Acute Chest Diseases: Infection and Trauma

José Fonseca Santos

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Abstract

Acute chest diseases include clinical situations with infectious and traumatic etiology. Pulmonary infection is the most common indication for performing chest radiography. Radiological imaging often confirms the diagnosis and allows the evaluation of the location and extent of infection. Chest radiography is the primary imaging procedure and the starting point for the evaluation of all children with acute chest disease. Accurate interpretation of pediatric chest films also requires a basic understanding of the physiologic and anatomic differences among adults, neonates, and infants and their most important differences will be referred. Characterization of pulmonary infiltrates is important, because patterns of abnormality suggest specific organisms and aetiologies. Although providing evidence suggestive of the causative agent, the chest radiograph cannot confirm viral infection, confirm or exclude bacterial etiology. In fact, in infancy, pneumonia usually produces a combination of alterations of the airspace and interstitium. However, some aspects may be useful in distinguishing between viral and bacterial pneumonia. Close attention to CT technique is crucial for imaging evaluation of pneumonia in pediatric patients, namely those with persistent symptoms and/or progressive symptoms despite medical or surgical therapy, or in immunocompromised patients. CT with low radiation dose technique should be carefully performed in these cases. CT examination with IV contrast is very useful for the evaluation of complications of chest infection. Thoracic trauma in children is rare, only 4–6 % of children are hospitalized following severe trauma. Only a small number of children with trauma have thoracic injury (14 %), but the injuries tend to be of serious nature. About 25–50 % of thoracic trauma cases occur in combination with other trauma locations. Pulmonary contusion and lacerations, tracheobronchial injuries, pneumothorax, and esophageal rupture are referred as

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P. Garcia-Peña and R. P. Guillerman (eds.), *Pediatric Chest Imaging*, Medical Radiology. Diagnostic Imaging,
DOI: 10.1007/174_2014_957, © Springer-Verlag Berlin Heidelberg 2014
Published Online: 1 February 2014

the main consequences of trauma. The decision for the appropriate use of imaging techniques must consider the specific case under review. Chest radiography should be the initial screening method. The decision to use CT is determined by the nature of the trauma, the clinical circumstances, and the prediction of future revaluation, always taking into account the radiation dose applied to the child.

1 Introduction

Acute chest diseases include all the clinical situations with infectious and traumatic etiology.

In considering the multiple entities of infectious cause in the pediatric age groups, two approaches to the differential diagnosis are available based on the clinical character of symptoms and on the age of the patient.

Accurate interpretation of pediatric chest films also requires a basic understanding of the physiologic and anatomic differences among adults, neonates, and infants and the most important differences will be referred. Characterization of pulmonary infiltrates (interstitial, alveolar, and mixed) is important, because patterns of abnormality suggest specific organisms and etiologies.

A small number of children with trauma have thoracic injury, but the injuries tend to be of a serious nature.

Pulmonary contusion, tracheobronchial injuries, pneumothorax, and esophageal rupture will be referred as consequences of trauma.

The decision for the appropriate use of imaging techniques must be due to the specific case under review. Chest radiography should be the initial screening method. The decision to use CT is determined by the nature of the trauma, the clinical circumstances, and the prediction of future revaluation, taking into account the use of radiation in children.

2 Thoracic Infection

One of the most common acute chest diseases in children is the respiratory tract infection.

2.1 Imaging Techniques

2.1.1 Radiography

This is the primary imaging procedure and the starting point for all children. The film should be well inspired, correctly centered, and coned. A supine film is preferable until the child is old enough to cooperate fully with an erect position. When the child is old enough, the film should be acquired in posteroanterior position to reduce the breast radiation. Unlike in adults, hidden pathology is unlikely. The localization of the focus of infection is usually easy on frontal film and lateral view is not routinely used (Carty 2000).

2.1.2 Ultrasound

Ultrasound (US) was initially applied to detect pleural fluid, however in recent years the applications of US for the chest have been widely extended. The technique has several advantages that are particularly beneficial in children. US does not use ionizing radiation and permits visualization of the lesions in real time in different planes (Enriquez et al. 2008). US has been advocated as an important initial aid in categorizing the pleural fluid (simple and complicated), and making therapeutic decisions for parapneumonic effusions, acute complication of pneumonia. US can also be used to provide imaging guidance for pleural fluid drainage, especially when is loculated. US is very useful initially to study patients presenting with an opaque hemithorax on plain film.

Patients with lung consolidation associated to pleural fluid can be initially evaluated at the same time by US. Color and power Doppler can analyze the perfusion of the lung parenchyma. It could be well vascularized and poorly vascularized with or without necrosis. Initially, US can provide diagnostic and prognostic information which may influence therapy.

2.1.3 Computed Tomography

CT can play an important role and is crucial for imaging evaluation of pneumonia in pediatric patients with persistent or progressive clinical symptoms or in immunocompromised patients. Close attention to CT technique is mandatory and CT with low radiation dose technique should be carefully performed in these cases.

Lung high resolution computed tomography (HRCT) gives exquisite pulmonary parenchymal detail and is of increasing importance in imaging infection particularly in its complications. The advent of spiral scanners with very fast scan times has made HRCT a practical proposition in most children without the need for sedation. The main indication in children with infection is the diagnosis of bronchiectasis and mapping its extent, particularly when assessing the effect of treatment or considering resection, confirming the presence of suspected areas of collapsed lung, and in the more acute situation confirming the presence of a lung abscess or empyema. Occasionally, CT is helpful in identifying appropriate placement of pleural drains. HRCT has been used to identify the extent of disease associated with opportunistic infections in children who are immunocompromised.

Contrast-enhanced CT should be performed for the evaluation of mediastinum, pleura, and lung parenchyma with suspected necrosis. CT allows easy identification of

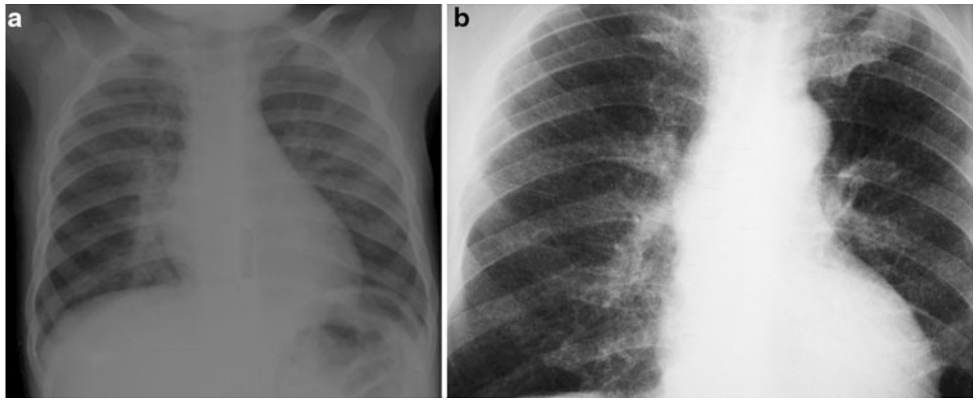

Fig. 1 Interstitial involvement in a child of 12 months with viral infection. **a** Chest radiograph shows an enlarged *right* hilum, with linear images. **b** Interstitial nodular pattern in a 17-year-old boy with CMV infection after BM transplant

mediastinal lymph nodes in tuberculosis or in other infection with lymphadenopathy, pleural fluid, and lung parenchyma hypoperfusion or necrosis. These findings are difficult to evaluate by chest X-ray (Carty 2000).

Focal CT scan should be tailored to the area of interest (especially if following a specific lesion serially over time) to further decrease the overall radiation dose (Hedieh et al. 2011).

2.1.4 Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI), with its combination of good resolution and multiplanar facilities, is the preferred first-choice tool for visualizing the mediastinum. MRI is useful for confirming the presence and the extent of nodal disease and for evaluating vascular anomalies or mass lesions associated with infection such as pulmonary sequestrations (Carty 2000).

Peltola and colleagues (Peltola et al. 2008) recently published their experience with MR imaging of lung infections in children using free-breathing T2-weighted, short tau inversion recovery, and T1-weighted with fat saturation precontrast and postcontrast sequences. Children with chronic lung conditions and recurrent infection, such as cystic fibrosis, who are often subjected to substantial radiation exposure from repeated CT studies, would benefit the most from MR imaging evaluation of the lungs instead of CT (Hedieh et al. 2011).

2.1.5 Fluoroscopy

Neurologically compromised children have a high incidence of aspiration fluid, saliva, and food, and have severe and recurrent infections. Videofluoroscopy of swallowing when challenged with liquids and food of varying consistencies is required to identify aspiration or gastroesophageal reflux. Children with tracheoesophageal fistula (TOF) are also prone to chest infections. The causes include an unrecognized H fistula, recurrent fistula, tracheomalacia, dysmotility, gastroesophageal reflux, and anastomotic stricture with proximal dilatation. The latter three are associated with aspiration which is maximal in the supine position (Carty 2000).

2.2 Physiological Considerations

Accurate interpretation of pediatric chest films also requires a basic understanding of the physiologic and anatomic differences among adults, neonates, and infants.

