is chosen, jet ventilation can be safely performed even with larger cross-sectional constrictions. This method is not required for common bronchoscopes or in stent application. Another indication is endoluminal stenting in tracheobronchial stenosis [26]. The application of a stent is possible under continuous ventilation and under optimal working conditions for the surgeon (Chap. 13). Supraglottic jet ventilation also opens up new perspectives for the surgical procedure for severe tracheal stenoses.

An essential key to success is continuous communication between anesthetist and surgeon with mutual consideration for each other's problems.

Contraindications Non-adjustability of the jet laryngoscope, extreme obesity, severe lung dysfunction, preoperatively existing significant restriction of pulmonary gas exchange, bleeding, patient not fasted.

Complications Insufficient oxygenation, hypercapnia, dehydration of the laryngeal and tracheal mucous membranes during prolonged procedures when no humidification is used.

Ventilation Procedure

Ventilation adjustment for stenosis and supraglottic jet ventilation	
Inspiration time:	***long***
Expiration time:	***short***
Jet discharge pressure:	***high***
Ventilation frequencies:	***higher***

Conclusions In laryngeal stenoses, it is necessary to use a higher working pressure of the respirator when using supraglottic jet ventilation in order to achieve sufficient pressure with sufficient tidal volume behind the stenosis. Since the pressure behind the stenosis cannot be measured, it is necessary to clinically observe the elevation during inspiration and the lowering of the thorax during expiration.

15.2 The Unexpected Difficult Airway "Cannot Intubate: Cannot Ventilate"

The clinical situation "cannot intubate—cannot ventilate" describes a form of difficult airway in which a patient does not breathe sufficiently with a mask or supraglottic airway aids and cannot be intubated. This is a life-threatening situation with the risk of hypoxia and asphyxia with cardiac failure due to the impossibility of oxygenation [27]. Priority should therefore be given to rapid oxygenation. Cricothyroidotomy is an emergency procedure in this situation [28, 29] Chap. 8. Cricothyroidotomy can be performed in several techniques under the aspect of jet ventilation: In principle, a standard surgical technique is the needle-cricothyroidotomy or different forms of Seldinger cricothyroidotomy, such as the Melker catheter set, Portex Seldinger kit, are applicable [30]. The Enk Oxygen Flow Modulator is an extension of the needle-cricothyroidotomy. After transcricoid puncture and placement of a transtracheal catheter, the Enk Oxygen Flow Modulator can be connected directly. A study by Helm et al. [[31] showed that the needle-cricothyroidotomy procedure is unsuitable for inexperienced users Chap. 8. According to our own opinion, children up to prepubertal age a needle cricothyoidotomie with jet ventilation should be given preference over surgical cricothyroidotomy due to the anatomical local situation. However, infants and toddlers should not be treated with a transcricoid but with median tracheal puncture due to the anatomical peculiarities [32]. Pressure-limited ventilation should be used, as indicated in the 2015 Paediatric Difficult Airway Guidelines. Prerequisites for the application are precise knowledge of the method and the existence of the technique as well as observance of the differential indications. The time required for the fastest possible oxygenation of the patient should be included in the considerations. Needle cricothyroidotomy is the fastest access route [33].

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Anesthesiological and Respiratory Specialties of Percutaneous Dilatational Tracheotomies

16

A. Nowak, E. Klemm, T. Usichenko, and W. Heller

16.1 General Aspects

Endotracheal intubation and controlled ventilation continue to be the standard for securing the airways of patients with respiratory insufficiency in preparation for tracheotomy in intensive care medicine. The situation known from laryngotracheal surgery of a close spatial relationship between the surgical area and the patient's airway also applies particularly to percutaneous dilatational tracheotomy (PDT).

Due to the safe anatomical identification of ring cartilage and tracheal braces in the course of the trachea required by PDT, the introduction of a flexible endoscope into the ventilation tube for fiber-optic control of the procedure is necessary when tracheal tubes are used. Flexible tracheobronchoscopy is most commonly used in PDT to visualize the endotracheal surgical site [1]. Notwithstanding the long obstruction of the endotracheal tube by a flexible endoscope during all phases of PDT with several proven drawbacks and

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Table 16.1 Lumen reduction of endotracheal tubes with the endoluminal introduction of flexible 6 mm endoscopes

Inner tube diameter (mm)	7.0	7.5	8.0	8.5
Remaining lumen after introduction of a 6 mm fiber optics (%)	25.5	36	44	50
Remaining lumen of the tube in relation to the inner diameter (mm)	3.6	4.5	5.3	6.0

hazards, this technique is recommended [2]. In the case of unfavorable size ratios of the tube and endoscope, the situation may arise that flexible endoscopes constrict the lumen of the endotracheal tube in such a way that the tracheotomy process must be interrupted repeatedly in order to optimize ventilation (Table 16.1) [3]. These situations were related to reduced minute ventilation. Increasing the tidal volume to 12 ml/kg predictive body weight was capable to reducing the development of respiratory acidosis. This effect is evident when endotracheal tube sizes similar or larger of 8 mm ID. This approach is not to be generally recommended due to risks of changing a tube in critically ill patients [4]. The tracheal lumen reduction by the dilator, the compression of the trachea and the escape of respiratory gases during the various steps of PDT represent an additional risk in terms of oxygen deficiency and CO_2 retention.

In addition to the anatomically existing possibility of direct puncture of the pleural cavity and injuries of the tracheal wall with the development of a pneumomediastinum [5], the increasing pulmonary retention of the respiratory gas in the event of obstruction of expiration by the fiber optics constricting the lumen of the respiratory tube is a possible mechanism for the development of a pneumothorax in PDT. The use of flexible endoscopes to control PDT may lead to situations that do not correspond to a secure and open airway, which is particularly problematic in patients with respiratory insufficiency.

The ideal form of ventilation during PDT surgery should enable safe and sufficient oxygenation and ventilation of the intensive care patient on the one hand, and ensure permanent endoscopic control of the surgical procedure on the other, without the occurrence of temporal limitations that hinder the management of emergency situations. These requirements cannot fully be met by the use of intermittent positive pressure ventilation (IPPV) via a ventilation tube with fiber optic control in PDT. With the propagated retreat of the tube into the glottis plane during fiberoptically controlled PDT, the safe respiratory tract is also abandoned. The possible loss of the airway due to dislocation of the ventilation tube during the gradual PDT procedure is always a dangerous situation. Such an event can be observed in an average of 2% of all PDTs. (Chap. 10).

The ideal form of ventilation for PDT must guarantee:

- *safe and uninterrupted oxygenation and ventilation of the intensive care patient*
- *permanent and clear endoscopic control of the surgical procedure*
- *no time limits when emergency situations occur*
- *free tracheal access to the surgical area*
- *prevention of aspiration of blood or tissue parts*

16.2 Ventilation with Intermittent Positive Pressure Ventilation (IPPV) for PDT Under Fiber-Optic Control via the Endotracheal Tube

PDT in intensive care patients should be performed under general anesthesia with relaxation to avoid coughing fits. Intensive care monitoring must be maintained. Analgosedation alone is not a general anesthesia. Although care must be taken to adhere to a 6-h preoperative feeding period, a gastric tube may be considered due to the frequently disturbed gastrointestinal passage in intensive care patients.

General anesthesia is required to perform PDT.

After reclination of the head, the ventilation tube is retracted into the vocal cord area by adjusting the glottis plane in direct laryngoscopy. In this position the ventilation tube and the patient's head are fixed (Fig. 16.1). Uncontrolled movements of the patient's head may lead to loss of the airway due to the tube slipping out of the vocal cord plane. The pressure limits and alarms of the ventilator must be set so that the partial displacement of the ventilation tube through the fiber optic is taken into account. The resistance created by the fiber optic introduced into the tube increases the inspiratory pressures measured on the ventilator. However, they do not correspond to the resulting intrapulmonary pressures. The poststenotic intrapulmonary ventilation pressures can at best be estimated depending on the size of the tube and bronchoscope. Experience has shown that, from a ventilation pressure of 30 mbar,

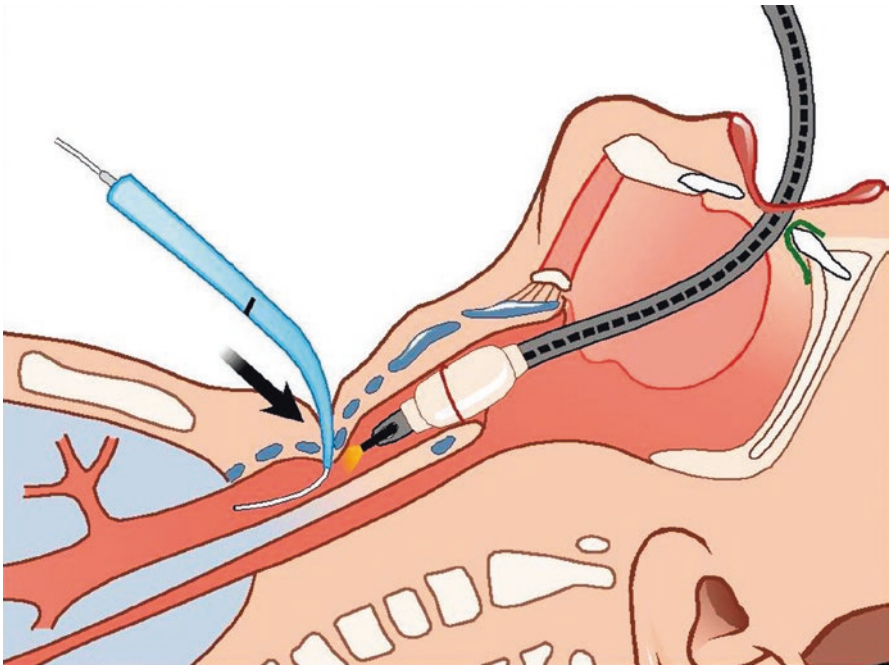

Fig. 16.1 To perform fiber optically controlled PDT, the endotracheal tube must be retracted into the vocal cord plane

the occurrence of leakages at the tube in intraglottic or supraglottic position can be expected to increase. The setting of a lower breathing rate and an I:E ratio adapted to the accidental obstruction of the tube with extended expiration time in conjunction with the monitoring of the pressure and flow curves on the ventilator with inserted fiber optics must be taken into account. The difficulty lies in maintaining the required breathing minute volume. In volume-controlled ventilation, an increase in the respiratory rate with the aim of increasing the respiratory minute volume through the resulting increase in auto-PEEP is limited. If suction maneuvers via fiber optics are required, respiratory gas is removed from the patient's airways. Depending on the patient's respiratory cycle, this may additionally reduce the respiratory time volume.

An example for general anesthesia for PDT:	
– *remifentanil*	*0.2–0.5 µg/kg/min intravenous*
– *propofol*	*3.5–5 mg/kg/min intravenous*
– *cisatracurium*	*0.1 mg/kg intravenous*
– $F_iO_2 = 1.0$	
– *Volume-controlled or pressure-regulated/volume-controlled ventilation*	
– *Observing and setting the pressure limits on the ventilator*	

16.3 Superimposed High-Frequency Jet Ventilation (SHFJV®) as a Ventilation Strategy to Perform PDT with Endoscopic Control via the Rigid Tracheotomy Endoscope (TED)

In the anesthesiological procedure for airway obstructions due to high-grade laryngeal or tracheal stenoses, ventilation forms have established themselves that can be transferred to the respiratory medical conditions of PDT. The use of Superimposed High-frequency Jet Ventilation (SHFJV®) in combination with the tracheotomy endoscope offers comfortable possibilities for oxygenation and ventilation, even if the airway is obstructed by instruments. While our clinical experience has shown that CO_2 retention may occur in patients with reduced pulmonary compliance (e.g., obesity, restrictive lung diseases) and when using only high-frequency jet ventilation (HFJV) with jet frequencies >5 Hz, the SHFJV is the more suitable form of jet ventilation for PDT [6] (Fig. 16.2).

16.3.1 Mode of Operation of SHFJV®

SHFJV is a pulsatile ventilation on two different pressure plateaus. Low-frequency jet ventilation and high-frequency jet ventilation are superimposed. The high-frequency gas flow generates an expiratory pressure plateau and delays its expiration by the flow opposite to the normofrequent jet flow. This results in an increase of the end-inspiratory pressure plateau and an increase of the tidal volume. The

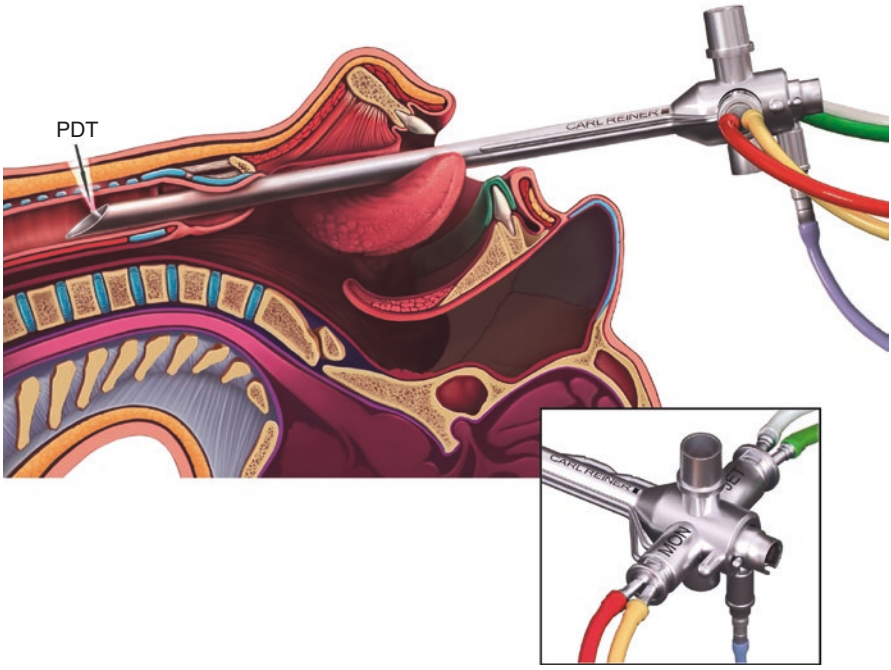

Fig. 16.2 Performing rigid endoscopically controlled PDT with the tracheotomy endoscope and SHFJV® (Made by Carl Reiner GmbH, Vienna, Austria). (Courtesy of Carl Reiner GmbH)

superposition of the high-frequency and low-frequency parts of the gas flow leads to better pulmonary volume filling in inspiration with volume filling obtained during expiration, even in respiratory obstructions [7]. The prestenotic application of SHFJV® prevents the development of barotrauma, as the poststenotic airway pressure is always lower than the airway pressure before stenosis. In contrast to manually performed forms of jet ventilation, the risk of barotrauma is additionally reduced by the use of state-of-the-art jet ventilators which automatically switch off the jet if the set pressure limits are exceeded [8]. The continuous backflow of respiratory gas from the lung resulting from high-frequency jet ventilation between the endoscope and the tracheal wall prevents aspiration and carry-over of blood, secretions and tissue parts into the deeper respiratory tract [9].

16.3.2 Equipment Technology for SHFJV®

For the use of the SHFJV® with the tracheotomy endoscope, a special jet ventilator—TwinStream™—is used. The multimode jet ventilator TwinStream™ is a microprocessor-controlled jet ventilator and consists of two separately or simultaneously operating ventilation parts (Fig. 16.3). The jet pulses are released according to the set parameters by fast reacting valves via jet nozzles.

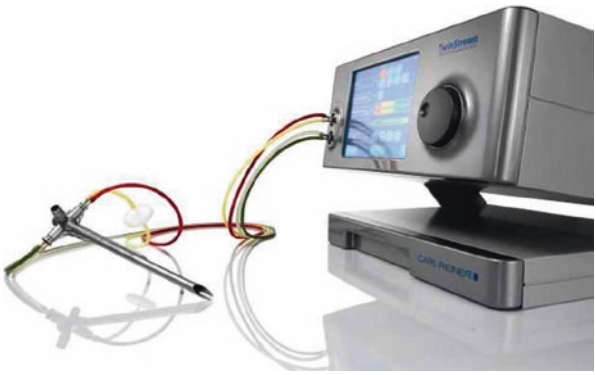

Fig. 16.3 Multimode jet ventilator TwinStream™ and rigid Tracheotomy endoscope (Made by Carl Reiner GmbH, Vienna, Austria). (Courtesy of Carl Reiner GmbH)

Superimposed High-frequency Jet Ventilation (SHFJV®) enables synchronous normofrequency and high-frequency jet ventilation over wide frequency ranges. In addition, this jet ventilator provides simultaneous ventilation at two different pressure levels. Both the height of the working pressures and the duration of inspiration and expiration are freely selectable. This means that oxygenation and CO_2 elimination can be controlled in a patient-adapted way. Measurements on the lung model show that the combination of low-frequency and high-frequency jet ventilation can achieve sufficient effective breathing stroke volumes even with limited pulmonary compliance. With jet ventilators that only have one frequency, sufficient gas exchange in the open system is often only possible to a limited extent, especially for patients with limited lung function [10]. With only high-frequency jet ventilation of these patients, there is a choice between a ventilation pattern of low jet frequency and sufficient CO_2 elimination at the expense of oxygenation, or a high-frequency ventilation pattern of good oxygenation but with rapid increase of p_aCO_2. In addition to measuring the gas concentrations (O_2 and CO_2) in the airway, state-of-the-art jet ventilators allow the measurement of airway pressures, i.e., pause pressure and peak pressure. If the set peak pressure is exceeded, the jet is automatically switched off. Pulmonary barotrauma is thus avoided (Fig. 16.3).

