Chapter 11

Imaging of Pneumonia in Children

Winnie CW Chu

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Introduction

Pneumonia is one of the most common serious infections of childhood. Plain chest radiographs remain the diagnostic mainstay in childhood pneumonia and chest computed tomography (CT) is rarely required in immunocompetent children presenting with symptoms and signs typical of chest infection. The appearance of different kinds of the childhood pneumonia is well established and fully described in the early literature of 1970s and 80s. Since then, there is no significant further update on the radiographic aspects of childhood pneumonia. The relatively old references are therefore omitted in this chapter.

The major indication of chest radiograph in children presenting with chest infection is to confirm or exclude the presence of pneumonia. A follow up chest x-ray is not routine in the management of children who have uneventful recovery, as post-obstruction pneumonia (secondary to pulmonary carcinoma) which occurs in adults, is not a concern in paediatric age group.

The other indications of imaging, including CT, in children presenting with chest infections are:
- To predict or suggest the nature of the infectious agent
- To look for any underlying developmental anomaly that predisposes a child to persistent or recurrent pneumonia
- To assess acute complications and to guide management
- To evaluate the sequelae of respiratory infection

Chest x-ray and common infective agents

The common etiologic agents that cause lower respiratory tract infection in children vary with age.

Infants, preschool children

**Causes**

In infants and preschool age children, viruses are the major cause of respiratory tract infections. The common viruses include adenovirus, respiratory syncytial virus, parainfluenza, influenza, measles or herpes virus.

**Radiological findings:**

**Viral pneumonia**

The most common roentgenographic findings in viral chest infection are:
- parahilar peribronchial infiltrates: viral infections predominantly involve respiratory mucosa of the airway, hence peribronchial inflammation and edema is demonstrated as increased peribronchial opacities radiating from the hila on radiography (Figure 1).
- bronchial wall thickening
- hyperexpansion of lungs
- segmental or lobar atelectasis: this can be explained by the small caliber of airways in children. The presence of minor amounts of edema, mucus or inflammatory debris may compromise or occlude bronchi or bronchioles. In infants, collateral pathways of ventilation are less well developed. Their airways are also more collapsible. All these factors contribute to the observation that atelectasis is more frequently encountered in paediatric age group. Hilar adenopathy is sometimes seen while the following roentgenographic findings are uncommon:
- diffuse interstitial infiltrates
- significant pleural effusion
- pneumothorax
- pneumatocele
- lung abscess

![Figure 1](Image)

Typical acute respiratory syncytial viral pneumonia a 3-year-old child. There is pulmonary overinflation and parahilar peribronchial shadowing (arrowheads).
Key Points

In viral pneumonia, the most common radiographic features are parahilar peribronchial infiltrates, bronchial wall thickening, hyperexpansion, segmental or lobar atelectasis. Significant pleural effusion, pneumothorax, pneumatocele and lung abscess are uncommon.

School age children

Causes

In school age children, though viral agents remain the most common cause of lower respiratory tract infections, there is an increased incidence of bacterial infection, such as streptococcus pneumoniae, staphylococcus aureus, haemophilus influenzae as well as mycoplasma pneumoniae.

Radiographic findings

It is difficult to differentiate between typical (i.e., bacterial) pneumonia and atypical (i.e., viral or mycoplasmal) pneumonia both clinically and radiologically.

(1) Bacterial pneumonia

The classical radiographic appearance is localized air space consolidation with or without air-bronchogram
- caused by inflammatory exudate and edema within the acini
- typical distribution is lobar or segmental
- associated pleural effusions are not uncommon (Figure 2)
- Sometimes, pneumonia in children may have a “round” appearance, simulating intrathoracic mass in both anteroposterior and lateral views. Although it may closely resemble a tumour on the initial study, it changes rapidly after appropriate antibiotic therapy (Figure 3)
- Round pneumonia is associated with pneumonococcal, staphyloccocal or klebsiella infection.
Figure 2
Streptococcal pneumonia in a 5-year-old child. There is bronchopneumonia in the right lower lobe associated with moderate amount of pleural effusion.

Figure 3
Round pneumonia in a 3-year-old child.
a. There rounded areas of consolidation are present (arrowheads) in the right lung, resemble tumours.
b. Three days after initiation of appropriate antibiotic therapy, there is change in configuration of the consolidation.
(2) Tuberculosis pneumonia
Primary tuberculosis is the commonest form encountered in children. Radiographic features include:
- hilar or mediastinal lymphadenopathy, with or without opacities in the lung.
- Occasionally, cavitation may be seen within the consolidation (Figure 4).

**Figure 4**
Chest radiograph of an 8-year-old boy with tuberculous infection. There are hazy infiltrates in both apical regions with cavitation (arrowheads) on the right side. There is also mild prominence of the right hilar region suggestive of presence of lymphadenopathy (arrow).

