16.1 General Considerations

16.1.1 Anatomy

- The respiratory system (Fig. 16.1) arises as an out-pouching from the primitive lung bud at the 3rd week of embryonic life. Between the 6th and 16th weeks of gestation, rapid bronchial division beyond the sub-segmental level occurs.

- Alveoli begin to develop at the 24th week of gestation by out-pouching, so that by 8 years of age the adult number of approximately 300 million alveoli is attained.

- Each lung is divided into 10 segments (Fig. 16.2). For certain localized lesions segmental and subsegmental resections rather than lobectomy should be performed.

- The pulmonary lymph nodes are located at points of division of segmental bronchi or at the bifurcations of the pulmonary artery. The hilar nodes are allocated along the main bronchi. The interlobar nodes are situated in the angles of the main bronchi into the lobar bronchi.

- The child’s thorax is more flexible than that of adults.
Fig. 16.1 Anatomy of the tracheobronchial tree

Fig. 16.2 Lung segmentation
16.1.2 Tracheostomy

General considerations

- Tracheostomy is occasionally an emergency procedure but is more usually semi-elective or elective
- A tracheostomy offers direct and established access to the major airways, reduces airway dead space, overcomes upper airway obstruction, and avoids interference with the vocal cords and larynx

Indication for operation

- Long-term mechanical ventilation (approx. 4–6 weeks, e.g., post cardiac surgery)
- Congenital laryngotracheal malformations (tracheal membrane, subglottic stenosis, micrognathia)
- Acute infection (acute epiglottitis, acute laryngotracheobronchitis)
- Upper airway injuries and edema (cervical trauma, inhalation burn injuries)
- Laryngeal edema following intubation
- Functional obstruction (vocal cord paralysis – recurrent laryngeal nerve damage)
- Laryngotracheal tumors (lymphangioma, hemangioma, papilloma)
- Respiratory insufficiency due to muscle dystrophy
- Preparatory to planned surgery on pharynx or larynx

Operation

- General anesthesia
- Hyperextended neck (shoulder roll)
- Vertical or horizontal incision midway between the cricoid and the suprasternal notch
- Division of superficial cervical fascia and platysma
- Subcutaneous preparation and division of the strap muscles in the mid-line
- Two U-stay retraction sutures 3-0 (2-0) through the skin on either lateral side of the proposed tracheal incision (3rd and 4th tracheal ring; caution because of the endotracheal tube)
- A single midline incision is created
- Removal of the tracheal cartilage is not recommended
- Insertion of appropriate diameter tracheostomy tube as the endotracheal tube is withdrawn slowly and the tracheostomy tube (size approx. the diameter of the patient’s 5th finger) is pushed in without allowing the trachea to collapse
- Two additional sutures are required to fix the skin to the tracheal wall. For larger tubes inflate the cuff carefully (less than 20 mmHg). The tracheostomy tube should remain unchanged until at least the postoperative day 5
- Secure fixation of the tracheostomy tube using tapes tied around the neck with or without suture to skin
- The operation is illustrated in Fig. 16.3

Fig. 16.3 Operative steps for tracheostomy
Postoperative

- Chest X-ray
- Flexible bronchoscopy if necessary

Complications

- Tube obstruction
- Granulation tissue
- Tracheomalacia (local inflammatory destruction)
- Severe hemorrhage (from the innominate artery especially in tracheotomies below the fourth tracheal ring, urgent median thoracotomy)
- Stricture
- Stenosis, delayed spontaneous closure of the tracheostomy by a skin flap

Tracheotomy care

- Check chest X-ray immediately after the operation
- Warm, humidified, filtered air/O₂ necessary
- Keep spare tracheotomy tube and tracheal dilator readily available
- Regular tube irrigation (0.9% NaCl) and aspiration
- Careful antiseptic technique of tube changing
- Change tube at regular intervals (2–3 days)
- Instruct the parents thoroughly

16.1.3 Thoracotomy

Median sternotomy

- Indicated for access to both lungs (metastases), the heart, and the anterior mediastinum (thymoma)
- Mobilization (digitally, long blunt clamp) of the retrosternal connective tissues from the suprasternal notch and the subxiphoidal region
- Median (sometimes difficult) sternal division using a chisel or saw. Mechanical ventilation should be stopped for a short time during this procedure to avoid making lesions in the pleura sacs and lungs
- Full exposure using the Finochietto retractor
- Closure using resorbable sutures (0, 1, 2) or surgical wire
Lateral thoracotomy

- Lateral thoracotomy is frequently used in pediatric surgery
- The patient is positioned overextended on his or her left or right side (Fig. 16.4), with support under the chest and the arm elevated. After surgical covering, the mammilla and the inferior angle of the scapula (palpation) should be visible for orientation
- The incision is made, starting far behind the mammilla and going around the inferior angle of the scapula or along the middle axillary line
- The latissimus dorsi muscle and the thoracodorsal fascia have to be divided (care should be taken to stay below the inferior angle of the scapula); the serratus muscle is partially divided
- The 4th intercostal space is used to enter the thorax. Therefore, a longitudinal periosteal incision is performed using a diathermy knife, in the middle of the 5th rib. The upper half of the periosteum is mobilized step by step from the rib starting dorsally and moving ventrally (Fig. 16.5)
- For operations on the diaphragm it is advisable to use the 5th or 6th intercostal spaces
- Rib resections are not necessary
- Make an incision in the partly mobilized periosteum
- The Finochietto retractor is inserted and opened
- Access to the mediastinum (e.g., esophageal atresia) should be performed extrapleurally (pleural lesions after blunt dissection are mainly located in the area of the anterior chest wall)
- At the end of the operation pleural drainage should be ensured (Fig. 16.6), usually with two chest tubes (short intrathoracic tube in the posterior position, long tube in the anterior position)
- Closure is achieved with resorbable sutures around the two ribs either side of the opened intercostal space, ensuring that they are not tied too firmly
- Closure of the muscle layers and the fascia thoracodorsalis as well as the subcutaneous tissues is made using resorbable sutures
- Skin closure
Fig. 16.4 Positioning for lateral thoracotomy

Fig. 16.5 Operative steps for lateral thoracotomy
Axillary thoracotomy

- This is only performed when limited exposure of the upper hemithorax is needed (i.e., biopsy, pleural abrasion)
- The skin incision parallels the course of the third rib in the axilla and extends from the anterior to the posterior axillary folds
- Division of the latissimus dorsi or the serratus muscle is not necessary

16.1.4 Bronchus Closure

Surgical procedure

- Closure of large bronchial stumps with commercial surgical stapling devices (Endo-GIA) is appropriate, especially in older children
- Closure of small and middle bronchi and of large bronchi in small children is best achieved with a simply sewn monophılıc resorbable suture (e.g., PDS®, Monosyn®)
- The distance between the stitches should be about 3 mm
- During suturing intermittent atraumatic bronchus occlusion using a wet peanut swab on a clamp should be performed
- The procedure is illustrated in Fig. 16.7

**16.1.5 Large Vessel Closure (Pulmonary Arteries and Veins)**

**Surgical procedure**
- Non-resorbable sutures (Prolene®, Gore®) are used
- A double closure technique is applied with a simple ligature centrally and a suture ligature peripherally
16.1.6 Lobe/Segmental Resection

Surgical procedure

- The operation is illustrated in Fig. 16.8
- Lateral thoracotomy (incision of the pleura using the scalpel)
- The Finochietto retractor is inserted and gradually opened taking care not to clump the lung; a rib resection is not necessary in children
- Careful intrathoracic exploration (e.g., look for pleural adhesions)
- The visceral pleura is carefully incised exposing the hilar structures
- Careful preparation of the vessel branches (pulmonary artery, pulmonary vein) and the bronchus (sometimes difficult because of enlarged lymph nodes)
- Identification of all structures before dissecting them after exposing the segmental branches of the vessels
- Vessel loops are helpful, as intermittent occlusion of the segment bronchi with soft vascular clamps (e.g., bulldogs) at the same time as lung inflation helps to detect the borders between the segments
- If the lesion is limited to lung segments, just segmental resection may be chosen
- After segment resections or after division of interlobar parenchymal bridges the lung surface may be sealed, if necessary with fibrin glue or a fibrin-coated collagen patch
- For lower lobe resection, preparation begins in the interlobium with an incision of the visceral pleura followed by preparation of the pulmonary artery and its branches
- In lower lobe resections, the pulmonary ligament can be dissected (use diathermy for hemostasis) to allow the lobe to be lifted up easily
- In upper lobe resections surgical preparation should start at the anterior aspect of the hilus
- The pulmonary veins are better exposed from the dorsal aspect of the hilus
- The arteries are closed before the veins with non-resorbable sutures
- In right lower lobe resection attention must be paid to the origin of the middle lobe bronchus. It may be necessary to cut the right main bron-
Chus below the origin of the middle lobe bronchus and the bronchus of the lower apical segment separately

- Parenchymal bridges between the lungs may be divided using a commercial stapling device (Endo-GIA) or mattress sutures (eventually reinforced with pledges)
- Occlusion of the bronchus in small children is usually made using long-term resorbable sutures (in older children stapling devices may be used)
- Air leaks may be controlled by filling the thoracic cavity with warm saline solution, whilst the anesthetist inflates the lung; no air bubbles should arise
- Hemostasis should be checked
- Two thoracic tubes are placed in the chest, a long one at the front for air drainage and a short one at the back for fluid drainage