16.4 Ventilation Parameters

16.4.1 Oxygen Concentration

The gas stream emerging from the jet nozzles carries away gas particles from the surroundings and causes the so-called entrainment. The resulting oxygen concentration (F_iO_2) in the trachea is therefore lower than the oxygen concentration ($F_{jet}O_2$) set at the jet fan. The entrainment of the ambient air causes a reduction of the F_iO_2 by up to 20%, depending on the device setting. The use of SHFJV® reduces this phenomenon.

Fig. 16.4 Effect of low frequency (LF) and high frequency (HF) on oxygenation and ventilation with separate application. (Courtesy of Carl Reiner GmbH, Vienna, Austria)

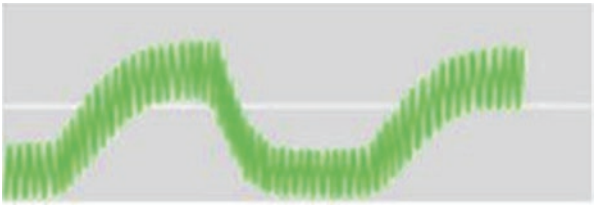

Fig. 16.5 The superposition of low-frequency (LF) and high-frequency (HF) components of the SHFJV® improves ventilation while retaining the benefits of HF jet ventilation for oxygenation. (Courtesy of Carl Reiner GmbH, Vienna, Austria)

16.4.2 Ventilation Frequency

With HFJV alone, the gas exchange is maintained over a broad frequency range (approx. 1.5–5 Hz) by a proportion of nonconvective mechanisms increasing with increasing frequency [11]. This phenomenon is dependent on resonance frequencies of the thorax but also the abdomen [12] and has an optimum between 1.5 and 2.5 Hz [13, 14]. From a jet frequency of more than 5 Hz, the CO_2 elimination decreases significantly with HFJV alone. However, higher jet frequencies >5 Hz may be required to maintain a certain PEEP. The increase of the jet frequency results in a shift of the breath excursions into a deeper inspirational position. A positive end-expiratory airway pressure ("intrinsic PEEP") develops. In this situation, the low-frequency portion of the SHFJV® provides the necessary CO_2 elimination by creating two alternating ventilation levels as well as by strengthening the entrainment and thus increasing the effective tidal volumes (Figs. 16.4 and 16.5).

16.4.3 Working Pressure

Central gas supply systems are under a pressure of approx. 4.5 to 5 bar. The reduction of this pressure by the jet ventilator results in the working pressure. This shows that the jet ventilator can only provide the pressure that is present in the primary gas

source. The application of the tracheotomy endoscope results in working pressures of 0.8–2.5 bar for intensive care patients, taking into account the limited pulmonary compliance. In accordance with the general gas equation ($p \times V \times T^{-1}$ = constant), the pressure of the gas portion applied to the jet is further reduced by a factor of 10^{-3} into physiological ranges (millibar) immediately after leaving the jet nozzle in the patient's airway. Slim patients tend to require lower working pressures of 0.8–1.5 bar, while obese patients and those with COPD or low pulmonary compliance sometimes require working pressures of up to approx. 2.0 bar.

16.4.4 I:E Ratio

As with conventional ventilators, the I:E ratio is also defined via the inspiratory duration (ID) for jet ventilation due to passive exhalation. The inspiration time is described as the opening time of the jet valve in relation to the time interval between two ventilation pulses. If the ID is extended, the gas volume applied to the airway increases and oxygenation and CO_2 elimination are improved [15]. The influence of the inspiration duration on the gas exchange is frequency dependent and characterized by interactions with other parameters of jet ventilation. With increasing jet frequency, the shortening of the available expiration time must be taken into account, which makes the setting of a longer inspiration time appear no longer meaningful depending on the device configuration. Therefore, an I:E ratio of 1:1 to 1:1.5 is used as a rule.

An example for setting the SHFJV® at the jet ventilator TwinStream™ (Carl Reiner GmbH, Wien):

- *select the bronchoscopy mode (BRO)*
- *enter the patient's weight*
- *check the suggested working pressures, frequencies and I:E ratios for the respective high-frequency and low-frequency part of jet ventilation*
- $p_{jet}HF$ *= 1.5–2.0 bar;* $p_{jet}LF$ *= 1.0–1.5 bar*
- f_{HF} *= 400–600 min*$^{-1}$*;* f_{LF} *= 8–15 min*$^{-1}$
- $I{:}E_{HF}$ *= 1:1.5;* $I{:}E_{LF}$ *= 1:1*
- *upper alarm limit: 30 mbar (shut-off pressure); lower alarm limit: 5 mbar*
- *set* $F_{jet}O_2$ *= 1.0*
- *check the effectiveness of ventilation and oxygenation through integrated* E_TCO_2 *measurement or measurement of* S_pO_2 *within the scope of standard anesthesiological monitoring during PDT.*

16.4.5 Monitoring

Apart from the standard monitoring of the intensive care patient, which in most cases offers comprehensive possibilities for monitoring oxygenation and ventilation in addition to the usual circulation parameters, current jet fans also have the

possibility of capnography. Transcutaneous blood gas measurement can also be used to measure the P_aCO_2 status. In capnography, the current limitations are the inertia of lateral flow measurement. This inertia ensures that a quantitatively useful E_TCO_2 signal can only be measured during normo-frequency jet ventilation or during interruptions in ventilation. The transcutaneous blood gas measurement is independent on the respiratory rate. Its disadvantages are the more complicated handling and the latency time of the display compared to the current arterial P_aCO_2 value. The monitoring of the jet ventilator continuously measures $F_{jet}O_2$, working pressure and respiratory pressure (P_{aw}). The pressure monitoring of the airway is carried out by continuously measuring the P_{aw} at the distal end of the endoscope, independent from the ventilation cycle. Exceeding the set pressure limits is reliably prevented in this way and with the help of an automatic shut-off of ventilation. The simultaneous monitoring and control of the PEEP, which inevitably occurs with SHFJV®, is also an advantage, especially for patients with intensive care ventilation.

For the application of jet ventilation to PDT, the tracheotomy endoscope must be aligned so that the bifurcation or depth of the trachea is visible to the endoscopic physician.

16.5 Contraindications

An absolute contraindication of the SHFJV®, like any other jet ventilation, is the severe obstruction of the gas flow from the respiratory tract. By keeping the outflow path of the respiratory gas permanently open with the endoscope tube of the rigid TED, the SHFJV® proves to be a suitable ventilation method throughout all phases of PDT.

16.6 Complications

16.6.1 Gas Exchange Disturbances

In the course of PDT, the settings of the jet ventilator must of course be monitored and adapted to the patient's conditions and the variable course of P_aO_2 and P_aCO_2. If the oxygen saturation is permanently good, $F_{jet}O_2$ settings lower than 1.0 can be set at the Jet respirator.

If *hypercapnia* occurs, a search must be made for pulmonary and interventional causes. In obese patients, the frequency of the low-frequency jet is increased first; in COPD patients, the jet discharge pressure of the low-frequency jet is increased first. Increases in working pressure may only be achieved under control of the intratracheal pressure. The lower the high frequency is set (valid for $f_{HF} < 500\ min^{-1}$) the more CO_2 is exhaled. Obstructions or discharge obstacles to the flow of air caused by imported instruments must be remedied by collegial agreements between the surgeon and the respiratory physician.

Table 16.2 Influence of ventilation parameters on blood gas values with SHFJV®

	F_iO_{jet}	p_{LF}	p_{HF}	f_{LF}	f_{HF}
p_aO_2 increase	↑	↑	↑	=	↑
p_aCO_2 decrease	=	↑	=	↑	↓

Hypoxemia and problems with oxygenation are life-threatening. The following causes of arterial *hypoxemia* are possible [11]:

- alveolar hypoventilation due to reduced tidal volume
- reduced F_iO_2 due to entrainment with ambient air
- decrease in jet ventilation efficiency in cases of obstructive and/or restrictive lung diseases

If the patient's oxygen saturation drops, the high frequency should be raised first, then the two jet discharge pressures of the SHFJV® ($F_iO_2 = 1.0$) (Table 16.2).

As the working pressure increases, the airway pressure (p_{aw}) and thus the tidal volume (V_t) are increased. Extending the inspiratory time can improve oxygenation by increasing intra-alveolar pressure. In any case, in patients with pulmonary function impairment and PDT, the $F_{jet}O_2$ must first be set to 1.0.

16.6.2 Aspiration

The presence of a leak for the continuous discharge of respiratory gases is obligatory for the performance of any type of jet ventilation. The frequency of the jet ventilation thus gains importance with regard to aspiration protection. From jet frequencies of approx. 100 min^{-1}, a continuous gas escape from the respiratory tract occurs [11]. By maintaining jet ventilation, the continuous return flow verifiably prevents the penetration of regurgitate, blood or secretion into the respiratory tract [9].

16.6.3 Pneumothorax

The possibility of pneumothorax formation under any kind of mechanical ventilation has already been known from the early years of clinical anesthesiology. Irrespective of the various pathophysiological mechanisms, an incipient pneumothorax in ventilated patients can only be clinically noticeable as unclear hypoxemia or hypotension. If the physician does not consider this possibility in time, the rescue diagnosis is dangerously delayed. A pneumothorax during ventilation can quickly develop into a life-threatening tension pneumothorax with cardiorespiratory failure.

The possibility of developing a pneumothorax is a potentially life-threatening complication that must be quickly detected and remedied. Pneumothorax can also occur bilaterally.

Pneumothorax symptoms in ventilated patients:

- decrease in pulmonary compliance with a consecutive increase in ventilation pressures
- signs of hypoxia
- tachycardia
- hypotonia
- increase in the central venous pressure
- subcutaneous emphysema
- cyanosis
- cardiac arrhythmia

Pneumothorax diagnosis:

- auscultationally attenuated respiratory sound
- hypersonic knocking sound on the affected side
- sonography, thorax X-ray in two levels, caution! ventral pneumothorax

Pneumothorax therapy:

– thoracic suction drainage
– in a life-threatening situation: If there is a strong suspicion of tension pneumothorax, a large-lumen cannula must be inserted medioclavicularly into the second intercostal space on the affected side. The escape of the air through the cannula and the disappearance of hypotension, hypoxemia and increased ventilation pressure provide evidence for the correct diagnosis. The further treatment of pneumothorax requires the insertion of a continuous thoracic suction drainage.

The absolute urgency of the situation when a tension pneumothorax occurs may, under certain circumstances, prohibit waiting for the definitive diagnosis by imaging and require immediate action due to the life-threatening situation.

16.7 Legal Medical Information

The repeated propagation of PDT in the literature as a simple, fast, low-complication intervention that can be carried out at any time from the bedside must not allow the necessary provision of personnel and technical resources to get out of sight. Due to the fact that tracheotomies are interventions that can lead to potentially life-threatening complications, minimum structural and process requirements are inevitable.

PDT is not an emergency intervention. Before PDT begins in patients with respiratory and cardio-circulatory stability, general anesthesia with associated intensive monitoring and relaxation must be established to avoid reflective coughing fits. Ventilation is performed with pure oxygen ($FiO_2 = 1.0$). The vocal cord level is then visualized with direct laryngoscopy. If this procedure or the patient's medical history indicates a difficult airway, tracheotomy may only be performed by open surgery.

PDT is no emergency intervention. No dilatational tracheotomy must be performed if there is a difficult airway.

All technical equipment and personnel requirements must be within reach in order to be able to restore safe conditions through immediate reintubation if the respiratory tract is lost in PDT. It must also be ensured that, in the event of disorders of the vital functions, medication or mechanical therapy up to and including cardiopulmonary resuscitation can be carried out at any time in accordance with the applicable guidelines. A therapeutic intervention option in the sense of volume or vasopressor administration must also be guaranteed at all times. The qualification of the medical and non-physician staff involved in PDT, the deepening of analgosedation to general anesthesia and its monitoring must be ensured through training and further education as well as regular further training. Both the endoscopic physician and the physician performing the puncture, dilatation and insertion of the tracheostomy tube are not fully able to monitor and control the vital functions of the intensive care patient to the extent required during PDT. This is especially true when complications occur which, for understandable reasons, require undivided attention for the surgical area. For this reason, another person who is not involved in the endoscopy and the operation must be present to ensure that the patient is monitored at all times. Since this is usually an intervention for intensive care patients, an increased risk profile must be assumed and monitoring and control of vital functions by the sole presence of a nursing assistant must be critically questioned. In the routine of most intensive care units, it is common practice for analgesia to be administered by nursing staff rather than by the prescribing physician. However, German guidelines clearly distinguish between sedation and anesthesia. For general anesthesia in the context of interventions or operations, the presence of an anesthetist who meets the specialist standard is generally required [16]. Parallel anesthesia, also in the sense of shared attention, is currently not permitted by German lawmakers. The surgeon's assumption of dual responsibility for the intervention and anesthesia procedure represents an unacceptable anachronism in the inpatient sector [17].

Planned anesthesia procedures with relaxation, as necessitated for PDT, require the involvement of an anesthetist or a physician experienced in intensive care medicine, who devote their undivided attention to the monitoring and control of general anesthesia and the monitoring and control of the vital parameters of the intensive care patient during the surgery.

If the personnel and structural requirements for the safe PDT procedure in the intensive care unit are not met, the patient should be placed in the surgical program or referred to a department with the appropriate requirements. The safety of patients and staff must also be given priority, taking into account economic concerns.

16.8 Results of Experimental and Computer-Based Simulations

The development of technical aids to secure the respiratory tract and their introduction into practice is mostly subject to empirical procedures nowadays. Anatomy, physiology and functional aspects of the human respiratory organs are well studied.

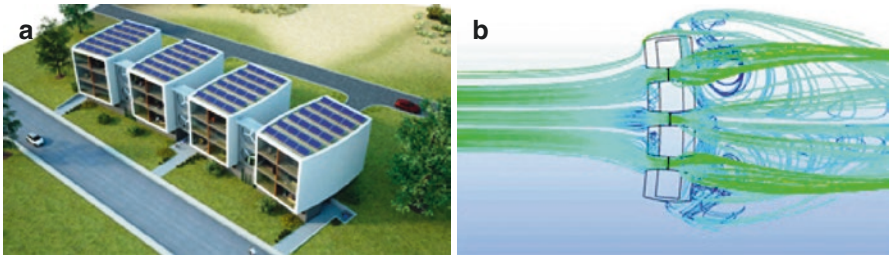

Fig. 16.6 (**a**, **b**) Numerical simulation for the visualization of flows using the example of a building complex

Physical principles, on the other hand, such as fluid mechanics phenomena in modern and clinically successful forms of ventilation are less well researched. Computer-based simulations for the analysis of air flows have been established in fluid mechanics for many years. These methods are rarely used in medical research. A possible cause for this is the high complexity and variability of the human body. Variability is the standard here. Especially in respiration, many aspects of gas transport and the complex anatomy of the respiratory tract must be considered in order to achieve realistic results in numerical simulations. The enormous knowledge potential hidden in the numerical simulation of flow processes in the medical field becomes clear when investigating the flow processes of the respiratory gas during ventilation with SHFJV® via the tracheotomy endoscope. Nevertheless, experimental investigations are indispensable to validate the accuracy of the numerical results [18, 19]. Both possibilities cannot be considered separately from each other and are used side by side for one and the same task.

This can impressively be shown by example of the floe around a building complex (Fig. 16.6). While a building complex is experimentally investigated in a wind tunnel on a model scale, the flows are calculated in parallel, e.g., by ANSYS™-CFX (Ansys Inc., Southpointe, Canonsburg, PA, USA). For this it is necessary that the systems of equations (Navier-Stokes equations) on which the calculation is based are resolved in several million space points. It is noticeable that the flow in the wake area can be made very well visible (Fig. 16.6). The representation is a snapshot of the constantly changing flow conditions. But it is possible to identify dominant flow and turbulence structures that allow an optimization of the arrangement of the buildings according to certain criteria. There are infinitely many, permanently changing flow structures, which means that even the complicated systems of equations for the calculation of chaotic flow structures have infinitely many possible solutions. The knowledge and experience of the fluid mechanics engineer as well as the quality of the calculation program determine how well the calculated results can be reconciled with those of the experiment or with the conditions of reality.

