Claus Petersen, Benno M. Ure (Eds.)

Thoracic Surgery in Children and Adolescents

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DE GRUYTER

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Prolog

Thoracic surgery in children and adolescents is no longer the same as 20 years ago. Antenatal detection of structural abnormalities has preponed diagnostic and therapeutic procedures and surgical as well as interventional techniques have undergone considerable development. Furthermore, substantial progress has been made in practitioners' general understanding of congenital thoracic malformations, in minimally invasive approaches to the thoracic cavity and surgery of the chest wall.

Today, neonatologists, pediatric pulmonologists and pediatric as well as thoracic surgeons are involved in the treatment of patients with thoracic problems, while imaging and anaesthesiological techniques remain particularly challenging in small and premature infants. However, correction of chest wall deformities is no longer recommended before puberty and transition of those patients has become a reality. As a consequence, the diagnosis and treatment of thoracic disorders are crossing borders and interdisciplinary cooperation has become mandatory.

Taking this evolution into account, the time for an innovative textbook of thoracic surgery for the first two decades of life has arisen. The idea behind this book is new: address to on experts and newcomers profit from an interactive concept.

We are very thankful that numerous well-known specialists have contributed to this book, be it through introducing topics, presenting their individual views or discussing some of the more controversial aspects related to this field. Recommended papers for further reading are included, and supplementary material can be found on the publisher's website. In addition to presenting the work, ideas and research of experts, this textbook opens the door for an interactive exchange between author and reader.

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Contents

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1 Anesthesia and analgesia for thoracic surgery

1.1 Introduction

The unpleasant times of years gone by when surgeons and anesthesiologists found themselves in conflict over competing perceptions of their respective importance and relevance are hopefully consigned to the past. Today, interdisciplinary collaboration and close cooperation are critical to ensuring that all patients are provided with the best practice and levels of care. This is particularly true when treating low-weight prematures or performing minimally invasive procedures in the thoracic cavity. In the following chapter, **Christian Seefelder** focuses not only on appropriate procedures and techniques, but also on perioperative pain management.

1.2 Anesthesia for pediatric thoracic surgery

The advances in pediatric surgery have resulted in the desire by the pediatric surgeon, by families and by medical consultants for earlier, more definitive, often video-assisted, "minimally invasive" surgery in younger and sicker patients than a decade ago. Anesthesia care for small, young and sick patients may have become safer more through better understanding, improved monitoring and more courage than through improvements in drugs, advances in technology or innovation in management. Pediatric anesthesiologists need intimate knowledge and understanding of the (congenital) surgical lesion and its pathophysiology, of the associated medical disorders and of the surgical procedure. In turn, pediatric surgeons need knowledge and understanding of the anesthetic techniques, concerns and limitations such as neurotoxicity of anesthesia in neonates, infants and young children, the difficulty of lung isolation in small patients or the physiologic challenges of minimally invasive surgery in pediatric patients.

1.2.1 Neurotoxicity of anesthesia in neonates, infants and young children

Animal and human data suggest that anesthesia in young animals as well as in human neonates, infants and young children may have unfavorable effects on the developing brain. The initial animal studies provoked disbelief, as a human neonate could not just be equated with a rat pup. Subsequently, clinical studies disturbingly confirmed the concerns rather than dispelling them [1, 2]. Further data are eagerly awaited by the pediatric anesthesia community, while surgeons not uncommonly have remained unaware of the whole discussion.

1.2.1.1 Animal data

Solid data from animal models suggest that exposure of neonatal animals to agents used in human anesthesia results in accelerated or premature neuroapoptosis and neurodevelopmental disadvantages. Common criticism of these studies includes the difficulty extrapolating from animal data to humans, difficulty comparing doses required for animals and humans, difficulty comparing animal outcomes to human outcomes, difficulty excluding the effect of disease and surgery requiring anesthesia on neurodevelopment and impossibility of providing necessary surgery without anesthesia. At the same time, suspicion has been brought forward that it is less the anesthetic agent than the physiologic milieu created that may be responsible for the changes (i.e. hypotension, desaturation). A clear recommendation regarding a safe or advantageous general anesthetic technique or agent is missing, but dexmedetomidine may be less detrimental than other anesthetic agents in regards to neurotoxicity.

1.2.1.2 Human data

Human data from retrospective and database studies indicate a neurodevelopmental disadvantage in children who have undergone (multiple) anesthetics as neonates, infants or young children compared to matched controls, siblings or twins without anesthesia. First results of a prospective randomized controlled study comparing one hour of sevoflurane anesthesia with awake/regional anesthesia for hernia repair in infants did not show a difference in neurodevelopmental outcomes at the 2-year follow-up [3]. Further information is sought through studies of neurodevelopment after intrauterine exposure to anesthesia, studies of sedation of neonates in the intensive care unit and studies of retinal apoptosis as "windows into the brain".