The most important differences include the following: (1) the peripheral airways of infants are relatively smaller than those of adults, and collateral pathways of ventilation are less developed; (2) the airways of infants are more prone to collapse in response to pressure changes than those of adults; (3) Infants also have relatively more mucous glands and a greater mucous production. For these reasons, the peripheral airways of infants are more susceptible to inflammatory narrowing than adult airways. In older children and adults, respiratory infections most commonly involve the interstitium and alveoli. Lower respiratory infections in infants, on the other hand, manifest their primary effects in the smaller airways, producing peripheral mucous obstruction and disproportionately severe respiratory distress. This is revealed on the chest films by generalized hyperaeration (air trapping) with focal irregularities of aeration that reflects atelectasis from mucous plugging. True consolidative (alveolar) pneumonia is a much less frequent occurrence (Wesenberg et al. 2006).

2.3 Characterization of Pulmonary Infiltrates

Characterization of pulmonary infiltrates is important because patterns of abnormality suggest specific organisms and aetiologies. The three basic kinds of infiltrates are interstitial, alveolar, and mixed.

The interstitial pattern has been described with a variety of confusing radiographic terms. When mild, an interstitial infiltrate is characterized by a string collection of densities

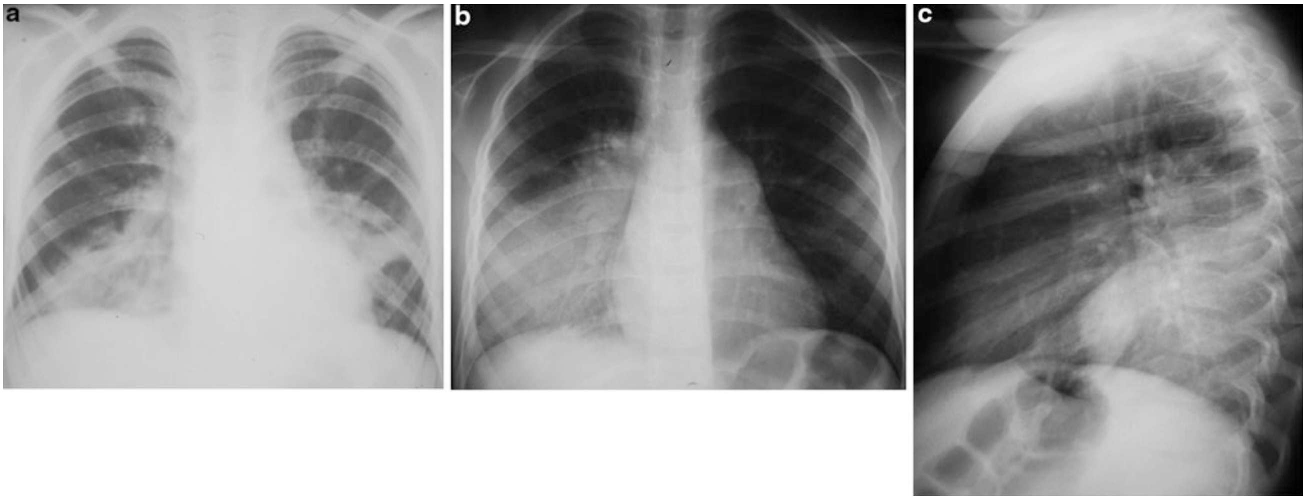

Fig. 2 Alveolar pattern on chest radiograph in a 10-year-old child with pneumococcal pneumonia. **a** Heterogeneous opacity with ill-defined boundaries air bronchogram in the *right* base and *lower third* of the *left* lung field. **b** and **c** Another similar case with alveolar pattern in a 11-year-old child with lobar pneumococcal pneumonia

Fig. 3 Mixed infiltrate on a chest radiograph in an 8-year-old girl with streptococcus pneumonia. There is an ill-defined area of mildly increased density (containing finely dilated air bronchioles). There is usually no significant pleural effusion

that run out from the hila (Fig. 1a), seen on the frontal projection as apparent enlargement and poor (fuzzy) definition of the hila.

When the pneumonia is severe, the pattern shows a diffuse, bilateral, sharply defined reticular (stringy) or nodular infiltrate (Fig. 1b). There is no air bronchogram and associated pleural effusion.

Alveolar (airspace) disease is characterized by a plethora of descriptive names. The typical alveolar infiltrate is a smooth, homogeneous increase in density (whiteness) of the lungs (Fig. 2). The most common alveolar infiltrate is well-defined, dense homogeneous lobar or segmental consolidation, with an air bronchogram within it. There is commonly associated pleural effusion.

Mixed infiltrates, not surprisingly, have features of both alveolar and interstitial patterns. If an unknown pulmonary infiltrate cannot comfortably be classified as either alveolar or interstitial, it is considered to have the mixed pattern (Fig. 3). The prototype of a mixed infiltrate is an ill-defined area of mildly increased density containing finely dilated air bronchioles. There is usually no significant pleural effusion.

2.4 Evaluation of Children with Pneumonia

Pulmonary infection is the most common indication for performing chest radiography. It is the radiological imaging that confirms the diagnosis and allows evaluating the location and extent of infection.

The common difficulties in the etiologic diagnosis of pneumonia led pediatricians and radiologists to a need to specify the causative infectious agents based on radiological patterns.

In this respect, special importance was placed on the distinction between viral and bacterial pneumonias, attributing to the viral disease interstitial pattern and the bacterial infection involving airspace.

Although providing evidence suggestive of the causative agent, the chest radiograph cannot confirm viral infection nor confirm or eliminate bacterial etiology. In fact, in infancy, pneumonia usually produces a combination of changing the airspace and interstitium. However, some

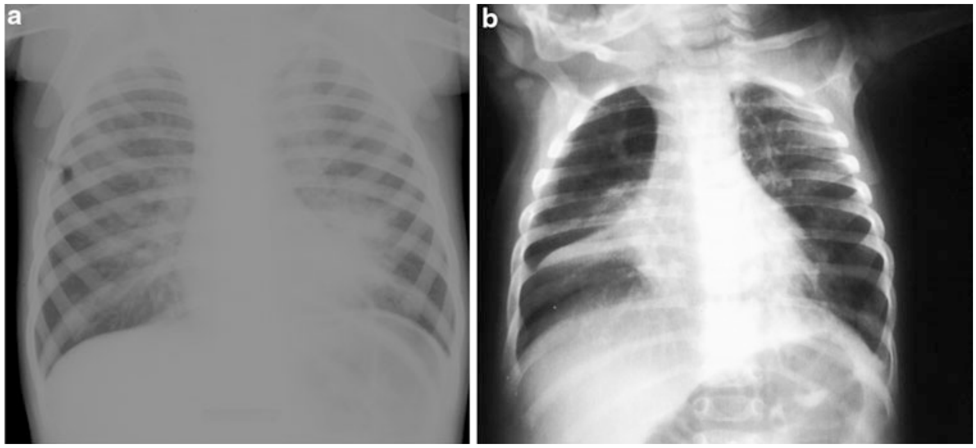

Fig. 4 Viral infection in a 22-month-old boy with fever and increased respiratory distress. **a** Radiography of the 4th day of hospitalization shows exuberant bilateral interstitial pattern. Serology revealed adenovirus infection. **b** Another similar case in a 12-month-old child with RSV infection. Atelectasis of the *middle* lobe is also shown

aspects may be useful in distinguishing between viral and bacterial pneumonia.

The roles of imaging in the evaluation of immunocompetent children with Community-acquired pneumonia are multiple: confirmation or exclusion of pneumonia, characterization and prediction of infectious agents, exclusion of other symptoms, evaluation when there is failure to resolve, and evaluation of all related complications (Donnelly and Klosterman 1997a).

Concerning characterization and prediction of infectious agents, the previously described patterns of radiographic and CT findings which suggest a specific infectious agent are rarely of clinical relevance in the previously healthy child who is imaged for suspected pneumonia (Donnelly 2002).

Cough and fever are two of the most common symptoms of illness in the pediatric age group and suggest respiratory pathogenesis, particularly pneumonia. Radiographic findings in combination with clinical evaluation are vital in deciding whether treatment with antibiotics or further study is indicated. The character of pneumonia that it is revealed radiographically, in combination with the clinical pattern of the disease, assists the physician in deciding whether antibiotics are indicated. Despite numerous advances in pediatric care and imaging modalities, the plain chest radiography remains the most valuable tool available for evaluating airway and the lungs and for assessing the site and gross character of pulmonary disease (Wesenberg et al. 2006).

In considering the multiple entities that cause cough and fever in the pediatric age groups, two approaches to the differential diagnosis are available.

The first is based on the clinical character of symptoms, specifically acute illness versus illness that is chronic or recurrent.

The second approach is based on the age of the patient, because there are distinct age predilections of agents that cause cough and fever in children.

2.5 Differential Diagnosis According to Clinical Character of Illness and Age of Patient

The three main causes of community-acquired pneumonia (CAPs) in pediatric patients are viral, atypical, and bacterial.

As a group, viruses account for approximately 65 % of all pneumonias that occur in pediatric patients. Respiratory syncytial virus (RSV) is the responsible organism in approximately 50 % of the cases.

The epidemic and seasonal occurrence of pneumonias and lower tract infections is a well-known phenomenon. RSV and metapneumovirus are responsible for yearly outbreaks, during winter.

The respiratory viruses, as a group, account for approximately 90 % of the agents recovered from children younger than 4 years of age (Wesenberg et al. 2006).

The most common specific agent that produces demonstrable pneumonia in pediatric age group is mycoplasma pneumonia, the most prevalent in school-age children. It is one of the main causes of atypical pneumonia. In children younger than 4 years of age, the incidence drops to approximately 5 %.