With the application of computer-based display and simulation methods to the flow conditions in the rigid Tracheotomy endoscope (TED), the turbulent flow processes with variable boundary conditions such as the jet frequency, the working pressure in the jet nozzle and the jet nozzle length are made visible and evaluated. The mode of action of the SHFJV® can be explained by this visualization, and

conclusions for an optimization of the endoscope can be drawn. By the parallel experimental investigation of the flow in the tracheotomy endoscope with smoke it could be shown that, with the application of the SHFJV®, no possibly microbially loaded air flows back from the lung of the patient into the endoscope. The explanation for this is that, depending on the jet frequencies and depending on the location of the jet nozzles in the environment, certain pressure conditions occur. The size of the pressure difference between the inside of the endoscope and the outside is responsible for the flow direction. In jet ventilation, the exhaled air flows back from the lungs via the remaining leak between the endoscope and the tracheal mucosa.

Figure 16.7 displays the calculated results for the flow velocities in the endoscope at different times during the application of the SHFJV® for ventilation. They agree with the results of the experimental investigation using smoke. The jet frequency of the low-frequency nozzle (top) used as a basis for the calculation is 12 min^{-1} and the jet frequency at the high-frequency nozzle (bottom) is 600 min^{-1}. The time interval between the individual figures (Fig. 16.7a–c) is 0.001 s. The constantly changing flow velocities at each location can be clearly seen, especially in the upward connection of the Tracheotomy endoscope for intermittent positive pressure ventilation (IPPV) and in the opening of the rigid tube directed towards the endoscopic physician.

The generated partial backflow at this side of the endoscope is caused by the inflow angle of the jet flow, which leads to a distinctive vortex formation in this area and consists exclusively of fresh air at this pipe end. It can be seen that at no time do backflows occur from the distal, patient-side opening in the endoscope, which is also confirmed by the representation of the calculated streamlines in Fig. 16.8.

The reason for the inflow or intake of ambient air via the upwardly directed connection option for IPPV is that the jet nozzles, relative to the cross-section of this connection, have been optimized according to the pressure distribution occurring there. Figure 16.9 shows the achievable intake volume flow depending on the location of the jet nozzles. The optimum is achieved by a displacement of the nozzles by 20 mm from the starting point and leads to an increase of the intake volume flow by approx. 70% compared to the non-optimized nozzle arrangement.

On the basis of clinical and experimental investigations [9, 20, 21], numerical simulation can be used to investigate clinically known positive effects in various ventilation methods. Although jet ventilation is currently not the focus of ARDS treatment, Superimposed High-frequency Jet Ventilation (SHFJV®) is an alternative approach to improve lung function and oxygenation in ARDS with lung-protective ventilation. Compared to extracorporeal membrane oxygenation (ECMO), SHFJV® is easier to use and has fewer complications [22].

However, the flow-mechanical causes for this have hardly been investigated yet. This means that numerical investigations must be carried out for the basic understanding of the complex flow within the trachea into the numerous generations of the bronchial tree. The analysis of the pressure fluctuations caused by jet ventilation, which generate resonance phenomena in the depth of the bronchial system depending on the individual pathophysiological tissue properties, plays an important role. If the jet frequencies are adjusted accordingly, resonance phenomena and

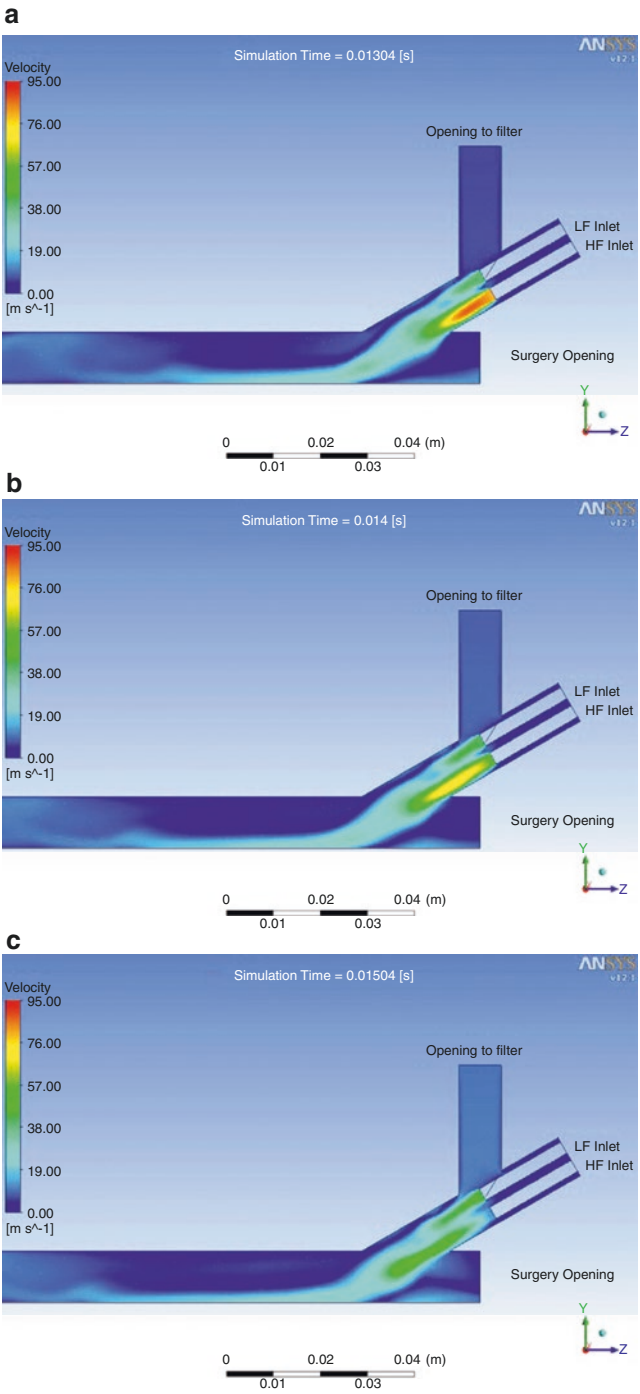

Fig. 16.7 (**a**–**c**) Numerical simulation of flow velocities in the rigid Tracheotomy endoscope (TED) at intervals of 0.001 s

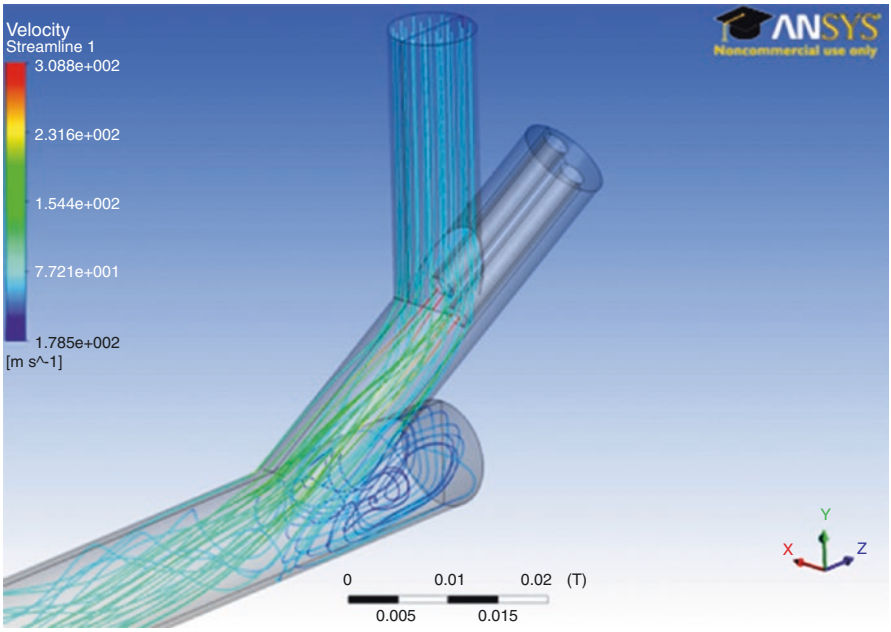

Fig. 16.8 Calculation of the streamlines in the rigid Tracheotomy endoscope (TED)

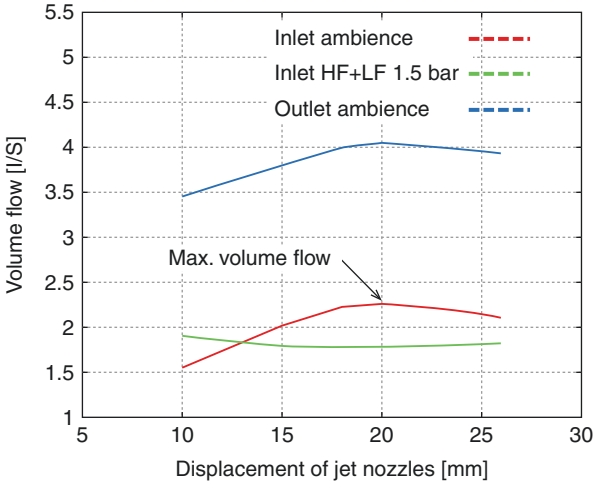

Fig. 16.9 Calculation of the nozzle position to optimize the volume flow in rigid Tracheotomy endoscope (TED)

frequency superpositions with the natural frequency of the thorax can occur, with which particularly large oscillation amplitudes occur. These can lead to optimal expansion of the ventilated alveoli and provide a maximum of gas exchange surface. By selecting the appropriate ventilation method, these physical processes can be taken into account and optimal conditions created for pulmonary gas exchange in patients with respiratory insufficiency.

16.9 Summary

The application of the SHFJV® via the rigid tracheotomy endoscope fulfils the requirements to be formulated for the ventilation procedure for a surgical intervention on the trachea in patients treated in intensive care. Good visibility and parallel continuous endoscopic access to the surgical site provide suitable conditions for safe PDT. At the same time, there is the possibility of continuous ventilation of the intensive care patient, which is particularly valuable in the event of delays or complications. By using the tracheotomy endoscope, a loss of the airway during the tracheotomy process is practically impossible. In addition, reintubation via the tracheotomy endoscope can be safely performed at any time during PDT. Due to the continuous gas flow from the respiratory tract at common higher jet frequencies, there is no danger of aspiration, even if bleeding occurs.

For the future, it is recommended that numerical simulations for reviewing clinical aspects and for optimizing ventilation techniques be included in research. This also applies to the design and clinical use of tracheotomy tubes.

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The Way to Decannulation

17

S. Sutarski

17.1 Introduction

In the context of acute medical and rehabilitative treatment of tracheotomized patients, a favorable course of treatment leads to a point in time when the indication for a tracheotomy no longer exists and the tracheostomy tube can be removed.

The assessment of when and under what conditions decannulation should take place is the responsibility of the medical disciplines providing care in close cooperation with the responsible therapists and nurses. It is recommended that, in addition to the specialist discipline that cares for the underlying disease of the patient, endoscopically experienced colleagues should also be consulted in order to be able to make decisions for the benefit of the patient in interdisciplinary cooperation, taking into account the morphological prerequisites, the functionality and the prognosis of the underlying disease [1–3].

17.2 Decannulation: Why?

17.2.1 Quality of Life of Patients

The presence of a tracheostoma and the inserted tracheostomy tube are often experienced as a strain and stigmatization by the affected patients and their relatives. Therefore, even with extensive information about the necessity of the tracheostoma, there is an urgent desire to be able to remove the tracheostomy tube as quickly as possible. If long-term tracheostomy tube care is indicated, this implies an increased need for medical and therapeutic support in order to avoid social withdrawal tendencies and to improve the acceptance of the tracheostomy tube [4–6].

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Significant adverse factors:

- reduced phonation depending on the tracheostomy tube type and thus limited verbal communication/information deficits
- tracheostomy tube—related swallowing disorders with limitation of oral food intake
- dyscrinia of the respiratory tract, mandatory aspiration
- increased need for nursing care
- Necessity of being subject to permanent medical care and nursing, restriction of privacy
- pain
- well visible foreign object
- fear of complications, especially shortness of breath

17.2.2 Tracheostomy Tube: Related Risks

The tracheostomy tube is a foreign body to the respiratory tract that can generate vital threatening situations [7]. This results in an individual risk associated with the tracheostomy tube, of which the attending physician and nursing staff must be aware and from which the necessity of a defined emergency management can be derived.

Acute Occlusion of the Tracheostomy Tube Lumen

If the tracheostomy tube is suddenly occluded by secretion, e.g. after coughing, acute respiratory insufficiency may occur, which can develop into apnea-triggered cardiovascular arrest in the course of time. Patients with a blocked tracheostomy tube cannot breathe next to the tracheostomy tube in an emergency and are therefore particularly at risk.

Unobstructed tracheostomy tubes of smaller lumen with sufficient distance to the tracheal wall reduce the risk, whereby knowledge of the tracheal morphology and targeted tracheostomy tube adjustment are required to determine the degree of risk.

Special consideration must be given to patients who are unable to help themselves or make themselves noticed in an emergency.

Acute Hemorrhage

Due to (mostly long-term) mechanical lesions of the tracheal wall, there is a risk of acute bleeding, especially in ulcerations that cause deep defects and reach large thoracic vessels as well as tracheal ones. The resulting blood loss may cause a hemorrhagic shock, but also respiratory tract obstruction due to blood aspiration with tracheobronchial coagulation and formation of respiratory insufficiency.

Tracheostomy Tube Dislocation

A sudden loss of the tracheostomy tube due to an automanipulation or repositioning of the patient may become critical, especially if

- suprastomal stenosis of the airway is present,

- own breathing is reduced,
- the tracheostoma does not represent sufficient airway access in case of a long shaft and a tendency to collapse,
- a "shifting-closure phenomenon" occurs (Chap. 10).

17.2.3 Decision-Making for Medical Care

The above-mentioned vital threatening situations ultimately result in a monitoring obligation for the affected patients, which can be realized by permanent monitoring or 24-hour observation by nursing staff.

In this context, ethical and legal questions arise as there are no binding guidelines for patient monitoring on the part of the professional societies. The risk potential is determined individually, the responsibility lies with the attending physicians.

Depending on the care decision taken, this results in increased personnel and financial expenditure, which can hardly be guaranteed outside the area of intensive care medicine and considerably reduces the self-determination of the affected patients [4].

If, therefore, there are no medically justifiable criteria for leaving the tracheostomy tube in its place, the decannulation should be endeavored in order to optimize further care.

17.3 Requirements for Decannulation

There are four indication groups [3] for the creation of a tracheostoma, which individually or in combination lead to the decision to open the trachea and thus shorten the airway:

- Invasive (long-term) ventilation
- stenoses of the upper airways
- dysphagia with aspiration
- reduced secretion management, i.e., inability to independently clean the respiratory tract

It is thus necessary to safely exclude the above criteria in order to consider decannulation [8].

Tracheotomized patients represent an extremely inhomogeneous patient population. It is mainly due to the development of modern intensive care medicine that tracheotomy can be regarded as the most frequently performed surgical intervention on critically ill patients, whereby mechanical ventilation in particular has contributed to the increase in the number of patients. The patient clientele includes neurological, traumatological, internal, pediatric and oncological diseases as well as complications after surgery. The question of whether the disease is acute or chronic can also influence the evaluation of the tracheostoma during the course of surgery.

In this respect, it seems to make sense to initially consider the indications for the tracheostoma rather than the underlying disease of the patient from the point of view of decannulation. If there are persistently relevant functional deficits or respiratory pathologies, the tracheostoma should be left in place if possible.

In addition, it should be noted that tracheotomized patients are increasingly being discharged from intensive acute care into rehabilitation or outpatient care. With reference to the above-mentioned need for trained personnel to decide on decannulation and by fragmentary standards, it is becoming increasingly difficult to provide the necessary care structures after the acute phase has expired [9]. An experienced interdisciplinary team and defined processes can help to minimize the risk of re-cannulation.

The aim of our patients' rehabilitation is to record the disturbed functionality in a complex way and to return it to a self-sufficiency through targeted therapeutic measures which permits the decannulation (Fig. 17.1). If no *restitutio ad integrum* can be achieved, the relevance of the remaining deficit must be assessed and brought into a justifiable relationship to the tracheostomy tube-related risk of the patient. Patients or their relatives should be involved in the decision-making process.

17.3.1 Breathing

The long-term goal of intensive care medicine is to reliably wean patients from the ventilator. The use of a tracheostoma can be helpful in this respect [10]:

- shortened weaning, shorter stay in the intensive care unit
- more efficient aspiration of secretions from the lower respiratory tract
- optimization of oral and throat hygiene
- more favorable ventilation parameters
- less need for sedatives
- improved swallowing and communication rehabilitation.