Fig. 16.8 Operative steps for lobectomy
16.1.7 Minimally Invasive Procedures

Indication for minimally invasive procedures
- Diagnostics and biopsy results (lung, lymphatic tissue, mediastinal masses)
- Debridement of fibrinopurulent pleural effusions
- Emphysematous blebs are usually found in the apical part of the upper lobes
- Benign mediastinal masses or pleurectomy, avoiding making lesions in the sympathetic chain especially in the apical area of the chest

Patients and team position
- Patient is usually in the standard lateral decubitus position
- Arm is elevated over the head
- Straight line principle (surgeon – target – monitor) (Fig. 16.9)
Ventilation

- Single lung ventilation (Carlens double lumen tube; smallest tube: 28 F; cannot be used in children below 30 kg bodyweight)
- Not mandatory for small children, but, if necessary, blockage of the ipsilateral main bronchus can be achieved using a Fogarty catheter (Fig. 16.10)
- Collapse of the lung can be achieved by CO₂ insufflation into the pleural cavity (max. flow: 1 l·min⁻¹; maximum pressure: 4–6 mmHg, 4 mmHg is better)

![Fig. 16.10 Single bronchus ventilation using a Fogarty catheter](image-url)
Port position

- Insert the telescope port (5 mm, 30°) in the middle axillary line, preferably opposite the area of interest to allow for the widest initial survey.
- Two to three working ports are inserted in the anterior and posterior axillary line, usually between the 4th and 8th interspaces (5–10 mm; valved trocars) (Fig. 16.11). Avoid liver and spleen puncture.
- Thoracic tubes can be inserted at the end of the procedure using the inferior port access ports.

Fig. 16.11 Port positions for minimally invasive procedures in the thorax
16.2 Chest Wall

16.2.1 Breast Diseases

Developmental breast disorders

- Polythelia; additional nipples and areolas may develop anywhere along the milk line from axilla to pubis (most common location of accessory nipples is on the chest below the actual breast)
- Breast hypoplasia
- Breast aplasia in Poland syndrome (absent or diminished underlying chest wall structures)
- Asynchronous thelarche: One breast bud may appear weeks to months ahead of the other (biopsy never indicted, just observation)
- Premature thelarche: breast development starts before the age of 8 (just observation)
- Swelling of the breast in the neonatal period (just observation)
- Virginal hypertrophy
- Unilateral hypertrophy

Gynecomastia

General considerations

- Unilateral or bilateral benign enlargement of the male breast mainly at puberty (greatest prevalence at 13–14 years; Fig. 16.12)
- Imbalances between estrogen and androgen concentrations
- Microscopically a proliferation of dense periductal connective tissue and marked hyperplasia of the ductal linings
- Enlargement may also occur in response to an excess of estrogen or decreased androgen production (Klinefelter syndrome, Leydig cell tumor, rarely because of Sertoli cell tumor, prolonged liver failure cirrhosis, sometimes seen in cases of hermaphroditism, in cases of severe malnutrition)
- Pseudogynecomastia due to adipositas
- Physiological slight hypertrophy is seen in the neonatal period (days 3–8) and during puberty
Signs

- Unilateral or bilateral enlargement of the male breast
- Palpation reveals a feeling of a disk of rubbery tissue (not palpable in pseudogynecomastia)
- Painful swelling is typical in adolescent boys (swelling of the gland, protrusion of the nipple, friction on the shirt)
- Pubertal gynecomastia generally resolves within 1 year

Preoperative work-up

- Ultrasonography of the testis and the liver
- Investigation of the testis, the liver, endocrinological work-up [human chorionic gonadotropin (hCG), luteinizing hormone (LH), testosterone, estradiol], chromosome analysis (Klinefelter syndrome), and history of drugs
- In cases of physiological gynecomastia, reassurance and follow-up at 1, 3, and 6 months are required to observe regression

Indication for operation

- Severe pain, tenderness
- Psychological distress
Operation
- Subcutaneous total mastectomy (reaching the fascia of the pectoral muscle) through a semicircular periareolar incision
- In severe cases mammary reduction plasty is necessary (McKissock technique)
- Suction drainage may be indicated

Postoperative care
- Remove suction drainage on the second postoperative day
- Remove skin sutures on the tenth postoperative day

Prognosis
- In cases of complete mastectomy, no recurrence

Mastitis

General considerations
- Bacterial (Staphylococcus, Streptococcus, Escherichia coli), unilateral inflammation of the breast
- Mastitis occurs more commonly after the thelarche
- Abscess formation is common

Signs
- Inflammatory painful enlargement of the breast

Preoperative work-up
- Palpation, fluctuance in cases of abscess formation
- Ultrasonography
- White blood cell count, C-reactive protein (CRP)

Indication for operation
- Rarely in mastitis of newborns (usually responds to intravenous antibiotics)
- Abscess formation
Operation
- Careful drainage via paramamillary small incision trying not to destroy breast parenchyma, especially in girls
- Material preservation for bacteriological work-up
- Careful debridement of necrotic tissue (sharp spoon)
- Rinsing with physiological sodium saline
- Insert a small rubber tube to keep incision open

Postoperative care
- Intravenous antibiotics
- Remove rubber drainage on the second postoperative day

Prognosis
- Good

Breast tumors
- Masses in prepubertal breast are nearly always benign
  - Fibroadenoma of the breast (in adolescence they are benign, solitary, firm, non-tender nodules; best therapy is local resection)
  - Hemangioma of the breast
- Phyllodes tumors and cancer are very rare (nipple discharge)
- Bone and soft tissue sarcomas of the chest wall

Preoperative work-up
- CT, MRI or positron emission tomography (PET)
- Exclude inflammatory lesions

Operation
- Malignant tumors should be resected en-bloc (muscles, ribs, pleura)
- Closure of the chest, performing a thoracoplasty (using a corium skin graft, an artificial resorbable net or a non-resorbable PTFE–Gore® patch)

Postoperative care
- Postoperative radiation and chemotherapy may be indicated
16.2.2 Pectus Excavatum

**General considerations**

- Condition in which the distance from the sternum to the vertebrae is decreased, giving a funnel-like appearance; located mostly in the distal part of the sternum (Fig. 16.13)
- Etiology is still unclear. There is a contiguity to a mechanical instability of the sternum and an overgrowth of the rib cartilage
- 90% are noticeable within the first year of life
- Occurs more frequently in boys (ratio 3:1)
- In the asymmetrical funnel the depression is deeper on the right side and the sternum is twisted
- In older patients (adolescents, adults) posterior angulation of the most anterior portion of the osseous part of the ribs occurs. This late stage should be avoided and surgical correction carried out before it occurs
- Mitral valve prolapse is frequently seen and sometimes also mild valve insufficiencies (compression and shifting of the heart to the left)
- 15%–20% show additional musculoskeletal abnormalities such as scoliosis
- 37% have family histories
Signs

- Pectus excavatum is well tolerated in infancy and childhood
- Psychological stress
- Palpitations
- Arrhythmias and tachyarrhythmia
- In cases of severe heart shift there is reduced stroke volume. Increased cardiac output is achieved primarily by increasing the heart rate because of the limited stroke volume
- Pain in the area of the funnel
- Exercise intolerance

Preoperative work-up

- X-ray a.p. and lateral with contrasted border of the funnel on the skin
- Determination of a funnel chest index
  - Vertebral index \( [VI = (\text{vertebral diameter} \times 100)/ (\text{sagittal diameter + vertebral diameter}); \text{normal value} \ 15–25\] \) (Fig. 16.14)
  - Fronto-sagittal index \( (FSI = \text{sagittal diameter} \times 100/\text{frontal diameter}; \text{normal value} \ 36–56)\)
    - Vertebral diameter \( (VD)\) = the diameter of the body of the vertebra directly behind the deepest point of the funnel
    - Sagittal diameter \( (SD)\) = the distance between the deepest point of the funnel behind the sternum and the ventral wall of the vertebra
    - Frontal diameter = the biggest distance between the ribs in the frontal plane
- CT scan (Fig. 16.15) or MRI
- Heart ultrasonography to detect insufficiencies or mitral valve prolapse
- 24-h ECG in different positions
- Pulmonary function
- Psychological evaluation (degree of psychological distress caused to the child)
Fig. 16.14 X-ray for determination of the vertebral index

Fig. 16.15 CT 3D funnel chest reconstruction
Indication for operation

- Psychological distress
- Arrhythmias, valve insufficiencies
- Exercise impairment
- Vertebral index >26

Operation

Reconstruction of the thorax wall can be performed by different operations. Minimally invasive methods are more accepted nowadays but do not always offer the expected result. Compared to the minimally invasive technique, the Ravitch–Welsh–Rehbein method is a more radical approach and its acceptance is limited. However, there are still patients suffering from a highly asymmetrical and/or very stiff funnel chest (e.g., adult patients) who benefit from this technique. Especially in mixed forms (pectus carinatum and excavatum) the techniques may be combined (resection of rib cartilage in the carinatum area and elevation using the retrosternal bar in the excavatum area).

Nuss procedure

- This is a minimally invasive surgical correction (Fig. 16.16) using an individually curved C-shaped steel bar with lateral stabilizers to elevate the sternum
- Via two lateral incisions the bar is placed behind the sternum at the area of the deepest point of the depression
- In older patients two bars as well as a partial horizontal sternotomy at the upper median edge of the funnel may be necessary
  - If possible, meet the requirements for single lung ventilation
  - The length of the pectus bar is determined by measuring the distance from the right to the left midaxillary line minus 1–2 cm to allow for the fact that the bar passes under the sternum
  - Two bilateral short incisions are made in the midaxillary lines followed by mobilization of the subcutaneous tissue
• A thoracoscopy (e.g., 5 mm port) is inserted usually from the right lateral incision to visualize the deepest point of the funnel and the introducer is inserted.