The most common cause of other bacterial pneumonia in pediatric age group is *Streptococcus pneumonia*. In addition, there has been a recent increase in the prevalence of pneumonias caused by community-acquired methicillin–resistant staphyllococcus aureus (MRSA). Less common causative bacteria are *S. pyogenes*, Klebsiella species, and gram-negative organisms (Wesenberg et al. 2006).

2.6 Viral Pneumonias

Viral pneumonia usually originates interstitial dispersed patterns, sometimes bilateral. They are frequently ill-defined opacities, involving one or more lobes, being located mainly

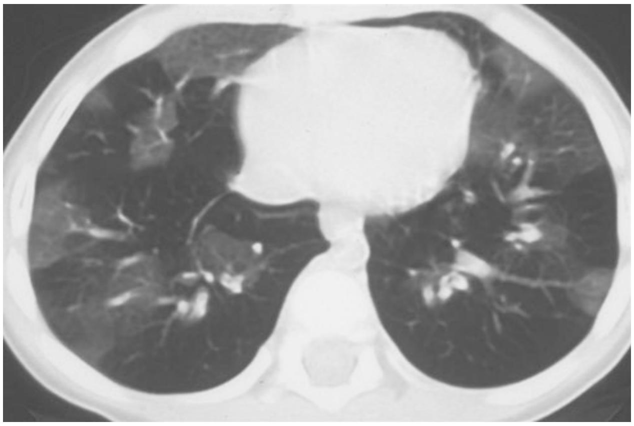

Fig. 5 Obliterative Bronchiolitis as sequelae of adenovirus pneumonia in an 8-year-old girl. Follow-up CT image shows a mosaic pattern with some patchy air-trapping areas and a normal expiratory ground-glass areas

in the perihilar regions. There is often thickening of the bronchial wall and densities and peribronchial opacities scattered non-confluent and areas of atelectasis affecting predominantly the upper lobes and middle lobe.

Often the small airways are involved causing anterior prolapse with hypersuflation of the lungs, prolapsed of the sternum, and lowering the of diaphragm.

The most common radiographic findings are bilateral, symmetrical, parahilar, and bronchial opacities with or without atelectasis and air trapping (Fig. 4). Focal and asymmetrical disease is not uncommon. Lymph node enlargement can occur, but pleural effusion is rare (Daltro et al. 2011).

Recently, viral infection has been recognized as a cause of severe pneumonias leading to respiratory failure and death. Higher mortality rates are associated to coronavirus A (SARS, severe acute respiratory syndrome), and influenza virus type A H5N1 (bird flu) and type A H1N1. As with other viral pneumonias, focal or diffuse interstitial opacities are the initial chest radiograph presentation, but they can progress rapidly to bilateral areas of consolidation (Daltro et al. 2011).

The radiographic findings in RSV bronchiolitis are predominantly those of hyperaeration of the lungs with a variable degree of perihilar interstitial infiltrate. Usually the lungs are clear peripherally. Typically the bilateral, perihilar interstitial infiltrate is suggestive of mild to moderate hilar enlargement that it is indistinct on both projections. A more widespread interstitial infiltrate occurs in more severe infections, and areas of subsegmental atelectasis are common, reflecting mucous plugging.

The lungs in pneumonia commonly are also hyperaerated but generally less so than in RSV bronchiolitis. Radiographic clearing is not as rapid as clinical recovery, and complete clearing may take as long as 2–5 months.

Fig. 6 *Mycoplasma pneumonia* in a 11-year-old girl with cough and fever. Chest radiograph shows areas of hypotransparencies and lung densities in both lungs. Serology was positive for *M. pneumoniae* and antibiotic therapy instituted led to clinical and radiological resolution

The initial radiographic findings in adenoviral pneumonia are nonspecific and are shared with the other viral pneumonias. The most common manifestation is bilateral, perihilar interstitial infiltrate.

The pulmonary sequelae of adenovirus pneumonia are usually evident on follow-up controls (Fig. 5). A mild form of adenoviral pneumonia is chronic pneumonitis, with associated fibrosis and mild bronchiectasis. In severe disease, necrotizing bronchiolitis progress to obliterative bronchiolitis, which leads to unilateral hyper lucent lung (Swyer-James syndrome) or bilateral hyperlucent lung, with or without areas of associated bronchiectasis and chronic atelectasis.

2.7 Atypical Pneumonia

A wide variety of infectious agents (virus and bacteria) may be the cause of atypical pneumonia. Atypical features in pneumonia include prominent extrapulmonary features (e.g., headache, sore throat, and pharyngeal exudates), minimal or disparate chest signs on physical examination, subacute onset, non focal lung opacity on chest radiographs, lack of clinical response to antibiotics, lack of substantial leukocytosis, and a slow disease course. On chest radiographs, the pulmonary opacity is seen as either airspace, reticular (linear), or band-like opacities in a non focal, patchy, or mottled distribution, with various degrees of

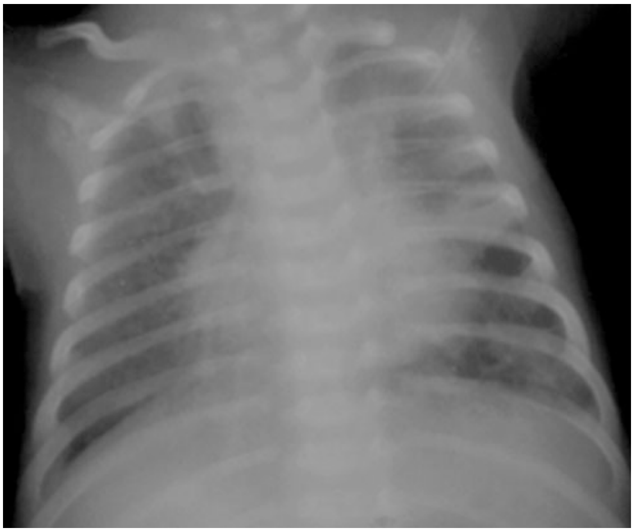

Fig. 7 Newborn with conjunctivitis and polipneia, with abnormal pulmonary auscultation. Chest radiography showed a bilateral interstitial linear pattern and consolidation. Serology was positive for *C. trachomatis* and clinical evolution was favorable with antibiotics

density, usually without a single dense area of consolidation (Hedieh et al. 2011).

The most specific agent that produces demonstrable pneumonia in the pediatric age group is a bacterium, *Mycoplasma pneumoniae*, most prevalent in school-age children.

The radiographic pattern produced by *M. pneumoniae* is most commonly an ill-defined, mildly increased density segmental or lobar consolidation with involvement that is usually in the lower lobes. Acutely, a perihilar interstitial pattern is present. Typically, there are areas bronchiolar and acinar dilatations, commonly within the consolidation, that suggest mild micro cyst formation. A patchy, alveolar bronchopneumonic pattern may occasionally be seen. There is usually no pleural effusion (Wesenberg et al. 2006).

In the mycoplasma pneumonia, radiological aspects are not specific. Often there are bronchopneumonic opacities mainly affecting the lower lobes. There may also be interstitial or peribronchial densities as well as segmental or subsegmental atelectasis. Pleural effusions are not uncommon and are usually minor and transient. Often there is discrepancy between the exuberant symptoms, the poor objective examination and marked radiographic lesions (Fig. 6).

Patients who have *Chlamydia trachomatis* pneumonia have a fairly typical bilateral, perihilar interstitial pattern of infiltrate. Patchy fluffy-appearing alveolar infiltrates are usually bilaterally superimposed on this pattern, and radiographic findings are often more severe than clinical symptoms.

Chlamydia pneumoniae causes an atypical pneumonia virtually indistinguishable from that caused by Mycoplasma (Wesenberg et al. 2006).

In *C. trachomatis* pneumonia, the chest radiograph often shows hyperinflation and diffuse interstitial or alveolar opacities.

There are also the aspects of clinical pneumonia (cough in infants 3 weeks to 4 months prior afebrile and conjunctivitis), the epidemiological context (mother gynecological infection in the last trimester of pregnancy), and the specific laboratory tests (hemogram with eosinophilia), which will lead us to the possible causing agent (Fig. 7).

2.8 Bacterial Pneumonias

Bacterial pneumonias account for only 3–5 % of all childhood pneumonias. In general, bacterial pneumonias have a sudden onset. The epidemic and seasonal occurrence of pneumonias and lower respiratory tract infections is a well-known phenomenon. A viral infection commonly precedes the bacterial pneumonia by several days to a week.

Radiologically, bacterial pneumonias usually cause dense lobar or segmental consolidation that frequently contains an air bronchogram. Patchy pneumonia is the second most common pattern. When present, findings that suggest bacterial rather than viral pneumonia include significant pleural effusion, abscess, and pneumatocele formation within pneumonic infiltrates.

The pattern of epidemic occurrence for school-age children (4–18 years) is distinctly different from that of preschool children.

The most common cause of other bacterial pneumonia in the pediatric age group is *S. pneumoniae*.

The bacterial pneumonia usually originates scattered opacities in infants, the segmental or lobar condensation is the most typical finding being located predominantly in the middle or at the periphery of the lung fields, especially when the agent is *S. pneumoniae* or *Haemophilus influenzae* (Fig. 8). Hilar engorgement is more common in pneumonia by *H. influenzae* or *Staphylococcus aureus* pneumonia, but can also occur in pneumococcal pneumonia. Pneumothorax or pleural effusion, including empyema, can occur particularly in staphylococcal infections and other purulent agents. Generally, the infection affects one lung but also can be bilateral (Fig. 9).