1.2.2 Basic anesthetic techniques in pediatric anesthesia

While thoracic surgery is performed under general anesthesia, there is often a misunderstanding by patients, families, medical specialists and surgeons about the degree of sedation for other studies and procedures. Not uncommonly, it has been agreed upon that a procedure can be done "under local" or "light sedation", but at the same time the patient has been promised to be "asleep" and the surgeon or radiologist expects the patient to be "not moving".

Few children are interested in being awake and aware and in lying still for procedures or studies. Small infants can sometimes be fed and bundled up and sleep through non-stimulating studies such as MRI. Distraction and entertainment with videos can be offered and parents can be present for reassurance for older children to undergo unsedated imaging studies or procedures such as lumbar puncture, bone marrow aspirate or central line placement under topical or local anesthesia.

Although light and moderate sedation with low doses of sedatives or systemic analgesics administered enterally or parenterally may relieve anxiety, by definition patients will respond to commands and stimulation and some children may move and cry, sometimes are disinhibited and may become more restless and less cooperative with the risk of escalating dosing of drugs.

For adequate surgical conditions and for imaging studies requiring immobility, deep sedation or general anesthesia are necessary; while spontaneous respirations may be maintained, concerns are progression to apnea, loss of protective airway reflexes, increasing airway obstruction and hemodynamic compromise.

1.2.3 Age at and timing of surgery

Cardiothoracic surgical intervention may occur as early as in utero, for example for aortic stenosis with evolving hypoplastic left heart syndrome, life threatening congenital pulmonary airway malformation or severe congenital diaphragmatic hernia. Some patients may require ex utero intra partum treatment or "EXIT" procedures with surgical intervention or placement on extracorporeal membrane oxygenation (ECMO) during birth and while on placental support. Anesthesia, monitoring and resuscitation of the fetus is provided by fetal anesthesia subspecialists while the mother is anesthetized and monitored by the obstetric anesthesiologist. Emergent or urgent neonatal thoracic surgery is required for large or enlarging congenital pulmonary lesions, for tracheo-esophageal fistula (TEF) and congenital diaphragmatic hernia. Many lung biopsies and tumor resections need to be performed whenever the patient presents. Given the neurodevelopmental risks of anesthesia in young patients, elective pediatric surgery should be postponed, but the age by which anesthesia in children is safe remains elusive. Irrespective of the neurodevelopmental concerns, the risk of anesthesia-related complications is highest in the youngest [4].

Surgical pathology in children is dominated by congenital abnormalities or pediatric-specific acquired disorders. Pediatric anesthesia and surgery provide care to patients from the 0.5 kg 24-week premature neonate to the 100 kg teenager. While "a child is not just a small adult", the main difference and the anesthetic implication for older children lie mostly in the psychological issues as well as in issues of equipment-size. For premature and term neonates as well as infants, drugs, equipment or technologies may not be available, formally approved or scientifically validated. The difference in physiology of the neonate and infant from the physiology of older children and adults is characterized by immaturity of the function of all organs and systems (central nervous, cardiovascular, respiratory system, renal, hepatic, endocrine, metabolic, gastrointestinal function, pharmacology, immunology, hematology), all of which need to be considered by the pediatric anesthesiologist during anesthesia in this patient population.

1.2.4 Preoperative evaluation and workup

The typical evaluation and workup will include all aspects of the history and physical exam, with focus on the thoracic pathology in question, specifically any respiratory symptoms and distress, stridor and any signs or symptoms indicating difficult airway management or risk of respiratory obstruction during anesthesia and surgery. Most studies will have been ordered by surgeons and pediatric specialists but should be reviewed by the pediatric anesthesiologist, including chest x-ray, computed tomography (CT), magnetic resonance imaging (MRI), angiograms, ventilation/perfusion scans, cardiologic studies, lung function tests, laboratory results, cultures and biopsies. Of particular importance is consultation with other pediatric specialists such as pediatric pulmonologists, cardiologists, hematologists, oncologists, endocrinologists and radiologists to optimize preoperative workup, evaluation, management and communication.

Especially in younger children with limited cooperation, many types of studies such as lung function tests may not be possible at all. Others such as CTs, MRIs, angiographies or biopsies will require the involvement of the anesthesiologist for sedation or anesthesia. To provide the patient with a safe anesthetic and a satisfactory study, requesting service, surgeon, radiologist and anesthesiologist should communicate before the study to understand each other's concerns and objectives. While case to case assessment and discussion are important, agreeing on a protocol across departments allows input from all specialties ahead of time and decreases case to case confrontation. Protocols appear reasonable for imaging studies in patients with anterior mediastinal masses or tracheomalacia. Early involvement has the advantage of familiarizing the anesthesiologist with the patient's airway anatomy and management and physiologic response to anesthesia prior to major thoracic surgery.