• For optimal bar placement the intercostal space should be perforated within the edges of the funnel using the introducer. Take care to avoid making lesions to the internal thoracic artery, the lungs, the pericardium or the heart.

• A strong tape is tied to the tip of the introducer, which is pulled through the thorax behind the sternum.

• The individually prepared C-shaped bar is then bound to one side of the tape and the bar is positioned behind the sternum with both ends facing anteriorly, i.e., the convexity facing posteriorly.

• Then the bar is rotated 180° to raise the sternum and anterior chest wall, and is then fixed with sutures to the lateral thoracic muscles (M. serratus) using a single stabilizer plate on one side. The latest generation of single-piece pectus bars have one integrated stabilizer lash which cannot be dislocated.

• No chest tubes are normally necessary, however one could use them.

**Fig. 16.16a–g** Operative steps for the Nuss procedure. **a** The patient has a symmetrical funnel chest. **b** Marking the preparatory landmarks: black spots are intercostal port sites. **c–g** see next page
Fig. 16.16 (continued) Operative steps for the Nuss procedure. 

- c The intercostal perforations are within the edge of the funnel. 
- d The C-shaped bar is rotated 180° to raise the sternum and anterior chest wall. 
- e Final aspect. 
- f X-ray (a.p.) after implantation of the bar. 
- g Profile X-ray after implantation of the C-shaped bar.
Rokitansky modifications

- For simple funnel chest
  - The above steps for the Nuss procedure are followed, however a single-piece pectus bar with an integrated stabilizer lash is used
- For stiff curved sternum
  - A horizontal partial sternotomy at the upper edge of the funnel is recommended
  - A small, third, median incision below the xiphoid process is made to introduce a sharp bone retractor (Rochards retractor) that elevates the sternum over a long period and helps to mobilizes the retrosternal adhesions between the sternum and pericardium. A mediastinoscopy could be performed
  - Where the thorax is extremely stiff, lateral thoracoscopy should be performed in order to conduct chondrotomies (the dissection or surgical division of cartilage) (Fig. 16.17) on involved ribs using electrocautery
  - Sometimes the Nuss procedure has to be completed by cartilage resections

Fig. 16.17 Operative steps for thoracoscopic chondrotomy
Postoperative care

- Analgesics are necessary particularly in the first postoperative week (piritramide 0.1 mg·kg$^{-1}$·bodyweight·h$^{-1}$ or preferably patient-controlled analgesia, PCA)
- Peridural or epidural pump-controlled anesthesia is useful in the first days postoperatively
- The patient should start breathing exercises as soon as possible
- Chest tubes should be taken out as soon as possible
- The bar should stay in place for at least 2–3 years
- The advantages of this technique over the Ravitch–Welsh–Rehbein method are the short duration of the operation, the short hospital stay, and the relatively short postoperative restriction on physical activity
- Difficulties may occur if this technique is used on patients suffering from an extremely asymmetric funnel (it gives a cosmetically poor result because of protrusion on the parasternal area of the left thorax)

Ravitch–Welsh–Rehbein procedure

- The sternum is elevated by partial bilateral resection of the elongated rib cartilages (ribs 3–7), sternotomy (wedge osteotomy), and stabilization using Rehbein metal struts (Fig. 16.18)
- This operation should not be performed below the age of 4 years (possible impairment of chest growth caused by a lesion at the costochondral junction)
  - A horizontal or sagittal incision is made in the central area of the funnel
  - The skin and pectoralis major are mobilized synchronously and elevated
  - The rib cartilage to be resected is determined and incisions made anteriorly in the perichondral tubes using electocautery. Especially in young patients complete resection of cartilage should be avoided, as the costochondral junction is important for growth
  - Pleural lesions occur most commonly on the 3rd or 4th right ribs
  - Take care to avoid making a lesion in the internal mammary vessels
• The xiphoid is divided from the lower sternum
• A partial horizontal wedge osteotomy at a level above the last deformed cartilage is performed
• A fibrin-coated collagen patch may be used to achieve hemostasis
• Fixation of the osteotomy using wire suture, inducing elevation of the sternum
• Bilateral insertion of the Rehbein struts into the bone marrow of one or two pairs of ribs (e.g., 3rd or 4th ribs). They are medially joined to each other by wire and/or non-resorbable sutures creating a metal arch anterior to the sternum
• The sternum is sewn to the artificial Rehbein strut arch to secure it in a forward-facing position
• The xiphoid is fixed again to the sternum and the pectoral muscles are approximated and sewn at the middle above the elevated sternum. If tension prevents complete approximation, a patch (e.g., Gore soft tissue®) should be used
• A submuscular and/or subcutaneous suction drain may be placed for 2 days postoperatively
Fig. 16.18 Operative steps for the Ravitch procedure
Postoperative care
- Remove pleural drainage in the first postoperative week (when the quantity of drained fluid is less than 100 ml·day\(^{-1}\)) and the suction drainage around the second postoperative day
- Intravenous analgesics (e.g., piritramide 0.1 mg·kg\(^{-1}\) bodyweight·h\(^{-1}\)) and antibiotics
- Start respiratory exercises as early as possible
- Full muscular training can start after complete healing once a mechanically resistant scar has developed (especially for thoracic and abdominal muscles; swimming is recommended), starting the second postoperative month
- The Rehbein struts should stay in place for at least 6 months

Silicon cushion
- A plastic cushion may be implanted in the funnel for cosmetic reasons, but due to growth the results are uncertain. This technique cannot be recommended because it does not resolve the symptoms and the physical as well as the respiratory and hemodynamic problems

Prognosis
- Recurrence rate is up to 5% or 10% (higher in patients with Marfan syndrome)
- Delaying surgery until the child has begun the pubertal growth spurt is beneficial

16.2.3 Pectus Carinatum

General considerations
- Protrusion deformity of the sternum (Fig. 16.19); less frequent than pectus excavatum
- Etiology remains unclear
- The deformity appears during adolescence and is noted very rarely at birth
- Occurs more frequently in males (ratio 3:1)
- Cardiopulmonary effects have not been demonstrated
- 15% show additional musculoskeletal abnormalities such as scoliosis

Fig. 16.19 Typical pectus carinatum

**Signs**
- Psychological stress
- Pain in the area of the protrusion (frequent local trauma)

**Preoperative work-up**
- X-ray a.p. and lateral
- CT scan or MRI

**Indication for operation**
- Psychological stress
- Local pain
Operation
- Depression of the sternum is achieved by partial bilateral resection of the elongated rib cartilages and sometimes additional sternotomy (wedge osteotomy)
  - A horizontal or sagittal incision is made in the central area of the defect
  - The skin and pectoral muscles are mobilized and elevated
  - The rib cartilages to be resected are determined and an incision made into the perichondral tubes anteriorly using electocautery. Especially in young patients complete resection of the cartilage should be avoided as the costochondral junction is important for growth
  - Pleural lesions most commonly occur on the 3rd or 4th right ribs
  - Take care to avoid making a lesion on the internal mammary vessels
  - A partial horizontal wedge osteotomy and fracture of the anterior cortex of the sternum is sometimes necessary
  - For blood hemostasis fibrin-coated collagen patches may be used

Postoperative care
- The rib cartilage is remodeled after a period of about 2 months
- Start respiratory exercises as early as possible
- Full muscular training can start after complete healing has occurred, once a mechanically resistant scar has developed (especially thoracic and abdominal muscles; swimming is recommended), starting the second postoperative month

Prognosis
- Good results with rare recurrence

16.2.4 Sternal Cleft

General considerations
- Developmental defect of the sternum with incomplete fusion of the sternal bars in the midline
- Compared to pectus excavatum, this is a very rare deformity
Chapter 16

- Upper, lower, partial as well as complete clefts have been described
- Upper defects are the most frequent
- Combination with ectopia cordis is possible

**Signs**
- Partial defects may be asymptomatic
- Protrusion from the defect during crying
- Depression of the defect during inhalation
- In large defects paradox breathing and respiratory insufficiency may occur

**Preoperative work-up**
- Thoracic X-ray, CT scan or MRI
- Cardiac ultrasonography examination

**Indication for operation**
- Signs of respiratory insufficiency
- Lower clefts of the sternum with the risk of cardiac trauma
- Sternal cleft with ectopia cordis
- Large clefts with signs of herniation of thoracic organs

**Operation**
- If repair is considered it should be within the first year of life
- Repair is performed in order to achieve mechanical stability and provide protective coverage of the heart. Artificial patches may be useful (e.g., Gore® dual mesh or soft tissue patch)
- Sternal cleft closure with low tension may be achieved by making additional oblique incisions through the costal cartilages as well as a wedge resection of the sternal cartilage at the sternal end of the defect to allow approximation of the two sternal halves

**Postoperative care**
- The child should be kept on artificial ventilation for 1 week
Prognosis

- Excellent results when approximation is possible with minimal tension

### 16.3 Pleura and Pleural Cavity

#### 16.3.1 Pneumothorax

**General considerations**

- Air within the pleural space
- Spontaneous pneumothorax is especially common in male teenagers, caused for example by rupture of a small lung bubble without any lung disease
- Risk of recurrence is 16% after the first and 80% after the third episode
- Pneumothorax may be caused by trauma (lung injured by broken ribs), a penetrating chest wall injury (sucking chest wound), injury to the tracheobronchial tree, a severe asthma attack, pulmonary infections with development of an air fistula, artificial ventilation, resuscitation, or by a congenital cystic lung disease
- Induced by a valve-like mechanism, tension pneumothorax is caused by increasing accumulation of air within the pleural cavity leading to a mediastinal shift which develops into a dangerous situation