Certain bacterial specimens originate necrotic foci in the parenchyma that communicate with the lumen of the airways, forming thin-walled and well-defined bubbles called pneumatoceles. In the course of pneumonia, an abscess can also arise, which differs from pneumatocel by presenting itself as an image with thick-walled cavitation that fades in

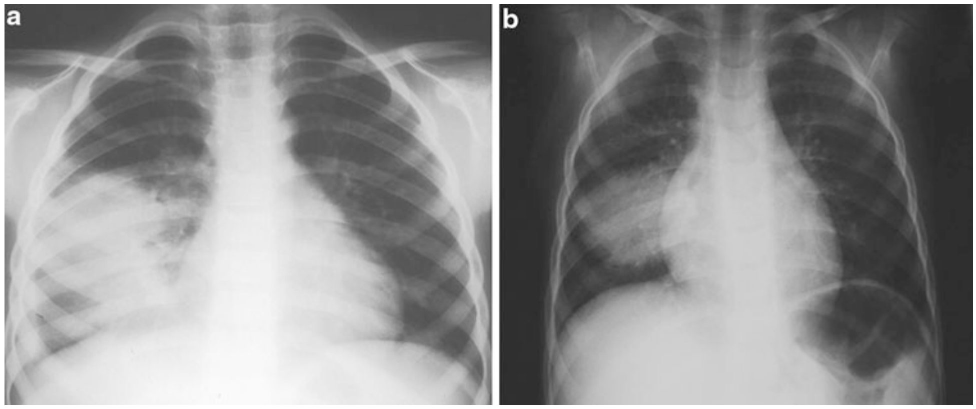

Fig. 8 Bacterial pneumonia in a 6-year-old boy with fever and thoracic pain. **a** The chest radiograph shows rounded opacity of the *right* lung and small lamellar spill along the *right* chest wall. A *S. pneumonia* was isolated. **b** Similar case of rounded pneumonia in a 7-year-old child with streptococcus infection

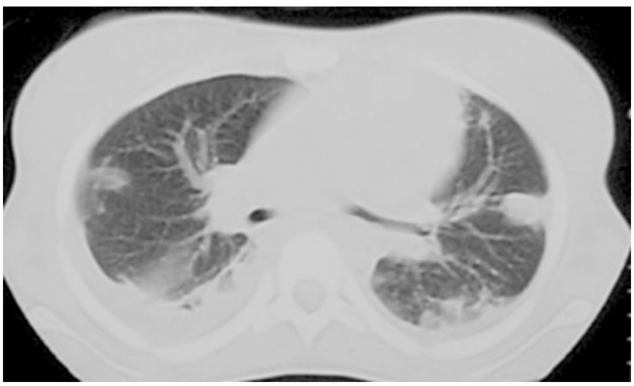

Fig. 9 Bacterial pneumonia in a 10-year-old girl, after cutaneous wound in the foot, developed fever and respiratory distress. Chest radiograph (*not shown*) and CT showed round opacities, and pleural fluid. A Staphilococcus aureus was isolated

the condensation surroundings, and often with liquid content (Fig. 10). Pneumotocels are more common in staphylococcal pneumonia, particularly in the convalescent phase, but other agents are also associated with bullous images, including *Klebsiella pneumoniae*, *H. influenzae*, *S. pyogenes* and *S. pneumoniae*. Sometimes bacterial pneumonia may present as spherical opacities (Fig. 8). Usually the edge of these pneumonias is not well-defined and the image does not look so round in two planes (PA and lateral). An X-ray follow-up days later often reveals a condensation without the initial round appearance.

Therefore, the presence of a segmental or lobar condensation, pleural effusion, necrotic foci, abscess, or pneumatocele in children with high fever and signs of toxicity suggest bacterial etiology.

S. pneumoniae pneumonia manifests as a dense, homogeneous, alveolar lobar, or segmental consolidation of lung parenchyma (Fig. 11). The consolidation begins in the peripheral air spaces and thus almost invariably abuts a pleural surface. The consolidation usually has an air bronchogram and middle well-defined border. Pleural effusion or empyema is common.

S. pneumoniae is one of the common organisms that produce a so-called "round pneumonia", seen almost exclusively in children (Fig. 8). Sometimes, because of the lack of collateral air drift openings, the exudates take the appearance of a spherical consolidation—a "round pneumonia". The inflammatory cells are confined under a mild degree of pressure, and these infants often have high fever. The radiographic appearance can be alarming because a round pneumonia can look like a neoplasm (Bransom et al. 2005).

Pneumatoceles may form during resolution and are considered a favorable prognostic sign.

The radiographic findings of staphylococcal pneumonia are indistinguishable from those of other bacterial pneumonias. There is a tendency, however, for staphylococcal pneumonia to manifest initially as a patchy bronchopneumonia, with dense alveolar consolidation developing rapidly, and usually involving a whole lobe or multiple lobes (Fig. 9). Pleural effusion (or empyema) occurs in more than 90 % of the cases and pneumatoceles occur in 40–60 % of the cases. Usually, pneumatoceles appear late in the first week of pneumonia and disappear spontaneously, generally within 6 weeks.

2.9 Fungal Pneumonias

Pulmonary fungal infections are rare in children, especially in immunocompetent patients. Fungal infection is suspected, when dealing with pneumonia that is usually localized and chronically persisting, despite antibiotic treatment.

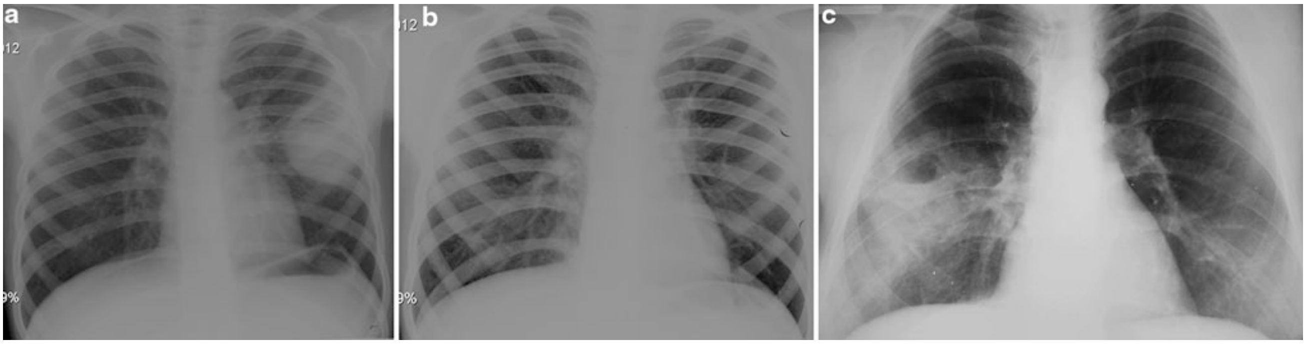

Fig. 10 Necrotic pneumonia in a 10-year-old boy with productive cough, fever and thoracic pain (**a**, **b**). **a** Chest radiograph revealed cavitated round opacity which evolved into pneumatocel after antibiotic theraphy. **b** A *S. pneumonia* was isolated. **c** Similar case of necrotic pneumonia in a 16-year-old boy with Stafilococcus aureus infection

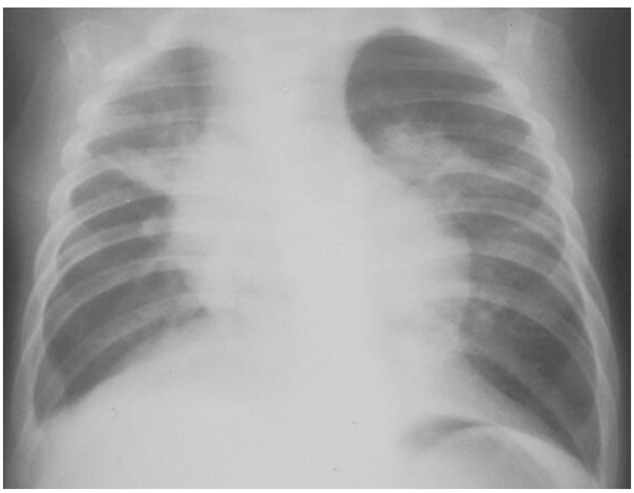

Fig. 11 *S. pneumonia* in a 45-day-old-girl, with fever, nasal obstruction, and respiratory distress. Chest radiograph showed bilateral opacities of the *upper* lobes. β-hemolytic Streptococcus was isolated in blood culture

The hallmark of CT findings, which is associated with possible fungal infection, is the presence of nodules, often clustered, with poorly defined margins, cavitation, or surrounding halo of ground-glass opacity (Donnelly 2002).

Pulmonary aspergillosis is the most common and can occur in three clinical forms: allergic, invasive, or cavity. Allergic aspergillosis is predominant in patients with asthma and especially as a complication in patients with cystic fibrosis. The radiological identification in these patients is difficult, but in general they have more mucous plugging. The invasive form is very severe and occurs predominantly in immunocompromised patients, such as those in treatment for leukemia or lymphoma, post bone marrow transplant, and other organ transplantation (Fig. 12). Pulmonary consolidation, central bronchiectasis, mucoid impaction, and appearance on secondarily infecting a preexisting pulmonary cavity are the most characteristic findings for fungal infection.

