Peripheral hypoechoic spaces in consolidated lung: a specific diagnostic sonographic finding for necrotizing pneumonia in children

Chih-Yung Chiu[1,3], Kin-Sun Wong[1], Shen-Hao Lai[1], Yu-Hsuan Huang[1]
Ming-Han Tsai[2], Yu-Ching Lin[1]

Divisions of [1]Pediatric Pulmonology, and [2]Pediatric Infectious Diseases, Chang Gung Memorial Hospital, Chang Gung University College of Medicine, and [3]Graduate Institute of Clinical Medical Sciences, Chang Gung University, Taoyuan, Taiwan

SUMMARY: Chiu C-Y, Wong K-S, Lai S-H, Huang Y-H, Tsai M-H, Lin Y-C. Peripheral hypoechoic spaces in consolidated lung: a specific diagnostic sonographic finding for necrotizing pneumonia in children. Turk J Pediatr 2008; 50: 58-62.

The aim of this study was to investigate the diagnostic usefulness and clinical values of the sonographic feature of peripheral hypoechoic spaces (PHES) in children with necrotizing pneumonia (NP). Between July 2002 and July 2004, 23 consecutive children with NP in whom we performed real-time chest ultrasound were enrolled into our study. Details of demographics, clinical characteristics, laboratory data, causative pathogens, complications and outcomes of these children were recorded and analyzed. PHES in ultrasonography (US) were defined as peripheral cavitations seen as hypoechoic areas in consolidated lung. The sonographic feature of PHES was correlated with the diagnosis of NP and was also used to correlate with the clinical characteristics, complications and outcomes in children with NP. Sensitivity, specificity, and positive predictive value of this sonographic finding for the diagnosis of NP were 35%, 100%, and 100%, respectively. Pneumothorax was seen more commonly in children who presented PHES in US, with a significant difference ($p<0.05$). In conclusion, the sonographic feature of PHES appears to be more specific for detecting NP in childhood pneumonia. In children with pneumonia with PHES in consolidated lung, the diagnosis of NP can be suggested with confidence, and it is important to be aware of the life-threatening complication of pneumothorax to decrease morbidity.

***Key words:** necrotizing pneumonia, peripheral hypoechoic spaces, ultrasonography.*

Necrotizing pneumonia (NP) is a rare manifestation of pneumonia in children and constitutes a most serious complication in this disease[1]. The demonstration of pulmonary liquification with cavities of nonenhancement on a contrast-enhanced computed tomography (CT) image confirms the diagnosis of NP. With the increasing use of CT scans of the chest, NP has been reported more frequently in the past decade following complicated pneumonias[2]. However, CT imaging is usually used later in guiding surgery by identifying and localizing the peripheral broncho-pleural fistula[3]. On the other hand, the applications of chest ultrasound have been greatly extended and are useful for the evaluation of pulmonary consolidation. The presence of a sonographic air bronchogram, fluid bronchogram or recognition of pulmonary vessels within the lesion are the characteristic features of lung consolidation[4]. Furthermore, chest ultrasonography (US) can also reveal hypoechoic or anechoic spaces representing necrotic tissue in the consolidated lung. The purpose of this retrospective study was to determine the diagnostic usefulness and clinical values of the sonographic feature of peripheral hypoechoic spaces (PHES) in children with NP.

Material and Methods

A retrospective chart review of 23 consecutive children with NP who underwent real-time chest ultrasound was conducted at a tertiary

pediatric facility Children's Hospital in northern Taiwan from July 2002 to July 2004. The diagnosis of NP was based upon multiple small lucencies on a chest radiograph or cavities of nonenhancement on a contrast-enhanced CT image. Details of demographics, clinical characteristics, laboratory data, causative pathogens, complications and outcomes of these children were recorded and analyzed. The pathogen of NP was retrospectively reviewed and pneumococcal pneumonia was defined as a clinical presentation consistent with pneumonia, radiographic confirmation of a consolidation pattern, and at least one positive blood or pleural fluid culture or positive detection of antigens in the pleural fluid by latex agglutination testing. Complications of NP were based on the evaluation of obtained chest radiographs and CT scans including cavitations, broncho-pleural fistula, pneumothorax, and lung abscess.

The sonographic study was performed by a pulmonologist using an Acuson TX 128 machine (Acuson, Mountain View, CA) with a 5.0-MHz curved array transducer. The Acuson 128 ultrasonic units were also equipped with Doppler ultrasound, which can be used in conjunction with sector transducers to evaluate blood flow. Patients were scanned in a supine or sitting position by means of an intercostal approach. The sonographic images were recorded on Polaroid film (Polaroid, Cambridge, MA) and reviewed retrospectively. PHES in US were defined as peripheral cavitations seen as hypoechoic areas in consolidated lung. The presence or absence of this sonographic finding was correlated with the diagnosis of NP and consensus ratings were used for the calculations of sensitivity and specificity of this sonographic finding for NP. For negative predictive value, children who were consecutively diagnosed with severe pneumonia without NP and underwent real-time chest ultrasound were enrolled and analyzed during the study period. The sonographic feature of PHES was also used to correlate with demographic data, clinical characteristics, complications and outcomes in children with NP.

