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REVIEW

What imaging should we perform for the diagnosis and management of pulmonary infections?

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Definition and pathophysiology

Pneumonia is an infection of the lower respiratory tract, involving the lung parenchyma. Whereas most pulmonary infections in children are viral and of the upper respiratory tract, bacterial pneumonias have a higher morbidity and are more frequent indications for imaging. It appears that the lung response to an infective antigen is more age-specific than antigen (i.e. bacteria vs. viral) dependent [1, 2].

The complications of pneumonia include parapneumonic (pleural) effusion, empyema, or abscess. Progression of a pleural effusion to empyema is through three stages: exudative, fibrinopurulent and organization. These complications may arise when there is an unbalance between the virulence of the offending organism and the defense mechanisms of the host, which may be compromised by anatomic factors that impede clearance of secretions (congenital malformations such as pulmonary sequestration and systemic disease such as cystic fibrosis) and/or immune deficiency conditions.

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Epidemiology

Worldwide, there are over 150 million cases of pneumonia annually in children less than 5 years of age [3]. In the United States, 20 million hospitalizations occur annually in children, but this count includes viral etiologies [3]. In the developed nations, 5–10% of children under the age of 5 years will develop pneumonia annually [4]. The incidence of pneumonia in children is 34 to 40 per 1,000 [5]. Complicated pneumonia such as necrotizing pneumonia and abscess formation increased in incidence over the years between 1990 and 2005 [6, 7]. Parapneumonic effusions complicate pneumonia in 36–56% of cases, resulting in an incidence of 0.4–0.6 per 1,000 [8]. Empyema complicates an estimated 0.6% of all childhood pneumonias, resulting in an incidence of 3.3 per 100,000 [9]. There has been a recent emergence of community-acquired Methicillin Resistant *Staphylococcus Aureus* (MRSA) pneumonias in children, originally thought to be mainly hospital-acquired [10] (Fig. 1).

Cost to society

In the adult population in Europe, the cost to society resulting from uncomplicated pneumonia (1.1 million cases annually) is estimated at 8 billion dollars [11]. Childhood pneumonias are a frequent cause of doctor visits, antibiotics prescription, loss of work days for parents, and reduction of quality of life [12]. Regarding treatment of pneumonia with pleural complications, gross total cost is approximately equal between thoracentesis, pleural drain placement, or video-assisted thorascopic surgery (VATS), but hospital length of stay is substantially shorter with VATS [8].

