Comparison of Ultrasound and CT in the Evaluation of Pneumonia Complicated by Parapneumonic Effusion in Children

OBJECTIVE. The purpose of our study was to compare chest ultrasound and chest CT in children with complicated pneumonia and parapneumonic effusion.

MATERIALS AND METHODS. We retrospectively compared chest ultrasound and chest CT in 19 children (nine girls and 10 boys; age range, 8 months–17 years) admitted with complicated pneumonia and parapneumonic effusion between December 2006 and January 2009. Images were evaluated for effusion, loculation, fibrin strands, parenchymal consolidation, necrosis, and abscess. In the subset of patients who underwent surgical management, imaging findings were correlated with operative findings.

RESULTS. Eighteen of 19 patients had an effusion on both chest ultrasound and chest CT. The findings of effusion loculation as well as parenchymal consolidation and necrosis or abscess were similar between the two techniques. Chest ultrasound was better able to visualize fibrin strands within the effusions. Of the 14 patients who underwent video-assisted thoracoscopy, five had surgically proven parenchymal abscess or necrosis. Preoperatively, chest ultrasound was able to show parenchymal abscess or necrosis in four patients, whereas chest CT was able to show parenchymal abscess or necrosis in three.

CONCLUSION. In our series, chest ultrasound and chest CT were similar in their ability to detect loculated effusion and lung necrosis or abscess resulting from complicated pneumonia. Chest CT did not provide any additional clinically useful information that was not also seen on chest ultrasound. We suggest that the imaging workup of complicated pediatric pneumonia include chest radiography and chest ultrasound, reserving chest CT for cases in which the chest ultrasound is technically limited or discrepant with the clinical findings.

Community-acquired pneumonia in the pediatric population is common, with 40 cases per 1,000 children under 5 years old diagnosed annually in Europe and North America [1]. Up to 53% of hospitalized cases are complicated by parapneumonic effusion, empyema, and pulmonary necrosis or pulmonary abscess [2]. Both the diagnosis and therapy of complicated pneumonia are guided by imaging. Although initial evaluation is based on chest radiography, chest CT has traditionally been used to evaluate the disease process in children before chest tube drainage (with or without thrombolytics), video-assisted thoracoscopy (VAT), or open thoracotomy and decortication. The British Thoracic Society (BTS) guidelines for the management of pediatric empyema recommend the use of chest ultrasound for detecting pleural effusion and guiding drain placement. However, the guidelines note that chest CT plays a role in complicated cases and is often required before surgery to characterize anatomy and evaluate for coexisting pulmonary abscess [3]. In light of increasing awareness of radiation exposure risks, particularly in children, we retrospectively compared the information obtained from chest ultrasound and chest CT in children with pneumonia and parapneumonic effusion to determine if chest ultrasound could serve as a useful alternative to chest CT. In those patients who underwent surgical management, operative findings were reviewed and correlated with imaging findings.

Materials and Methods

Patient Population

The study met requirements for exemption from institution review board approval. Children diagnosed with complicated pneumonia (pneumonia and effusion) on the basis of clinical examination and chest radiography, who underwent both chest CT and chest ultrasound during their...
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admission between December 2006 and January 2009 were included in the study. Nineteen patients (nine boys and 10 girls) with a mean age of 5.4 years (age range, 8 months–17 years) who met the study criteria were identified. The mean time between chest ultrasound and CT was 2.7 days (range, 0–8 days).

Chest Ultrasound Technique

Chest ultrasound was performed by two experienced staff ultrasound technologists on an iU22 ultrasound system (Philips Healthcare) \((n = 15)\), an HDI 5000 ultrasound system (Philips Healthcare) \((n = 3)\), or an Acuson Sequoia 512 ultrasound system (Siemens Healthcare) \((n = 1)\). Linear (5–12 MHz), curved linear (2–5, 4–9, or 5–8 MHz), and vector (5–8 MHz) transducers were used. The chest abnormality was localized on the basis of chest radiography findings. Anterior, posterior, and midaxillary images were obtained using an intercostal approach in transverse and longitudinal planes from the apex to the diaphragm with the patient in a supine or decubitus position. Color Doppler ultrasound was performed to evaluate the vascularity of regional parenchymal abnormalities.

Chest CT Technique

Chest CT was performed on an MX-8000 IDT 16-MDCT scanner (Philips Healthcare) \((n = 7)\), a Brilliance 16-MDCT scanner (Philips Healthcare Electronics) \((n = 6)\), or a LightSpeed VCT 64-MDCT scanner (GE Healthcare) \((n = 5)\). Images were obtained from the level of the thoracic inlet to the diaphragm using a pitch of 1.0, 120 kVp, and a weight-based low-dose tube current. Thirteen of the patients underwent CT with the administration of nonionic IV contrast material (320 mg I/mL iohexol, Visipaque, GE Healthcare) at a dose of 1 mL/kg. CT data were reconstructed at a slice thickness of either 3 or 5 mm for image review. For one patient, images from an unenhanced chest CT performed at an outside hospital on the day of transfer to our institution were reviewed.