**Signs**

- Mild dyspnea or no signs in cases of mild spontaneous pneumothorax
- Chest pain and shortness of breath
- Varying degrees of respiratory distress
- Reduced or absent breath sounds on the side of the pneumothorax
- In patients suffering from tension pneumothorax (in addition to respiratory insufficiency) hemodynamic deterioration (neck vein distension in normovolemic patients) occurs
Preoperative work-up

- Chest X-ray (misinterpretation of medial margin of the scapula with the lung surface)
- CT scan if necessary

Therapy

- Observation in cases of minimally closed stable pneumothorax. Supplemental oxygen may be necessary

Chest tube insertion

- If significant signs occur insert a chest tube [2nd or 3rd intercostal space in the midclavicular line (classic technique) or in the midaxillary line at the level of the breast nipples] to provide a water seal drainage (Bülau drainage)
  - Make a small skin incision with the patient under general anesthetic
  - Perforate the intercostal space slowly via the upper edge of the rib with the tip of a clamp
  - Remove the clamp and insert the chest tube (reinforced by a trocar) through the prepared canal
  - Remove the trocar and fix the tube with sutures (size: 3-0 to 1). A second purse suture is placed to close the skin after the chest tube has been removed
  - Connect the chest tube to the water-sealed drainage system (Bülau system)
  - Induced by breathing movements, air bubbles should pass through the water-sealed drainage system

Operation

- Surgical therapy should be considered under the following conditions:
  - If the air leak is persistent over a period of 1 week of water-sealed drainage
  - If the CT scan shows an underlying lung disease
  - In the case of a second episode
  - If full lung expansion is not possible
Surgical methods
- Closure of the air leak (suture or stapling with bleb resection) and/or parietal pleurectomy (apical and anterolateral areas) via thoracotomy or thoracoscopic surgery. Pulmonary blebs may be overlooked when using just the thoracoscopic approach.
- In cases of multiple recurrence, intrapleural instillation of tetracycline (for pain control instill 2% lidocaine into the chest tube 30 min beforehand) to obliterate the pleural cavity (pleurodesis) may be indicated.

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease to below 20–50 ml within a 24-h period.
- Start respiratory exercises and physiotherapy as soon as possible.

Prognosis
- Lung function may be permanently impaired if the lung is not completely re-expanded.
- Children younger than 9 years of age are unlikely to develop a recurrence.
- After simple drainage therapy older children have a mean recurrence rate of about 50% (16% after the first, 80% after the third episode).
- Thoracotomy, resection of the blebs, and pleurectomy together form the most suitable surgical method to avoid recurrence.

16.3.2 Empyema

General considerations
- Bacterial infection of a pleural effusion following pneumonia. Pneumococci and staphylococci remain the predominant organisms.
- In two-thirds of cases this follows failure of medical therapy for parapneumonic effusions.
- Empyema can be due to thoracic surgery or trauma.
- A bronchopleural fistula may be involved (infected fluido-pneumothorax).
Classification

- There are three stages of development, distinguished by radiographic, clinical and pleural fluid characteristics (Table 16.1)

Table 16.1 The three stages of development of empyema (exudative, fibrinopurulent, and organizing). (LDH Lactate dehydrogenase, WBC white blood cell count)

| Phase           | Laboratory findings | Characteristic                                           |
|-----------------|---------------------|---------------------------------------------------------|
| Exudative       | Low WBC             | Fluid in the pleuropulmonary space                       |
|                 | Low LDH             |                                                          |
|                 | Normal glucose      |                                                          |
|                 | Normal pH levels    |                                                          |
| Fibrinopurulent | Increased WBC count | Fibrin depositions producing a “peel”                   |
|                 | Increased LDH (>1000 U·l⁻¹) | Limited lung expansion                             |
|                 | Low glucose (<40 mg·dl⁻¹) |                                                          |
| Organizing      | High WBC count      | Thick fibrous inelastic “peel” with scar formation      |
|                 | High LDH            | Lung entrapment                                         |
|                 | Very low glucose   | Erosion of the lung or the chest wall                   |

Signs

- Tachypnea, dyspnea
- Fever
- Productive cough
- Tachycardia
- Chest pain
- Reduced mobility of the chest wall at the affected site
- Decreased breath sounds and dullness to percussion on the involved side

Preoperative work-up

- Chest X-ray
- CT scan or MRI in order to differentiate between empyema and lung abscess
Ultrasonography to determine the stage of empyema (Table 16.1) according to detection of the thick pleural peel

- Ultrasonography- or CT-guided needle thoracocentesis
- Chest tube drain (see “Thoracoscopy” below)
- Aspirated fluid should be analyzed (Gram stain, aerobic and anaerobic cultures, search for mycobacteria, and fungi)
- White blood cell count (WBC), glucose level, lactate dehydrogenase (LDH), pH
- Non-specific leukocytosis, drastically increased C-reactive protein levels

**Therapy**

- In the early stages (exudative phase of parapneumonic empyema) administration of antimicrobial agents alone may be sufficient
- Conservative therapy has to be successful within the first 72 h

**Indication for operation**

- Late stage II (fibrinopurulent effusion)
- Effusion of more than 3 cm on the X-ray that does not improve despite aggressive treatment (i.v. antibiotics, multiple drainage) over a period of 72 h
- Bronchopleural fistula

**Thoracoscopy**

- Especially in young children, for whom anesthesia is necessary in order to insert a chest tube, it is better to perform a thoracoscopy instead
  - Make a small skin incision after induction of general anesthesia
  - Introduce the trocar
  - Aspirate as much effusion as possible
  - Visualize the thoracic cavity
  - The fibrinous septa can be destroyed with the scope to make the thorax one cavity
  - Irrigate with at least 2 l of warm saline
  - Place the tube
Operation

- Most empyemas require invasive interventions (large size chest tube drainage, thoracotomy with decortication)
- It is better to drain the chest and sometimes more than one chest tube is necessary to ensure adequate drainage
- If simple drainage fails intrapleural fibrinolytic agents (250,000 units of streptokinase or urokinase in 100 ml of sterile saline; chest tubes remain clamped for at least for 4 h) may be useful. Afterwards continuous suction on the chest tubes is necessary to increase the drained fluid volume and to expand the lung
- Thoracoscopy is useful in the treatment of multiloculated empyema when there is no thick visceral pleural peel. Simple debridement in the middle exudative phase is possible
- Open drainage, lavage of the pleural cavity via thoracotomy combined with decortication is indicated in the late fibrinopurulent and the organizing phases. The peel on the visceral pleura becomes a barrier to expansion, entrapping and immobilizing the lung
- Decortication with removal of fibrin leaving the visceral pleura largely intact allows re-expansion of the lung
- In cases of bronchopleural fistula thoracotomy, open drainage and resection of the involved lung parenchyma is always necessary (usually a lobectomy). Bronchus closure may be reinforced by a dorsally based intercostal muscle flap

Postoperative care

- Chest tubes may be removed if the lung is fully expanded and drainage volumes fall below 20–50 ml within a 24-h period
- Antibiotic management based on cultures should be continued until the chest tubes are removed and the pulmonary infection is controlled

Prognosis

- A lung entrapment from empyema is uncommon if the patient receives proper and timely (in terms of the three phases) treatment
16.3.3 Hemothorax

General considerations
- Blunt (rib fractures) or penetrating trauma may produce a hemothorax
- Frequently accompanied by a pneumothorax
- Bleeding from the intercostal vessels, internal mammary vessels, or great thoracic vessels
- A mediastinal shift is possible

Signs
- Chest pain
- Decreased or no breath sounds on the involved side
- Dullness to percussion on the involved side
- Respiratory distress
- Depending on the blood loss (25% loss: prehypotensive; 40% loss: hypotensive – hypovolemic shock) there may be an increased heart rate
- Shock signs, i.e., unconsciousness, decreased capillary refill, cold extremities, skin color, decreased urinary output

Preoperative work-up
- Physical examination
- Monitor the respiratory and circulatory status (blood gases, blood pressure, red blood cell count, RBC)
- Blood examination (RBC, match the patient’s blood type)
- Ultrasonography, looking for effluent
- Chest X-ray in an upright position (hemothorax may be missed in the supine position)
- Repeated chest X-ray (CT) to control drainage

Therapy
- Immediate volume resuscitation is necessary initially with 20 ml·kg\(^{-1}\) of crystalloid. The aim is to decrease the heart rate and increase the urine output (1–2 ml·kg\(^{-1}\)·h\(^{-1}\))
- Red blood cell transfusion (initial 10 ml·kg\(^{-1}\))
- Chest tube insertion (early placement, large size for full drainage)
Indication for operation

- Ongoing hemorrhage, more than 20% of child’s blood volume drained (blood volume: 90 ml·kg\(^{-1}\) in a newborn, 80 ml·kg\(^{-1}\) in 1 year old, 70 ml·kg\(^{-1}\) in early adolescence)
- Failure of complete drainage after several days

Operation

- Limited thoracotomy
- Evacuation of the clot
- Removal of pleural peel
- Two chest drains should be placed

Postoperative care

- Chest tubes may be removed if the lung is fully expanded and drainage volumes fall below 20–50 ml within 24 h
- Antibiotics

Prognosis

- Persistent blood in the thorax increases the risk of empyema and lung entrapment

16.3.4 Chylothorax

General considerations

- Accumulation of chyle in the pleural space
- Physiologically, the chyle from the right and left lumbar trunk flows into the left subclavian vein via the cisterna chyli and the thoracic duct (aortic hiatus, at the level of the 5th thoracic vertebra inclining to the left)
- The thoracic duct has smooth muscle in its wall and valves
- Malformations of the thoracic duct, birth trauma or an unclear etiology are commonly given as causes of pleural effusion in the first few days of life
Insertion of a central venous line, previous cardiac surgery or operations on the mediastinum, chest tubes, blunt thoracic trauma, pneumonia, and neoplasms may also induce chylothorax.