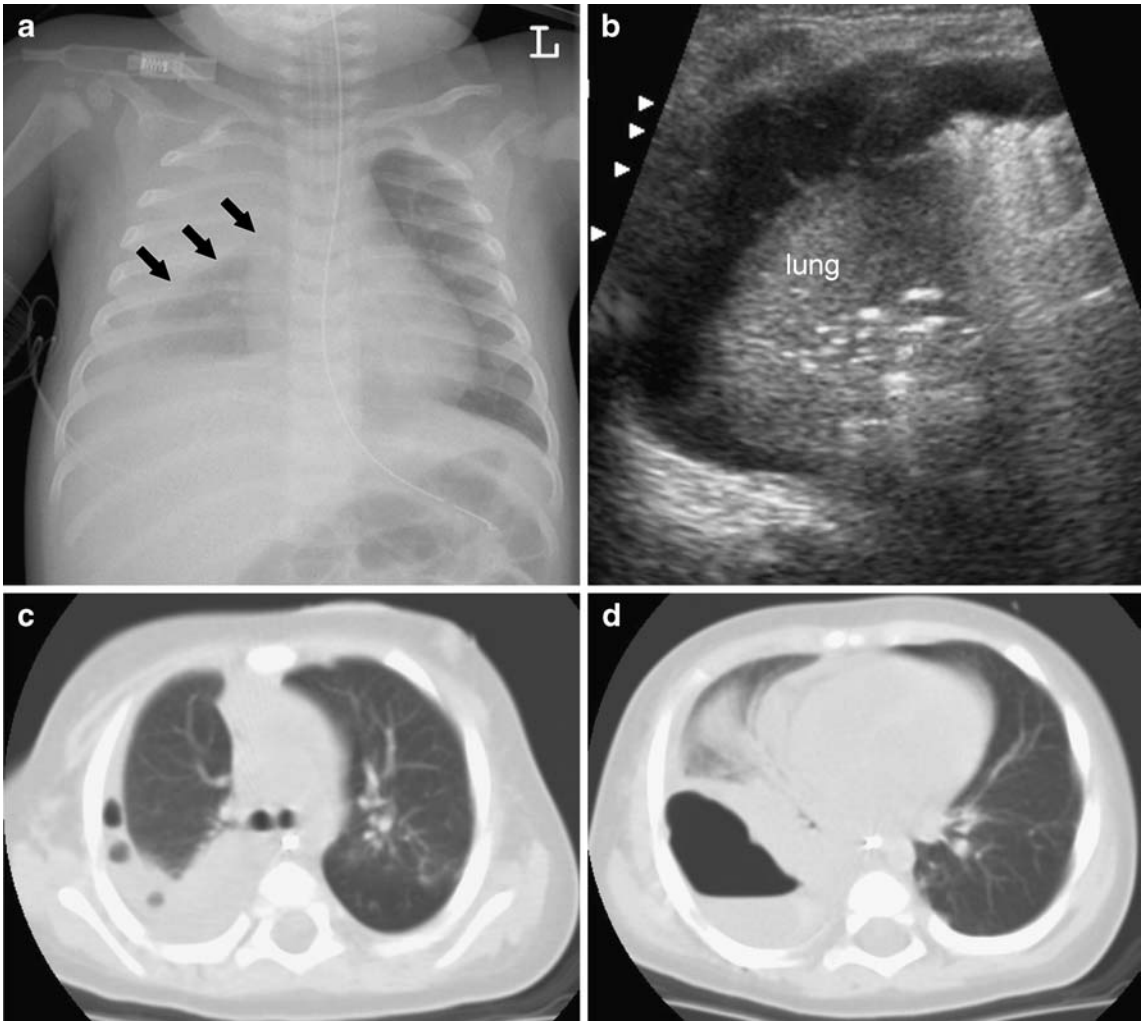

Fig. 1 Empyema, role of cross-sectional imaging. Radiograph in 7-month-old girl with pneumonia demonstrates right pleural thickening, which has a convex margin toward the lung (**a**, *arrow*). Transverse US image of the right chest (**b**) shows an echo-complex pleural effusion, containing thin septations. CT confirms the presence of loculated pleural fluid collections, containing trapped gas bubbles (**c**) and, more inferiorly, an air-fluid level (**d**). The child underwent several ultrasound-guided thoracocenteses yielding *S. aureus*, but eventually required surgical decortication

Goals of imaging

The main goal in imaging pulmonary infections is early diagnosis, which is particularly important in children with an underlying lung abnormality or a weakened immune system. When there is pleural effusion, cross-sectional imaging guides appropriate management.

Issues

Diagnosis of pneumonia

In the neonatal period, viral pneumonia is rare due to conferred maternal antibody protection, whereas bacterial pneumonia is most frequently due to pathogens acquired during labor and delivery, and is more prevalent in premature babies [13]. In keeping with dropping maternal antibody levels, viral pneumonia occurs at a peak between 2 months to 2 years of age [14]. In older children from 2 years to 18 years of age, bacterial infections become relatively more common.

Presenting symptoms and signs of pneumonia are often non-specific, but include cough, fever or temperature instability, abnormal leukocyte count, findings of sepsis, and respiratory distress [15]. The presence of all four symptoms fever, cough, sputum, and course crackles yields a sensitivity and specificity of 91.7% and 92.7% for clinical detection of pneumonia [16]. Another study identified tachypnea as the single best clinical sign for identifying pneumonia, with a sensitivity of 74% and a specificity of 67% [17](Table 1).

Table 1 Diagnostic performance of clinical exam and chest radiography in the detection of pneumonia in immunocompetent patients.

Clinical exam:						
Author	Year	Study size	Finding	Sensitivity	Specificity	
Palafox, et al [17]	2000	110	Tachypnea	74%	67%	
Okimoto, et al [16]	2006	79	If all of following present: Fever, Cough, Sputum production, Dyspnea	91.7%	92.7%	
Chest radiography						
Author	Year	Study size	Sensitivity	Specificity	PPV	NPV
Rigsby, et al [23]	2004	240	85%	98%	n/a	n/a
Lamme, et al [24]	1986	179	81–87%	95–96%	n/a	n/a
Patenaude, et al [25]	1995	373	71%	90%	n/a	n/a
Graffelman, et al [52]	2007	129	n/a	n/a	75%	57%

Summary: reported sensitivities range between 71% and 87% and specificities from 90–98% [23–25]