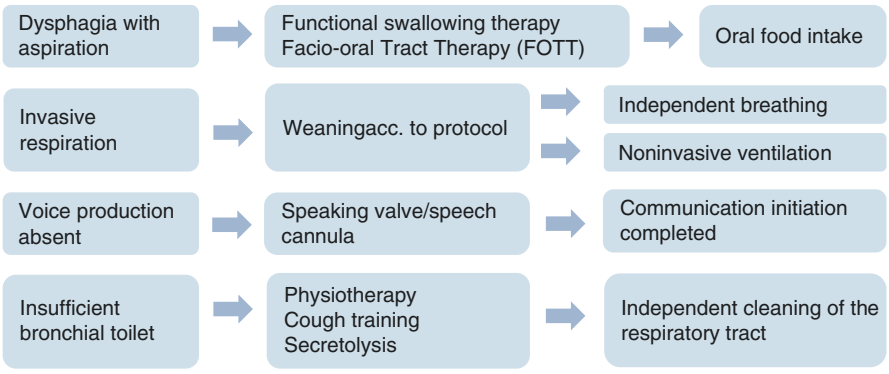

Fig. 17.1 Detection of impaired functionality, therapeutic measures

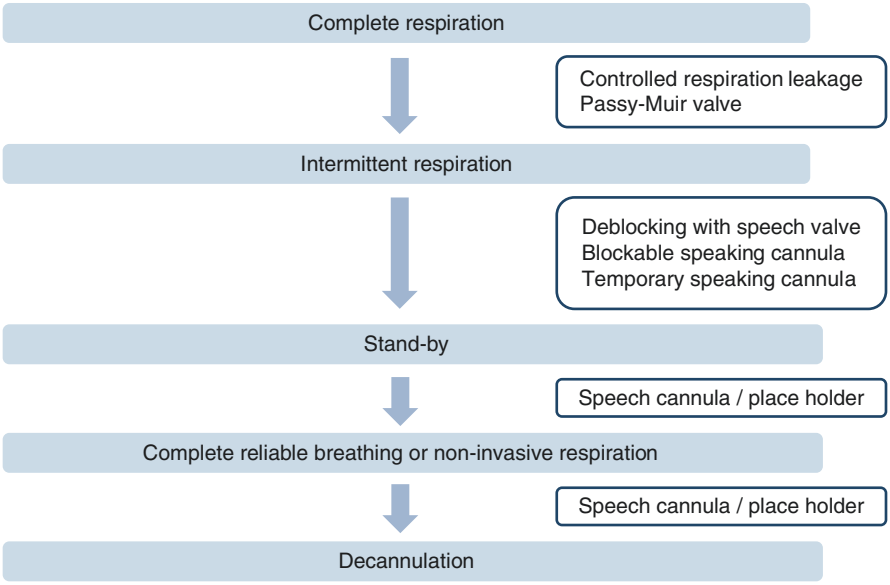

Fig. 17.2 Step program of weaning

During ventilatory weaning, an accompanying tracheostomy tube management with regular unblocking of the tracheostomy tube using a speech unit during ventilation breaks is recommended [11]. The exhalation flow is directed via the upper respiratory tract (Fig. 17.2).

Advantages:

- training the respiratory muscles
- stimulation of the nociception of the laryngeal and pharyngeal mucosa by the respiratory flow → positive effects on the swallowing function (swallowing reflex triggering, increasing swallowing effectiveness and frequency, perception of residuals)
- possibility of phonation → communication, postdeglutitive voice control
- training for independent airway cleaning

In addition to the weaning protocol, the unblocking times of the tracheostomy tube can be extended, which can have a positive influence on the ventilation weaning process. Unfortunately, this simultaneous procedure does not always succeed in every case, high respiration can be pressed, strained or quickly exhausted—possibly until the inability to expiration next to the tracheostomy tube. The use of a blockable tracheostomy speaking tube with an exactly positioned tube perforation can be helpful in these cases.

Caution! The combination of a blocked tracheostomy speaking tube with an attached speaking valve is life-threatening (Chap. 10 "Tracheotomy-related death").

Causes of a limitation of unblocking times:

- *tracheal or thoracic instability*
- *subglottic or tracheal stenoses*
- *respiratory infections*
- *diaphragmatic or abdominal wall defects*
- *obesity*
- *neuromuscular diseases*
- *bronchopulmonary diseases*
- *central respiratory disorders*
- *severe aspiration*
- *bronchial secretion retention*
- *patient anxiety*

The risk of respiratory exhaustion after long-term ventilation must always be taken into account, whereby pre-existing bronchopulmonary and neuromuscular diseases can have an aggravating effect. A positive history of Obstructive Sleep Apnea Syndrome (OSAS) or obesity-related hypoventilation also requires special attention, since with prolonged dead space after decannulation with different latency times (possibly several days!) may lead to decompensation of the respiratory situation [12, 13].

There are no binding recommendations as to what interval between successful weaning and decannulation must be observed, which is why an individual decision must be made taking into account pre-existing conditions and ventilation duration. If there is a justified risk of renewed respiratory insufficiency, the temporary use of a tracheostomy placeholder can be used to test respiratory performance [14] (Fig. 17.3 a, b). The patient should be on the monitor for observation; in addition, laboratory chemical controls of the acid-base status are recommended.

In order to facilitate continued outpatient care, the aim is to adapt noninvasive ventilation in the case of continuous (intermittent) mandatory ventilation [15]. This results in a special case of the decannulation:

In order to be able to switch patients from invasive to noninvasive ventilation (NIV) via mask, no other indications for tracheotomy must exist apart from ventilation, which must be checked beforehand. Mask adjustment is then performed using a placeholder to retain the tracheostoma as airway access if mask ventilation is not tolerated. Only after successful conversion to NIV can the placeholder be removed, which is equivalent to decannulation.

If a dilated tracheostoma with narrow and/or collapsing shaft lumen is present, a prior surgical tracheostomy revision should be discussed in order to secure the airway and be able to use a placeholder. It should be noted that a relatively large tracheostoma with a slow shrinkage tendency can only be sealed to a limited extent after removal of the placeholder and that relevant leakage may develop during ventilation. The tracheostoma should then quickly be closed surgically.

It is not recommended to perform decannulation and NIV mask placement at the same time, as in case of failure of mask ventilation with a shrunken tracheostoma,

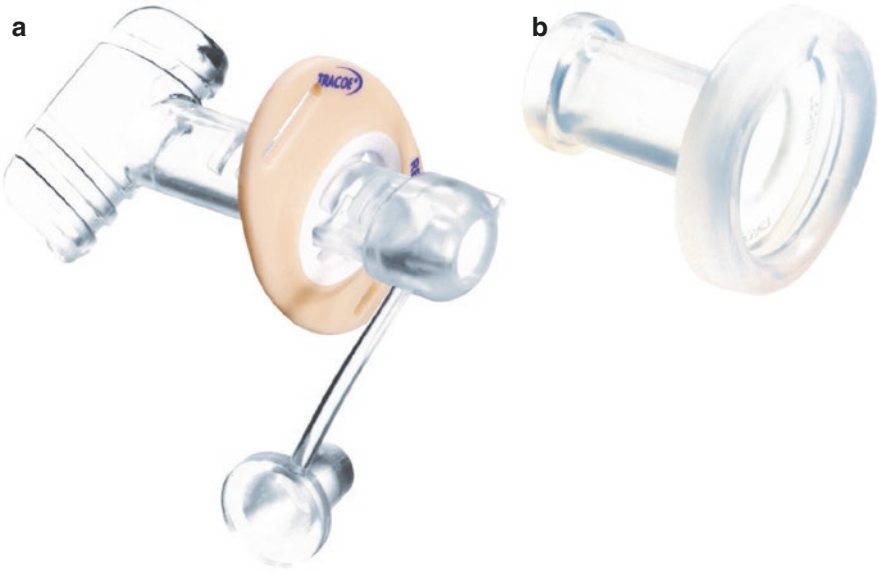

Fig. 17.3 (**a**) Placeholder for temporary tracheostoma closure TRACOE button plus (TRACOE, Nieder-Olm, Germany), (**b**) TRACOE *larynx* stoma button (TRACOE, Nieder-Olm, Germany)

recannulation may become difficult or impossible and intubation and re-tracheotomy may be necessary.

But if this procedure is decided upon, the patient must be intensively informed about the risk of intubation. If difficult intubation is expected, primary decannulation with mask adjustment is contraindicated.

In the course of decannulation, hypoxia appears faster than hypercapnia. This results in a long-term monitoring obligation of the patients for up to 7 days if the respiratory parameters are doubtfully stable.

17.3.2 Airway Morphology

Before planned decannulation, it is essential to assess the respiratory tract up to the main bronchia by means of mirror examinations and endoscopy. The examination is carried out on the conscious patient; if handled properly, surface anesthesia is not mandatorily necessary.

The first step is an anterior rhinoscopy of the main nasal cavity on both sides as well as a mirror examination of the oral cavity and the oropharynx. Then an endoscope of a suitable diameter is inserted transnasally and flexibly over the more suitable nasal side (lower nasal passage, orientation at the nasal floor) in order to view the pharynx (epi- meso- and hypopharynx) and larynx. Then the tracheostomy tube is removed.

Only an assessment without an inserted tracheostomy tube creates a comprehensive impression of the respiratory tract, as the tracheostomy tube can push pathological findings aside and cover them.

In addition to a thorough examination of the tracheostoma itself, the transstomal tracheoscopy is carried out, if possible, without touching the wall in order to avoid provoking coughing. If the patient is sufficiently cooperative, the endoscope is placed endotracheally and the tracheostoma is closed on the outside (with auxiliary personnel). The patient is asked to sound their voice or cough in order to assess the stability of the tracheal wall with increasing subglottic pressure build-up. If there is no cooperativeness, a cough reflex may be triggered in a targeted manner.

What needs to be paid attention to?

Nose/nasopharynx:

- pathological secretions
- mucosal condition (reddening, edema, dryness, encrustation)
- obturating processes

A nasal breathing obstruction only becomes relevant after the decannulation has been removed, as mouth breathing subsequently occurs, which can lead to dehydration of the respiratory tract and mucous incrustation. Nasal inflammatory processes can develop caudally and subsequently cause the development of laryngotracheitis. If possible, the nasal pathology should be rehabilitated before the decannulation.

Oral cavity/oropharynx:

- mucosal condition (reddening, deposits, edemas, ulcerations, bite injuries)
- dental status
- tissue defects
- tonsillar hyperplasia

Hypopharynx/larynx:

- space requirements
- secretion or food residues
- mucosal condition (edema, reddening, indications of reflux?)
- vocal fold motility (Caution! Unilateral or bilateral standstill? In case of bilateral standstill before decannulation, glottis-expanding intervention with the disadvantage of voice deterioration and reduced cough efficiency may be necessary.
- hyperplasia of Plica vestibularis right/left
- intubation damage

Tracheostoma:

- lumen/shaft depth
- inflammation (also peristomal)

- granulations
- stability

Trachea:

- distance of the tracheostoma to the glottis plane/indications of ring cartilage affections?
- stability? (Fig. 17.4)
- stenosis? (Fig. 17.5)
- suprastomal impressions in the anterior wall?
- evidence of tracheal compression from outside?
- mucosal condition

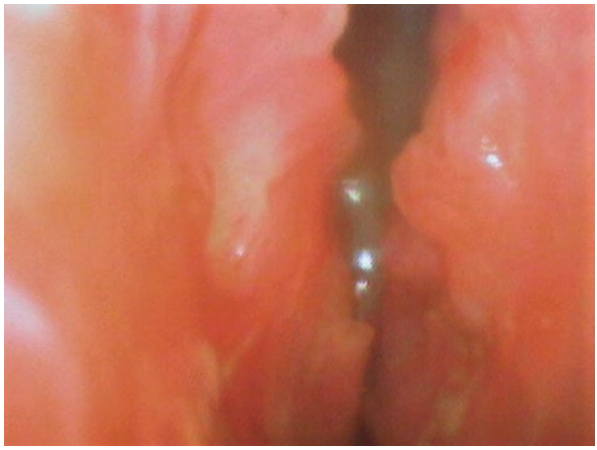

Fig. 17.4 Instability of lateral tracheal wall (Photo by S. Sutarski)

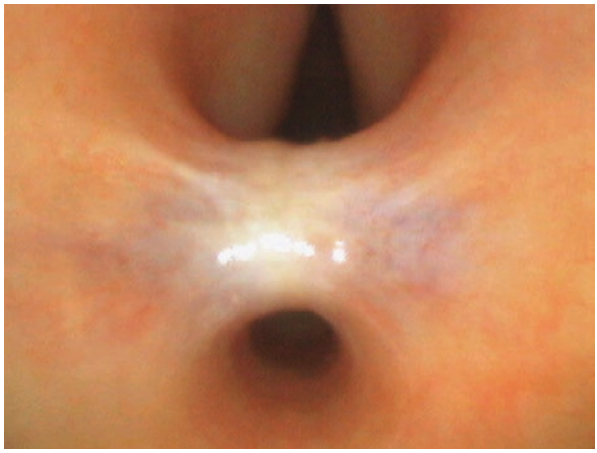

Fig. 17.5 Subglottic synechia (Photo by S. Sutarski)

- bronchial secretion retention and deposits?
- exposed cartilage braces?

Inflammatory reactions of the tracheostoma and the trachea can also be differentially diagnosed through the tracheostomy tube itself, so that it can be considered to remove the tracheostomy tube anyway, provided that the airways are sufficiently wide and stable.

Granulations on the outer tracheostoma do not usually disturb the decannulation: an ablation is recommended on the inner orificium or endotracheally before removal of the tracheostomy tube. It is important to determine the cause of the granulations, as these usually represent reactions to a chronic stimulus (tracheostomy tube intolerance? secretion/aspiration?) [16].

Decannulation cannot be performed in the presence of respiratory stenoses or instabilities. Depending on the localization, interdisciplinary decisions about the further procedure are necessary, in particular about the possibility of a surgical remediation or a temporary stent placement. If this is not possible, e.g., in the case of inoperability of the findings or concomitant multimorbidity, long-term cannulation cannot be avoided, which represents a considerable burden for the affected patients.

For this reason, it must be pointed out that even proper primary application of the tracheostoma, but also regular endoscopic follow-up with individual tracheostomy tube adjustment and standardized care measures can contribute to avoiding such situations with long-term impairment of the patient's quality of life.

17.3.3 Swallowing Function

The assessment of the presence of dysphagia requires a lot of experience within the context of planned decannulation. Trained medical personnel as well as swallowing therapists are requested to accompany the process up to the decannulation in repeated joint decision-making. Clinical swallowing diagnostics as well as endoscopic diagnostics (Flexible Endoscopic Evaluation of Swallowing—FEES) are to be considered, possibly supplemented by imaging radiological procedures such as high-frequency cinematography or Videofluoroscopic swallow study (VFSS) [17, 18]. In Germany, the swallowing diagnostics is an unassignable task of a physician.

Decannulation is not determined by the presence of dysphagia *per se*, but by the question whether the patients have a relevant disorder of the pharyngeal swallowing phase with laryngeal penetration and/or aspiration and how the lower respiratory tract can be cleaned of aspirated material. This means a qualitative and quantitative assessment of the aspiration tendency and amount in relation to the resulting risk to the patient (please refer to Figs. 17.6 and 17.7).

If the reflexive swallowing is undisturbed, oral disturbances are usually not decisive for whether to leave the tracheostomy tube in place or remove it [2].

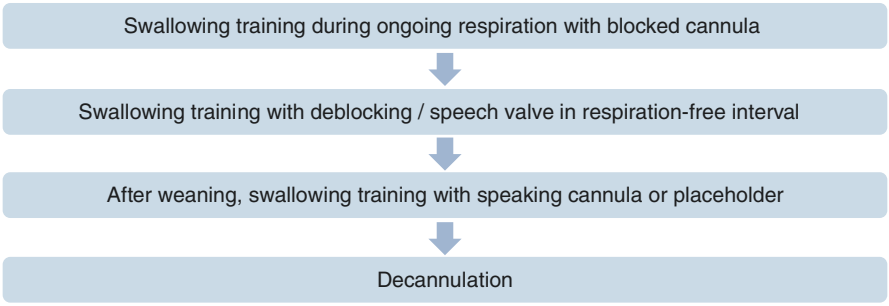

Fig. 17.6 Approach in dysphagia and respiration

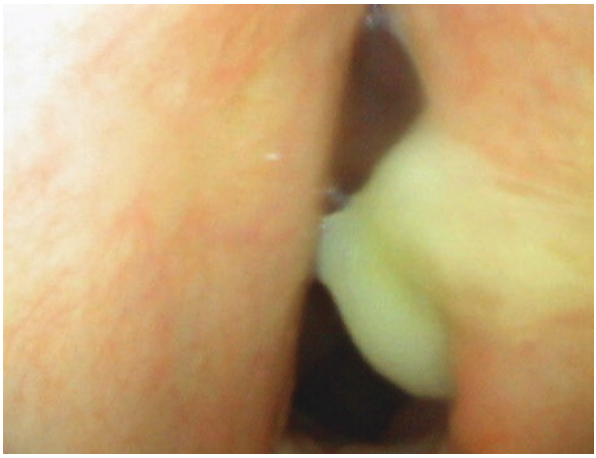

Fig. 17.7 Silent aspiration (Photo by S. Sutarski)

A further essential criterion for the assessment of the prognosis of aspiration-endangering dysphagia is the cause of the disorder, which requires knowledge of the underlying disease and close interdisciplinary consultation, especially when determining the time of decannulation.

- neurogenic dysphagia
  - generally progressing, chronical neurological diseases
  - generally regressing, e.g., after craniocerebral trauma, acute cerebrovascular diseases
- structural-morphological dysphagia
  - temporary, e.g., posttraumatic dysphagia resulting from facial bone fractures
  - inpatient findings, e.g., oncologically caused postoperative substance defects
  - progression in, e.g., postradiogenic fibrosis or vertebragenic dysphagia

The swallowing therapy uses the tracheostomy tube management to optimize the swallowing act depending on accompanying circumstances, such as ventilation and

cough function. It is desirable to have an organ diagnosis that is video-supported at best, which enables a targeted therapeutic approach and helps to determine the necessary measures. In addition, the amount and quality of secretion can be influenced by medication.