Image Evaluation

The chest CT and chest ultrasound images were retrospectively reviewed in consensus by a board-certified pediatric radiologist and a radiology resident. The interpreting radiologists were blinded to the results of the chest CT and chest ultrasound when reviewing either study. Images were examined for the presence of pleural effusion and fibrin strands within the effusion. Pleural effusion was defined as loculated if the collection had a lobulated or lenticular shape with a convex border [4, 5].

Chest CT and chest ultrasound images were also examined for parenchymal consolidation and the presence of lung necrosis or abscess. On chest CT, consolidation was defined as air-space opacity with air bronchograms. On chest ultrasound, it was defined as replacement of normal reflections of aerated lung by solid-appearing areas, with
bright linear and branching echoes representing sonographic air bronchograms [6, 7]. On chest CT, pulmonary necrosis was assessed on contrast-enhanced scans and was defined as a low-density area within a consolidated lung that had diminished enhancement relative to the adjacent parenchyma [4, 8]. On chest ultrasound, pulmonary necrosis was defined as a focal rounded area of decreased echogenicity within a portion of consolidated lung [9]. Although the use of color Doppler ultrasound in the evaluation of necrotizing pneumonia has not been well studied, a lack of central color Doppler flow within the hypoechogenic pulmonary lesions was used to support the diagnosis of necrosis because it has been suggested that necrosis is related to areas of ischemic lung arising from adjacent inflammation [8]. Abscess was defined as an intrapulmonary cavity containing fluid or air, with no central enhancement on chest CT or no central color Doppler flow on chest ultrasound [4, 10].

Surgical Correlation

In addition to antibiotics, therapeutic options for the treatment of pneumonia complicated by effusion include chest tube placement with instillation of fibrinolitics into the pleural space, or VAT [11, 12]. At our institution, VAT is the preferred method in patients who fail antibiotic therapy either with or without chest tube drainage. Typically, the decision to proceed to surgery is based on assessment of the patient by a surgeon in conjunction with a multidisciplinary clinical team. Laboratory and radiologic data are taken into account. For the patients in our study who were managed surgically, operative and histopathology reports were reviewed for the presence of pleural fluid, empyema, and lung necrosis or abscess. The chest CT and chest ultrasound findings were compared with operative findings.

Results

Pleurial Findings

Of the 19 patients in whom pneumonia with parapneumonic effusion was diagnosed on chest radiography, 18 had an effusion confirmed on both chest CT and chest ultrasound, and one had no effusion on either examination. Fifteen effusions were loculated on chest CT, and 13 were loculated on chest ultrasound; in one patient, loculation seen on chest CT could not be determined on chest ultrasound because of scan quality limitations. Fibrin strands were identified in all patients with effusion except for one patient with only trace fluid; some patients showed few fibrin strands, whereas others showed numerous strands of variable
### TABLE 1: Patient Characteristics and Pleural, Parenchymal, and Surgical Findings