Certain lung infections occur mainly in patients with immunological problems, including congenital or acquired immune defects, or therapy with corticosteroids or immunosuppressants. These are infections by opportunistic agents such as Pneumocystis, Cytomegalovirus, or Herpes simplex.

2.10 Parasitic Lung Infection

The parasitic lung infections are rare in infancy. The most common is Echinococcus granulosus infection (hydatic disease). Radiologically present as one or more homogeneous, well-defined round opacities, which are replaced by liquid level when the cyst ruptures (Fig. 13).

2.11 Follow-up Controls in Pneumonia

In general, the clinical healing of pneumonia is not parallel to radiological resolution which is typically slow. In the respiratory syncytial virus pneumonia (RSV) and parainfluenza with uncomplicated clinical course, radiological healing occurs up to 3–4 weeks. Adenoviral pneumonia is often severe (Fig. 5) with prolonged evolution. In these cases, the radiological changes may still persist after 6–12 months and sequelae are common.

In *M. pneumoniae* pneumonia and *C. trachomatis*, the response to therapeutic and healing is usually quick with no radiological sequellae consequences.

In most cases of bacterial pneumonia, where the agent is *S. pneumoniae* or *H. influenzae*, a normal chest radiography and follow-up control without complications are expected 3–4 weeks after treatment. The remaining cases usually normalize in 3–4 months. When the clinical course is slow or complications arise (pleural effusion, empyema, necrosis, pneumatoceles), control radiographs are useful. These are particularly important in staphylococcal pneumonia in which these complications are very common, requiring radiological controls and sometimes thoracic CT.

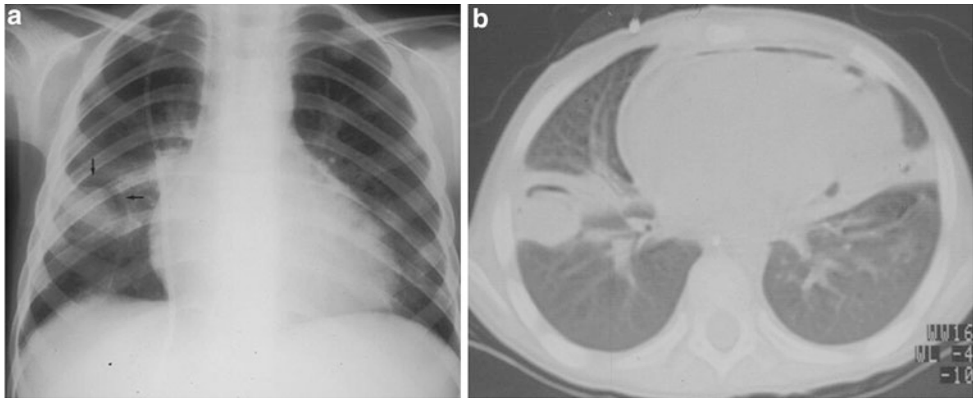

Fig. 12 Fungal infection in a 6-year-old-girl, with acute lymphatic leukemia and bone marrow aplasia. **a** Chest radiograph showed a rounded opacity with peripheral cavitation at the *middle* third of the *right* lung field. **b** CT showed bilateral lesions related to invasive aspergillosis

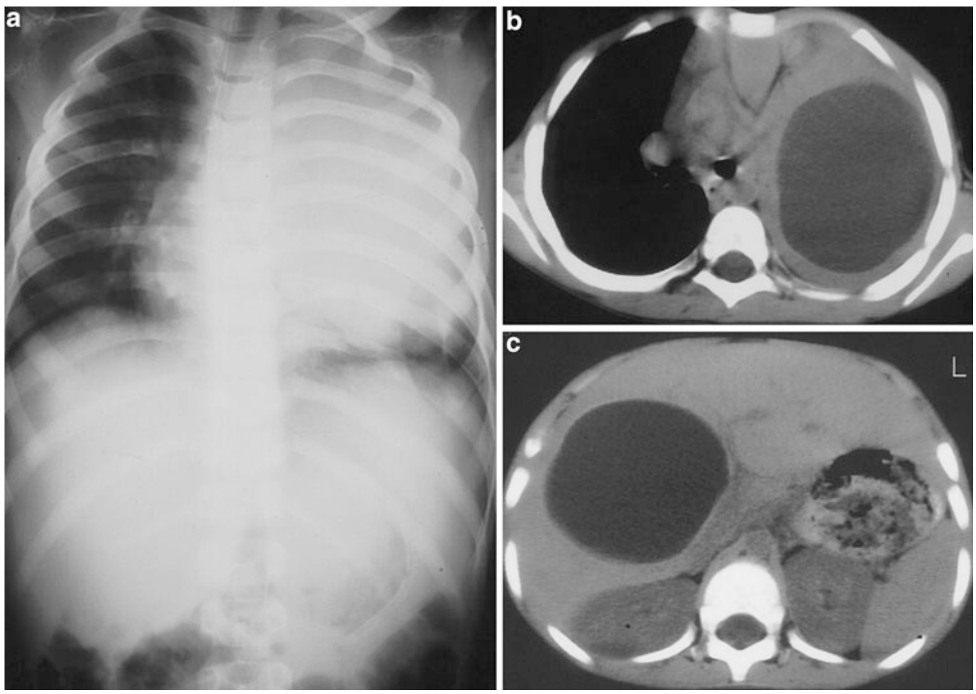

Fig. 13 Echinococcus infection in a 10-year-old boy with fever and progressive respiratory distress. **a** Chest radiograph revealed a round dense lesion in the *left* lung, located in CT in the posterior *lower* lobe, showing the mass as a cystic lesion (**b**). **c** CT shows another intrahepatic cystic lesion. Serology for hydatid disease was positive, and resection of the cysts was performed

Pneumatoceles or pleural thickening can take 6–12 months to resolve.

Follow-up radiographs should be reserved for those children who have persistent or recurrent symptoms and those who have an underlying condition such as immunodeficiency. When follow-up radiographs are indicated, they should be obtained at least 2–3 week after treatment (Hedlund et al. 1997).

Development lung masses, such as sequestration, bronchogenic cyst, and cystic congenital malformation, may become infected and present as a recurrent or persistent pneumonia. CT is helpful in confirming and characterizing the presence of developmental masses. In cases of sequestration, CT is capable of identifying the characteristic systemic arterial supply.

2.12 Complications of Pneumonia

CT has an important role in the evaluation of complications related to pneumonia when the child has persistent or progressive symptoms despite medical or surgical therapy.

Imaging pleural effusion reflects the patterns of management at specific institutions. Traditionally, the aggressiveness of therapy has been based on categorizing **parapneumonic effusions** as empyema or transudative effusion (Donnelly and Klosterman 1997a; Donnelly 2002). The differentiation has been based on US findings and analysis of pleural fluid.

No individual CT findings (pleural enhancement, pleural thickening, extrapleural subcostal tissue abnormally, or adjacent chest wall edema) nor a score based on a

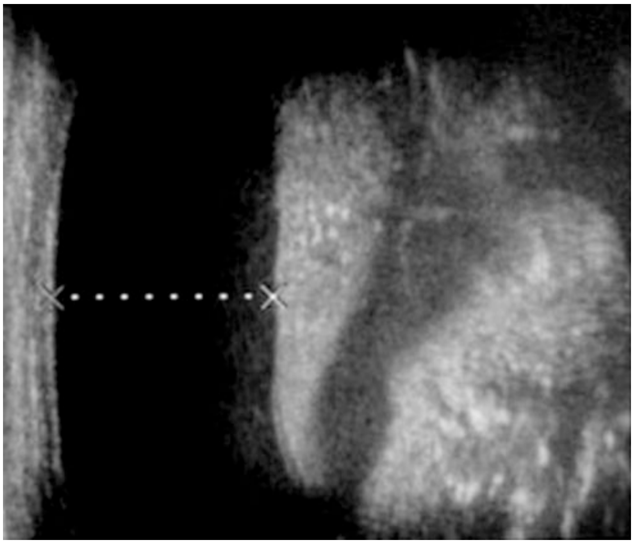

Fig. 14 Pleural fluid in a boy with an opaque hemithorax. US shows an anechoic band of pleural fluid. There is a lung consolidation

combination of CT findings could accurately separate empyema from effusion (Donnelly and Klosterman 1997a).

The use of sonography in characterizing the pleural fluid (simple or complicated) in making therapeutic decisions for parapneumonic effusions has been advocated. Massive pleural effusion is one of the main causes of opaque hemithorax seen on chest X-ray films. Ultrasound is extremely useful for studying children with this radiological finding, which can be due to other entities, such as pulmonary and chest wall masses or consolidation.

US can also be used to provide imaging guidance for pleural drainage procedures, particularly when the pleural fluid is loculated. With US, one can determine the depth of the collection and decide on the safest manner to approach to drain it (Fig. 14) (Enriquez et al. 2008).

In the setting of a child with a noncontributory radiograph who has not responded appropriately to therapy, contrast-enhanced CT has been shown to be useful in detecting clinically significant suppurative complications. CT can help differentiate whether the reason for persistent illness is pleural or related to lung parenchyma, directing therapy in the appropriate direction (Donnelly and Klosterman 1997b).

On contrast-enhanced CT, uncomplicated pneumonia usually enhance the lung parenchyma. Enhancement is not a reliable way to differentiate atelectasis from pneumonia (Donnelly and Klosterman 1997b). On contrast-enhanced CT, complicated pneumonia shows a decrease and heterogeneous parenchymal enhancement (Donnelly 2008).