In addition to clinical assessments of the swallowing function by nursing staff, swallowing therapists and physicians, FEES serves as a standard for the targeted clarification of functional and morphological changes. It must be left to the future to develop standards in a consensus statement for the swallowing diagnostics in tracheotomized patients with different underlying diseases [19]. Transnasal-flexible endoscopy has already been discussed—airway assessment also serves to examine the structures involved in the swallowing act and their function.

At the same time, the method offers the advantage of being able to administer food of different consistency and represent the pharyngeal swallowing phase with good tolerance and proper endopharyngeal placement of the endoscope. This can be combined with testing the effectiveness of compensatory maneuvers.

CAUTION!

- *After the swallowing reflex has been triggered, there is no endoscopic visibility ("white out") during pharyngeal transport due to contraction of the pharyngeal muscles and sealing of the airways.*
- *Intradeglutitive silent aspiration cannot be sufficiently identified endoscopically—transnasally.*
- *If bolus parts become visible before or after swallowing, a pathological finding is present.*

If a tracheostoma is present, the swallowing function via the tracheostoma can then be examined endoscopically. In free tracheal conditions, this allows good assessment of the quantitative aspiration, the intradeglutitive glottis closure and the reliability and efficiency of the protective reflexes, which also allows a silent aspiration to be safely distinguished. In this case, supplementary radiological diagnostics is not absolutely necessary.

The decision on decannulation depends on the following questions:

1. *Can the patient consume the necessary amount of food and drink over the natural way?*
2. *If not: What consistencies can be ingested safely? Does this provide a sufficient diet?*
3. *In case of insufficient food quantity, is additional food supply secured via feeding tube or port?*
4. *Does the patient agree to limited food intake?*
5. *If not, are the protective reflexes sufficient to clean the lower respiratory tract in the event of aspiration?*
6. *Is saliva aspirated? Can the aspirated saliva be coughed up?*
7. *Is the patient able to perform compensatory maneuvers for conscious airway cleaning?*
8. *May the remaining dysphagia be tracheostomy tube-related?*

In case of doubt, the temporary use of a tracheostomy placeholder is recommended for testing the nutritional situation. In case of a remaining dysphagia with danger of aspiration, however, the decision may be made to leave the tracheostomy tube in place in order to perform suction if the patient explicitly wishes to eat or, if the patient wishes to be decannulated, to limit the food intake to safe consistencies or to completely refrain from eating.

These questions must be discussed in detail with the patients and their relatives and, for medical-legal reasons, documented.

The same applies if there is a suspicion of (proportionally) tracheostomy tube-related dysphagia. Here, too, an explanation must be given before decannulation that in the case of a remaining swallowing disorder, a replacement of the tracheostomy tube may be necessary.

17.3.4 Secretion Management

In the case of tracheobronchial secretion retention, tracheotomy can be followed by aspiration of the airways via the lying tracheostomy tube or placeholder. This procedure is well tolerated by the patient if carefully performed and contributes to the prophylaxis of bronchopulmonary complications.

However, after tracheostomy tube removal, patients are encouraged to reliably transport retinal secretion or aspirated material from the lower respiratory tract into the pharynx.

Prerequisites:

- wall stability of the airways including the thorax
- positive cough reflex
- efficient cough thrust
  - Sufficient subglottic pressure build-up is required, which in turn depends on the tightness of the vocal fold closure and the tone build-up of the muscle groups involved.

The decannulation and the closure of the tracheostoma extend the transport path of the secretion. In patients with deficits in the above-mentioned functions, this can cause secretion retention, which in the case of a rapidly spontaneously occluding tracheostoma remains unnoticed until respiratory complications up to renewed respiratory insufficiency occur (please refer to Fig. 17.8).

For this reason, depending on the underlying disease, a critical examination of the amount of secretion, the consistency of the secretion and the secretion transport, e.g., peak flow measurement, is recommended before deciding on decannulation [20]. In case of doubt, the use of a tracheostoma placeholder can also be recommended in this context (Fig. 17.3 a, b).

Supportive therapeutic measures

- *the amount and consistency of secretion influenced by medication*
- *physiotherapeutic measures for secretion mobilization*

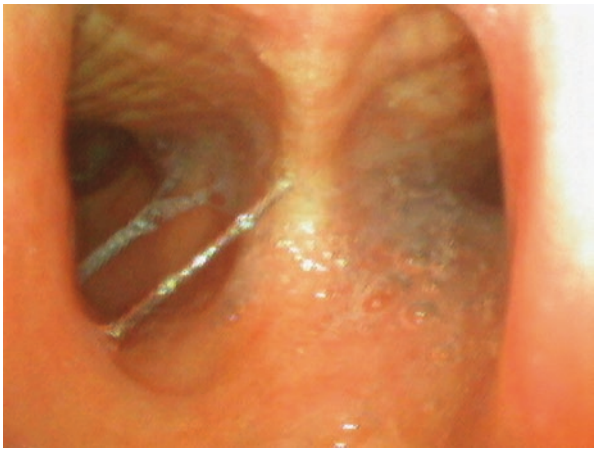

Fig. 17.8 Bronchial saliva residues (Photo by S. Sutarski)

- *general physical strengthening and posture correction*
- *logopedic exercise of vocal fold function, possibly even phonosurgical therapy for vocal fold medialization*
- *support of cough efficiency through physiotherapeutic maneuvers or Cough Assist™ E70 (made by Löwenstein Medical GmbH & Co. KG, Bad Ems, Germany)*

In the absence of a cough reflex and persistent or even increasing muscular insufficiency, decannulation is contraindicated because of the impending chronic secretion behavior, since the possibility of aspiration of the respiratory tract should be maintained.

As a compromise, the adaptation of a tracheostoma button should be mentioned, which, after individual adaptation by a prosthodontist, closes the tracheostoma tightly only at the outer orificium and can be opened for suction. However, this measure must be checked individually and applied for at the respective cost unit before execution.

17.4 Performing Decannulation

Tracheotomized patients can be found in hospitals, but also in rehabilitation medicine or outpatient care. The care structures and transition management between the individual areas are not the subject of these considerations. However, from a medical, nursing, therapeutic and not least economic point of view, the tracheostoma is an important influencing factor with regard to the resources to be kept available—in addition to the impairment of the patient by the tracheostoma and the possibly increasing risk due to unclear responsibilities and processes.

It should be pointed out in this context that it is important to critically question the necessity of a tracheostomy tube in every phase of care. Particularly in the

outpatient sector, it is often necessary for caregivers to take a major initiative to repeatedly focus on this question.

After examination of all prerequisites for decannulation and taking into account the underlying disease, further factors are considered in the decision:

- the patient's will
- social framework conditions
- forecast for the further course of disease

There may well be borderline decisions, which should be discussed and documented with the patients and their relatives:

1. Decannulation at the express request of the patient or in a palliative situation despite remaining functional deficits or with respiratory pathologies.
2. Currently absent indications for tracheostoma, but expected re-tracheotomy in case of deterioration of function and/or morphology in the course of the disease.
3. In oncological patients the decannulation is embedded in the oncological treatment concept.

The removal of the tracheostomy tube must be performed under supervised conditions, which requires hospitalization for outpatients. After an individual risk assessment (see above), the patients remain in the monitoring ward for 24 h to 1 week (Chap. 9).

Controls of the respiratory tract and the functionality are sensible until the patient has stabilized safely.

If the result of the risk assessment is unclear or if testing of the stability of the functions or respiratory tract is desired, a tracheostoma placeholder can be used prior to decannulation under supervision.

We do not recommend "capping" the tracheostomy tube, i.e. closing the lumen by a button with the tracheostomy tube remaining in the trachea, and this does not bring any traceable advantage over direct decannulation, provided that the above criteria have been carefully checked. In borderline cases, the use of a placeholder is an option in which the relevant parameters can be tested physiologically without a time limit.

Reasons:

- Breathing with the tracheostomy tube capped takes place inspiratorily and expiratorily next to the tracheostomy tube or through the tube perforation, which must be positioned exactly in the tracheal lumen. As a result of the ensuing narrowing of the airways, the work of breathing increases during inspiration and expiration.
- Safe testing of the situation without a tracheostomy tube is not possible, since the tracheostomy tube itself can bridge pathological structures.
- Not every patient may make themselves felt of the situation in the event of decompensation or take remedial action.

According to flow-mechanical investigations, capping leads to increased work of breathing. In addition, it was found that the cuff is responsible for a large part of the increased work of breathing. Total deflation of the cuff can significantly reduce this effect (personally communicated in 2019 to the author from S. Friebel, W. Heller, M. Höhne, E. Klemm and A. Nowak, fluid mechanics working group at the Dresden University of Applied Sciences and University Teaching Hospital Dresden-Friedrichstadt).

By observing all the above requirements for decannulation, it is possible to minimize the risk of recannulation during the course of the treatment. In spite of intensive efforts to establish uniform standards and test criteria, the experience of the judging personnel (physicians/nurses/speech therapists) is still the essential factor.

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Special Aspects of Skin and Mucosal Care After Tracheotomy

18

U. Wollina and F. Pabst

18.1 Introduction

The tracheostoma represents a *locus minoris resistentiae*, and therefore warrants special care to prevent complications and to ensure its functionality.

18.2 Irritations

Depending on the type of tracheostoma and tracheostomy tube, secretions may occur. In combination with mechanical tube movement, this can cause irritation on the surrounding skin (Fig. 18.1). The following factors may contribute:

- wet skin,
- salivary enzymes,
- food stuff with mechanical or chemical irritation potential,
- bacterial contamination with the consequence of biofilm.

These factors impair the protective barrier function of the skin. The skin barrier is a complex and dynamic structure in the *Stratum corneum* composed of cholesterol, ceramides, and free fatty acids. Emulgators and irritants like sodium lauryl sulfate in skin care products may alter the barrier function as well [1].

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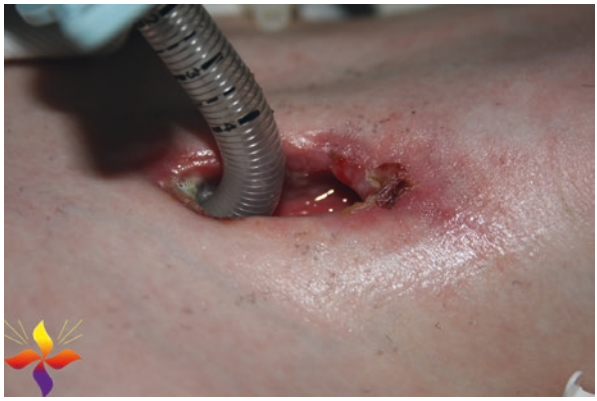

Fig. 18.1 Irritative contact dermatitis with borky lesions

Breathing through a tracheostoma results in reduced humidification of inhaled air. Significantly reduced humidification can cause a barky tracheitis, which may obstruct the tracheostomy tube. Regular humidification of the inhaled air ("wet nose") is a prophylactic tool.

Due to mechanical factors of the tracheostomy tube, such as fitting too tightly, nonflexible material, irritations by the filter of the speech inner cannula, a chronic granulomatous inflammation may develop which can rarely result in a closure of the stoma [2]. More common is bleeding from the rich vascularized granulation tissue. If bleedings occur bleedings with a delay of more than 72 h after surgery, an arterial fistula has to be excluded [3].

18.2.1 Treatment

Saliva should be absorbed by soft absorbing gauze compressed directly at the tracheostoma. Metalline dressings cannot handle the moisture and may worsen the irritative stoma-dermatitis. Some authors recommend flexible, thinner polyurethane foam dressings to protect the skin like ALLEVYN◊ Thin etc. Studies to compare foam dressing with gauze compresses have not been performed yet.

Granulations become more frequent if the tracheostoma is necessary for more than 6 weeks. These granulations can be treated conservatively by silver nitrate etching or surgically with either ablative and/or vascular lasers or radio wave surgery. Radio waves cause less thermogenic alterations of the neighboring tissue than electro-dissection, which makes them more appropriate.

Regular topical skin care is most important to prevent skin barrier impairment. Ointments rich of lipids are recommended for the adjacent skin. To improve barrier function, ointments containing ceramides and panthenol are of particular benefit [4].

Tracheostomy tubes become completely covered by biofilms with or without fungi within 7 days. A regular daily cleansing of the tube and its disinfection is essential [5].

Bleedings of the granulation tissue can be managed with topical hemostatic products or vasoconstrictive agents. By correct placement of the tube, a tamponade in the stoma duct is possible [6].

18.3 Wounds

Wound healing problems after a minor trauma, such as tube change, is more frequent in patients with immunosuppressive disorders or immunosuppressive therapy. Radio therapy and cytotoxic drugs interfere negatively with the wound healing process.

In case of unfortunate placement of the tube and increased cuff pressure, pressure sores may develop in the stoma duct or on the tracheal mucosa.

18.3.1 Treatment

In the postoperative period, gauzes and alcoholic disinfections are used commonly. However, they can cause wound pain and may disturb wound healing by cellular cytotoxic effects. We recommend gels that absorb fluids and support blood clotting. Sodium carboxymethyl-cellulose as tamponades or sheets are beneficial and are more cost-effective compared to gauze as long as direct treatment costs are considered [7, 8]. Maltodextrin gel represents an alternative to support wound healing. It can be used as monotherapy or—in case of wounds at risk of infection—together with silver alginate foams [9].

Chronic wounds are characterized by an overexpression of matrix-metalloproteinases (MMP). Therefore, normalization of the MMP activity by topical MMP inhibitors seems logical. It has been shown that such products are capable of improving the local microcirculation as well, which is indispensable for an optimal wound healing process [10].

The backbone of the treatment of pressure sores is off-loading. Tubes or cannulas that are not exactly placed increase local pressure in the stoma or the trachea which can lead to pressure sores. In patients with artificial ventilation, stress-free and pressure-free fixation is essential.

18.4 Local Infections

Local infections can occur as a result of impaired barrier function of skin or due to chronic wounds. A wet environment around the tracheostoma supports yeast infections. High-risk patients are those after burns. In those patients, a local *Candida* infection may develop into a *Candida* sepsis [11]. A membranous obstructive *Candida* tracheitis may seal the airways [12].

In case of bacterial infections (impetigo, intertrigo), mixed bacteria can be observed commonly in microbial cultures. Prevention, treatment and care has to be

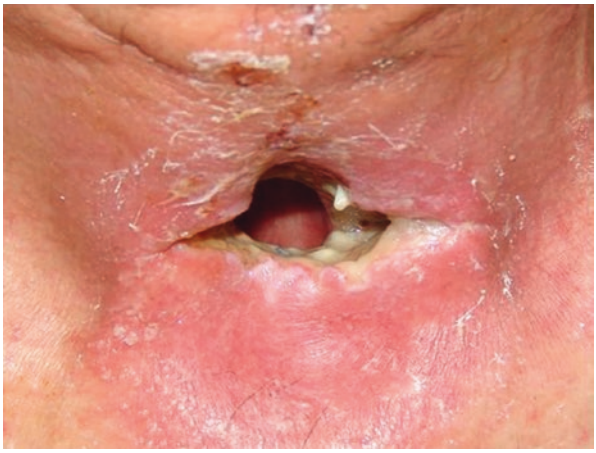

Fig. 18.2 Cellulitis of the tracheostoma

done in accordance with the hygiene guidelines of the hospital. In addition to local infections, deep soft tissue infections can occur, such as cellulitis, due to *Streptococci* or phlegmonous infections by anerobic germs. These infections require targeted individualized systemic antibiotic treatment (Fig.18.2).

Among intravenous drug users, wound botulism has increasingly been observed. Early symptoms include visual impairment such as diplopia, ptosis, weakness of facial muscles, dysphagia, dysphonia, and dysarthria.

18.4.1 Treatment

The prevention of any local infections starts with consequent oral hygiene [13]. Wounds with a risk of infection can be treated topically by iode cadexomer (Iodosorb™). The amount of exudate, erythema and maceration of the surrounding skin reduces [14].

Necrosis has to be removed surgically, since it increases the risk of bacterial infections. Low-level local infections of peristomal skin should be treated according to the microbiological analysis of germs and their resistance topically. Any other infections require systemic antibiotic therapy including fungal infections [15].

A feared complication is invasive tracheal aspergillosis, which can run a deadly course among immunosuppressive patients. Voriconazole is the drug of first choice [16]. Coccidiomycosis is more frequent in the southwest of the United States, but more and more also outside the endemic areas. In these cases, Posaconazole is an alternative [17]. Zygomycosis is increasingly seen in emergency units. It has a high morbidity even among otherwise healthy people. Amphotericin B and other systemic antimycotics are used for their management [18].

In case of wound botulism, the rapid application of the antidote followed by intensive care can save lives [19].

18.5 Special Problems with Preexisting Skin Disorders

Preexisting skin disorders can hamper the care and function of a tracheostoma. The following selection should illustrate possible interactions, despite the fact that the list of disorders is incomplete.

