Pulmonary infections in children - Multimodality evaluation

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Learning objectives

- To illustrate typical imaging findings of pediatric pulmonary infections and its complications.
- To assess different imaging modalities options and to understand their role in specific contexts, regarding when and how to perform imaging evaluation in pediatric pulmonary infections.
Background

Pulmonary infections in children are common, ranging from a self-limited disease to life-threatening conditions.

Pneumonia is defined as an acute inflammation of the pulmonary parenchyma. Pathogens can reach the lungs through three different pathways which include inhalation, direct spread from adjacent structures and hematogeneous spread, with aspiration occurring in the majority of cases.

Virus are the most common causative pathogenic agents of pediatric pneumonias, and account for more than 90% of pneumonias in infants under 2 year old [1]. In pre-school aged children, bacterial pneumonias are more frequently caused by Streptococcus pneumonia whereas in school aged children other pathogens such as Mycoplasma pneumonia and Chlamydia pneumonia often appear [2].

Imaging studies are frequently unnecessary to diagnose pulmonary infections; however, the clinical severity, symptoms persistence and/or uncertainty of diagnosis may warrant an initial chest radiography.

Further imaging studies with ultrasound (US) and computed tomography (CT) are particularly useful to evaluate those children with complicating pneumonia, recurrent infections and suspected pneumonia in immunocompromised patients, or to better characterize chest X-ray abnormalities. Detailed evaluation of pulmonary infections in the immunocompromised child is beyond the scope of this review.
Imaging findings OR Procedure details

ACUTE PULMONARY INFECTION - CHEST RADIOGRAPHY

The usefulness of chest radiography for the diagnosis of pneumonia is still controversial; however it is generally accepted as a reasonable diagnostic test in children with fever and respiratory symptoms [3].

There are three classic radiographic patterns of pulmonary involvement: interstitial, lobar (alveolar) and lobular (bronchopneumonia).

Viruses typically present by an interstitial lung pattern with peribronchial edema and small airway occlusion.

Chest X-ray findings (Fig. 1 on page 8):

- bronchial wall thickening and irregularity
- atelectasis
- pulmonary hyperinflation

Airways narrowing occurs more frequently in children than in adults due to the smaller airway diameter, greater mucus production and relative hyperreactivity as well as the still underdeveloped airspace communication channels (channels of Lambert and pores of Kohn). Therefore, air trapping is a sensitive indicator of low respiratory infection in young children [2].

Bacterial pneumonia can lead to a lobar consolidation due to alveolar filling. *Streptococcus pneumonia* is the classic example.

Chest X-ray findings (Fig. 2 on page 8):

- lung opacification without volume reduction
- well defined border when abutting a pleural fissure
- air bronchogram - airways are relatively spared
- associated pleural effusion

Round pneumonia manifests as a sphere-shaped consolidation, which can mimic a mass-like lesion (Fig. 3 on page 9). It is more frequently caused by *S. pneumonia*, with a lower lobe predilection, and typically occurs in young children (<8 year old) in whom airspaces communication channels haven't yet matured.
Other agents such as M. pneumonia and S. aureus may present as bronchopneumonia, characterized by involvement of the terminal and respiratory bronchioli with spread to the alveoli. Radiographic findings from both interstitial and lobar pneumonias can be found.

These typical patterns, however, are not specific and there are considerable overlap between different pathogens [4]. Additionally, patients with viral infections may develop a superimposed bacterial infection resulting in mixed radiographic patterns. Thus, it is not possible to accurately distinguish viral from bacterial etiology on the basis of radiological findings alone. In clinical practice, children with a consolidation/alveolar infiltrate seen on chest radiography, especially those with lobar involvement, have higher probability of bacterial pneumonia and should be treated accordingly [4].

The lateral view of chest radiography can help locating the infectious process within the lung. It is more sensitive than the frontal view to detect hyperinflation [3] and abnormalities in some hidden regions (retrocardiac, left lower lobe, pleural space). Its benefits should be weighed against the increased additional radiation dose, especially in younger children.

Routine follow-up chest X-rays are not recommended in patients with good clinical outcome [2]. Radiographic abnormalities may last up to 4 weeks after the initial infection, even in patients with adequate treatment and full clinical recovery [3]. Subsequent radiographs are justified in children with recurrent/persistent symptoms and/or in those with specific underlying conditions (such as immunocompromised patients).