- Impaired immunological status due to chronic loss of T-cells
- Fluid and electrolyte imbalance, malnutrition
- Possible mediastinal shift

**Signs**

- Tachypnea
- Decreased or no breath sounds and dullness to percussion on the involved side
- Lymphocytopenia as a consequence of chyle loss

**Preoperative work-up**

- Physical examination
- Monitoring of the respiratory and circulatory status (blood gases, blood pressure, RBC)
- Ultrasonography
- Chest X-ray in an upright position
- Thoracocentesis (aspiration of a milky fluid after oral nutrition, chylomicrons, elevated numbers of lymphocytes)

**Indication for operation**

- Operative therapy is not always successful and difficult, so waiting reduces the need for surgical intervention
- If chyle flow continues (more than 15 ml·kg$^{-1}$·day$^{-1}$) for a period of 1 month (patient on total parenteral nutrition)

**Therapy**

- Repeated thoracocentesis or chest tube to expand the lung
- Total parenteral nutrition (no oral intake) to drastically decrease the chyle flow
- Feedings restricted to medium chain triglycerides
Operation
- Detect the lesion by thoracoscopy or thoracotomy
- Place surgical clips or multiple sutures, possibly ligation of the thoracic duct (main duct) above and below the leak
- A pleuroperitoneal shunt may be effective
- In resistant cases pleurodesis may be helpful

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes fall below 20–50 ml
- No suction on the chest tubes
- Antibiotics

Prognosis
- Most chylothoraces resolve spontaneously after some weeks

16.4 Laryngotracheal Lesions

16.4.1 Laryngomalacia

General considerations
- Immaturity of the larynx with problems in infancy in 60% of cases
- Male preponderance
- Shortened aryepiglottic folds, omega- or tubular-shaped epiglottis, anteriorly and medially aligned collapsing movements of the arytenoid cartilages, excessive tissue in the supra-arytenoid area
- Increasing inspiratory effort followed by increasing obstruction

Signs
- Stridor (inspiratory fluttering noise, especially in the supine position), sometimes only during exercise. Expiration is usually noiseless
- Respiratory difficulties usually present within the first 2 weeks of life and signs may increase during the first months
- Condition exacerbated by crying
- Sometimes feeding problems
- Signs usually resolve at the age of 2 years with a benign clinical course

**Preoperative work-up**
- Physical examination
- Respiratory function (blood gases, oxygen saturation monitoring)
- Direct flexible laryngo-bronchoscopy (with the child under topical or general anesthesia, but breathing spontaneously, the scope is passed through the nose and the epipharynx). In severe cases, the vocal cords cannot be seen because of supraglottic collapse

**Indication for operation**
- Respiratory distress
- Phases of obstructive apnea
- Failure to thrive

**Operation**
- Tracheostomy
- Dissection (CO₂ laser) of the shortened right and left aryepiglottic fold
- Supraglottoplasty: unilateral or bilateral removal of supraglottic obstructive tissue

**Postoperative care**
- Antibiotics

**Complications**
- Postoperative supraglottic stenosis after removal of too much tissue

**Prognosis**
- Usually good, self-limiting condition
16.4.2 Laryngotracheal (Subglottic) Stenosis

General considerations

- Congenital malformation
- Acquired, usually after long-term artificial ventilation in neonates by a tube-related mucosal lesion in the area of the cricoid cartilage (impaired blood perfusion due to a tight fitting tube)

Classification

| Obstruction | None | 50% | 70% | 99% |
|-------------|------|-----|-----|-----|
| View        | ![Diagram](image) | ![Diagram](image) | ![Diagram](image) | ![Diagram](image) |

Signs

- Stridor and respiratory distress
- Recurrent croup-like infections
- Conjoined gastroesophageal reflux is possible

Preoperative work-up

- Respiratory function (blood gases, oxygen saturation monitoring)
- Direct flexible laryngo-bronchoscopy in a spontaneously breathing child. Intubation should be avoided especially when high-grade stenosis is suspected because of the risk of complete obstruction due to mucosal swelling. Examination under conditions for urgent tracheotomy. Endoscopy should be repeated every 6 months
- Plain X-rays
- CT or MRI is better than X-rays, especially for measuring the length of the stenosis
Differential diagnosis
- Hemangioma
- Rarely lymphangioma

Indication for operation
- Respiratory distress, phases of obstructive apnea and failure to thrive
- Stenosis grade III and more

Operation
- Tracheotomy under jet ventilation (this allows the child time to grow, it allows the stenosis to mature, however language skills may be delayed)
- Laser incision/ablation in highly selected cases of low-grade stenosis due to possible induction of scar tissue. Four quadrant incisions followed by dilatations
- Gentle dilatations in early stages including systemic steroids
- Grade III and IV lesions require open reconstruction:
  - Anterior cricoid split
  - Anterior and/or posterior cricoid split, extended 5–10 mm into the tracheal wall
  - Costal cartilage expansion, if required distraction is >3 mm
  - Perichondrium should be removed from the outer surface and preserved at the inner surface for improved epithelialization

Postoperative care
- Repeated endoscopies after 4 weeks, 3 months, 6 months, 12 months, and 24 months
- Antibiotics for 3–4 weeks
- Treat gastroesophageal reflux if necessary

Prognosis
- Good in grade I and II
- Moderate in grade III and IV
16.4.3 Benign Laryngeal Tumors

Papilloma

General considerations
- The most common benign neoplasm of the larynx
- Multiple locations (vocal cords and the anterior commissure), with possible extension into the distal airway
- No histological differences between the juvenile and adult forms
- Frequently detected between the ages of 2 and 5 years
- Caused by the human papilloma virus (HPV-6, HPV-11)
- The mothers of 50% of children with recurrent respiratory papillomas had active cervical papillomas at the time of the child’s birth

Signs
- Hoarseness
- Respiratory distress

Preoperative work-up
- Respiratory function (blood gases, oxygen saturation monitoring)
- Direct flexible laryngo-bronchoscopy

Indication for operation
- Maintenance of an open airway (20%–30% require tracheotomy)

Therapy
- Antiviral agents (interferon α) with variable results

Operation
- Laser ablation/vaporization (complications: scar tissue, fixation of the vocal cord)
- Tracheotomy

Prognosis
- Recurrence is typical over a certain period
- There is no universally effective treatment
**Subglottic Hemangioma**

**General considerations**
- Rarely present at birth; develops within the first months of life
- 50% also have cutaneous hemangiomas
- Rapid growth in the first few months
- Regression by the age of 1 year (complete resolution by the age of 5 years)
- Usually a history of complete resolution

**Signs**
- Stridor (in the early stages: inspiratory stridor)
- Respiratory distress

**Preoperative work-up**
- Respiratory function (blood gases, oxygen saturation monitoring)
- Direct flexible laryngo-bronchoscopy showing a compressible lesion, usually arising from the posterolateral aspect of the subglottis
- Abdominal ultrasonography to detect liver hemangiomas
- Cardiac ultrasonography

**Indication for operation**
- Maintenance of the airway

**Therapy**
- Steroid (1 mg·kg\(^{-1}\)·day\(^{-1}\))

**Operation**
- Tracheotomy to bypass the lesion and wait for regression
- Intralesional laser vaporization (Nd:YAG laser) with postoperative intubation for about 1 week

**Prognosis**
- Mostly spontaneous involution
16.4.4 Tracheomalacia

General considerations

- Intrinsic defect of the trachea. Inability of the cartilages to keep the trachea open during respiration
- Unusually an obstruction; due to positive intrathoracic pressure the flattened trachea collapses during expiration
- In patients after corrected esophageal atresia type IIIb, the site of collapse is usually above the entry of the esophagotracheal fistula
- Unusually severe signs as long as more than 20% of the lumen remains open during the breathing cycle

Differential diagnosis

- Compression from outside, due to vascular malformations (aberrant innominate artery, double aortic arch, pulmonary artery sling)
- Compression from outside, due to cardiac malformations (left pulmonary artery, left atrium, right pulmonary artery)

Signs

- Expiratory stridor
- Respiratory distress

Preoperative work-up

- Respiratory function (blood gases, oxygen saturation monitoring)
- Direct flexible laryngo-bronchoscopy (with the child under local or general anesthetic, but breathing spontaneously)
- CT or MRI

Indication for operation

- Maintenance of the airway
Operation
- Tracheotomy with an extra long cannula to bypass the lesion
- Aortopexy
  - Left thoracotomy
  - Resection of the left thymus lobe
  - The aortic arch is sutured to the sternal periosteum with three sutures making several attachments to the aortic adventitia. The sutures are tied while the sternum is manually pressed towards the heart so that when they are released the anterior tracheal wall stretches
- Endoluminal stents (problematic because of difficulties with removing and changing the device, and with granulation tissue; in future perhaps resorbable stents could be the solution)