Suppurative lung parenchymal complications represent a spectrum of abnormalities and include cavitary necrosis, lung abscess, pneumatocele, bronchopleural fistula, and pulmonary gangrene (Donnelly and Klosterman 1998a, b).

Cavitary necrosis represents a dominant area of necrosis of a consolidated lobe associated with a variable number of thin wall cysts. Unlike in adults, among whom the mortality rate of cavitary necrosis is high and early surgical removal of the affected lung has been advocated, the long-term outcome in children with cavitary necrosis is favorable with medical management alone (Donnelly 2002).

Lung abscess represents a dominant focus of suppuration surrounded by a well-formed fibrous wall. On contrast-enhanced CT, lung abscesses appear as fluid- or air-filled cavities with definable enhancing walls (Donnelly 2008).

On chest radiography, it is often difficult to determine how much of a detected opacity is due to pleural effusion and how much is due to consolidated lung, when both are present. Accurate determination of the amount of pleural fluid and its location, provided by CT also affects therapeutic decisions regarding drainage (Donnelly and Klosterman 1998b; Enriquez et al. 2008). CT gives helpful information depicting loculated pleural collections not in communication with the chest tube, or poor chest tube placement.

There are a number of potential complications from pneumonia that can cause chronic respiratory difficulties. These include bronchiectasis, Swyer-James syndrome or bronchiolitis obliterans, parenchymal scarring, and fibrothorax.

Swyer-James syndrome is defined as the presence of unilateral hyperlucent lung in association with decreased pulmonary vasculature. It is thought to represent an obliterative bronchiolitis that occurs secondary to viral infection, often related with adenovirus. Bilateral lung involvement is quite frequent (Lucaya et al. 1998, 1999; Garcia-peña and Lucaya 2004).

Bronchiectasis is probably the most common chronic complication of childhood pneumonia. Reversible bronchiectasis can occur during acute pneumonia. Chronic bronchiectasis most commonly occurs due to adenovirus or bacterial infection. (Donnelly 2008; Lucaya and Ducou Le Point 2008).

3 Thoracic Trauma

Thoracic trauma in children is rare, with only 4–6 % of children hospitalized with an indication of severe trauma. Only a small number of children with trauma have thoracic injury (14 %), but the injuries tend to be of a serious nature.

It occurs in 15 % of cases in isolation and in 25–50 % of cases in combination with other trauma locations (Chaumoitre et al. 2008).

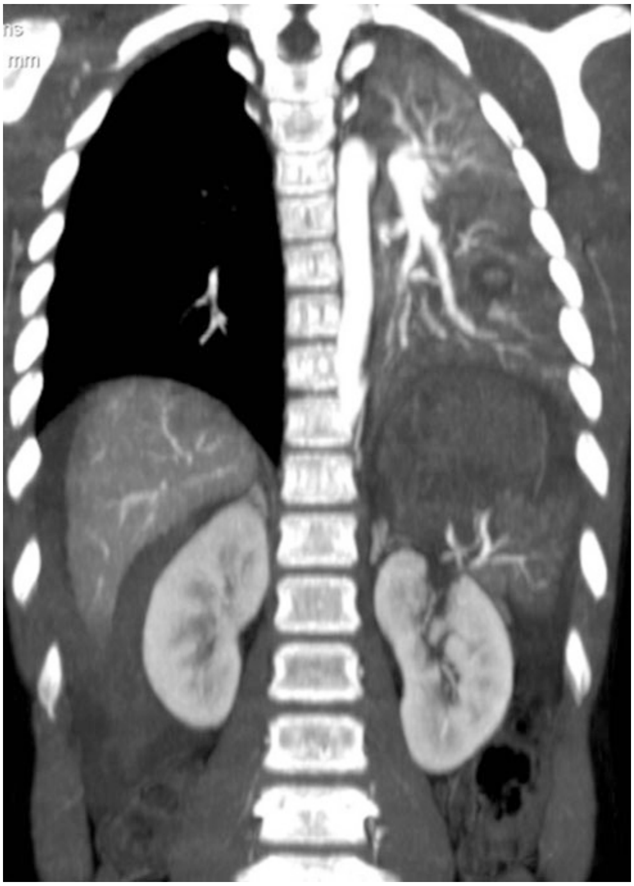

Fig. 15 Polytrauma by car accident in 10-year-old boy. Coronal MCDT image shows pulmonary laceration, spleen fracture, kidney fracture and hemoperitoneum

Polytraumatized children have a great risk of mortality and thoracic trauma is the second leading cause of death (the first is the CNS).

In more than 85 % of cases the trauma is closed, as a result of car accidents, pedestrian accidents or falls from a height.

The most commons chest injuries are pulmonary contusion, laceration, hemothorax, pneumothorax, and rib fractures. Less common lesions are the aortic arch lesion, cardiac contusion, tracheobronchial tree rupture, esophageal rupture, and diaphragmatic rupture. Most of traumatic thoracic lesions are treated conservatively, not requiring surgery.

Because of the plasticity of the pediatric rib cage, rib fractures are infrequent, and severe parenchymal injuries can be present in the absence of rib fracture.

Mediastinal lesions are unusual. The increased mobility of solid intra-abdominal organs combined with a weaker abdominal wall is specific to pediatric patients (Chaumoitre et al. 2008).

Children are different from adults due to the small body surface area, the compliance of the chest wall, the mediastinal mobility, and high vascular elasticity. The reliable diagnosis of chest injuries in the acutely injured patient is often clinically difficult.

Cardiopulmonary symptoms may not be present in the first 24 h and there is no consistent relationship between external chest wall injuries and underlying abnormalities. This is particularly true with children in whom increased compliance of the bony thorax allows major internal injury to occur without associated skeletal injury. (Sivit et al. 1989).

High physiological reserves can compensate up to 40 % loss of volume and can obscure serious injury.

Children and adults can have the same type of injury, but with different patterns.

Rib fractures, flail chest, aortic injury, and diaphragmatic rupture are more common in adults, whereas pulmonary contusion, pneumothorax, and intrathoracic injury without bony injury predominate in children.

The differing pattern of injury may be explained by the anatomic and physiologic differences between children and adults.

The smaller size of the tracheobronchial tree in children leads to greater respiratory distress for small caliber changes.

The trachea is relatively narrow, short, and more readily compressible in children, so that small changes in airway caliber from external compression or inhaled foreign body may result in more significant respiratory compromise (Moore et al. 2011).

Taking into account that major trauma does not respect anatomic boundaries and may lead to multisystemic injury, this approach should be diagnostically accurate, cost effective, and provide efficient treatment decisions, using the lowest possible radiation dose (Moore et al. 2011).

3.1 Imaging Techniques

Chest radiograph is basic and important, often conditioned by artifacts and technical limitations. Chest radiograph allows rapid analysis of the lungs, pleura, mediastinum, chest wall, and drainage systems in place. It is often a means of fast diagnosis in circumstances of severe instability.

Chest radiography plays an important role in the initial evaluation of blunt and penetrating chest trauma, providing rapid imaging information to supplement the history and physical examination. In the emergency department, familiarity with the spectrum of injuries that can occur in the chest and upper abdomen is important for accurate interpretation of chest radiographs as well as establishment of appropriate recommendations for management and follow up (Mai-Lan 2009).

CT of the chest is the most reliable and sensitive instrument to assess the trauma, allowing a detailed analysis of all intrathoracic organ. It has a variable clinical impact,

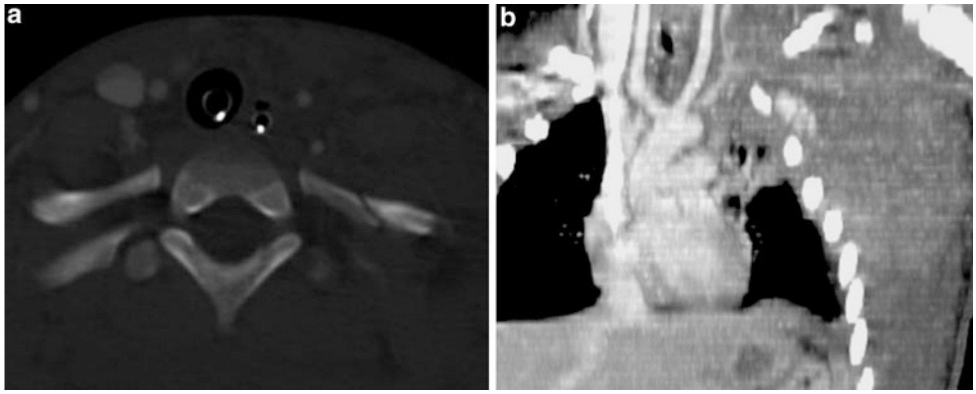

Fig. 16 Arterial axilar injury by car accident in a 12-year-old girl. **a** *Left* rib fracture in axial CT. **b** Laceration of *left* axilar artery with chest wall hematoma in coronal contrast enhanced CT

however it can use high doses of radiation and should therefore be reserved for selected patients (Markel et al. 2009).

When CT is being performed to evaluate traumatic injury to either the abdominal contents or mediastinum, it is important to evaluate the lung for lung contusion or other trauma-related lung opacity.