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Age</th>
<th>Sex</th>
<th>Chest CT</th>
<th>Pleural Effusion</th>
<th>Parenchymal Findings</th>
<th>Surgical Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Loculated, left</td>
<td>Multilobar, left consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>2</td>
<td>4 y</td>
<td>F</td>
<td>Contrast-enhanced</td>
<td>Loculated, left</td>
<td>Multilobar, left consolidation, LUL necrosis</td>
<td>Empyema, LUL abscess</td>
</tr>
<tr>
<td>3</td>
<td>6 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Loculated, right</td>
<td>Multilobar, right consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>4</td>
<td>7 y</td>
<td>F</td>
<td>Contrast-enhanced</td>
<td>Loculated, left</td>
<td>LLL consolidation, necrosis</td>
<td>Empyema, LLL necrosis, abscess</td>
</tr>
<tr>
<td>5</td>
<td>4 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Loculated, right</td>
<td>LLL, multilobar, right consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>6</td>
<td>8 mo</td>
<td>F</td>
<td>Contrast-enhanced</td>
<td>Loculated, left</td>
<td>LLL consolidation</td>
<td>Empyema, LLL abscess</td>
</tr>
<tr>
<td>7</td>
<td>2 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Loculated, right</td>
<td>RML/RLL abscess</td>
<td>Empyema, RLL necrosis, RLL abscess</td>
</tr>
<tr>
<td>8</td>
<td>4 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Loculated, right</td>
<td>RLL abscess</td>
<td>Empyema</td>
</tr>
<tr>
<td>9</td>
<td>4 y</td>
<td>F</td>
<td>Contrast-enhanced</td>
<td>Nonloculated, left</td>
<td>Multilobar, right consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>10</td>
<td>11 mo</td>
<td>F</td>
<td>Contrast-enhanced</td>
<td>Trace</td>
<td>LLL consolidation, necrosis</td>
<td>Empyema</td>
</tr>
<tr>
<td>11</td>
<td>12 y</td>
<td>F</td>
<td>Unenhanced</td>
<td>Loculated, left</td>
<td>LLL consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>12</td>
<td>3 y</td>
<td>F</td>
<td>Unenhanced</td>
<td>Loculated, right</td>
<td>Multilobar, right consolidation</td>
<td>Empyema, two RLL abscesses</td>
</tr>
<tr>
<td>13</td>
<td>3 y</td>
<td>F</td>
<td>Unenhanced</td>
<td>Loculated, right</td>
<td>Multilobar, right consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>14</td>
<td>2 y</td>
<td>F</td>
<td>Unenhanced</td>
<td>Loculated, right</td>
<td>Multilobar, right consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>15</td>
<td>3 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Nonloculated, left</td>
<td>Multilobar, right consolidation, RLL necrosis</td>
<td>Empyema</td>
</tr>
<tr>
<td>16</td>
<td>5 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>Loculated, right</td>
<td>RLL consolidation, necrosis</td>
<td>Empyema</td>
</tr>
<tr>
<td>17</td>
<td>16 y</td>
<td>M</td>
<td>Contrast-enhanced</td>
<td>None</td>
<td>Multilobar, right consolidation, RML necrosis</td>
<td>Empyema</td>
</tr>
<tr>
<td>18</td>
<td>5 y</td>
<td>F</td>
<td>Unenhanced</td>
<td>Loculated, right</td>
<td>RUL consolidation</td>
<td>Empyema</td>
</tr>
<tr>
<td>19</td>
<td>17 y</td>
<td>M</td>
<td>Unenhanced</td>
<td>Loculated, right</td>
<td>RLL consolidation</td>
<td>Empyema</td>
</tr>
</tbody>
</table>

Note—LUL = left upper lobe, LLL = left lower lobe, RML = right middle lobe, RLL = right lower lobe, RUL = right upper lobe.

*Unable to determine loculation or consolidation due to suboptimal scan quality.

*Linear transducer not used in this chest ultrasound.
thickness. Although presumably present, fibrin strands could not be clearly delineated on any of the chest CT images (Figs. 1 and 2).

**Parenchymal Findings**

Of the 19 chest CT examinations, 13 were contrast-enhanced and six were unenhanced. All chest CT examinations showed parenchymal consolidation. The contrast-enhanced examinations identified six patients with coexisting necrosis and two with coexisting abscess. Of the 19 chest ultrasound examinations, 18 showed parenchymal consolidation. Six of these had coexisting necrosis, and one had a coexisting abscess.

Consolidation was shown in all patients on both chest CT and chest ultrasound except for one chest ultrasound in which technical limitations precluded evaluation of the lung. Chest CT and chest ultrasound concurred on the presence of necrosis in five patients (Fig. 3) and differed in two; necrosis was identified on chest CT in one patient for whom the ultrasound was limited by lack of evaluation with a linear transducer (patient 17, Table 1), and necrosis was identified on chest ultrasound in another patient for whom the chest CT was unenhanced (patient 12, Table 1).

**Surgical Findings**

Fourteen patients underwent VAT, and five were treated with antibiotics with or without chest tube drainage. In the surgically managed group, 13 patients were found to have empyema; of these, five also had pulmonary abscess or necrosis, and one was found to have underlying cystic lung disease.

Loculation seen preoperatively on chest ultrasound or chest CT correlated with the presence of empyema in 12 of the 13 patients (12 loculated effusions on chest CT and 11 on chest ultrasound). One patient with empyema did not have loculation on either imaging examination but did have fibrin stranding on chest ultrasound. All patients with empyema had debris and fibrin strands within pleural fluid on chest ultrasound.

Of the five patients with parenchymal abscess (Fig. 4) or necrosis at surgery, either necrosis or abscess was seen preoperatively on chest ultrasound in four patients and on chest CT in three patients (in one patient, necrosis could not be determined on an unenhanced chest CT).

There was one false-negative imaging diagnosis in which a surgically diagnosed abscess was not seen on either chest ultrasound or chest CT (patient 6, Table 1).

There were two false-positive parenchymal diagnoses. In one patient, an abscess was identified on chest CT but not chest ultrasound, and abscess was not confirmed at surgery (patient 8, Table 1 and Fig. 5). In another patient, necrosis was diagnosed on both chest ultrasound and chest CT, and at surgery underlying cystic lung disease without necrosis was seen (patient 10, Table 1 and Fig. 6).

There were no cases in which a surgically confirmed parenchymal abnormality was seen preoperatively on chest CT but not also seen on chest ultrasound.