Prognosis
- Good in cases treated with simple aortopexy

16.5 Lung

16.5.1 Foreign Body Aspiration

General considerations
- Patients present aged between 1 and 3 years, most commonly at age 2 (toddlers)
- Aspirated material: peanuts, popcorn, seeds, pieces of meat, or other small objects
- Larger objects may lodge within the glottic opening (cause of death, especially in the group around the age of 1 year)
- Smaller objects are usually inhaled into the more distal branches of the airways (frequent location: right or left main bronchus, right and left bronchi of the lower lobes)
- Significant local inflammation usually starts 2–3 days after aspiration
Signs

- Coughing, wheezing, suprasternal retractions
- Respiratory distress, cyanosis
- In cases of minor aspiration, unspecific signs comparable to those seen in respiratory infections
- Pneumonitis after prolonged occlusion
- Atelectasis after complete occlusion
- Tracheal deviation, mediastinal shift

Preoperative work-up

- Full history (extraordinary episode of coughing, peanut ingestion)
- Chest X-ray with overinflation of the involved lung (air entrapment due to a ball-valve effect), possible mediastinal shift (Fig. 16.20)
Therapy
- Heimlich maneuver in children older than 1 year (designed to force the diaphragm upward, which generates increased intrathoracic pressure) to dislodge a large foreign body from the larynx

Operation
- Rigid laryngo-bronchoscopy under general anesthesia, avoiding high ventilatory pressures which could drive the foreign body further into the airway
- Extraction of the foreign body (effective in 95% with a complication rate of less than 1%) with forceps, alligator forceps, peanut forceps, balloon catheter, basket forceps, suction and lavage catheters
- Very rarely thoracotomy, bronchotomy or sometimes localized lung resection is necessary

Postoperative care
- Plain chest X-ray
- In questionable cases repeated bronchoscopy

Prognosis
- Good, directly related to timely diagnosis and treatment

16.5.2 Shock Lung (Acute Respiratory Distress Syndrome)

Definition of acute respiratory failure
- Inadequate oxygenation ($\text{PaO}_2 < 55 \text{ mmHg, FiO}_2 > 0.5$)
- Inadequate ventilation ($\text{PaCO}_2 > 50 \text{ mmHg}$)
- Acute lung injury (ALI): $\text{PaO}_2/\text{FiO}_2 < 200 \text{ mmHg}$
- Acute respiratory distress syndrome (ARDS): $\text{PaO}_2/\text{FiO}_2 < 300 \text{ mmHg}$, static compliance $< 40–50 \text{ l·cmH}_2\text{O}^{-1}$
Classification

- Hypoxemic respiratory failure
  - Inadequate oxygenation (low or normal \( PaCO_2 \))
  - Acute lung injury
  - Systemic inflammatory reaction (SIRS)
  - Extracorporeal circulation
  - Shock of any cause, trauma
  - Systemic infection: sepsis
  - Pulmonary inflammation: pneumonia, inhalation injury, aspiration
  - Pulmonary infection: pneumonia
  - Lung contusion

- Hypercapnic respiratory failure (ventilatory failure)
  - Hypercapnia plus acute respiratory acidosis
  - \( PaCO_2 = kVCO_2/V_T (1-V_D/V_T) \)
  - \( CO_2 \) production \( (VCO_2) = V_A \times F_A CO_2 \)
  - Fractional concentration of \( CO_2 \) in the alveolar gas \( (F_A CO_2) \)
  - Alveolar volume \( (V_A) = VCO_2/F_A CO_2 \)
  - Tidal volume \( (V_T) = V_D + V_A \)
  - Minute ventilation (=\( V_T \times RR \))
  - Dead space \( (V_D) = V_E \times [(PaCO_2-P_E CO_2)]/PaCO_2 \)
  - \( ↑ \) \( CO_2 \) production \( (VCO_2) \): fever, sepsis, pain
  - \( ↑ \) \( V_D/V_T \) (increased \( V_D \)): ARDS, bronchoconstriction
  - \( ↓ \) Minute ventilation
  - Ventilatory pump dysfunction
  - Central respiratory drive (traumatic brain injury, sedatives, anesthetics, etc.)
  - Abnormal respiratory efferents (spinal cord injury, etc.)
  - Abnormal chest/abdominal wall: pleural fluid, ascites, scoliosis, etc.
  - Upper air way obstruction

Pathophysiology

- Diffuse alveolar injury
- Heterogeneous alveolar injury (different time constants)
- Alveolar consolidation (atelectasis, dependent lung regions, ↓ functional residual capacity)
- Alveolar overstretching (non-dependent regions)
- Shear trauma (between consolidated and overstretched lung areas)
- Pulmonary hypertension: vasoconstriction, microthrombi, obstruction of the airways with mucous that is then infiltrated with leukocytes to form a plug (leuko-plugging), interstitial edema
- ↓ Hypoxic pulmonary vasoconstriction: ventilation/perfusion mismatch
- ↑ Intrapulmonary shunting (no significant improvement with FiO₂ 1.0)
- Endothelial dysfunction: mediator imbalance, inflammation, procoagulatory state
- Epithelial injury: surfactant deficiency, fluid and ion flux across the membrane
- Alveolar–capillary barrier lesion
- Bronchial obstruction (edema, secretions, terminal airway instability, spasm)
- ↑ Extravascular lung water (EVLW): permeability, decreased lymphatic flow
- ↓ Pulmonary compliance (surfactant dysfunction, edema, hyaline membranes) \( C = \frac{\Delta V}{\Delta P} \)
- ↓ Chest wall compliance (edema, injury)
- ↓ Abdominal wall compliance (abdominal compartment syndrome)
- Ventilator-induced lung injury (shear trauma, overstretching)
- Air leak (shear trauma, over distension)
- Fibroproliferative alveolitis

**Signs**

- Cardiorespiratory
  - Tachypnea, dyspnea, ↑ labored breathing
  - Pallor, cyanosis, stridor, retractions
  - Coarse lung crackles
  - Tachycardia, hemodynamic instability, poor skin perfusion
- Distant organ dysfunction (systemic inflammatory response)
  - Disseminated intravascular coagulation (DIC)
  - Encephalopathy (agitation, altered mental status)
  - Acute renal failure
  - Acute liver failure
  - Sepsis (gut: bacterial translocation, lung: ventilator-induced lung injury)
  - Hyperglycemia

**Investigations**
- Arterial blood gases (ABGs): hypoxemia, hypocapnia, acute respiratory alkalosis or acute metabolic acidosis
- Chest X-ray (bilateral infiltrates, pleural effusions)
- CT scan of the thorax, lung, abdomen
- Cultures (sputum, blood, effusion)
- Respiratory mechanics

**Therapy**
- Non-invasive correction of hypoxemia, hypercapnia, O₂ supplementation, CPAP, BiPAP (nasal airway, face mask)
- Mechanical ventilation
  - Open the lung and keep the lung open, inspiratory alveolar recruitment: plateau pressure ($P_{pl}$), tidal volume ($V_T$) expiratory alveolar recruitment: PEEP
  - Preventing lung injury: $V_T \leq 6 \text{ ml·kg}^{-1}$, $P_{pl} < 3.5 \text{ kPa (36 cmH}_2\text{O)}$ (prevents lung overinflation) $V_T$, peak inspiratory pressure (PIP) minimizing (overstretching, shear injury) PEEP optimization (early sufficient expiratory recruitment). IRV (inverse ratio ventilation, I:E > 1:1): increasing – inspiratory time (Ti), ↑ mean airway pressure ($P_{mean}$), ↓ PIP, auto-PEEP
  - PCV (pressure control ventilation), PSV (pressure support ventilation) better than volume controlled MV
• Early spontaneous breathing (CPAP/ASB, BiPAP)
• FiO$_2$ reduction before pressure reduction PIP/PEEP (alveolar stability)
  • Permissive hypercapnia (PaCO$_2$: 50–60 mmHg, arterial pH >7.25)
  • Permissive hypoxemia (SpO$_2$: 88%–92%)
• High-frequency ventilation, early indication if FiO$_2$ >0.5/4 h on conventional mechanical ventilation (CMV), percussive (VDR4) or oscillating ventilation
• Kinetic therapy
• Selective pulmonary vasodilatation: inhalation of NO, prostacyclin
• Anti-inflammatory therapy
  • Prostacyclin inhalation
  • Steroids
  • Ibuprofen
• Antiproliferative therapy with steroids
  • Surfactant
  • Reduction in EVLW: negative fluid balance
  • β-agonist (bronchodilatation, ↑ interstitial and alveolar fluid transport)
  • Extracorporeal membrane oxygenation (ECMO) support if shunt >30%, FiO$_2$>60%, compliance <0.5 ml·cmH$_2$O$^{-1}$·kg$^{-1}$
  • Diagnosis and treatment of complications (air leak, pneumothorax)
• Supportive therapy
  • Hemodynamic optimization: oxygen delivery (DO$_2$) preload, cardiac output, SvO$_2$ (mixed venous oxygen saturation)
  • Drainage of pleural fluid, ascites (intra-abdominal pressure)
  • Bronchoscopy (lavage, source of bleeding)
  • Intestinal therapy
  • Early enteral feeding (bacterial translocation)
  • Stimulation of bowel motility
  • Closed tracheobronchial suction system (high respiratory support)
  • Nutritional support (early enteral feeding)
Prognosis