CHEST ULTRASOUND AND COMPUTED TOMOGRAPHY

Ultrasound is an invaluable imaging modality in the pediatric population, especially considering its lack of ionizing radiation. Chest ultrasound may offer important additional information, and it is particularly useful when chest radiography findings are equivocal [5]. It may also help to reduce radiation exposure in follow-up examinations. When a consolidation reaches the chest wall or diaphragm, it is accessible to US evaluation. Its typical image is a "liver-like" appearance of the lung parenchyma, with air bronchogram manifesting as branching linear echogenicities (Fig. 4 on page 10). Furthermore, chest US is the most sensitive imaging technique to detect and characterize pleural effusion.

Chest CT has great anatomic detail and can provide large amounts of information concerning not only the respiratory but also mediastinal and chest wall abnormalities. It is usually reserved for selected patients, namely those with complicated or recurrent infections. Application of the ALARA ("as low as reasonably achievable") principle [6] is of utmost importance to reduce the significant radiation burden of CT. Besides the
pertinence of the exam, technical aspects should be thoroughly optimized to each patients' clinical condition and specific age and body weight [7].

**COMPLICATED PULMONARY INFECTION**

In patients with persistence and/or progression of symptoms despite adequate treatment, a suppurative complication should be suspected. If chest radiography is noncontributory or insufficient, further evaluation with chest US and/or CT might be needed to clearly identify those complications, thus allowing for adequate treatment decision. In general, chest CT should be performed with intravenous iodine contrast administration whenever possible, to increase the accuracy for detection and characterization of pleural and pulmonary complications.

*Pleural Complications - Effusion and Empyema*

Pleural effusion is the most common complication of bacterial pneumonia.

Chest US is more sensitive than chest radiography to detect small pleural effusions and more sensitive than chest CT to identify pleural septations [5]. Echogenic material and/or loculations suggest a complicated pleural effusion (Fig. 5 on page 11), although the definitive diagnosis of empyema requires laboratory tests. Moreover, chest US is a safe way to guide pleural drainage and/or chest tube placement.

CT has a limited role in characterizing pleural effusions. Findings such as parietal pleural enhancement and thickening (Fig. 6 on page 12) are inaccurate in distinguishing empyema from transudative effusion [8]. However, it can be valuable to detect residual loculated collections and malpositioned chest tubes when the patient presents progressive illness.

*Lung Parenchymal Complications - Cavitary necrosis, Pulmonary abscess and Bronchopleural fistula*

Chest CT is the modality of choice to depict these complications. Cavitary necrosis, the most frequent of this group of complication, non-surprisingly, can be identified earlier on CT than on chest radiography [3]. It is characterized by a necrotic area with decreased or no contrast enhancement, disruption of normal lung anatomy and thin-walled cavities, filled with liquid and/or air (Fig. 6 on page 12; Fig. 7 on page 13). Hypoenhancing lung parenchyma may be an early finding of necrosis [9]. Lung abscess is suggested by
the presence of a liquid or liquid and gas collection with an enhancing and well-defined wall.

If peripheral located in the lungs, US imaging may show loss of normal lung anatomy, perfusion defects on color Doppler and presence of a hypoechoic areas within lung consolidation (necrotizing pneumonia Fig. 8 on page 14) or a hydric collection in the parenchyma, delimited by a thick wall (abscess formation Fig. 9 on page 15). It is possible to avoid CT scan when echographic, radiographic, and clinical findings are in agreement [5]. Abscess drainage can also be guided by US.

Bronchopleural fistula is defined as a communication between the bronchial tree and the pleural space, directly or through lung parenchyma [10]. CT scan may identify the exact communication channel (Fig. 10 on page 16), allowing for treatment planning. Pneumothorax is not a requirement, given that a fistula can present as communication between an effusion and a parenchymal liquid collection with visceral pleural discontinuity.

**PERSISTENT AND RECURRENT INFECTIONS**

Besides acute pneumonia complications, other causes must be considered in children with persisting clinical symptoms and in those with recurrent pulmonary infections including developmental lesions, bronchial obstruction, gastroesophageal reflux aspiration and underlying systemic disorders (such as immunodeficiency states).

Developmental lesions, more commonly congenital cystic adenomatoid malformation (Fig. 11 on page 17) and sequestration (Fig. 12 on page 18), and rarely bronchogenic cysts, may become infected and may present as a persistent or recurrent pneumonia [3]. CT is helpful to identify and characterize these lesions.