1.2.5 Intraoperative monitoring

Standard monitoring includes electrocardiogram (ECG), non-invasive blood pressure (NIBP), pulse oximetry, patient temperature, inspiratory oxygen concentration (F_iO_2) and end-tidal CO_2 concentration ($ETCO_2$). It may be difficult to establish all monitors prior to induction in children.

Invasive arterial monitoring allows arterial blood gas sampling and immediate recognition of hemodynamic effects of surgical retraction, mechanical arrhythmias or air embolism. It is indicated in lobectomy or pneumonectomy, in thoracic tumor resections, major neonatal thoracic surgery for congenital diaphragmatic hernia or TEF repair, in infant thoracoscopy or for the patient's general medical condition. Lung isolation in itself is not an indication for placement of an arterial catheter, and it may not be necessary for simple lung wedge resections or biopsies, thoracoscopic pleurodesis or pectus repair. Risks include ischemic complications from local skin necrosis to loss of an extremity. Placement aids for small patients are transillumination, Doppler and more recently ultrasound.

Central venous pressure monitoring may not be reliable in situations of an open chest, retraction of cardiovascular structures and capnothorax but may have a place for perioperative monitoring. A central venous catheter also serves as secure perioperative venous access and for the administration of vasoactive agents and should be considered whenever their need is anticipated.

Pulse oximeters, arterial catheter and blood pressure cuff are distributed over several extremities. In neonates, pre- (right arm) and post-ductal (lower extremity) oxygen saturation should be monitored to detect right to left shunting across the ductus arteriosus. Electroencephalographic monitors are available for anesthetic depth, seizure and ischemia monitoring. Transesophageal echocardiography is available for children, non-invasive cardiac output monitors are being evaluated, pulmonary arterial catheters are used less commonly in the pediatric population.

Cerebral blood flow can be monitored via transcranial Doppler, and near-infrared spectroscopy (NIRS) measures brain oxygenation. In particular cerebral or somatic tissue oxygenation monitoring is rapidly gaining importance and popularity, since hemodynamic parameters alone do not reflect actual end organ supply. Intraoperative decreases of regional brain oxygenation must be responded to promptly by improving hemodynamics and cerebrovascular perfusion but also by correcting surgical maneuvers such as retraction, increased intrathoracic pressure or hypercarbia from CO_2 insufflation.

1.2.6 Lung isolation and one lung ventilation in children [5, 6]

Indications for lung isolation with double lumen tubes include protection of one lung from bleeding or contamination from the other lung and bronchopleural fistula with inability to ventilate. More commonly, the indication for lung isolation is a relative indication to provide an immobile surgical field, in particular for surgery of the lung and thoracoscopic surgeries. While double lumen tubes are not available for small children, non-ventilation of one lung may be achieved with bronchial blockers and main stem intubation. Both can easily dislodge, initial deflation of the non-ventilated lung may be delayed, and easy re-expansion and re-isolation of the non-ventilated lung may not be possible. This isolation technique can be time consuming and requires patience by surgeon and anesthesiologist. For non-pulmonary thoracic surgery, surgical immobilization of the lung by retraction or packing and creating a capnothorax for thoracoscopic surgery is therefore often applied.

Main stem intubation is achieved over a flexible or rigid bronchoscope or with fluoroscopic guidance. The main stem bronchi are smaller than the trachea and a smaller or uncuffed tube is selected for successful endobronchial intubation. The proximity of the right upper lobe bronchus to the carina (Fig. 1.2.1; 1.2.2) makes this technique less successful for ventilating the right than the left lung, as loss of the right upper lobe ventilation may result in unacceptable desaturation. However, ventilating the left lung via main stem intubation with non-ventilation of the right lung is quite successful due to the length of the left main stem bronchus and left main stem intubation is practiced widely for right thoracoscopic surgery.

Tab. 1.2.1: Options for lung isolation and single lung ventilation at different ages.

Age	Weight	Endotracheal tube size	Cuff type[1]	Main stem intubation tube size	Bronchial blocker type[2]	Blocker inside / outside the tube	Bronchial blocker size (French)	Univent™ tube size (mm inner diameter)[3]	Double lumen tube size (French)[4]
neonate	3 kg	3.0 cuffed 3.5 uncuffed	LoPro Microcuff	3 uncuffed	Fogarty	outside	2–4		
<6 months	3–6 kg	3.5 uncuffed/ cuffed	LoPro Microcuff	3 uncuffed/ cuffed	Arndt	outside	5		
6–12 months	6–10 kg	3.5–4 uncuffed/ cuffed	LoPro Microcuff	3–3.5 uncuffed/ cuffed	Arndt	outside	5		
1–2 years	<15 kg	4–4.5 uncuffed/ cuffed	LoPro Microcuff	3.5 uncuffed/ cuffed	Arndt	outside	5		
2–4 years	<20 kg	4.5–5 cuffed	LoPro Microcuff	4–4.5 cuffed	Arndt	inside/outside	5		
4–6 years	<25 kg	5–5.5 cuffed	LoPro Microcuff	4.5–5 cuffed	Arndt	inside outside	5 5, 7		
6–8 years	<30 kg	5.5–6 cuffed	LoPro Microcuff	5 cuffed	Arndt	inside outside	5 7	3.5	
8–10 years	>30 kg	6 cuffed	HiLo Microcuff		Arndt	inside outside	5 7	3.5	26
10–12 years	<40 kg	6.5 cuffed	HiLo		Arndt	inside	7	4.5	26–28
12–14 years	40–50 kg	6.5 cuffed	HiLo		Arndt	inside	7	4.5	28