- In children better than adults
- Early mortality: multi-organ failure rather than lung failure, oxygen utilization defect not hypoxemia
- Long-term pulmonary dysfunction, broncho-pulmonary dysplasia (neonate), greater susceptibility to bronchial obstruction and airway infection

16.5.3 Lung Contusion

General considerations

- In children often without rib fracture
- Caused by severe shearing force and serial rib fractures
- Frequently pneumothorax, hemothorax
- Additional injuries: abdomen, cervical spinal cord

Investigations

- Chest X-ray with a fluffy infiltrate that progresses in extent and density over a period of 24–48 h
- CT of the thorax is recommended early in the course to detect consolidation areas, injury of the lung and other organs
- Abdominal ultrasonography examination (liver or spleen ruptures, free abdominal fluid)
- Echocardiography: pericardial effusion, myocardial contractility, injury of great vessels

Therapy

- Early intubation and mechanical ventilation in cases of obvious respiratory insufficiency: $\text{SpO}_2 < 85\%$ ($\text{PaO}_2 < 50$ mmHg, $\text{PaCO}_2 > 50$ mmHg) with $\text{FiO}_2$ 0.21
- Temporary assisted high-frequency ventilation should be preferred
Operation

- Bronchoscopy: initially often without a result but in many cases helpful for guided pulmonary lavage and suctioning of blood plugs as well as defining the source of bleeding. Topical injection of surfactant
- Sufficient drainage: pneumothorax/hemothorax
- Continued or uncontrollable hemorrhage and/or massive air leak generally mandates an early thoracotomy

16.5.4 Lung Abscess

General considerations

- Result of a necrotizing pneumonia, e.g., after aspiration of gastric juice, gastroesophageal reflux
- Streptococci, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, or other Gram-negative enteric organisms
- Frequent in children with neurological impairment, seizure disorders, and immune suppression
- Location: posterior segment of the right upper lobe and the superior segments of the right and left lower lobe
- 10% of the affected children have more than one abscess
- Abscess formation related etiologically to an unknown pre-existing localized pulmonary malformation (congenital cystic adenomatoid malformation or CCAM, bronchogenic cyst, lung cyst, infected sequestration)

Signs

- Respiratory distress with tachypnea and cough
- Fever
- Decreased or no breath sounds and dullness to percussion on the involved side
- Pulmonary infiltrate, cavity with fluid level
- Quick development of pleural effusion
- Perforation into the pleural cavity leads to empyema usually combined with pneumothorax
Chapter 16

Preoperative work-up

- Chest X-ray a.p. and lateral (Fig. 16.21)
- CT or MRI
- Bronchial lavage guided by flexible fiber optic bronchoscopy or thoracocentesis is useful for obtaining culture material used to determine specific antibiotic treatment

Indication for operation

- Bronchopleural fistula
- Operation frequently needed in younger and more debilitated children
- Large abscesses (approx. more than 5 cm in diameter) with fluid levels, especially located near the lung surface, unresponsive to aggressive conservative treatment
- No complete expansion of the lung over a period of 2 weeks
- Superficial lung abscess leading to partial pleura necrosis

Therapy

- Intravenous antibiotic management continued orally
Operation

- Care must be taken on anesthetic induction or when positioning the patient to prevent spillage of the abscess's contents into the contralateral lung (bronchoscopically guided suction)
- Closed drainage (multiple chest tubes sometimes necessary)
- Open drainage (including decortication) of the pleural effusion, usually with two large chest tubes
- Resection, usually of the complete involved lobe (covering the bronchial closure additionally with a dorsally based intercostal muscle flap)

Postoperative care

- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h
- Antibiotic management continued orally after discharge from hospital

Prognosis

- Good
- Resolution of a sufficiently drained abscess needs several weeks

16.5.5 Pneumatocele

General considerations

- Thin-walled, air-filled cyst usually after a necrotizing *Staphylococcus aureus* pneumonia (other germs involved: *Streptococcus, Hemophilus influenzae, Klebsiella, Escherichia coli* and *Pseudomonas*)
- Endotoxin released from the staphylococcal organisms contributes to the extremely destructive inflammatory process
- Mechanically ventilated patients are at increased risk of developing pneumatocele
- Adjacent structures may be compressed or a mediastinal shift may occur when a tension pneumatocele develops
- 25% of the pneumatoceles rupture, causing a, usually insignificant, pneumothorax
Chapter 16

Signs
- Respiratory distress

Preoperative work-up
- Chest X-ray
- CT scan
- Ultrasonography

Indication for operation
- Rapidly enlarging pneumatocele producing mediastinal shift (tension pneumatocele)

Therapy
- Most pneumatoceles require no treatment, only observation
- Percutaneous needle aspiration or chest tube for drainage of large cysts

Operation
- Thoracotomy, suture or resection is rarely necessary

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within a period of 24 h

Prognosis
- Good. About 50% resolve within 6 weeks and the remaining within 12 months

16.5.6 Chronic Atelectasis (Middle Lobe Syndrome)

General considerations
- Absent lung expansion over a period of at least 2–3 weeks due to bronchial stenosis (slit fashioned bronchi, malformation of the bronchial wall, compression from outside by enlarged lymph nodes or vascular anomalies) or intraluminal bronchial obstruction (foreign body)
Signs
- Asymptomatic at the beginning
- Recurrent signs of pulmonary infections
- Chronic cough

Preoperative work-up
- Chest X-ray (Fig. 16.22)
- CT scan
- Bronchoscopy
- Ventilatory and perfusion scintigraphy

Indication for operation
- No improvement after intensive conservative treatment over a period of 8 weeks
Operation
- Middle lobe lobectomy

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h

Prognosis
- Good

16.5.7 Bronchiectasis

General considerations
- Low incidence in industrialized nations
- Permanent localized or diffuse abnormal dilatation (fusiform, cylindrical, saccular) of the segmental and subsegmental bronchi and their branches
- Principal areas of involvement: lower lobes most often affected, followed by the right middle lobe and the lingula
- Etiology: chronic suppurative lung disease, repeated pulmonary infections and poor clearance of lung secretions leading to destruction of the bronchial wall tissue with bronchomalacia and muscular hypertrophy. Bronchus obstruction may be worsened by compression due to enlarged lymph nodes
- Congenital bronchiectasis is rare (Klippel–Feil short neck, rib anomalies or Kartagener syndrome with ciliary dyskinesia, situs inversus, pansinusitis and bronchiectasis, infertility)
- Cystic fibrosis is the most common underlying disease causing bronchiectasis
- A foreign body may also cause local bronchiectasis
Signs
- Fever, cough, significant amounts of purulent sputum
- Physical activity (change of position) stimulates paroxysmal coughing
- Musical rales may be detected by auscultation
- Hemoptysis may occur
- Clubbing of the fingers in the late stages

Preoperative work-up
- High-resolution CT scan
- Bronchoscopy and biopsy to determine ciliary morphology
- Ventilatory/perfusion lung scans
- Investigation for cystic fibrosis

Indication for operation
- Recurrent lung infections in relation to localized bronchiectasis

Conservative therapy
- In early stages, conservative treatment (antibiotics, mucolytic, thorough pulmonary toilet)

Operation
- Lobe or segment resection. The operation may be difficult because of post infectious pleural adhesions and lymph node hypertrophy
- In patients with diffuse bronchiectasis lung resection may be required
- Cystic fibrosis of the lungs is the main indication for lung transplantation in childhood

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h

Prognosis
- Good
- Relapse may occur in patients with poor clearance of lung secretions
16.5.8 Bronchogenic Cysts

General considerations

- Arises from parenchymal cells that have been isolated during budding and branching to form a mass of non-functioning pulmonary tissue. Central cysts are of early embryonic origin. They are solitary and usually asymptomatic until infection occurs.
- Located near the pulmonary hilum or in the mediastinum (near the esophagus).
- The lesions appear as solid masses or they are air filled (fluid level) when they communicate with the airways.
- Rapid enlargement of a tension cyst may produce sudden respiratory distress.
- Malignant transformation has been described.

Signs

- Usually asymptomatic.
- If the lesion becomes infected symptoms such as fever, hemoptysis, and cough with purulent secretions occur.

Preoperative work-up

- X-ray.
- High-resolution CT scan.

Indication for operation

- The asymptomatic cyst is also a clear indication for excision.

Operation

- Thoracotomy, cyst excision or lobectomy.