Bullous Diseases During childhood and adolescence, the heterogeneous group of epidermolysis bullosa is of importance. These are genetic diseases caused by mutations of various structural proteins which are responsible for a reduced mechanical stability of the basement membrane zone. Shearing forces can easily produce lacerating wounds with significantly delayed healing. In such cases the indication for tracheostomy should be made very carefully [20].

Inflammatory Skin Disorders In patients with psoriasis, koebnerization may occur due to the tracheostomy tube. Koebnerization or isomorphic response describes the induction of new lesions by mechanical stimuli [21]. Among patients suffering from atopic dermatitis, peristomal maceration can develop impetiginization, since the endogenous antimicrobial peptides of skin (like cathelicidin) are reduced [22].

Contact allergies to stoma care products, medical drugs or vulcanization accelerators are possible. Despite peristomal allergic contact, dermatitis is rarely reported, type-IV contact sensitizations against asthma drugs (salbutamol, aldecin) [23] and wet cleaning clothes (perfumes, preservatives) have been described in the medical literature [24].

Even more challenging are allergic mucosal reactions, since they can result in tracheal stenosis. Thiomersal and vulcanization accelerators have been identified as possible allergens. The sensitization can be acquired before tracheostomy, e.g., during an exposed occupation [25, 26]. A particular group at risk are patients with long-standing leg ulcers. In case of suspicion of an allergic reaction, patch tests according to the guidelines of the German Contact-Allergy Group (DKG) or comparable bodies of the given country should be performed [27].

18.6 Scars

The formation of scars after tracheostomy is dependent upon surgical techniques used and the individual wound healing capacity. An analysis of patients in the intensive care unit reported a scar risk of 17% for percutaneous tracheostomy versus 100% for surgical tracheostomy [28]. Other authors have not seen these big differences between the two techniques [29].

If tracheostomy tubes or cannulas have been used for a very long time, there is a risk of unesthetic sunken scars which may cause problems to swallow. For surgical reconstruction, combined muscle-skin flaps have proven themselves [30, 31].

Table 18.1 Treatment of scars and keloids

Silicon gels or sheets and flavonoid-containing gels	Primarily to prevent hypertrophic scars or keloids, to optimize scar formation
	Disadvantage: longer application times (at least 2–3 months), limited efficacy
Botulinumtoxin type A contraindications	Only for prophylaxis
	Myasthenia gravis, Lambert-Eaton syndrome, pregnancy and lactation
Intralesional triamcinolone acetonide	By Dermojet as first line therapy of pronounced hypertrophic scars and keloids, preferably during the erythematous inflammatory phase
	Disadvantage: Skin atrophy and teleangiectasia
Cryo contact therapy with liquid	Serial treatment, leads to bullous reactions, is painful
Laser therapy	During the inflammatory phase; short pulsed dye or long pulsed diode laser
Interferon-α, intralesional	During the inflammatory phase, frequent adverse events: Flue-like symptoms
5-Fluoro-uracil, intralesional (50 mg/mL)	During the growth-phase of hypertrophic scars or keloids. Contraindications May induce anemia or other cytopenia
Imiquimod 5%, topicals	Imiquimod stimulates the endogenous
	Interferon synthesis; for secondary prophylaxis after keloid excision

Further possible complications are hypertrophic scars and keloids. Hypertrophic scars occur within the first 2 months after injury or wound infection. An initial, rapidly growing phase is followed by a delayed and slow regression phase. In contrast, keloids do not have any spontaneous regression. Keloids are considered as benign mesenchymal tumors. The risk for keloids is the highest among patients of African descent. The essentials to prevent hypertrophic scars are tension-free suturing and undisturbed wound healing [32].

Important treatment options for scars are listed in Table 18.1. Radiotherapy is of less importance for tracheostomy scars compared to scars of other body parts. The local injection of botulinum toxin type A around sutures has been investigated to improve the quality of scars by reducing the tension by muscular fiber activity [33]. An experimental approach is the use of either recombinant transforming growth factor-β3 or mannose-6-phosphate (Avotermin) [32]. Intralesional injections of hyaluronidase (e.g. Hylase Dessau®) loosen up the scar tissue [34].

18.7 Standards of Care

To ensure the function and to prevent complications the use of a standard of care algorithm is recommendable. A good example represents the tracheostoma care protocol of the Agency for Healthcare Research and Quality [35] (Table 18.2).

Table 18.2 Standard of care algorithm (modified acc. to Claire [35])

Inspection of stoma for bleeding/secretion	Stoma care, origin of bleeding?
Inspection of neck flange and dressing	Dressing change, cleansing of the neck flange
Inspection of placement and cleanliness of the cuff	Probably replacement and cleansing
Airway control	In case of borky mucosa, humidified O_2

These standards of care have to be included in the training of nurses—not only in theory, but practice [36].

A good choice is a multidisciplinary team for tracheostoma patients after discharge from the intensive care unit. Hereby, the duration of the temporary tracheostoma and the time of hospitalization can be reduced [37] please refer to Chap. 17.

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Tracheostomy Tubes and Tube Care

19

A. Fahl

19.1 Introduction

Much has been done in recent decades in the manufacture of tracheostomy tubes. In the development, product details are becoming more and more the focus of attention, which means that many special tracheostomy tubes can be offered for the individual areas of application. However, this large product range also means that the selection of tracheostomy tubes has become a complex issue for doctors and speech therapists. There are approx. 4000 different tracheostomy tubes, which differ in numerous features, such as material, size, length and type of design. Finding the optimal tracheostomy tube for the individual patient requires a high level of expertise. When deciding on the use of a tracheostomy tube, various factors play a role, whereby the focus should always be on an individually fitting treatment and care. The diagnosis and prognosis is decisive (laryngectomy, laryngectomy with placement of a tracheoesophageal shunt, tracheotomy permanent or temporary, ventilation). In the search for the right tracheostomy tube, it is necessary to examine product-decisive factors in detail.

1. Diagnosis
   - ventilation or spontaneous breathing
   - tracheotomy with preserved vocal cord function
   - Chronic obstructive pulmonary disease (COPD)
   - stenosis (due to recurrent paresis or tumor)
   - laryngectomy
   - laryngectomy with placement of a tracheoesophageal shunt (voice prosthesis)
   - dysphagia

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- apoplexy
- hypoxic brain damage

2. Type of performing the tracheostoma
   - percutaneous dilatational tracheotomy
   - surgical tracheotomy/tracheostomy
3. Goals for optimal (holistic) rehabilitation
   - securing the airway
   - pulmonary rehabilitation
   - possibility of phonation
   - optimization of the act of swallowing
   - optimization in hypersalivation care
   - decannulation
   - mobilization
4. Vigilance (possibility of cooperating with the tracheostomy tube wearer)

19.2 Decision-Making

19.2.1 Choice of Tracheostomy Tube Size

When selecting the tracheostomy tube, ensure that a tracheostomy tube with the largest possible inner diameter is used. This allows the tracheostomy tube wearer to breathe safely and with little resistance and reduces the risk of lumen obstruction due to secretion accumulation.

To avoid accumulation of secretions in the tracheostomy tube, it is possible to use tracheostomy tubes with an inner cannula. The inner cannula can be quickly removed and cleaned if necessary. This means that it is not necessary to change the entire outer cannula. When selecting tracheostomy tubes of different materials, it should be noted that the thickness of the material also influences the inner lumen of the cannula itself. A plastic cannula, for example, has a smaller inner lumen than a thin-walled silver cannula due to the relatively thick-walled material. A comparison must therefore take both the inner diameter and the outer diameter into account. In practice, this has an effect above all when a tracheostomy tube type is changed, e.g., from a silver tube to a plastic spiral tube.

Of course, the outer diameter, which is relevant for the exact adaptation of the tracheostomy tube to the individual anatomy of the tracheostoma and trachea, must first be observed. All tracheostomy tubes on the market are subject to a size standard. The indicated size is derived from the inner diameter of the outer cannula (Fig. 19.1). This means, for example, that size 9 always has an inner diameter (of the outer cannula) of approx. 9 mm. When selecting the size, it should be noted that the different materials and their respective wall thicknesses have different effects on the outer diameter. For example, a tracheostomy tube in size 9 will have a 2–5 mm larger outer diameter depending on the preferred material.

In addition, care must be taken with tracheostomy tube as to whether it is a tapered tracheal tube or a cylindrical tube, whereby tapered tracheal tubes are more

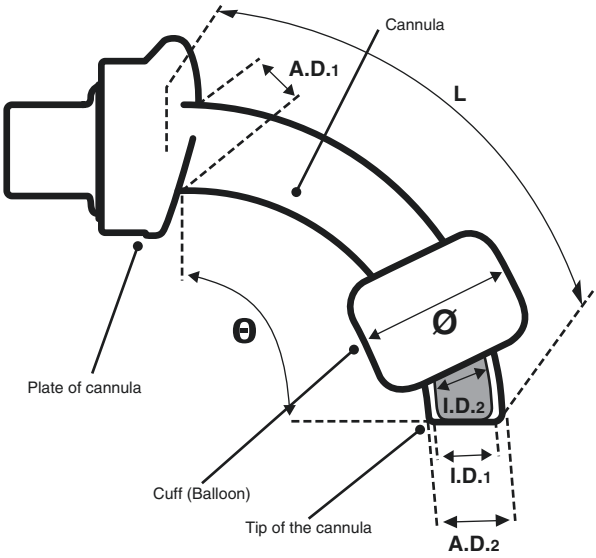

Fig. 19.1 Size determination of tracheostomy tubes. *A.D.* outer diameter, *I.D.* inner diameter, *L* length, *Θ* angle, *Ø* cuff diameter

convenient to insert when changing tracheostomy tubes. Since tapered tracheostomy tubes have a smaller diameter at their tip than directly behind the neck flange, the standard defines that the size designation of the tracheostomy tube refers to the inner diameter at the tip of the tracheostomy tube. Since tapered tracheostomy tubes have a smaller diameter at their tip than directly behind the tube inner diameter at the tip of the tube.

When changing to a different tracheostomy tube type taking into account the outside diameter, it must also be considered that, under certain circumstances, the inside diameter may be reduced due to the material used. This can impair the subjective breathing sensation of the tracheostomy tube wearer (shortness of breath/performance restrictions). With regard to phonation, a larger inner diameter can sometimes be problematic for the patient, as the pressure of the air flow decreases and thus speech is made more difficult.

The following information is based on experience and can be used as a guide when using and selecting the size of tracheostomy tubes:

Preterm infants <2.5 kg	ID 2.0 mm–3.0 mm
Neonates 2.5–5 kg	ID 3.0 mm–3.5 mm
Infants 5–8 kg	ID 3.5 mm–4.5 mm
Children 8–10 kg	ID 4.0 mm–5.0 mm
Children 10–15 kg	ID 4.5 mm–5.5 mm
Children 15–20 kg	ID 5.0 mm–6.0 mm
Children 20–35 kg	ID 6.0 mm–7.5 mm
Women	ID 7.0 mm–9.0 mm
Men	ID 8.0 mm–10.5 mm

Care must be taken to ensure that the tracheostomy tube in children must be continuously adapted to their growth/development phases.

19.2.2 Choice of Tracheostomy Tube Length

When selecting the length of the tracheostomy tube, the special conditions of the tracheostoma and trachea play a decisive role. In order to effectively prevent tracheomalacia or tracheal stenosis, care should be taken to use tracheostomy tubes of different lengths in alternation. In general, extra-long tracheostomy tubes serve optimally to bridge stenoses, whereas short tracheostomy tubes are well suited for the exclusive stabilization of the tracheostoma, e.g., after laryngectomy. They avoid irritations as far as possible, e.g., foreign body sensation, increased secretion, etc.

The length of the tracheostomy tube must always be adapted to the individual anatomy.

19.2.3 Material

Today there is a variety of materials used to manufacture tracheostomy tubes. Incompatibilities with materials must be avoided (e.g., allergies to silver or latex).

Tracheostomy tubes made of metal (silver, stainless steel).

Advantages:

- very long durability with regular reconditioning by the manufacturer
- very large inner diameter due to thin material thickness
- antibacterial effect through silver
- easy tracheostomy tube cleaning possible
- sterilization possible
- individual product modifications possible

Disadvantages:

- not flexible, in incorrect tracheostomy tube placement
- risk of pressure ulcerations inside the trachea and the tracheal stoma canal
- inner cannulas are compatible with only a specific outer cannula
- cold conductor at very low outside temperatures
- high weight
- no variant with cuff available

Tracheostomy tubes made of plastic (silicone, polyurethane (PUR), polyvinyl chloride (PVC), thermosensitive plastics, diethylhexylphthalate (DEHP)-free plastics).

Tracheostomy tubes made of silicone.

Advantages:

- very soft and pliable quality
- useful life up to approx. 3 months
- easy tracheostomy tube change by patients themselves
- special sieving possible, thus individual adaptation for voice prosthesis wearers or phonation optimization for tracheotomized patients
- various lengths available
- can be used very well for weaning from the tracheostomy tube
- can be used under radiation therapy
- sterilization possible (depending on product/see manufacturer's specifications)

Disadvantages:

- relatively thick-walled tube
- Candida colonization possible
- almost no variants with inner cannula available

Tracheostomy tubes made of thermosensitive plastics.
Advantages:

- plastic tubes become softer at body temperature and therefore adapt very well to anatomical structures
- high variability due to the use of different inner cannulas
- easy tracheostomy tube change by the patient
- can be used during magnetic resonance imaging (MRI) (applies only to tracheostomy tubes without metal parts)
- can be used very well for weaning from the tracheostomy tube
- several lengths available
- low weight
- lndividual product modifications (e.g., sieving) possible
- many plastic tracheostomy tubes have an X-ray contrast strip

Disadvantages:

- more elaborate preparation (e.g. thermal cleaning only possible up to 65 ° C)
- no steam sterilization possible

Tracheostomy tubes made of polyurethane (PUR).
Advantages:

- manufactured by injection molding
- high variability due to the use of different inner cannulas
- easy tracheostomy tube change by the patient

- can be used during magnetic resonance imaging (MRI) (applies only to tracheostomy tubes without metal parts)
- many polyurethane tracheostomy tubes have an X-ray contrast strip
- high dimensional stability
- lower wall thickness

Disadvantages:

- more elaborate preparation (e.g. thermal cleaning only possible up to 65 ° C)
- no steam sterilization possible
- rarely available in different lengths
- individual product modifications rarely possible

Spiral tracheostomy tubes with a metal spiral.
Advantages:

- highly flexible, thus good adaptation to the anatomy and good acceptance by the tracheostomy tube wearer
- good adaptation to the skin level possible with adjustable neck flange
- very good for use by obese patients
- also available as sieved versions
- various lengths available

Disadvantages:

- no individual product modifications possible (e.g., special sieving)
- relatively thick-walled tube, thus small inner diameter
- contraindication for radiotherapy in the tracheostomy region with lying tube (risk of burns)
- not applicable during MRI (causing artifacts in imaging)

Spiral tracheostomy tubes with plastic spiral.
Advantages:

- very high flexibility, thus good adaptation to the anatomy and good acceptance by the tracheostomy tube wearer
- good adaptation to the skin level possible with adjustable neck flange
- very good for use by obese patients
- use possible during magnetic resonance imaging (MRI) due to the plastic spiral
- also available as sieved versions and in various lengths

Disadvantages:

- no individual product modifications possible (e.g., special sieving)
- relatively thick-walled tube, thus small inner diameter

The physician treating the patient is responsible for selecting the tracheostomy tube characteristics in accordance with the indication.

19.3 Tracheostomy Tube Components

19.3.1 Tracheostomy Tubes with Cuff

The cuff serves to seal the tube against the tracheal wall. It can be inflated like a balloon. A distinction is made between tracheostomy tubes with a low-pressure cuff in order to keep the pressure load on the tracheal mucosa as low as possible or high-pressure cuffs where a higher pressure is built up in the cuff (these variants are virtually no longer used today). The small control balloon on the filling tube shows whether the tracheostomy tube is in a blocked (filled) or unblocked state.

Furthermore, self-blocking cuffs made of polyurethane foam can be used (foam cuff).

Of course, regular and documented cuff pressure control should be carried out for blocked tracheostomy tubes. The cuff pressure must be checked and adjusted every 6 h with the aid of a cuff pressure gauge (Fig. 19.2). In addition, this check should be carried out each time the patient changes position.

Indication:

- in ventilated patients
- in patients with dysphagia
- as aspiration protection
- in patients with increased bleeding tendency due to tumors

Fig. 19.2 Cuff pressure gauge

Disadvantages:

- more elaborate tracheostomy tube change than tubes without cuff
- with the help of a cuff pressure gauge, a cuff check must be carried out regularly. The cuff pressure should be kept constant at 20–25mbar (20.4–25.5 cmH_2O).
- risk of complications, e.g. pressure necrosis in the trachea due to identical contact surface of the cuffs. Continuous use of equal tube lengths or excessive cuff pressure, risk of tracheomalacia and dangerous tracheoesophageal fistulas. In addition, the swallowing may be impaired and irritations may occur.

Care should always be taken that the cuff does not rest continuously in the same position.

A special variant of a tracheostomy tube with cuff is the tube with *subglottic suction* (Fig. 19.3).