Tab. 1.2.1 (continued)

Age	Weight	Endotracheal tube size	Cuff type[1]	Main stem intubation tube size	Bronchial blocker type[2]	Blocker inside / outside the tube	Bronchial blocker size (French)	Univent™ tube size (mm inner diameter)[3]	Double lumen tube size (French)[4]
14–16 years	>50 kg	6.5–7 cuffed	HiLo		Arndt	inside	7	6	32
Adult female	>60 kg	6.5–7 cuffed	HiLo		Arndt	inside	7	6.5	32–35
Adult male	>70 kg	7–7.5 cuffed	HiLo		Arndt Cohen EZ-Blocker™	inside	9 9 7	7	35–37

[1] Microcuff tube, Halyard Health Care, formerly Kimberly-Clark®, HiLo = high volume low pressure cuffs, LoPro = low profile cuffs, Medtronic, Covidien, formerly Mallinckrodt™; [2] Arndt Endobronchial Blocker: 5, 7, 9F, Cohen Endobronchial Blocker: 9F: Cook® Medical; Uniblocker™: 5, 9F: Teleflex®, formerly Fuji Systems, EZ-Blocker™ Endobronchial Blocker, Teleflex®, formerly Rüsch®; [3] Univent™, Teleflex®, formerly Fuji Systems; [4] 26F DLT, Teleflex®, formerly Rüsch® (modified from Table 6, page 1428 in: Hammer GB, Fitzmaurice BG, Brodsky JB. Methods for Single-Lung Ventilation in Pediatric Patients. Anesth Analg 1999;89:1426–9) [5].

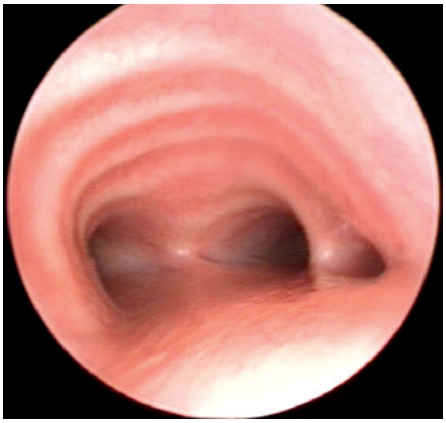

Fig. 1.2.1: Bronchoscopic view of the distal trachea and carina of an infant with the right upper lobe bronchus coming off the trachea (pig bronchus).

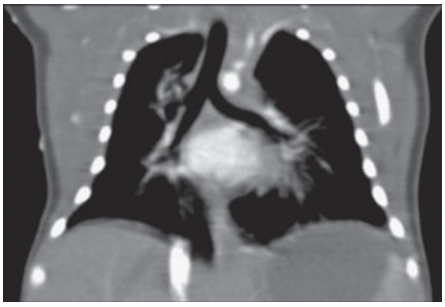

Fig. 1.2.2: Chest CT of an infant showing proximal take-off of the right upper lobe bronchus.

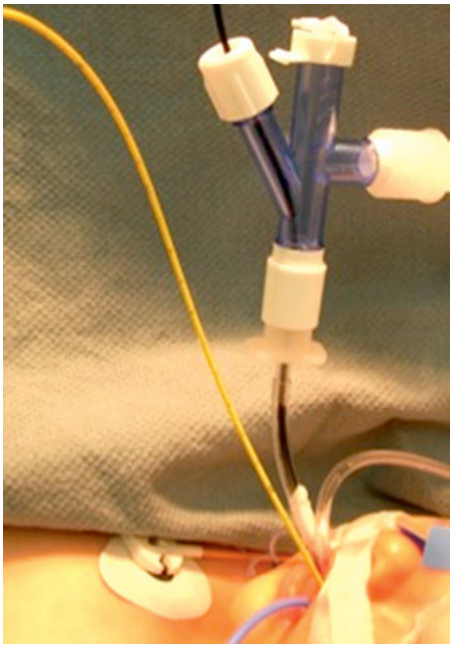

Fig. 1.2.3: Placement of an extraluminal bronchial blocker: Fiberoptic bronchoscopy through the adjustable lumen port of the triple port adaptor of an Arndt Endobronchial Blocker while the bronchial blocker is entering the airway parallel to the endotracheal tube.