Differentiation between bacterial and viral etiologies of pneumonia would be helpful for treatment decisions. In bacterial infection, physical findings are most commonly limited to one anatomic area, and symptoms that are more specific for bacterial infection are high fever and, in older children, pleuritic chest pain [18]. Primary viral infection is considered more likely if onset of symptoms is more gradual and include wheezing, rhinorrhea and congestion [18]. In addition, viral illnesses may often precede bacterial infection [18]. In keeping with the concept that the pattern of lung response to infection is more influenced by age than by the offending organism, lobar and alveolar lung opacities are more common in older children and are more frequently due to bacterial infections, whereas interstitial opacities are seen in all age groups, and are therefore non-specific as to the type of causative organism [1, 2].

In children, microbiology of sputum and blood cultures have limited utility, and the diagnosis of pneumonia is most often confirmed with radiography [19, 20]. Accepted clinical indications for chest radiography are severe disease, confirmation of non-specific clinical findings, assessment of complications, and exclusion of other thoracic causes of respiratory symptoms [21, 22]. Despite their limitations, there is moderate evidence to suggest that chest radiographs are sufficiently sensitive and highly specific for the diagnosis of community-acquired pneumonia, with reported sensitivities of 71–87%, and specificities of 90–98% [23–25] (Table 1). Of note, a large randomized clinical trial of children under 5 years of age presenting in an ambulatory care setting with uncomplicated pneumonias failed to demonstrate any evidence that the routine performance of chest radiography improves clinical outcomes [26]. Clinicians typically do not obtain chest radiographs in first-time wheezing episodes presumed to be viral in etiology, whereas there is a higher utilization of radiographs in patients with elevated temperature, absence of family history of asthma, and localized wheezing on physical examination [27]. Use of a set of evidence-based guidelines, as implemented at a major children's hospital, has demonstrated a 20% decrease in the number of chest radiographs ordered for respiratory tract infections [27, 28].

In children less aged less than 5 years old presenting with fever of unknown origin and leucocytosis, there is limited evidence to suggest that chest radiographs may help diagnose occult pneumonia, which has an estimated incidence of at least 19% in this population [29].

Diagnosis of pneumonia with complications and complicating host factors

There is moderate evidence to suggest that CT provides more information than plain radiographs for complicated

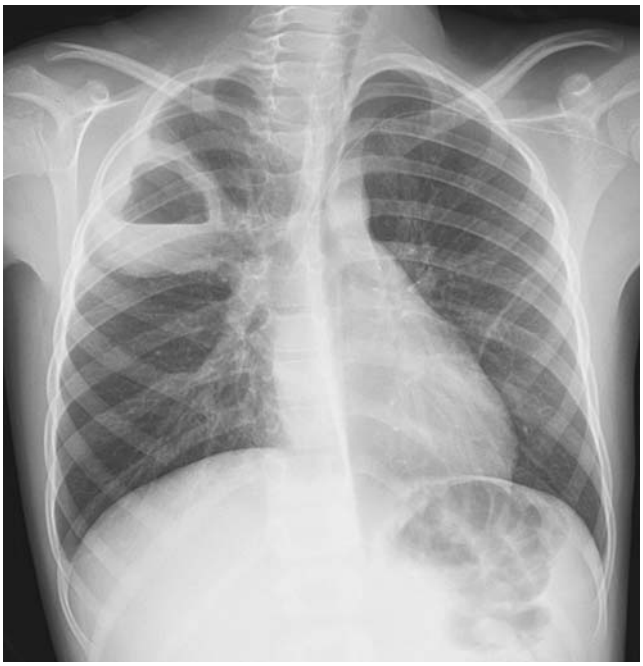

Fig. 2 Chest radiograph in 7-year-old boy with developmental delay, seizures and a history of a near-drowning episode, demonstrates a round opacity in the right upper lung zone which forms an acute angle with the pleura and contains an air-fluid level, consistent with a lung abscess

pulmonary infections with extensive necrosis and lung abscesses (Fig. 2), loculated pleural effusions including empyemas (Fig. 1), bronchopleural fistulae, or those that are caused by opportunistic organisms such as fungi [30–37].