**Key Points**
- In bacterial pneumonia, the most common radiographic features are areas of consolidation with or without air bronchograms, typically segmental or lobar distribution. Pleural effusion is more common.
- In primary tuberculosis, the most common radiographic features are hilar or mediastinal lymphadenopathy, with or without opacities in the lung.
Computed tomography and common infective agents

Why is it sparingly used in kids

Due to the added radiation, CT is rarely indicated in the primary assessment of uncomplicated respiratory infections in the immunocompetent child. Like chest radiography, CT features of typical (bacterial) and atypical (viral or mycoplasma) pneumonia do overlap and some features are more frequently visualized in a certain group of pneumonia.

CT features

(a) Bacterial infection

The most common CT manifestations are:

- areas of consolidation with or without air bronchograms (Figure 5)
- typically with a segmental or lobar distribution
- tends to be located at the middle and outer zones.

Consolidation on CT is defined as areas of increased pulmonary opacity with obscuration of underlying bronchovascular structures.

(b) Viral infection

- The commonest CT feature is peribronchial thickening, reflecting the inflammatory changes and edema of bronchial mucosa
- The presence of ground-glass attenuation (defined as hazy increased attenuation without obscuration of bronchovascular structures) without associated consolidation, a lobular distribution, at the inner layer of the lung in addition to the middle and outer layers, are more in favour of a viral pneumonia, i.e. no zonal predominance.

(c) Tuberculosis

In children with primary tuberculosis, the presence of CT features such as:

- low attenuation lymph nodes, lymph node calcifications (Figure 6)
- branching centrilobular nodules (‘tree-in-bud’ appearance) (Figure 7)
- miliary nodules (Figure 8)

are helpful in suggesting the diagnosis in cases where the radiograph is normal or equivocal.
**Figure 5**
Bacterial pneumonia in a 2-year-old child. CT shows segmental air space consolidation with air bronchograms (arrowheads) in the right lower lobe.

**Figure 6**
CT of an 8-year-old boy with tuberculous infection. Note the calcified lymph nodes (arrows) in both hilar regions. A central venous catheter is in-situ.

**Figure 7(a,b)**
HRCT of a 17-year-old boy with pulmonary tuberculosis. Note numerous centrilobular nodules (arrowheads) and linear branching structure (“tree-in-bud” appearance, arrow) highly suggestive of endobronchial spread of tuberculosis.

**Figure 8**
HRCT of a 16-year-old boy with miliary tuberculosis. There are well-defined 1- to 2-mm nodules disseminated throughout both lungs (arrowheads).
**Key Points**

- **In bacterial infection, the most common CT features are areas of consolidation with or without air bronchograms.**
- **In viral infection, the suggestive CT features are peribronchial thickening, presence of ground-glass attenuation without associated consolidation, a lobular and inner distribution.**
- **In tuberculosis infection, the suggestive CT features are low attenuation lymph nodes, lymph node calcifications, branching centrilobular nodules ("tree-in-bud" appearance) and miliary nodules.**

**Evaluation of Persistent or Recurrent Pneumonia**

(a) Underlying predisposing conditions

Children with persistent or recurrent respiratory tract infection may have an underlying condition that predisposes them to the susceptibility of pneumonia, such as:

- immunodeficiency
- gastroesophageal reflux
- repeated aspiration
- inhalation of foreign bodies
- underlying bronchiectasis such as cystic fibrosis (Figure 9)

(b) Developmental abnormalities

If the above predisposing conditions are excluded, developmental abnormalities of the lung should always be considered, such as:

- Pulmonary sequestration: demonstration of a systemic arterial supply to the consolidated lung tissue on contrast enhanced CT is diagnostic of the condition 11 (Figure 10).
- Cystic adenomatoid malformations: these are characterized by multi-septated air-fluid filled cysts 12 (Figure 11)
- Bronchogenic cyst: usually presents as an ovoid or round lesion of water or soft tissue attenuation (Figure 12). Sometimes the cyst may appear hyperdense due to intracystic haemorrhage, protein content or milk of calcium. The bronchogenic cyst may get infected or cause compression onto the adjacent bronchus.
Figure 9
An 8-year-old Jewish boy with cystic fibrosis.

a. HRCT shows cylindrical bronchiectasis (arrows) of bilateral upper lobes
b. Chest radiograph taken during acute infective exacerbation shows peribronchial thickening and patchy infiltrates in both upper zones as well as nodular shadowing in the lower zones.

Figure 10
Pulmonary sequestration in a 11-year-old boy who suffers from recurrent left lower lobe consolidation.

a. Contrast enhanced CT shows an aberrant artery (arrow) arising from the thoracic aorta, supplying the pulmonary tissue in the left lower lobe.
b. Three-dimensional CT reconstruction shows the relationship of the aberrant artery (arrows) with adjacent vertebrae and ribs.
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Figure 11
Congenital cystic adenomatoid malformation in an infant. CT shows multiple thin walled cystic lesions with surrounding consolidation in the right lung.