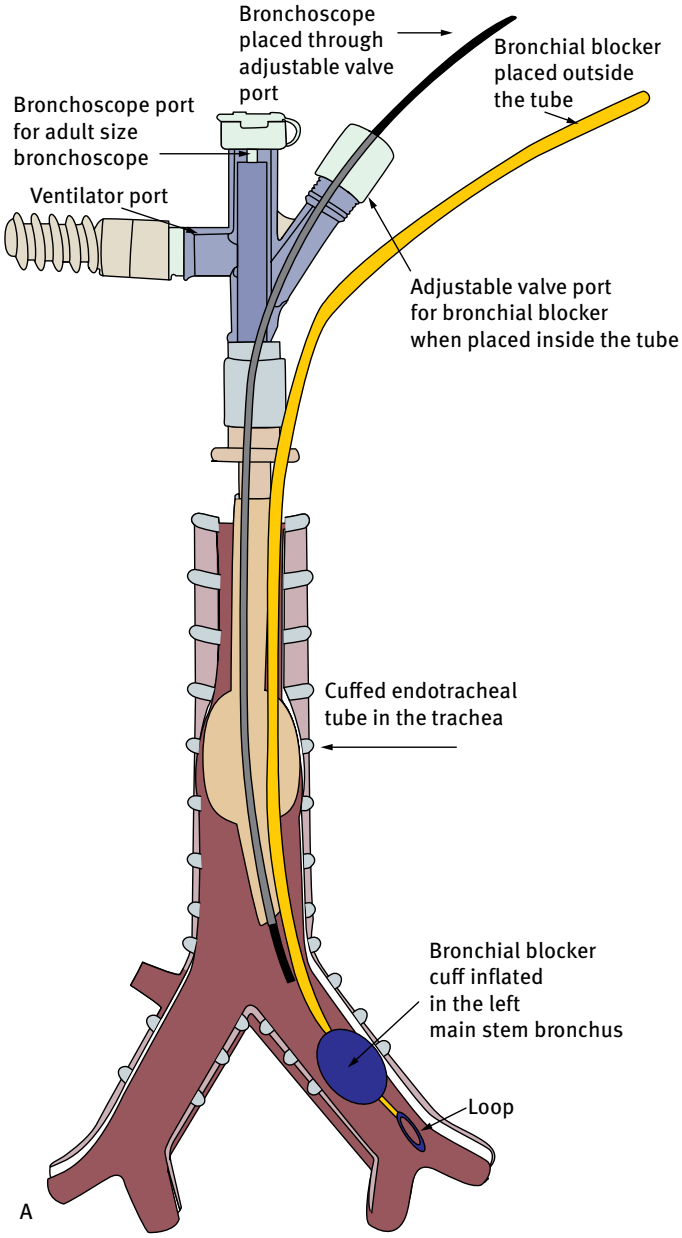

Fig. 1.2.4: Depiction of the extraluminal placement of a bronchial blocker in infants and young children.

Bronchial blockers, for example the Arndt endobronchial blocker from Cook or the Uniblocker from Fuji, available in 5, 7 and 9 French (F), or Fogarty catheters in sizes 2, 3 and 4 F can be used for lung isolation [7]. The bronchial blocker can be placed outside the endotracheal tube in infants and young children (Fig. 1.2.3; 1.2.4).

Video showing the placement of extraluminal 5F bronchial blocker into the left main stem bronchus of an infant guided with 2.2 mm fiberoptic bronchoscope. https://www.degruyter.com/view/supplement/9783110419825_placement_bronchial_blocker.mp4

Although the blocker naturally enters the right main stem more readily, it can be directed into the left main stem under fiberoptic control (supplementary video online). Due to the longer left main stem, lung isolation is more likely to be successful with a blocker in the left main stem, allowing ventilation of the right lung and non-ventilation of the left lung (Fig. 1.2.5; 1.2.6). Conversely, placement of the bronchial blocker into the right main stem is more likely to result in incomplete lung isolation due to the proximity of the right upper lobe bronchus to the carina, or in dislodgement of a very proximally placed blocker into the trachea with loss of isolation and obstruction to ventilation via the endotracheal tube. In older patients, use of the bronchial blocker through the endotracheal tube is the recommended technique. The 9 F Rüsch® EZ-Blocker™ with two balloons is an option not available in pediatric sizes at this time.