These tracheal tracheostomy tubes are usually applied to patients with a high risk of aspiration.

Indication:

- for suction of secretions in the subglottic space above the cuff
- to prevent microaspiration and recurrent bronchopulmonary infection

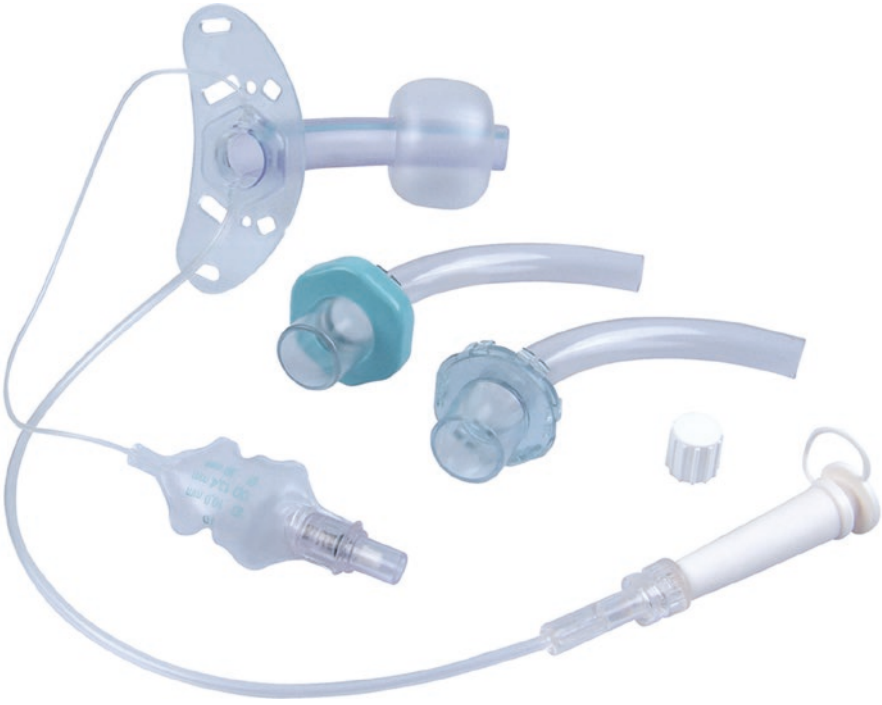

Fig. 19.3 Tracheostomy tube with cuff and subglottic suction

- in patients with dysphagia
- in patients with hypersalivation

Disadvantages:

- not to be used with anticoagulant therapy (risk of hemorrhaging)
- fast occlusion of the suction channel with viscous secretion

19.3.2 Tracheostomy Tubes Without Cuff

Tracheostomy tubes without cuff should be used for patients who are usually not ventilated or are not at high risk of aspiration. The prerequisite for the use of these tracheostomy tubes is an efficient and safe swallowing process of the patient.

The tracheostomy tubes without cuff usually have an inner cannula, which facilitates secretion management for the user.

These tracheostomy tubes play an important role in the care of children, especially with regard to ventilation, since unblocked tracheostomy tubes are generally used here.

19.3.3 Inner Cannulas

Inner cannulas are generally used to facilitate secretion management for the user, so that the inner cannula can be quickly and easily replaced at any time when the tracheostomy tube is being obstructed. Inner cannulas are available with a wide variety of connectors and adapters. The correct size and length of the inner cannula must be selected.

A further advantage when using inner cannulas is a possible reduction of the suction intervals. Changing the inner cannula is unproblematic and can easily be done in front of a mirror according to instructions to the patient. The change and the associated cleaning of the inner cannula should take place three times a day but can also take place at other intervals and/or according to medical indication if required.

- *15 mm connectors/adapters*
  Connectors/adapters are used to connect compatible tracheostomy tube accessories. They are usually firmly attached to the inner cannula. This is a universal attachment (15 mm connector) which allows the use of so-called "artificial noses" (filters for heat-humidity exchange). Special connectors are also available in a 15 mm swivel version. The rotating version of the 15 mm connector is, e.g., suitable to relieve the tracheostomy tube when using a ventilation tube system and to stabilize the position. Thus, the occurrence of mucous membrane irritations in the trachea can be largely reduced.
- *22 mm combi-adapter*

The 22 mm combi-adapter (Fig. 19.4) enables the mounting of compatible filter and valve systems with 22 mm mounting, e.g., speaking valves, HME filters or tracheostomy valves. The use of a combi-adapter offers the possibility of using relatively flat, close-fitting filter and speaking valve systems that are optically less conspicuous. The possible use in individual cases also depends on the clinical picture, e.g., condition after laryngectomy or tracheotomy.

19.3.4 Sieved Tracheostomy Tubes

Sieved tracheostomy tubes are usually used for phonation in tracheotomized patients with intact glottis function and sufficient subglottic pressure. It is important that a free airway towards the larynx is guaranteed when such tracheostomy tubes are used.

Furthermore, the field of application also refers to laryngectomized patients who are provided with a shunt valve ("voice prosthesis"). Care must be taken to ensure that the sieving is not located in the tracheostoma canal and does not come into direct contact with the tracheal mucosa. This prevents the infiltration of tissue into the sieve, which could otherwise result in injuries during tracheostomy tube exchange. Especially in children, an unsieved tracheostomy tube of a smaller size should be used instead of a sieved tracheostomy tube.

There are tracheostomy tubes in which the sieving is carried out horizontally and stepped into the tube (see Fig. 19.5). This roof tile-like sieving (see Fig. 19.6)

Fig. 19.4 Inner cannula with 22 mm combi-adapter

Fig. 19.5 Standard sieving—increased risk of aspiration

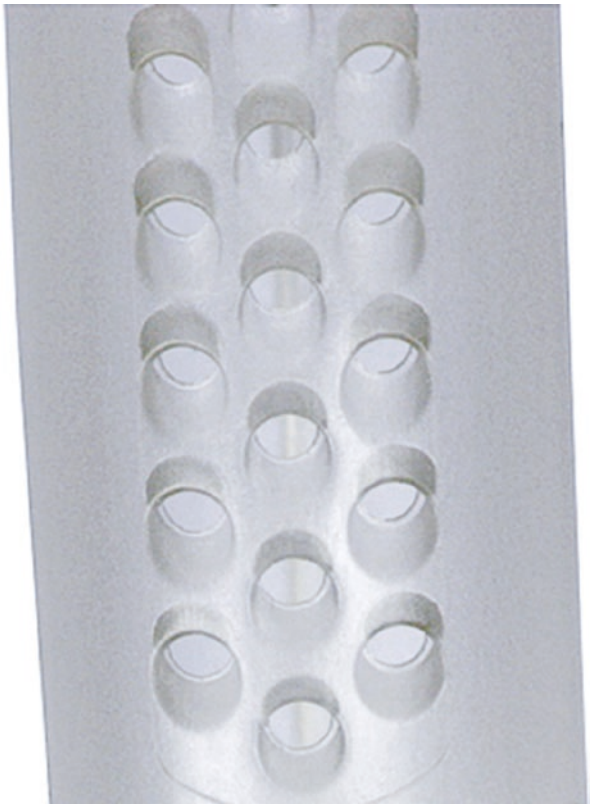

Fig. 19.6 Roof-tile sieving—reduces secretion leakage

reduces secretion leakage through the perforations into the tracheobronchial system. At the same time, the atraumatic tracheostomy tube sieving ensures that the formation of granulation is reduced.

If possible, continuous fenestration of outer cannulas should be avoided, as this can on the one hand promote tissue infiltration and on the other hand increase the risk of catheter-related injuries to the tracheal mucosa during suction procedures.

19.3.5 Speaking Valves

Speaking valves (Fig. 19.7a) can be used in tracheotomized patients in conjunction with a sieved outer cannula. The speaking valve closes during exhalation and air flows through the sieve in the outer cannula towards the larynx to help voice formation. There are two different types of valves. On the one hand, there are those which close themselves (actively) and those which close (passively) due to the air flow acting on them. Which one is used for which patient depends on the individual situation of the patient and their breathing capacity. In laryngectomized patients, the use of a classic tracheostomy tube with speaking valve is generally not possible. In

Fig. 19.7 (**a**) Speaking valve with oxygen connection for tracheotomized patients. (**b**) Tracheostomy valve with and without connection of an HME filter cassette for laryngectomized and tracheotomized patients

patients who are provided with a shunt valve for voice formation, special tracheostomy valves (Fig. 19.7b) are used for phonation (those that are only closed for speech when the blowing pressure is increased) in combination with a sieved tracheal tracheostomy tube, stoma button or base plate of the finger-free speech function.

19.3.6 Oxygen Connection

There are inner cannulas which have an additional port which serves as an oxygen connection (Fig. 19.8). This enables the supply of pure oxygen via an oxygen device. If the tracheostomy tube used does not have this additional option, an artificial nose (Fig. 19.9) with oxygen connection or an oxygen mask can be used.

Fig. 19.8 Inner cannula with connecting port for oxygen

Fig. 19.9 Artificial nose with connecting port for oxygen

19.3.7 Neck Flange

The selection of the appropriate tracheostomy tube often also depends on the neck flange. Due to the variety of different materials and shapes available on the tracheostomy tube market, care must be taken to ensure that individual needs and anatomical conditions are taken into account. These include, for example, very deep stomas and protruding muscle strands of the patient. There are rigid, flexible, straight, oval and concave neck flanges that are usually fixed to the tube. An additional variant is a horizontally adjustable neck flange, which allows variable tracheostomy tube length of the proximal part.

In addition, there are tracheostomy tubes with a neck flange (Fig. 19.10) that can be moved vertically and horizontally or in a ball joint by means of a special suspension. The placement of the retaining eyelets for the tracheostomy tube holder also

Fig. 19.10 Tracheostomy tube with movable neck flange

plays a decisive role. Slightly vertically angled holding eyes may prevent unwanted dislocation from the tracheostoma. The retaining strap should not move the tracheostomy tube in a cranial direction, as such a permanent load can greatly alter the shape of the tracheostoma.

19.4 Tracheostomy Tube Care

In addition to the correct selection of the individually suitable tracheostomy tube, professional provision of patients with tracheostomy tubes also includes regular and correct care of the medical product.

For hygienic reasons, to avoid the risk of infection and to maintain product quality, the correct implementation of general recommendations and the special manufacturer's instructions must be observed.

Even the distinction between blocked and unblocked tracheostomy tubes requires different care and, if necessary, change intervals. In general, it should be noted that a tracheostomy tube change always means stress for the patient, therefore it must be planned accordingly and carried out professionally, and for reasons of safety should preferably be done in pairs.

In general, an unblocked tracheostomy tube should be changed at least twice a day and more frequently if necessary, e.g., in case of strong secretion. Blocked tracheostomy tubes usually remain longer in the tracheostoma, since changing tracheostomy tubes with cuff creates more stress for the patient.

Tracheostomy tubes with an inner cannula system are suitable for simplified secretion management. These can be conveniently removed for cleaning in the event of soiling or obstruction, while the outer cannula remains in the tracheostoma.

When caring for tracheostomy tubes, a distinction must be made between cleaning and disinfection.

For cleaning, all components of the tracheostomy tube should first be rinsed under running water. They should then be completely covered in a lukewarm cleaning solution. A tracheostomy tube cleaning tub with a sieve insert is ideally suited for this purpose. The dosage of the cleaning agent and the exposure time of the

solution can be found in the manufacturer's instructions. Exceeding the exposure time may lead to material damage, especially with plastic tracheostomy tubes. Cleaning agents other than those approved by the manufacturer, e.g., high-proof alcohol, dental prosthesis cleaner, aggressive household cleaners, etc., must not be used in order to avoid health hazards and to avoid negative effects on the durability of the tracheostomy tube. Neither may dishwashers, steam cookers, microwave ovens, washing machines or the like be used to clean the tracheostomy tubes. Even poorer compatibility of the inner and outer cannula can be a sign of incorrect cleaning.

Silver tracheostomy tubes oxidize during prolonged use and show black spots on the material surface. These do not impair the material and can usually be removed manually with a silver immersion bath. Regular tracheostomy tube reprocessing by the manufacturer is recommended.

After the cleaning bath, the thorough removal of all cleaning agent residues is important. Remaining secretion residues can be removed with a size-adapted tracheostomy tube cleaning brush. Unadjusted large cleaning brushes can damage the tracheostomy tube. To avoid damage to the tube tip, the brush should always be inserted retrogradely, i.e., from the tube tip to the neck flange. Too frequent or careless cleaning techniques can also lead to cracks or sharp edges. Checking the tip of the tracheostomy tube for unevenness with your finger is very important and should be done regularly.

In patients with multi resistant pathogens (MRP) where there is an increased risk of re-infection, simple cleaning of the outer cannula is not sufficient to meet the special hygiene requirements for avoiding infections. In these cases, the tracheostomy tube must be disinfected with a tube disinfectant according to the manufacturer's instructions. Under no circumstances should disinfectants be used which release chlorine or contain strong alkalis or phenol derivatives, as these can cause considerable damage to the tubes. Disinfection of outer cannulas with cuff should be avoided as far as possible, as the cuff may become damaged and porous under certain circumstances.

After the tracheostomy tube has dried, the inner and outer cannula should be wetted with stoma oil. The oil prevents sticking of the inner and outer cannula and facilitates later insertion into the tracheostoma. At the same time, the cannula material of plastic cannulas is kept supple. Tracheostomy tubes that are not in use should be stored in a dry environment protected from sunlight and/or heat.

Like the skin care of the tracheostoma, tracheostomy tube care is an elementary component of professional care.

The History of Tracheotomy

20

H. Swoboda and E. Klemm

Ensuring free breathing is a priority in biological, cultural and medical ethics [1]. The evolution of the respiratory tract out of the pharynx in the transition from water to land is a failure-prone compromise. The upright posture of humans is accompanied by an increased neuromuscular coordination of reflex-protected breathing and vertically redirected swallowing. The phonetically so advantageous angulation between the shortened jaw and the advanced spine and the deep, narrowly extrathoracic larynx make access to the trachea difficult both naturally and percutaneously. The history of airway protection is thus a struggle for a method that can be safely applied in the field of tension between biological urgency and technical difficulty [2]. *Tracheotomy* is one of the oldest and most controversial surgical operations.

Between 1500 and 1800, only a few successful tracheotomies have become known to us. General confidence did not emerge until the nineteenth century; and in the twentieth century, tracheotomy became a routine procedure, in this context recalling the severity of the poliomyelitis epidemic in Copenhagen in 1952 with a mass outbreak in 2899 people suffering from respiratory insufficiency [3].

The tracheotomy was probably performed from Greco-Roman times at the latest to bridge acute respiratory stenoses. The Rig Veda (2000–1000 B.C.) reports an opening of the airways, the Papyros Ebers (approx. 1550 B.C.) of a neck section and warns of the vessels (Fig. 20.1) [2, 4–6]. Hippocrates (460–377) mentions the securing of the airway. Asklepiades of Bythynia (124–136 B.C.) is attributed with the first elective tracheotomy. However, contemporaries of Asklepiades vehemently rejected the method of tracheotomy and the Roman physician Caelius Arelianus

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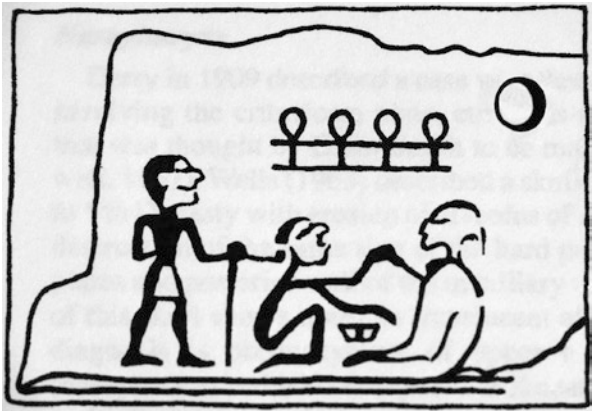

Fig. 20.1 Presumed tracheotomy scene drawn from the Table Abydos, 1st Dynasty (3030–2850 B.C.) Papyros Ebers 860 "Notice the vessels when cutting" [4] or a human sacrifice of the Pharaoh's followers for his burial? (personally communicated in 2015 from S. Kubisch, Egyptologist, to E. Klemm)

even branded the operation a crime [7]. The Greek physician Antyllus then recommended the transverse opening between the 3rd and 4th tracheal ring in the second century AD. Recommended by Galen, the tracheotomy was described in detail by Paul of Aegina (625–690 AD), the last classical Greek physician and source author for the succeeding Arab physicians.