Figure 12
Bronchogenic cyst in an 8-year-old boy. CT shows a classical appearance of an ovoid lesion with soft tissue density (arrow) in the right paravertebral region.

Key Points

Causes of persistent and recurrent chest infection
- Gastroesophageal reflux
- Aspiration
- Foreign body inhalation
- Immunodeficiency
- Underlying bronchiectasis,
- Developmental lung masses
  - Pulmonary sequestration
  - Cystic adenomatoid malformation
  - Bronchogenic cyst

Complications of pneumonia and role of CT

CT is useful for evaluation of complications related to community-acquired pneumonia and helpful in guiding the management.
(1) Parapneumonic effusion/empyema
Parapneumonic effusions (Figure 13) occur commonly in children with bacterial pneumonia. Plain radiograph is good enough for initial diagnosis. However, if the effusion is large, loculated, has delayed appearance, or clinically not responsive to antibiotic therapy alone, an empyema should be suspected. Contrast enhanced CT is advocated in differentiating empyema and transudative parapneumonic effusion. A combination of the following features is highly suggestive of empyema \(^{14,15}\) (Figure 14).
- enhancement and thickening of the parietal and visceral pleura
- thickening of extrapleural subcostal tissues
- increased attenuation of the extrapleural subcostal fat
- adjacent chest wall edema
A more aggressive therapy is therefore indicated in this circumstance such as chest tube placement, thrombolytic therapy \(^{16}\), thoracoscopy and debridement \(^{17}\) for management of empyema.

(2) Necrotizing pneumonia
Underlying suppurative parenchymal complications should be suspected in children with persistent fever and sepsis despite appropriate medical treatment of pneumonia.

CT features of compromised and non-compromised lung:
In necrotizing pneumonia:
- there are areas of decreased or absent enhancement in the consolidated lung (Figure 15) indicating parenchymal ischaemia or impending infarction \(^{18}\). This is in contrast to the diffuse enhancement of non-compromised lung parenchyma consolidated with pneumonia (Figure 13)
- In addition, the necrotic lung tissue may become liquefied thus forming multiple thin-wall cavities containing air or fluid but without enhancing border \(^{19}\) (Figure 15).

(3) Abscess
Lung abscesses are characterized by fluid- or air-filled cavities with enhancing wall (Figure 16). The surrounding lung shows no evidence of necrosis.
It is important to differentiate lung abscesses and necrotising pneumonia. The former requires aspiration or drainage if there is poor response to medical therapy, whereas necrotising
pneumonia does not require invasive treatment, which may even be harmful to the patient resulting in complications such as bronchopleural fistula\textsuperscript{20}.

(4) Pneumatocele
The presence of air cavities within the consolidation does not always point to severe stage of complicated pneumonia. Pneumatoceles are thin walled cysts, which represent a stage of resolving or healing necrosis (Figure 17). The wall of the pneumatocele does not enhance and the surrounding consolidated lung does not demonstrate evidence of necrosis.

(5) Other roles of CT
Besides its diagnostic role, CT is also useful in monitoring treatment progress and guiding therapy:
- detection of inadequately drained effusion
- detection of loculated collection (Figure 18)
- identify mal-positioned chest tube (Figure 19) which requires re-adjustment
- guide the aspiration or drainage procedure for abscesses not responding to medical therapy.

\textbf{Figure 13}
Bacterial pneumonia in a 6-year-old child. There is presence of a large right parapneumonic effusion. Contrast enhanced CT shows homogeneous enhancement of the consolidated lung (arrow) indicating that the lung parenchyma is non-complicated.

\textbf{Figure 14}
Empyema complicating staphylococcus pneumoniae pneumonia in a 3-year-old girl. Contrast enhanced CT shows enhancement and thickening of the pleura (black arrows), increased attenuation of the extrapleural subcostal space (arrowheads) and edema of the chest wall (white arrow).
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Department of Diagnostic Radiology and Organ Imaging, CUHK

Figure 15
Necrotising pneumonia in a 6-year-old boy. There are areas of decreased enhancement in the consolidated lung (arrow) and multiple tiny air cavities (arrowhead) indicating cavitary necrosis of the underlying lung parenchyma. There is also presence of pleural effusion.

Figure 16
Lung abscess in a 15-year-old. CT shows a cavitary lesion containing air-fluid level (arrow). The luminal margin is characteristically thick and irregular.

Figure 17
Pneumatocele in a 2-year-old child. CT shows a thin-walled cavity (arrow) within the consolidated right lung. Air-bronchograms are evident in both consolidated lungs.