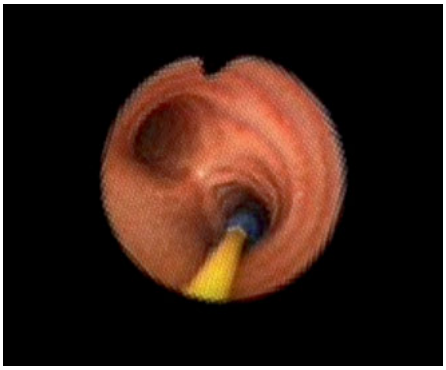

Fig. 1.2.5: Endobronchial blocker placed outside the endotracheal tube and entering the right main stem bronchus of an infant.

The Univent™ Inoue tube from Fuji has a channel for a bronchial blocker incorporated into the wall of the tube. Even though pediatric sizes are available, they appear to have an unfavorable ratio between inner and outer diameters: the "3.5 ID" uncuffed tube has a 7.5–8 mm outer diameter, the "4.5 ID" cuffed tube 8.5–9 mm. These tubes therefore are only suitable for older children and adolescents.

Double lumen tubes are commercially available from size 26 F. This smallest tube fits patients above 8 years of age, 30 kg weight and 130 cm height [8]. Marraro custom-made a double lumen tube for neonates and infants, which consists of two attached small tubes, and some practitioners have used two separate small tubes for selective lung ventilation in infants.

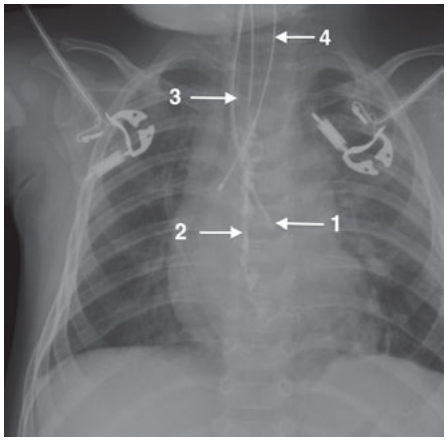

Fig. 1.2.6: Chest x-ray of an infant showing endobronchial blocker in the left main stem bronchus (1), epidural catheter and epidural contrast (2), endotracheal tube in the trachea (3), and temperature probe in the esophagus (4).

Lastly, if lung separation is necessary but technically not possible, the use of **ECMO or cardiopulmonary bypass** has been reported, for example for whole lung lavage in infants and small children.

1.2.6.1 Surgical capnothorax

Commonly, pediatric thoracic surgeons insufflate CO_2 into the pleural cavity, creating a surgical capnothorax to improve the work space for thoracoscopic procedures and to accelerate lung collapse of the non-ventilated lung. Hypercarbia results from increased CO_2 absorption and impaired ventilation due to decreased compliance and formation of atelectasis of the ventilated dependent lung. Capnothorax and hypercarbia have been shown to be associated with decreased cerebral blood flow, decreased cerebral oxygenation and severe acidosis in thoracoscopic repair of congenital diaphragmatic hernia (CDH), although increased cerebral oxygenation has also been seen, likely related to hypercarbia induced cerebral vasodilation. NIRS monitoring of cerebral oxygenation is indicated. Increased intrathoracic pressure can also result in decreased venous return with hypotension and increased venous bleeding [9, 10, 11].

Generally, in neonates and in patients with successful lung isolation, pressures of 2–3 cm H_2O should suffice, occasionally pressures of 4–5 cm H_2O may be helpful. Only on rare occasions do pressures need to be increased above 5 cm H_2O, for example to assist in reducing abdominal content during thoracoscopic CDH repair. This should be temporary and always be discussed between surgeon and anesthesiologist who will monitor ventilation, oxygenation and hemodynamics. These higher pressures may be tolerated hemodynamically while they are immediately noticeable through worsening compliance and hypercarbia.

Occasionally, the surgeon will flush CO_2 through the pleural cavity to scavenge electrocautery smoke without actually establishing pressure. This is tolerated well with less hypercarbia, but may result in more temperature or moisture loss. CO_2 insufflators with the capability to warm and humidify the insufflated CO_2 are available.

1.2.6.2 Ventilation during one lung ventilation

Decompression of the non-ventilated lung in main stem intubation and with bronchial blockers may be slow. Use of 100% oxygen or oxygen/nitrous oxide prior to isolation rather than oxygen/air accelerates lung collapse through the faster absorption of oxygen and nitrous oxide than nitrogen from the non-ventilated lung.

Pressure control ventilation is preferred over volume control ventilation to optimize tidal volumes while limiting ventilation pressures. Peak inspiratory pressures (PIPs) are chosen to achieve a desirable tidal volume of 5–8 ml/kg. Especially with the use of bronchial blockers, PIPs should be limited due to the risk of exceeding balloon seal and trapping ventilation in the non-ventilated lung. Positive end expiratory pressure (PEEP) of 3 to 5 cm H_2O helps to reduce the risk of atelectasis in the dependent/ventilated lung due to positioning, surgical compression and capnothorax.