The MDCT used in trauma provides a large amount of information in a short time interval (Fig. 15). It is the ideal technique for severe multiple trauma with greater sensitivity than chest radiography. The use of the MDCT in detecting chest injuries should wonder about their impact on the clinical management and the final result, taking into account the radiation burden.

Initial indications for the use of CT include fractures of ribs, sternum or shoulder, abnormal mediastinum on chest radiograph, penetrating trauma or positive pressure ventilation. Delayed CT indications are persistent hemorrhagic drainage and progressive pneumomediastinum.

The use of CT in trauma should consider an adapted pediatric protocol, efficient immobilization, and avoid multiple phases. The optimization of radiation should be adjusted for age and weight, considering the mAs and the kVp, scan times, collimation, pitch, and the use of modulation systems.

The other imaging techniques (US, angiography, and MRI) are more limited and present more precise indications.

Ultrasound is useful in the assessment of pleural collections in mediastinal deviation and allows quick analysis of the lower chest. Angiography is reserved for intervention in cases of acute bleeding, and MRI should be considered when there is suspicion of spinal cord injury.

3.2 Chest Wall Injuries

The rib fractures are uncommon in children. They are more frequent in the posterior arcs and can be multiple. When there is fracture of the three first ribs (Fig. 16) and the sternum, associated vascular injury should be suspected (Durant et al. 2005).

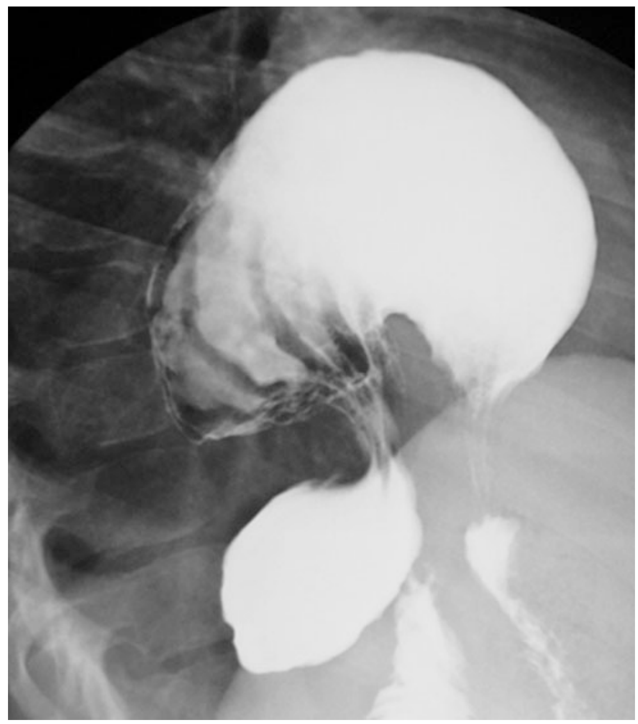

Fig. 17 Traumatic intrathoracic gastric hernia by car accident in a 10-year-old boy. Contrast GI shows a gastric hernia going into the chest cavity through a small diaphragmatic rupture

3.3 Diaphragmatic Rupture

Diaphragmatic rupture is rare, the diagnosis can be delayed, often overlooked with herniated viscera complication (Fig. 17).

Diaphragmatic rupture is most frequently caused by compressive blunt trauma to the abdomen but it is also described with penetrating trauma. Left diaphragmatic hernias are more common due to the protective effect of the liver on the right side.

CT may show the diaphragmatic rupture and air in the bowel loops above the diaphragm. If CT is equivocal or unavailable and if the patient's condition permits,

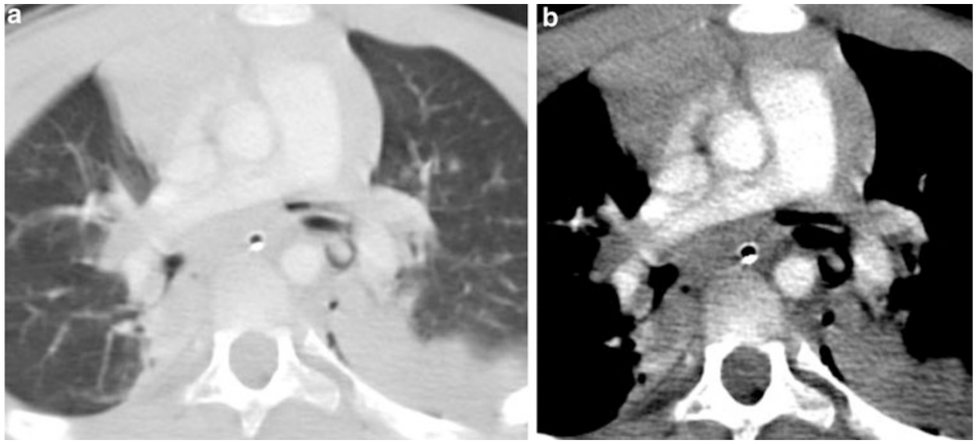

Fig. 18 Tracheobronchial tear by car accident in a 10-year-old boy. **a** Axial lung window CT image mainly shows consolidation of *left* lower lobe and small *right* consolidation. **b** Contrast enhanced CT better shows *left* lower lobe bronchial tear

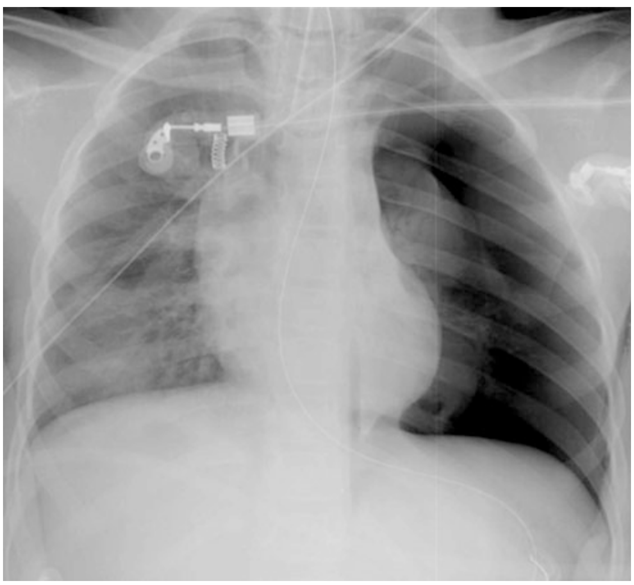

Fig. 19 *Left* traumatic tension pneumothorax in a 13-year-old boy. Chest radiograh shows a hyperlucent hemithorax with mediastinal shift to the *right* and descent *left* diaphragm. Lung is collapsed

water-soluble contrast studies are extremely helpful and can show the hollow viscus (Duncan 2002).

3.4 Tracheobronchial Injuries

Tracheobronchial injuries are rare and, if proximal, cause mediastinal and cervical emphysema. More distal damage is intrapleural and causes a pneumothorax. Patients with trauma, who have hoarseness or stridor in addition to dyspnoea, cough, and haemoptysis should be suspected of having tracheobronchial injury. These clinical signs with pneumothorax or mediastinal subcutaneous emphysema should alert to the possibility of tracheobronchial injury (Duncan 2002) (Fig. 18).

3.5 Pneumothorax

CT is the most sensitive technique in the pneumothorax evaluation.

Pneumothorax may be secondary to injury to the lung, airways or esophagus, or to be due to direct penetration of the chest. Lack of response to drainage may indicate tracheal or bronchial tear.

A tension pneumothorax in addition to the hyperlucent hemithorax on the chest radiograph can produce shift of the mediastinum. Lung contusion and hematoma may, however, prevent total collapse of the lung and it is possible to have a marked tension pneumothorax without the ipsilateral lung being totally collapsed (Fig. 19).

A large opaque hemithorax is not always due to a hemothorax. Rupture of the hemidiaphragma can allow abdominal viscera to herniate into the chest, giving an opaque hemithorax appearance on the chest film (Duncan 2002).

3.6 Pulmonary Contusion

Lung contusion is defined as hemorrhage and edema formation in the alveoli and interstitium secondary to blunt chest trauma, without accompanying parenchymal laceration. On CT, lung contusions are characteristically nonsegmental in distribution, not following segmental or lobar anatomic boundaries (Sivit et al. 1989; Donnelly and Klosterman 1997c; Wylie et al. 2009).

Contusions are usually located posteriorly, crescentic, or amorphous in shape and mixed confluent nodular quality.

The lung contusions of children may also demonstrate a 1–2 mm region of uniformly non-opacified subpleural lung, separating the area of lung consolidation from the adjacent chest wall (Donnelly and Klosterman 1997c) (Fig. 20).