Figure 18
This is the follow up CT of the same patient in figure 14. Despite antibiotic treatment, the child still has persistent fever. There is a residual loculated collection (arrow) in the right lung despite resolution of the consolidation and pleural effusion.
Key Points

CT is useful for evaluation of acute complications related to community-acquired pneumonia:
- parapneumonic effusion
- empyema
- necrotizing pneumonia
- lung abscess
- pneumatocele

CT is also useful in guiding management of acute pulmonary or pleural complications:
- placement of chest tube
- guided aspiration of loculated effusion or abscess

Chronic sequelae and role of CT

There are a number of complications that are commonly associated with chest infection in children.

(1) Brochiolitis obliterans
Cause
Bronchiolitis obliterans is observed in children following a chest infection, in particular
adenoviral or mycoplasma infection. It is characterized by inflammatory damage to the small airways, resulting in bronchiole wall thickening, mucostasis, progressive bronchiole narrowing and distortion 21.

Radiological findings
Chest radiographs are usually normal, although hyperaeration and vascular attenuation are sometimes seen. HRCT demonstrates a mosaic perfusion pattern due to oligemia and air-trapping. There are areas of decreased parenchymal attenuation in the affected lung segments as compared with the higher attenuation in the normal parenchyma (Figure 20). The mosaic attenuation pattern is further exaggerated on an expiratory scan 22.

(2) Swyer-James syndrome
Swyer-James or Macleod’s syndrome is a variant of postinfectious constrictive bronchiolitis after respiratory chest infection in early childhood 23. The cardinal sign on chest radiograph is unilateral hypertransradiancy (Figure 21a). HRCT shows unilateral hyperlucency and decreased pulmonary vascularity (Figure 21b).

(3) Fibrosis
Results of remodeling of pulmonary architecture post infection include parenchymal scarring or fibrosis, distortion of bronchiovascular bundles (Figure 22) and bronchial wall thickening (Figure 23)

(4) Bronchiectasis
Bronchiectasis (Figure 24) is one of the most common chronic complications of childhood pneumonia. HRCT is more sensitive than chest radiograph in making the diagnosis. HRCT features of bronchiectasis are 24:
- bronchial dilatation in relation to the accompanying pulmonary artery (“signet ring’ sign)
- bronchial wall thickening
- visualization of airways more distally than usual, within 1cm of costal or paravertebral pleura 25
- crowding of airways
- absence of normal tapering of airways
Chronic bronchiectasis most commonly occurs secondary to adenovirus, bacterial and tuberculous infection 26 (Figure 25).
**Figure 20**
HRCT of a 5-year-old child with postviral bronchiolitis obliterans. Note the difference in attenuation of the lung parenchyma (mosaic attenuation pattern). The affected lung segments (arrows) shows a lower attenuation than the normal parenchyma (arrowheads).

**Figure 21**
Swyer-James syndrome in a 12-year-old girl.
(a) Chest radiograph shows the cardinal sign of unilateral hypertransradiancy of the right lung.
(b) HRCT shows reduced attenuation and paucity of bronchiovascular markings in the right lung.

**Figure 22**
Post infective pulmonary fibrosis in a 5-year-old boy. There is evidence of parenchyma bands (arrow) and minor bronchiovascular distortion in the right posterior lung compatible with scars.
**Figure 23**
Post infective bronchial wall thickening in a 6-year-old boy. There is diffuse bronchial wall thickening (arrowheads) in the right lung. Minor parenchymal band is also present.

**Figure 24**
Bronchiectasis in a 17-year-old boy with viral pneumonia at early childhood. HRCT shows dilatation of the bronchioles in the left lower lobe. The caliber of the bronchiole is much larger than its accompanying vessel, giving rise to the ‘signet ring’ sign (arrow).

**Figure 25**
Persistent bronchiectasis in a 10-year-old girl post tuberculous infection. HRCT shows bronchiectasis (arrow) in the chronically consolidated right middle lobe.

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**Key Points**

Chronic sequelae of respiratory chest infection is well demonstrated by HRCT, these include:

- Bronchiolitis obliterans
- Swyer-James’ syndrome
- Parenchymal scarring / fibrosis
- Bronchiovascular bundle distortion
Conclusion

Plain radiograph is the primary imaging modality for diagnosing pneumonia in children. It is usually not possible to make a definitive diagnosis as to the pathogen responsible for a lower respiratory infection using either plain radiographs or CT; however, certain radiological features are relatively more frequent in a certain group of pathogens. CT including conventional or high resolution CT has superior imaging accuracy than plain radiographs and is indicated in the following circumstances: ¹ to exclude an underlying abnormality in unresolved and recurrent infections; ² when a complication is suspected; ³ to assess the sequelae of respiratory infection.

- Bronchial wall thickening
- Bronchiectasis
References