In the higher risk immunocompromised patients, it is critical to have a high sensitivity, as failure to detect results in failure to treat and subsequent high mortality [32]. CT has been shown to have higher accuracy than plain radiography for early detection of fungal and Pneumocystic carinii pneumonias in immunocompromised and hospitalized patients [32, 35]. Compared to chest radiography, CT often adds confidence and changes management (biopsy, changing antibiotics, bronchoscopy) [38]. In the case of nosocomial infections, such as multidrug resistant (MRSA) pneumonias, CT offers a rapid and decisive diagnosis [10].

In children with pleural complications of pneumonias, there are several studies evaluating the prognostic implications of the use of ultrasound versus CT and the implications for treatment decisions [39–44]. There is moderate evidence to suggest that ultrasound is more accurate than CT to identify and characterize complicated effusions, in addition to being more cost-effective and not employing ionizing radiation. Early sonographic evaluation of parapneumonic effusions can lead to decreased hospital length of stay for echo-complex effusions, and effective triage into operative versus non-operative treatment groups [42].

Image-guidance of treatment of pleural complications of pneumonias

Thoracentesis is a standard procedure for the management of pleural effusions in adults. However, in children, thoracentesis is not easily performed, as this procedure requires cooperation and frequently sedation. Patients treated with thoracentesis often require additional interventions due to recurrences [9, 45, 46]. Single chest tube placement versus repeated thoracentesis has no significant difference in outcome, thereby supporting that in children early thoracostomy tube drainage is preferred to thoracentesis, in order to avoid repeat-interventions [47]. Currently, there is insufficient evidence to support fibrinolytic therapy for childhood empyema in conjunction with thoracostomy drainage. A recent meta-analysis has shown that, in adults, intrapleural fibrinolytic therapy confers significant benefit in reducing the requirements for surgical intervention only in the early studies included in the review, but not in the more recently published studies [48]. In children, fibrinolytic therapy has been reported to have a failure rate of 9.3%, a complication rate of 12.5%, and a slightly reduced length of hospital stay compared to the saline group [49]. The side effects and the pain from this treatment currently limit its use in children. A surgical concern with this therapy is that patients may be more likely to fail rescue VATS, as urokinase may cause pleural septations to become very adhesive [9].

In children who are not amenable to minimally invasive image-guided procedures such as thoracentesis or simple chest tube placement without or with fibrinolysis, surgical interventions including video assisted thorascopic surgery (VATS) or thoracotomy are effective options [8, 49]. The advantage of early VATS over conventional thoracostomy drainage is well supported in the surgical literature by a prospective randomized trial [8] and a meta-analysis study [9, 49].

Summary of the evidence and Key Points

- Imaging studies have limited value in the differentiation between viral and bacterial lower respiratory tract infection.
- CT provides more information than plain radiographs for complicated pulmonary infections with pleural effusions, empyema or bronchopleural fistula.
- In immunocompromised patients, CT has been shown to characterize the type of infection better than plain radiographs.
- Ultrasound has an advantage over CT in the identification and characterization of complex pleural effusions.
- Early surgery (VATS) is more cost-effective than thoracostomy (without or with image guidance) in the treatment of empyemas in children.

Imaging protocols

Radiography Posterior-Anterior (PA) and lateral views are optimal whenever possible. Anterior-Posterior (AP) views are also very useful. In suspected effusions, decubitus views can be useful in distinguishing free flowing pleural fluid versus loculated fluid collections.

Ultrasound Technique includes screening of the whole pleural space, not just the lung bases. Lower frequency (3.5–7 MHz) sector transducers are used initially for more overview through inter- and subcostal scanning; higher frequency (10–12.5 MHz) linear transducers are helpful for more detail in the near field, prior to marking for needle placement [50].

Chest CT In chest infections, use of intravenous contrast is almost always indicated. Lower mA techniques (and kVp reduction in small children) should be used than in the abdomen, due to the high intrinsic contrast of lung parenchyma; further dose reduction is possible with follow up of large lesions, and for checking the position of chest tubes.

Future research

- What is the cost-effectiveness of CT in the management of parapneumonic effusions and empyema?
- Can findings on imaging (plain radiography, ultrasound, CT) predict the likelihood of success of various interventions for complications of pneumonia?
- How can ultrasound, a non-irradiating modality, be utilized more in the evaluation of pulmonary infections?
- What is the role of MR, a more expensive but non-ionizing modality, for evaluation of pulmonary infection complications? [51]
- A prospective clinical trial, to compare the benefits (including cost-effectiveness) of optimal imaging-guided intervention (with fibrinolysis) to early surgery (VATS) for the treatment of empyemas in children.

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