Pioneers of the Middle Ages increasingly improved the technique. Pietro d'Abano (1250–1315) from Padua recommends a seated posture with the head retracted. Antonio Brasavola (1490–1554) from Ferrara reported of a tracheotomy successfully performed by himself in 1546. Ambroise Paré (1510–1590) speaks of a prophylactic tracheotomy before risky interventions on the tonsils. Nicolas Habicot (1550–1624) tracheotomized a young person in Paris because of asphyxia by an impacted coin bag swallowed to protect him from robbery. Illustrated descriptions of surgical techniques and instruments by Julius Casserius (1545–1616) and Johann Scultetus (1595–1645) from Ulm have been handed down to us (Fig. 20.2). The *diphtheria epidemic* of 1610 (Angina gangraenosa) in Naples described by Marco Severino (1580–1656), as well as the infantile *croup* dealt with by Francis Home (1719–1813) in 1765, point to the long predominant indication [8]. The term *tracheotomy* was coined by Thomas Fienus (1567–1631) in the Libri chirurgiae XII, Loewen 1649, and was introduced into general usage in 1739 via Lorenz Heister (1683–1758) [2]. Fienus recommended a lying position and a marking of the surgical field with ink [9].

According to Antyllus, the skin incision should be made transversely in consideration of the sensitive cartilage; according to Fabricius Ab Aquapendente (1537–1619) and Julius Casserius longitudinally in order to avoid injuries to paratracheal vessels. Since Bingel 1922, a modified collar cut according to Kocher (1841–1917) has been preferred for esthetic reasons. In ancient times, the

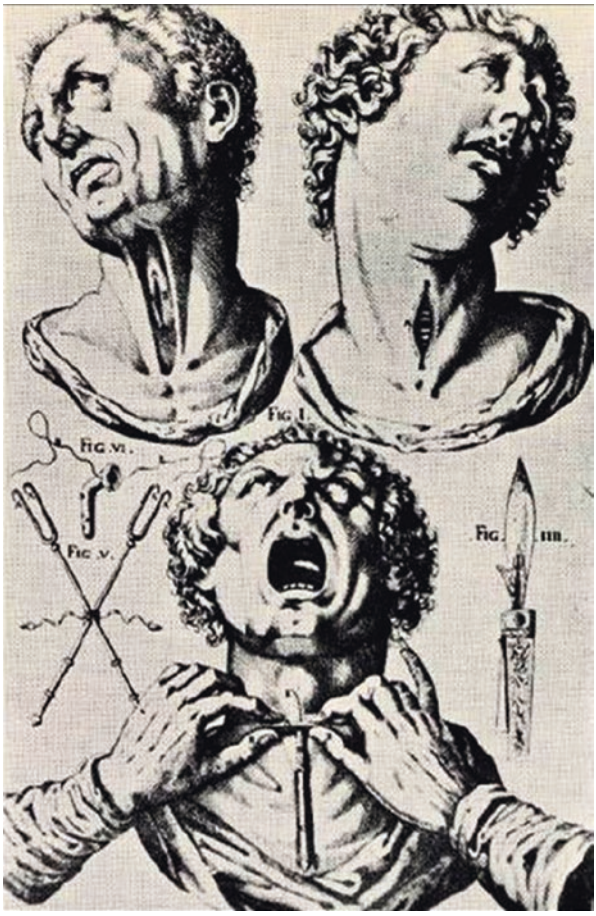

Fig. 20.2 Julius Casserius (1545–1616). Tabulae anatomicae Padua 1627

sensitivity of cartilage tissue was feared in the transverse opening of the trachea between cartilage rings. Abucassis (936–1013) was able to observe cartilage healing after tracheal suturing due to suicide attempts. In the eighteenth century, the median cut, which is also often recommended today for children, came up, whereby old definitions of "pharyngotomy", "laryngotomy" or "tracheotomy" continued to be discussed, probably initiated in the direction of tracheotomy by Desault (1744–1795) [10]. In 1912 Rohmer pointed out pressure necroses of the cartilage, Waldapfel recommended window excision in 1931 (Fig. 20.3). For this, he presented a punch, which is proposed again today in a similar for [11, 12].

The caudally pedunculated anterior wall lobe according to Viking O. Björk [13] found wide acceptance.

Cannulas have been used since the sixteenth century (Vidius Vidius 1509–1569). Table 20.1 gives a historical overview up to today's plastic tracheostomy tubes [14–16]. Jean-Baptiste Verduc (died around 1700), guided the cannula over a *guide rod*—he warned of an injury of the posterior tracheal wall [2].

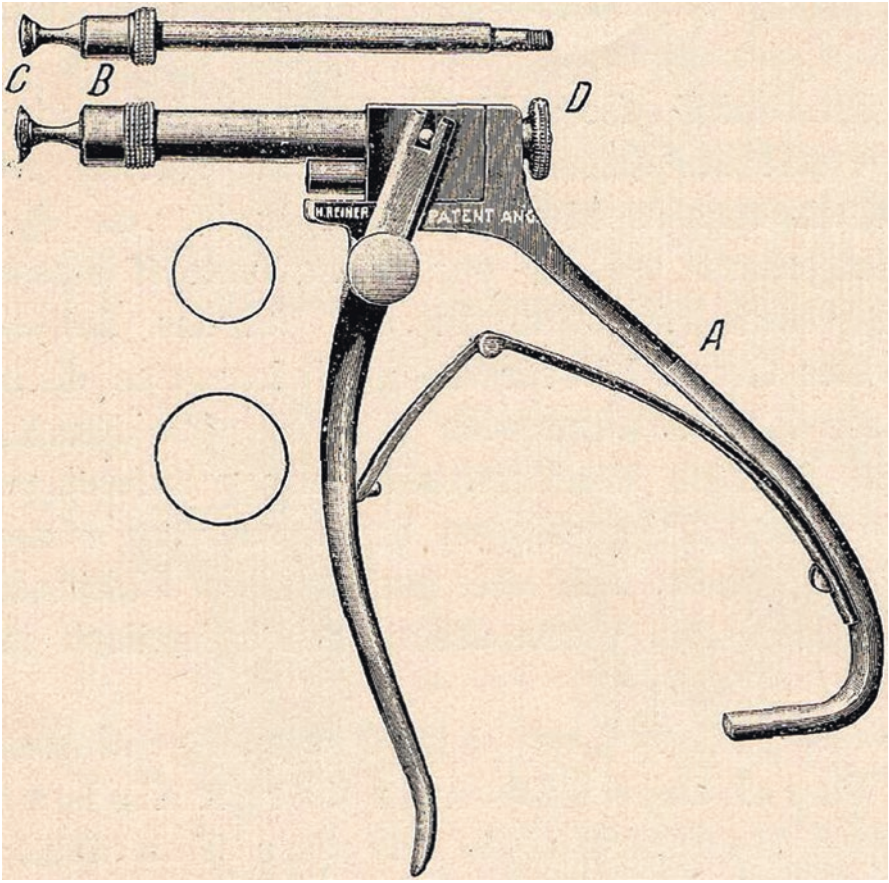

Fig. 20.3 Punch according to Waldapfel

Prominent patients illustrate the further development of tracheotomy. In 1799, George Washington's council of doctors could not decide to undergo tracheotomy and had to accept his death from a supraglottic inflammation. In 1807, on occasion of his nephew's death, Napoleon Bonaparte gave an indirect impulse by offering a prize to have *diphtheria* clinically defined by Pierre Bretonneau (1778–1862), who performed a tracheotomy on a 4-year-old girl in 1825 [8]. Armand Trousseau (1801–1867) elevated it to become the standard method [2, 17] (Fig. 20.4).

Joseph Škoda (1805–1881), who perfectioned the physical examination, had, still in the 1830s, been transferred to the lunatic asylum department of the Vienna General Hospital because, without the permission of the hospital directorate, he had performed a tracheotomy on a suffocating person [17]. Later, Josef Weinlechner (1829–1906), a pioneer of pediatric surgery at St. Anna Children's Hospital in Vienna, was to find an important field of work in tracheotomy for diphtheria, where he also did preliminary work on intubation [18, 19].

Table 20.1 Developments of tracheostomy tubes (without claim to completeness) [2, 14–16, 28–30]

Guido Guidi (Vidius Vidius 1509–1569)—1544: small gold, silver tubes
Thomas Fienus (1567–1631)—small tubes in the tracheostoma
Giulio Casserio (1550–1616)—1600: curved flattened cannula
August Richter (1742–1812)—1776: Göttingen, today's cannula shape
George Martin (1702–1741)—1730: double cannula
Armand Trousseau (1801–1867)—1851: quarter circle cannula (with inner cannula)
Hermann Wülfing Lüer (gest. 1883)—1861: valve cannula (ball-valve)
Paul Broca (1824–1880)—1867: speech cannula with flap valve
Friedrich Trendelenburg (1844–1924)—1869: tampon cannula
M. Baker (London)—1877: elastic rubber cannula
Charles T. Stent (UK) (1807–1885)—1856: Material for endoluminal splinting (stent)
Przemyslaw Pieniazek (1850–1916)—1887: split cannula
Arthur Durham 1869, Franz König: 1876—flexible "lobster-tail cannulas"
Karl Störk (1832–1899)—1887: sieve cannula
Ottokar von Chiari (1853–1918)—1916: T (Tau)—cannula silver
Peter Biesalski (1915–2001) and Rudolf Köhler (1902–1972)—1958: first tracheostomy tube made of plastics
W. W. Montgomery (1933–2003)—1965: tracheal stent silicone
N. Lomholt—1981: high-volume, low-pressure cuff tubes

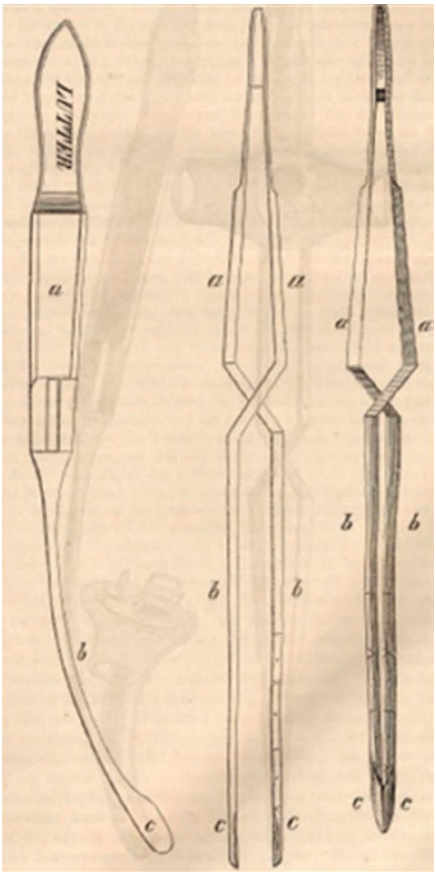

Fig. 20.4 Dilating forceps according to Hasse

Crown Prince Frederick III became German Emperor for 99 days on March 9, 1888, after he had been tracheotomized by Friedrich Gustav von Bramann (1854–1913) a month earlier for a stenosing glottic carcinoma. Immunoserum therapy, which had been used since the end of 1891, largely relieved diphtheria of its horrors and tracheotomy of its main indication [8, 20]. This should increasingly focus on craniofacial dysmorphia, trauma and surgery, laryngotracheal stenosis, long-term ventilation and neurodegenerative diseases [2, 21].

In German-speaking countries, Wilhelm Baum (1799–1883) in Greifswald and Franz von Pitha (1810–1875) in Prague contributed to its establishment [2, 22]. In 1884, Monti presented a statistic on 12,736 tracheotomies in Vienna, which showed a recovery rate of 26.7% for diphtheria.

The first artificial respiration was performed in 1871 by Friedrich Trendelenburg (1844–1924) via a tracheostoma [2]. The tampon cannula had been introduced in 1869. Leopold von Schrötter (1837–1908) and his pupil Arthur Thost (1854–1937) treated the frequent, mostly posttubercular laryngeal stenoses by bouginaging [15]. Przemislav Pieniazek (1850–1916), trained by Leopold von Schrötter, developed a split cannula and worked on tracheobronchoscopy in Kraków since 1884 [23]. Chevalier Jackson (1865–1958) finally standardized the modern tracheotomy technique, which was subsequently only slightly modified [24]. Nevertheless, Mikhail Bulgakov (1891–1940) was able to describe tracheotomy as an example of a medical border crossing at the beginning of the twentieth century: A freshly licensed country doctor is faced with the decision to perform an immediate tracheotomy on a suffocating child with diphtheria—and, encouraged by the nurse, carries it out successfully [25].

Intubation and *percutaneous puncture procedures* developed parallel to tracheotomy and left their mark on modern methodology, which only became practicable through reliable visual control. The roots of percutaneous procedures go back to Alexander the Great (356–323 BC): He is said to have uncovered a bone aspirated by a soldier with the tip of a sword [21]. Sanctorius Sanctorius (1561–1636) used Paré's tube for ascites puncture in 1627, Friedrich Dekkers (1648–1720) used a specific, straight and therefore dangerous trocar cannula [2]. In 1913 Alfred Denker (1863–1941) developed a *coniotomy* set in four sizes, which was widely used after its testing on 50 corpses of persons aged between 1 and 60 (Fig. 20.5).

Intubations have been proposed for newborns since ancient times, and for drowning victims in the eighteenth century. J. O'Dwyer (1841–1898) developed an indirect finger-guided intubation technique in view of the diphtheria rampant in New York in 1885, after Bouchut had narrowly failed before the charisma of Trousseau in 1858 [8, 15, 27]. Ivan W. Magill (1888–1986) standardized orotrachel and nasotracheal intubation, as did R. R. MacIntosh (1897–1989) using the intubation spatula. Shigeto Ikeda (1925–2001) introduced fiber-optic bronchoscopy in 1968 [2].

Figure 20.6 shows metallic intubation tubes with a connection valve according to Gustav Killian (1860–1921) for intubation according to Franz Kuhn (1866–1929)

Fig. 20.5 Intercricothyreotomy set according to Denker [26] (made by Fischer, Freiburg i. Br. Germany)

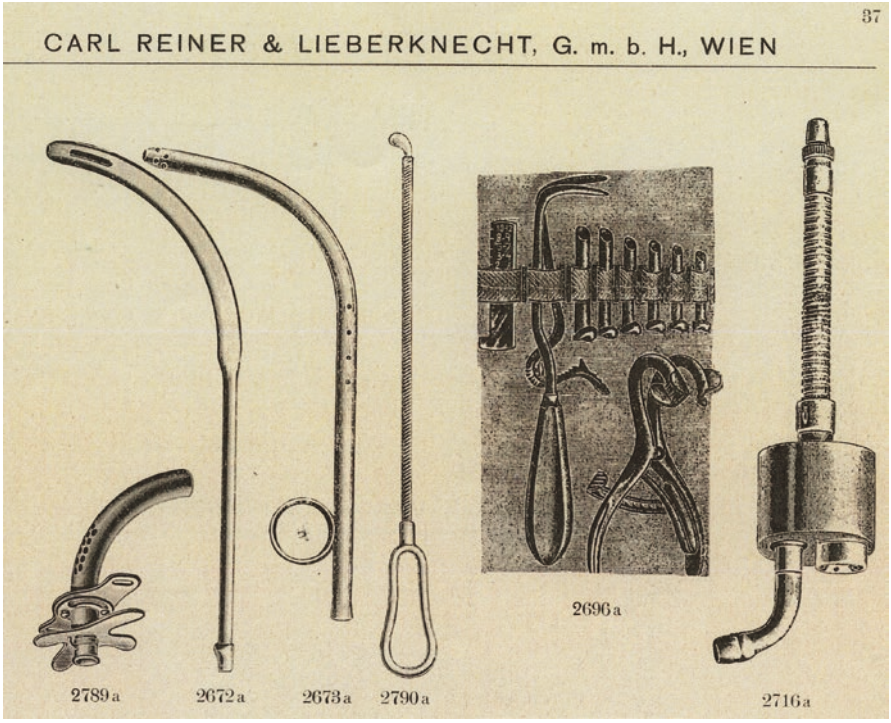

Fig. 20.6 Metal bougies and tubes (Cataloge of Carl Reiner and Lieberknecht GmbH, Vienna, Austria 1913) [31]. 2789a Tracheal cannula (so-called star cannula) acc. to Hajek. 2672a Dilatator acc. to von Schrötter, for laryngeal stenosis, made of solid metal, twelve sizes. 2673a Dilatator acc. to Brünings, made of metal, six tube thicknesses. 2790a Cleaning spring acc. to Marschik. 2696a Intubation set, consisting of six intubation cannulas, one instrument to insert and lift out the cannulas, one mouth gag acc. to Denhardt. 2716a Connecting tube acc. to Killian, D. R. G. M. for the range of instruments for oral intubation acc. to Kuhn

from a 1913 instrument catalog [31]. Also at that time, the rule was to try bouginage and intubation attempts with larynx stenoses (tuberculosis, diphtheria) before a tracheotomy.

The decisive development of today's *tracheostomy tubes* goes back to engineer Rudolf Köhler (1902–1972) in Frankfurt/M, who used plexiglass for the first time in 1950 and polyvinyl chloride (PVC) for the manufacture of individual tracheostomy tubes from 1955 onwards and successfully tested them on patients together with the physician Peter Bisalski in Mainz [14, 28].

Of course, every country is proud of its own pioneers in the history of tracheotomy.

The exciting and eventful history of tracheotomy over thousands of years and its historical sources teach us seven steps:

- *Know the anatomy*
- *Match diseases and symptoms*
- *Note body position*
- *Mark the surgical site*
- *Take blood vessels and bleeding seriously*
- *Master the instruments*
- *Keep the trachea sufficiently open*

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