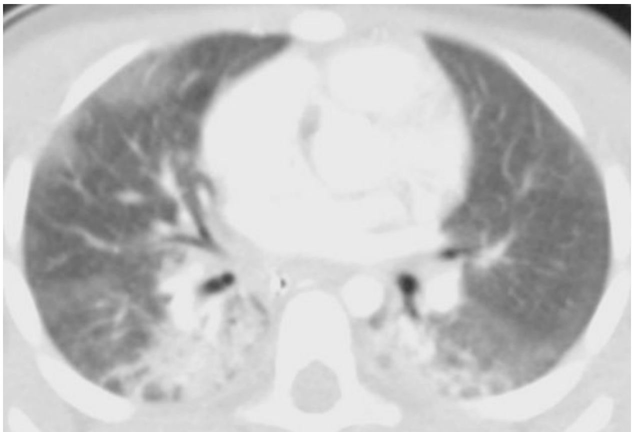

Fig. 20 Bilateral lung contusion with subpleural sparing in a 10-year-old boy. CT shows bilateral areas of contusion of *lower* lobes

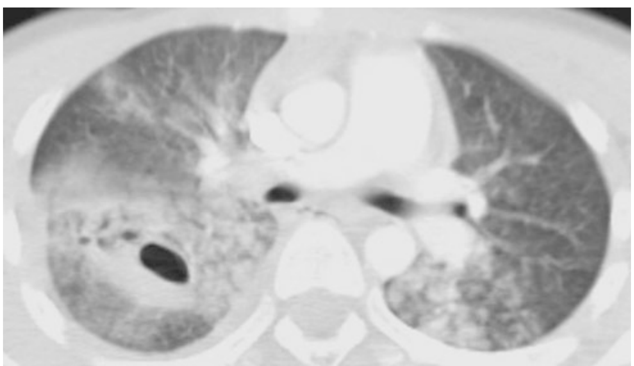

Fig. 21 Lung laceration in a 10-year-old boy. CT image shows bilateral consolidations with blood- and air-filled cavities due to alveolar disruption

Lung contusions are a result of alveolar capillary damage with extravasation of edema and hemorrhage into alveoli and interstitial spaces.

3.7 Lung Laceration

Pulmonary laceration differs from contusion in that with laceration there is a frank tear within the lung parenchyma. The characteristic CT finding of pulmonary laceration is the presence of an air- or fluid-filled cavity (Fig. 21).

Lacerations result from penetrating injuries, such as adjacent displaced rib fractures, or shearing blunt forces to the lung. Initially, they may be indistinguishable from surrounding contusion. Because of the disruption of the lung tissue, one or more air cavities develop over time and may contain a central density or fluid level because of intrapulmonary hematoma. Pulmonary lacerations tend to heal more slowly than contusions, and, especially in children, they may leave behind a persistent cavity called a posttraumatic pulmonary pseudocyst (Westra and Wallace 2005).

3.8 Mediastinal Injuries

Pneumomediastinum is recognized by streaky air collections outlining mediastinal structures such as the thymus and mediastinal vessels, or the superior surface of the diaphragm. It can be due to benign causes and be self-limiting, or it can be a sign of serious trauma, such as penetrating injury and tracheobronchial and esophageal rupture (Westra and Wallace 2005).

Detection of mediastinal hematoma is extremely important, because it may be a clue to an occult traumatic aortic injury, which is often clinically silent (Westra and Wallace 2005) (Fig. 22). The aortic lesion is extremely rare in children, but early detection improves the outcome.

Tracheobronchial laceration is a life-threatening emergency, rare and if proximal, can cause mediastinal and cervical emphysema. Distal damage is intrapleural and causes a pneumothorax. Emphysema and pneumothorax should alert to the possibility of tracheobronchial injury (Duncan 2002). Pleural fluid could accompany distal esophageal damage.

3.9 Traumatic Lung Cysts

Traumatic lung cysts have a similar radiological appearance to pneumatoceles and are often referred to as traumatic pneumatoceles (Fig. 23). They are usually due to blunt trauma without associated rib fracture. The etiology is thought to be fracture of small bronchi due to a sudden compression restricting the air outflow at the same time as compressing the lung. This causes distal lung tissue to burst in a balloon-like manner. They appear on a chest X-ray or CT within 1–3 days of injury as the pulmonary contusion or hematoma resolves and, like inflammatory pneumatoceles, they resolve spontaneously within 2–16 weeks. Rupture will cause a pneumothorax (Duncan 2002).

3.10 Esophageal Rupture

Except in cases of direct injury, esophageal rupture is extremely rare; this is especially true in children, and can be easily missed. When rupture occurs, it usually involves the lower third of the esophagus and the content enters to the mediastinum, aided by the negative pressures of inspiration. Pneumomediastinum, pneumothorax, and pleural effusions are radiographic signs (Fig. 24).

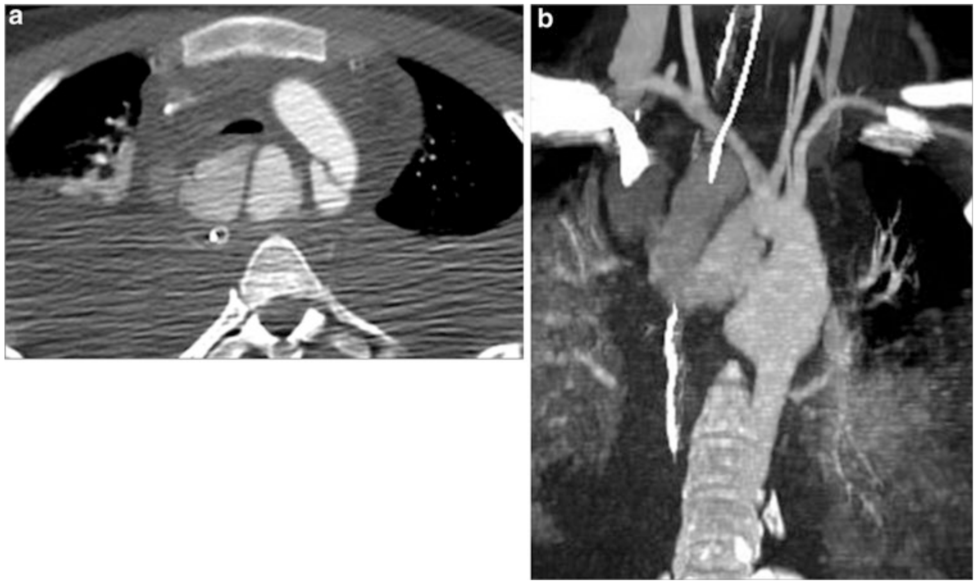

Fig. 22 Postraumatic aortic injury in a 15-year-old boy. **a** Axial enhanced CT scan shows dissection of aortic arch. **b** Coronal enhancement CT scan shows aortic pseudoaneurism

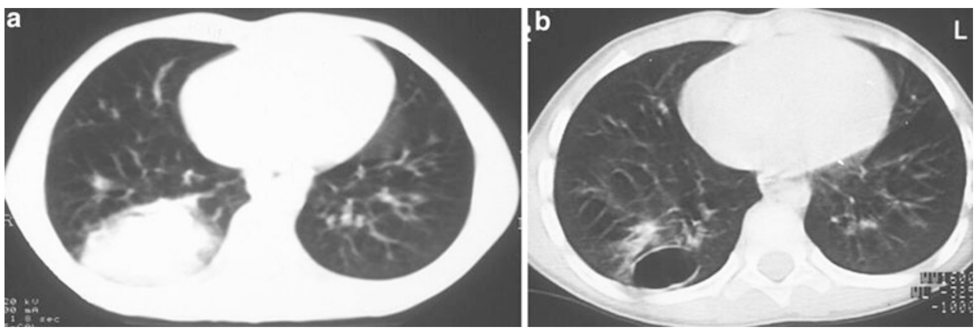

Fig. 23 Traumatic pneumatocel post pulmonary hematoma in a 13-year-old girl. **a** CT shows a *round* density in RLL. **b** CT scan control after 30 days shows a cystic lesion

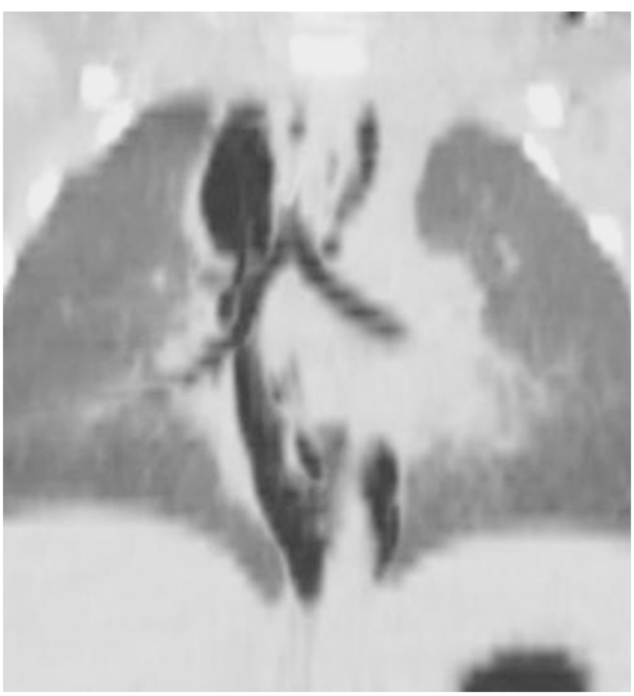

Fig. 24 Esophageal rupture, post penetrating trauma in a 9-year-old-boy. Coronal reconstruction CT image shows pneumomediastinum

Most esophageal ruptures are iatrogenic in children and caused during the passage of a nasogastric tube or occur as the result of impaction of a foreign body or during endoscopy removal.

4 Summary

Pulmonary infection is caused by a variety of agents, and incidence and frequency are variable in different age groups of children. Chronic infection may have underlying congenital lung malformations or sequelae of previous infections. It is important to know the different patterns of presentation and their complications, which lead to an appropriate use of imaging techniques and therapeutic.

The decision for the appropriate use of imaging techniques in thoracic trauma must depend on the specific case under review. Chest radiography should be the initial screening method. The decision to use CT is determined by the nature of the trauma, the clinical circumstances, and the prediction of future revaluation, taking into account the use of radiation in children.

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