Bronchial obstruction is more frequently caused by foreign body aspiration, which can be located on chest CT by an endobronchial filling defect. Moreover, CT is particularly useful to evaluate chronic lung complications from previously unsuspected foreign body aspiration episode such as bronchiectasis, atelectasis and/or obstructive hyperinflation of the affected pulmonary segment or lobe (Fig. 13 on page 19).

Pulmonary infections are an important cause of morbidity and mortality in the immunocompromised patients. CT is more frequently justified to study these patients given the need for early diagnosis (Fig. 14 on page 20) and treatment [7].
**Fig. 1:** Chest radiography in a 12 month old child with suspected respiratory infection. Moderate hyperinflation particularly of the right lung, with prominent peribronchial markings and linear dense opacity in the right upper lobe from atelectasis (arrow).

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Fig. 2: Chest radiography in a 5 year old child. Left lower lobe consolidation with air bronchogram sign (arrow). Blurring of the left cardiac border suspicious of additional lingula lobe consolidation. Homogeneous peripheral low density with obliteration of the left cardiophrenic angle suggests pleural effusion which was confirmed by chest ultrasound (not shown).

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**Fig. 3:** Chest radiography in a 4 year old child. Round pneumonia in the left upper lobe (arrow) seen as a nodular parenchymal opacity with ill defined borders.

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**Fig. 4:** Chest ultrasound in a 9 year old child. Lung consolidation seen as a "liver-like" lung parenchymal appearance with sonographic bronchogram sign seen as linear branching hyperechoic dots (arrow). Simple anechoic pleural effusion also present(*)

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Fig. 5: Chest ultrasound in a 12 year old child. Complicated pleural effusion. Multiple loculated pleural fluid (arrows), delimited by thick septa, and debris.

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**Fig. 6:** Chest CT scan with IV contrast in a 5 year old child with necrotizing pneumonia with lung cavitation (arrow). Left pleural effusion (*) with contrast enhancement and thickening of the parietal pleurae. Pericardial effusion also noted.

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Fig. 7: Chest CT scan in a 2 year old child. Left lower lobe consolidation with two air filed cavities (arrows).

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Fig. 8: Chest ultrasound with color Doppler in a 5 year old child. Lung consolidation with hypoechoic areas with no Doppler signal within them (arrow), suggestive of necrosis. Simple pleural effusion (*) also noted.

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**Fig. 9:** Chest ultrasound in a 4 month old patient. Lung parenchymal disruption and a fluid collection (*), with echogenic material within, that is delimited by a thick wall (arrow) suggestive of a lung abscess.

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**Fig. 10:** Chest CT scan in a 2 year old child. Coronal oblique reformat image. Left loculated pneumothorax (*), with contralateral displacement of the mediastinum. Pleural discontinuity (arrow) with communication between the pleural cavity and bronchus lumen confirming a bronchopleural fistula.

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**Fig. 11:** Chest CT scan with IV contrast in a 6 month old child. Left lower lobe type II congenital pulmonary airways malformation with multiple small cysts (arrow), with blood supply arising from the pulmonary circulation.

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Fig. 12: Chest CT scan with IV contrast in a 6 year old child with recurrent pulmonary infections. A - axial image shows posterior left lower lobe pulmonary malformation with solid and cystic components. B - coronal MIP reformat image shows systemic arterial blood supply with a feeding vessel (arrow) arising from the abdominal aorta (not shown).

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**Fig. 13:** Chest CT scan in a 10 year old child with recurrent pulmonary infection after long standing foreign body aspiration history that was lodged within the intermediate bronchus. Atelectasis with bronchiectasis (arrow) in the right lower lobe and middle lobe. Hyperinflation of the adjacent right lung with micronodular infiltrates (*).

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Fig. 14: Chest CT scan in an immunocompromised 12 year old child after bone marrow transplant for aplastic anemia. Left upper lobe consolidation with air crescent sign (arrow) suggestive of fungal infection.

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Conclusion

Familiarity with each imaging modality capabilities, and their respective strengths and weaknesses, allows optimization of imaging evaluation in pediatric pulmonary infections while minimizing ionizing radiation exposure and avoiding unnecessary studies.

Knowledge of radiologic findings may help narrow down the list of differential diagnoses.

US is an excellent imaging modality to evaluate pleural effusions, and also to guide chest tube placement. Furthermore, if located in the peripheral lung US can be used to evaluate lung parenchymal consolidations and to help differentiating between necrotizing pneumonia and empyema.

In complicated or recurrent pneumonias and pneumonia affecting immunocompromised patients, CT has an important diagnostic role.
References