Intraoperative hypercarbia is managed with limited increase in tidal volume by increasing peak inspiratory pressure or inspiratory time, and by increasing respiratory rate. Minimizing dead space and using low-compliance circuits may prove beneficial. Intraoperative flexible fiberoptic bronchoscopy, for example during tracheopexy, increases resistance to ventilation and may need to be limited if hypercarbia is difficult to manage. If CO_2 elimination by ventilation is difficult, avoiding patient hyperthermia helps limiting endogenous CO_2 production from increased patient metabolism. As CO_2 insufflation into the pleural cavity by the surgeon is the major contributor of hypercarbia during thoracoscopy, limiting insufflation pressures or avoiding insufflation is the best option to reduce hypercarbia.

In the absence of other contraindications to hypercarbia such as pulmonary hypertension or need for low pulmonary vascular resistance (Fontan circulation), some degree of temporary permissive hypercarbia may be reasonable and tolerated, but the degree of acceptable hypercarbia remains undefined. p_aCO_2 below 50 mm Hg is likely unproblematic and up to 60 mm Hg probably acceptable. It is important to correlate endtidal CO_2 with p_aCO_2 to be able to track changes.

1.2.6.3 Physiology of one lung ventilation [12]

When lung isolation is initiated and one lung ventilation commences, the non-ventilated lung initially remains perfused and the oxygen in the lung gradually is absorbed. Due to their higher oxygen requirement and lower oxygen reserve in the lung, this process is markedly shorter in infants and small children than in older patients, similar to the apnea time in infants. With the complete removal of the alveolar oxygen, shunting becomes obvious and oxygen desaturation can be noted. Hypoxic pulmonary vasoconstriction HPV is activated, resulting in a decreased perfusion of the non-ventilated lung and a reduction in the shunt fraction. Oxygenation and oxygen saturation improve again. Degree and duration of desaturation are variable, but transient desaturation into

the 80s is not uncommon even while ventilating with 100% oxygen. Ample literature discusses influences on HPV with opportunities for intervention in adults. This is less well documented in children. In general, vasodilators including inhalational agents may impair HPV and intravenous anesthesia has been considered favorable for maintaining HPV and decreasing shunting. High PEEP or mean airway pressures may divert blood flow from the ventilated to the non-ventilated lung.

Intraoperative desaturation in pediatric thoracic anesthesia is managed similar to adults. Inspiratory oxygen concentration is increased and normoventilation is attempted. Lateral positioning, padding, surgical retraction and pressure may result in intraoperative atelectasis of the ventilated dependent lung and contribute to pulmonary desaturation. Gentle recruitment breaths can be attempted remembering the possible loss of lung isolation when bronchial blockers or main stem intubation are used and the ventilation pressures exceed the cuff pressure. PEEP is added to the dependent lung or increased. Secretions or blood may block the airway. However, suctioning any pediatric endotracheal tube and in particular suctioning during one lung ventilation may result in rapid desaturation, which may be slow to recover. Double lumen tubes and some bronchial blockers allow upper-lung CPAP (continuous positive airway pressure) and recovery of oxygenation albeit at the price of a distended lung which may not please the surgeon. Nitric oxide may improve ventilation/perfusion matching of the dependent lung. Changing the anesthetic to an intravenous technique supports HPV in adults. Finally, clamping of the pulmonary artery, especially when lobectomy or pneumonectomy are performed, (temporarily) aborting one lung ventilation, and considering ECMO or cardiopulmonary bypass would restore oxygenation.

1.2.7 Anesthetic implications for specific disorders

1.2.7.1 Congenital lung lesions in neonates and infants

These lesions can overlap and are congenital pulmonary airway malformation (CPAM, connected to the airway), including previously termed congenital cystic adenomatoid malformation (CCAM), pulmonary sequestration (PS, not connected to the airway, systemic blood supply), congenital lobar emphysema (CLE, connected to the airway with large bullae), bronchogenic and enteric duplication cysts (cysts not connected to the airway).

Expanding lesions in the neonate

Large or expanding congenital lobar emphysema or congenital pulmonary airway malformation can cause mediastinal shift and respiratory distress or produce high output cardiac failure and may require urgent surgery in the neonate. Positive pressure ventilation increases the risk of further distention, but patients are often intubated preoperatively for respiratory distress, they may be on high frequency oscillatory ventilation

(HFOV) or may required ECMO. Nitrous oxide is avoided. If the patient is unstable, anesthesia time between induction and incision should be minimized and open repair should be pursued expeditiously. Surgical "rescue" during problems under anesthesia is thoracotomy and delivery of the mass to allow the remainder of the lung to be ventilated. An arterial line and good venous access should be established and blood products should be available. Regional anesthesia may be placed postoperatively and the patient will be monitored in an intensive care unit (ICU) postoperatively.