Postoperative care

- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h.
Prognosis
- Good

16.5.9  Pulmonary Cysts

General considerations
- Lesion develops between the 6th and 16th weeks of gestation. In contrast to the central (bronchogenic) cyst, they may be multiple and extensive
- Bronchial communication is more common
- A typical X-ray image is shown in Fig. 16.23

Differential diagnosis
- CCAM
- Congenital lobar emphysema
- Pneumothorax (sharp costophrenic angle)
- Congenital diaphragmatic hernia
- Arteriovenous lung aneurysm (Fig. 16.24)
Signs
- Respiratory distress shortly after birth

Preoperative work-up
- Chest X-ray
- CT scan

Indication for operation
- Clear indication for resection

Operation
- Thoracotomy, segmentectomy or lobectomy

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h

Prognosis
- Good
16.5.10 Congenital Cystic Adenomatoid Malformation (CCAM)

General considerations

- Non-cystic or multi-cystic mass of pulmonary tissue lined by cuboidal or columnar epithelium (sometimes skeletal muscle can be detected in the cyst wall). There is an overgrowth of bronchioles with suppression of alveolar development
- Usually only a single lobe is affected
- The lesion can enlarge because of fluid and air trapping. Over-distension of the involved lobe may lead to mediastinal shift, anasarca, hydramnion, hypoplasia of the ipsilateral and contralateral lung, fetal death, or respiratory distress after birth
- Spontaneous regression is possible
- Risk of pneumothorax, infection and malignant change (small risk)

Classification

- Classification of CCAM is given in Table 16.2

Table 16.2 Classification of CCAM

| Type | Incidence | Description |
|------|-----------|-------------|
| I    | 50%–75%   | Single or multiple cysts more than 2 cm in diameter, lined by ciliated pseudostratified columnar epithelium with thick smooth muscle and elastic tissue walls |
| II   | 10%–40%   | Multiple small cysts less than 1 cm in diameter, lined by ciliated cuboidal or columnar epithelium. Respiratory bronchioles and distended alveoli may be present between these cysts. This type is frequently associated with other congenital anomalies such as renal agenesis, heart defects |
| III  | 10%       | Non-cystic adenomatous solid mass. Poor prognosis |

Signs

- May be asymptomatic
- Respiratory distress in types II and III
Preoperative work-up
- Prenatal serial ultrasonography examinations (detectable in the 12th to 14th gestational weeks)
- Repeated X-ray
- CT scan (Fig. 16.25) or MRI

Indication for operation
- Fetal intervention (before the 32nd week) in severe cases with mediastinal shift: thoracocentesis of large cysts or resection of the lesion in utero
- Persistent (no signs of regression after 3 months of observation)
- Growing lesion, even if the patient is asymptomatic

Operation
- Thoracotomy and usually lobectomy within the first year of life

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h
- Problem of pulmonary hypertension and shunting may provoke ECMO (after successful resection) support
Prognosis

- Macrocystic lesions (>5 mm): good prognosis
- Microcystic lesions (<5 mm): poor prognosis

16.5.11 Congenital Lobar Emphysema

General considerations

- Postnatal overdistension of one or more lobes of a histologically normal lung, as a result of the collapse of bronchi
- Cartilaginous deficiency in the tracheobronchial tree with possible obstruction with air trapping or extrinsic pressure (anomalous pulmonary artery) on the airway or idiopathic causes
- The normal lobes are compressed and the mediastinum is shifted away from the affected side
- The upper lobes are more commonly involved, especially the left
- Males are more affected than females
- Associated anomalies (heart, kidney), in about 40% of the cases

Signs

- Respiratory failure with cyanosis
- Sometimes dramatic presentation due to overdistension of the affected lobe mimicking a tension pneumothorax

Preoperative work-up

- Chest X-ray
- CT scan
- Ventilation/perfusion lung scans

Indication for operation

- Conservative therapy is useless in congenital forms, which are a clear indication for resection
Operation
- Urgent lobe or segment resection
- Placement of a chest tube into emphysematous lobe can have catastrophic results (air leak, bleeding)
- In rare cases, the cause of the bronchial obstruction can be operatively treated

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h

Prognosis
- Good

16.5.12 Pulmonary Sequestration

General considerations
- Mass of non-functioning lung tissue that lacks an obvious communication with the tracheobronchial tree and receives its arterial blood from the systemic circulation. The venous drainage is either into the pulmonary vein (large shunts may develop >30% of cardiac output) or the azygos vein
- More than two-thirds receive their arterial blood supply from the abdominal aorta with the large vessel passing through the diaphragm in the aortic hiatus
- More than two-thirds are located in the lower lobes
- Two-thirds of the sequestrations are on the left side
- More than two-thirds have only one arterial supporting vessel
- Extralobar sequestrations in particular are associated with other abnormalities such as diaphragmatic hernia
Classification
- The interlobar sequestrations are classified according to the arterial blood supply and the ventilation pattern (Table 16.3)

Table 16.3 Pryce classification of interlobar sequestrations

| Interlobar | The sequestration is located within the normal lung |
|------------|---------------------------------------------------|
| Type I     | Regularly ventilated lung tissue perfused by two arterial blood supplies (pulmonary artery, systemic artery) |
| Type II    | Irregularly ventilated (atelectatic) lung tissue perfused by two arterial blood supplies on the margins (pulmonary artery, systemic artery) |
| Type III   | Lung tissue not ventilated and perfused only by the systemic artery blood supply |

| Extralob   | The sequestration is completely separated as an accessory lobe from the normal lung (Rokitansky lobe). The arterial blood supply usually originates from the abdominal aorta, the venous blood usually returns into the azygos vein |

Signs
- Interlobar sequestrations
  - Tend to provoke infections in the non-functioning lung tissue and the compressed surrounding lung
  - Children with unexplained recurrent pneumonias must be suspected of having sequestration
- Extralobar sequestrations (Fig. 16.26)
  - Small sequestrations may be completely asymptomatic
- Inter- and extralobar sequestrations
  - Hemothorax
  - Hemophthisis
  - Cyanosis
  - Clubbing of the fingers
  - Dyspnea
Preoperative work-up

- Prenatal ultrasonography
- The most specific diagnostic criterion for sequestration is the atypical artery, which is detected by high-resolution CT and CT angiography at the level of the diaphragm
- Doppler ultrasonography shows the abnormal arterial blood supply
- MRI
- Angiography

Indication for operation

- Always indicated as prophylaxis for recurrent pneumonias
- When recurrent pneumonias occur
Operation

- Lobe resection in cases of interlobar sequestration
- Sequester resection in cases of extralobar sequestration
- The transection of this transdiaphragmatic artery has to be performed meticulously as the ruptured vessel could retract into the abdomen causing massive bleeding in a compartment that is not very accessible. A splitting incision of the diaphragm is then necessary to access the abdomen and control the bleeding vessel
- In cases of obvious abdominal aorta vessel laparoscopic ligature of the vessel prior to resection is possible
- Thoracoscopic resection of extralobar sequesters is feasible

Postoperative care

- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h

Prognosis

- Good

16.5.13 Pulmonary Arteriovenous Aneurysm

General considerations

- Vascular malformation producing a high flow shunt between the pulmonary artery and the pulmonary vein
- High shunt volumes may lead to a hyperdynamic cardiac failure
- Location mainly in the right lung

Signs

- Cyanosis
- Clubbing of the fingers
- Polyglobulia
- Right heart insufficiency
Preoperative work-up
- CT angiography
- Angiography (Fig. 16.27) of the pulmonary artery
- Heart ultrasonography (increased cardiac output; hypertrophic or dilated ventricles)
- ECG (hypertrophy)

Indication for operation
- Clear indication for resection on an urgent basis

Operation
- Thoracotomy with segmentectomy or lobectomy

Postoperative care
- Chest tubes may be removed if the lung is fully expanded and drainage volumes decrease below 20–50 ml within 24 h

Prognosis
- Good if cardiac insufficiency is reversible
16.6 Mediastinum

16.6.1 Patent Ductus Arteriosus

General considerations

- The ductus arteriosus is a vascular connection between the pulmonary artery and the aortic arch, a physiologic situation in the fetal circulation
- The duct should close within the first few days after birth
- If not closed an effective hemodynamic shunt between the pulmonary artery and the aorta is maintained

Signs

- High cardiac output failure
- Respiratory insufficiency, dependence on mechanical ventilation
- Elevated pulsatility index

Preoperative work-up

- Heart ultrasonography (increased cardiac output; hypertrophic right ventricle)

Indication for operation

- Hemodynamically effective shunt
- Exclude a shunt-dependent heart malformation
- Exclude a persistent pulmonary hypertension (PPHT)
- Thrombopenia (<50,000 mm\(^{-3}\)), recent bleeding
- Signs of renal insufficiency (urine volume <1 ml·kg\(^{-1}\)·h\(^{-1}\)) is a contraindication for conservative treatment with indomethacin or ibuprofen

Therapy

- Conservative treatment with indomethacin or ibuprofen

Operation

- Operative closure through a left lateral thoracotomy using a Hemoclip
Postoperative care
- A chest tube for lung expansion, gain hemostasis and drain secretions

Prognosis
- Good
- Increase of the mean arterial blood pressure

16.6.2 Mediastinitis

General considerations
- Bacterial infection of the mediastinum caused mainly by esophageal or tracheal trauma (perforations, anastomotic insufficiencies, deep caustic lesions due to lye ingestion, penetrating thoracic wounds)
- In cases of esophageal or tracheal perforation mediastinal emphysema is likely to develop
- Some patients develop pleural effusions

Signs
- High fever
- Elevated heart rate, in some cases venous inflow congestion
- Respiratory distress

Preoperative work-up
- Chest X-ray (widening of the mediastinum; thoracic effusion)
- Blood cultures
- Material from the mediastinum for bacterial culture should be obtained

Indication for operation
- Always in cases of fully developed mediastinitis
Operation
- Jugular median incision
- Blunt preparation
- Lavage with povidone-iodine solution
- More than one thick chest tube to drain the anterior mediastinum
- The middle and posterior mediastinum should be drained via a lateral posterior thoracotomy using the extrapleural approach
- More than one thick chest tube should be inserted
- Anastomotic insufficiencies are repaired by an intercostal muscle flap covering the defect
- Simple suture closure of distal recent esophageal perforations should be covered by a cuff on the gastric wall (intrathoracic partial fundoplication)
- In overlooked esophageal perforations (>72 h) esophageal resection and later replacement are usually indicated
- Artificial material in inflamed tissues is contraindicated

Postoperative care
- Aggressive treatment with antibiotics
- Repeated CT examinations to control the drainage and to detect new abscess formations

Prognosis
- Depends on the patient's constitution, the involved bacteria, and the distribution of the inflammation