**Discussion**

No consensus exists on the optimal technique for imaging complicated pneumonia in children. In many centers, patients routinely undergo chest CT for characterization of pleural effusion and underlying parenchymal disease before chest tube placement or surgery for drainage and decortication. Although chest CT allows rapid image acquisition, the rising use of CT in the pediatric population raises the concern of an increasing ionizing radiation burden. Because the risk of radiation-induced cancer in children from medical imaging is estimated to be as high as one in 500 [13], it is incumbent on the radiologist to investigate alternative imaging strategies.

Few studies have compared the efficacy of chest ultrasound and chest CT in patients with complicated pneumonia and parapneumonic effusion. Prior investigations in both children
[14, 15] and adults [16, 17] have focused primarily on the ability of chest ultrasound or chest CT to correlate with effusion stage or to predict clinical outcome and have shown variable results. Neither chest ultrasound nor chest CT has been shown to accurately predict effusion stage [5]. Most recently, Jaffe et al. [4] compared chest CT and chest ultrasound in 31 children with complicated pneumonia and found only a weak correlation in effusion scores. The study did not include a comparison of parenchymal findings.

Our results concur with reports published previously on the use of chest ultrasound in the evaluation of parapneumonic effusion [3, 5]. Although chest ultrasound may be limited by its small field of view and shadowing of deep structures by overlying air, we found that it was equally able to detect pleural fluid and loculation when compared with chest CT. Chest ultrasound was superior to chest CT in its ability to resolve the internal components of pleural fluid including fibrin strands, which may indicate early organization of an effusion [7]. In our study, loculation seen on chest CT was also seen on chest ultrasound in all patients except one, in whom a delay between the chest ultrasound and chest CT may have allowed time for the effusion to become more organized. In the subset of patients who underwent VAT, all but one patient with surgically confirmed empyema showed loculated fluid on both chest ultrasound and chest CT when performed within a few days of each other, and all showed fibrin stranding on chest ultrasound.

The most recent BTS recommendations encourage the use of chest ultrasound to confirm the presence of pleural effusion, but the guidelines note that contrast-enhanced chest CT is useful for evaluation of advanced parenchymal disease [3]. This can be clinically significant because the presence of necrotizing pneumonia requires a prolonged course of antibiotics [5]. However, in our patient group, chest ultrasound was similar to contrast-enhanced chest CT in its ability to diagnose pulmonary consolidation, lung necrosis, and abscess. Except for one patient in whom the chest ultrasound was technically limited, pulmonary consolidation identified on chest CT was also seen on chest ultrasound. Chest CT and chest ultrasound concurred on the presence of pulmonary necrosis except in two patients, including one in whom the chest ultrasound was limited by technique and one in whom the chest CT was performed without IV contrast administration. In the subset of patients who underwent VAT, there were no parenchymal abnormalities found at surgery that were seen on chest CT but not also seen on chest ultrasound.

Two false-positive imaging diagnoses were identified. In one patient, an abscess was diagnosed on chest CT but not on chest ultrasound, and no abscess was identified at surgery. On further review of the case, the amorphous collection of air initially interpreted as an abscess on chest CT may have represented loculated pleural air within the major fissure in this patient who had a suspected bronchopleural fistula (Fig. 5). The process was not appreciated on chest ultrasound, possibly because of acoustic shadowing from air within the pleural space. In another patient, lung necrosis shown on both chest ultrasound and chest CT corresponded to an area of soft and cystic lung at surgery, without true necrosis and without empyema (Fig. 6). A preexisting lung anomaly was postulated.

This study is limited by its small sample size. Additionally, the chest ultrasound images were not evaluated in real time because of the retrospective nature of the investigation. We also acknowledge that, whereas acquisition of chest CT can be standardized by machine settings, the technical quality of chest ultrasound was more variable in our sample. Of note, images obtained with a linear transducer appeared to be superior to those obtained with a vector transducer in detecting both pleural and parenchymal abnormalities.

In this series of children with pneumonia complicated by parapneumonic effusion, chest ultrasound provided data similar to chest CT in the evaluation of pleural fluid as well as the assessment of underlying parenchymal consolidation, necrosis, or abscess. Chest CT did not provide any additional clinically useful information that was not also seen on chest ultrasound. The benefits of chest ultrasound over chest CT include its portability, absence of need for patient sedation, and superior ability to detect fibrin strands within an effusion, which corresponded to the presence of empyema in our study group. In accordance with the as low as reasonably achievable principle of minimizing radiation exposure, we suggest that the evaluation of children with complicated pneumonia include chest radiography and chest ultrasound. Chest CT may be reserved for patients in whom chest ultrasound is technically difficult or discrepant with the clinical findings.

**Acknowledgment**

We thank Betsy Castillo for her help in performing chest ultrasound.

**References**

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