Stable lesions

Most patients with congenital lung lesions are stable and elective thoracoscopic resection is scheduled in infancy [13]. Routine echocardiographic workup is not indicated. Postnatal imaging can help to characterize the lesion. Anesthesia induction can be performed by inhalation or intravenously. Positive pressure ventilation is of no concern in pure pulmonary sequestration and bronchogenic cysts without connection to the airway, but in patients with congenital pulmonary airway malformation or congenital lobar emphysema, positive pressure ventilation should be carried out gently, as these lesions could still expand. Solid venous and arterial access is indicated especially for lobectomy, pneumonectomy, resection of pulmonary sequestration with blood supply from the aorta, and any thoracoscopy in neonates and infants. Bleeding, air embolism and inadvertent tension capnothorax are specific risks. Lung isolation via main stem intubation or bronchial blocker is helpful. Regional anesthesia can be added for intra- and postoperative analgesia. Postoperative monitoring of respiratory sufficiency and pain control should occur in an ICU for young patients.

1.2.7.2 Esophageal atresia and tracheo-esophageal fistula repair in the neonate [14, 15]

The most common variants of congenital tracheo-esophageal anomalies and the most relevant for anesthesia management are pure esophageal atresia (EA), proximal EA with distal TEF, and H-type fistula between trachea and esophagus. Patients with EA may have polyhydramnios on prenatal ultrasound and postnatally present with coughing and signs and symptoms of aspiration when feeding. A nasogastric tube will fail to pass into the stomach and can be seen curled in the proximal esophagus on a chest x-ray.

The high association of tracheo-esophageal anomalies with other congenital anomalies such as congenital heart disease and VACTERL association (**v**ertebral, **a**norectal, **c**ardiac, **t**racheo-**e**sophageal, **r**enal, **l**imb abnormalities) makes a preoperative workup advisable. An echocardiogram is performed to exclude or define congenital heart disease and to identify the position of the aortic arch (left arch, right thoracic approach and vice versa). A babygram will be evaluated for gas in the stomach and intestines (presence of a TEF), pulmonary infiltrates, heart size, vertebral anomalies or

the double bubble of duodenal atresia. Duodenal atresia or imperforate anus require additional procedures at the time of a TEF repair (duodenal atresia repair, gastrostomy, colostomy). Workup for renal pathology and spinal anomalies are often delayed until after TEF repair.

Tracheo-esophageal fistula (TEF)

Patients with pure EA (gas free abdomen) can be subjected to positive pressure ventilation as necessary. In the presence of a TEF, the abdomen is gas filled and pronounced gastric distention may exist, if positive pressure ventilation was performed during neonatal resuscitation. The patient should not be intubated electively preoperatively, spontaneous respirations should be maintained as long as possible. Positive pressure ventilation during anesthetic management can similarly distend the stomach, impair diaphragmatic excursion, limit ventilation and result in hypercarbia and desaturation. Management varies by institution, and anesthesiologist and surgeon should discuss their plans preoperatively.

One possible approach is to induce anesthesia maintaining spontaneous respirations. Topical anesthesia is administered to the vocal cords and to supra- and infraglottic structures with direct laryngoscopy, keeping the maximum allowed local anesthetic dose in mind. Number and location of the fistula(s) is then identified by (rigid) bronchoscopy. If the fistula is located distal in the trachea or at the level of the carina, a Fogarty catheter can be passed through the fistula into the stomach, inflated and withdrawn (Fig. 1.2.7; 1.2.8). This provides some intraoperative guidance to the location of the fistula and at the same time a modest seal if low pressure positive pressure ventilation is performed. If positive pressure ventilation has resulted in massive gastric distention, gastrostomy tube decompression may be required. TEFs higher in the trachea can be occluded by a 3.0 mm inner diameter (ID) cuffed endotracheal tube. If right thoracoscopic TEF repair is planned, the left main stem bronchus is intubated with a 3.0 mm ID uncuffed endotracheal tube.

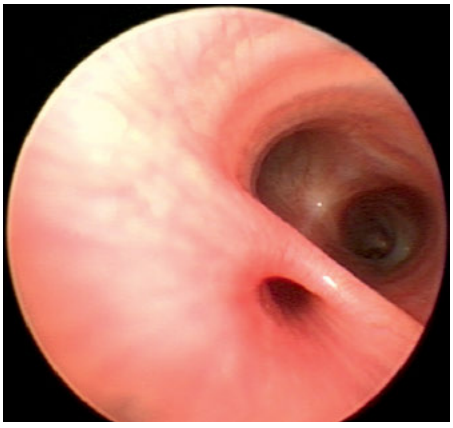

Fig. 1.2.7: Bronchoscopic view of the carina with a tracheo-esophageal fistula.