The Student's t test was used to compare continuous variables, and the χ^2 or Fisher's exact test was used to compare the nominal data. Statistical analysis was performed using the Statistical Program for Social Sciences (SPSS 10.0 for Windows, SPSS Inc., Chicago, IL, USA). A P value of less than 0.05 was considered to indicate statistical significance.

Results

A total of 23 children who had NP were enrolled into our study. The average age of the patients was 4.3±1.1 years (mean±SD). All patients were previously healthy and acquired their pneumonias in the community. The most common symptoms of children with complicated pneumonia were fever >39°C (100%), productive cough (100%), respiratory distress (78%) and sepsis (57%). A total of 15 cases were consistent with pneumococcal pneumonia. Penicillin-resistant *Streptococcus pneumoniae* (PRSP) was identified in seven patients. No organisms were isolated in pleural aspirates or blood specimens in eight patients.

All 23 patients were treated with empiric antibiotic therapy initially according to the clinical manifestations and laboratory results. Thirteen patients (57%) required intensive management due to persistent respiratory distress and systemic inflammatory response syndrome/sepsis. Eleven patients (48%) were managed successfully using antibiotic therapy and closed tube drainage. Eighteen patients (78%) received chest tube drainage with a mean of 13.1±3.1 days. No chest tube was inserted in five patients. Twelve patients (52%) underwent thoracoscopy or thoracotomy for decortication and removal of loculated empyema. All patients revealed decreased parenchymal enhancement on contrast-enhanced chest CT scan. Complications of broncho-pleural fistula, pneumothorax and lung abscess were identified in 12, 7 and 5 patients, respectively. Total duration of fever was 15.3±2.7 days and the mean hospital stay was 23.1±4.1 days. All patients recovered completely without sequelae after adequate antibiotic treatment.

Sonographically, consolidated lung was triangular in shape, hypoechoic, and heterogeneous in echotexture. Air bronchogram and fluid bronchogram were the classic characteristics and were identified in all 23 children. PHES within the consolidated lung in US were identified in eight patients. The sonographic features of these hypoechoic spaces were multiple, irregular and peripheral (Fig. 1a, 1b). The average time of detection of PHES was 10 days after onset of fever (range, 6-22 days).

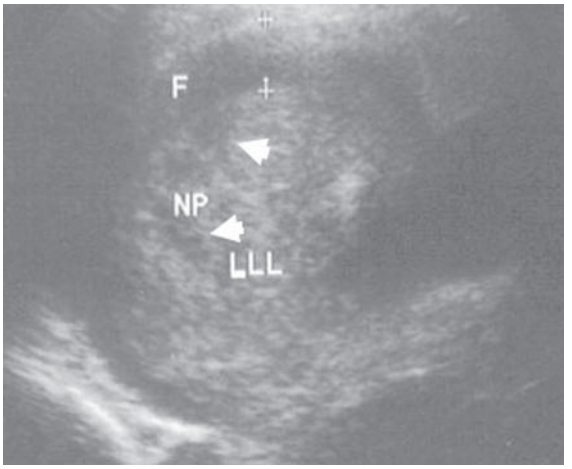

Fig. 1a. Transverse ultrasound scan of the left lingula lobe (LLL) obtained with the patient in the supine position at six days after fever showing multiple, peripheral, hypoechoic lesions with irregular outer margins (white arrow); this appearance is reflective of parenchymal necrosis. The sonolucent band corresponds to pleural fluid (F).

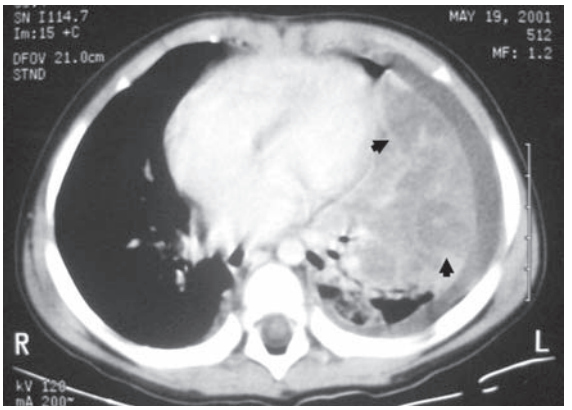

Fig. 1b. Computed tomography scan of the chest obtained at the same time showing lobar pulmonary liquification with multiple decreased parenchymal enhancements (black arrow). Subsequent plain chest radiograph showing multiple small lucencies with cavitation formation confirmed the diagnosis of necrotizing pneumonia (NP).

Contrast-enhanced chest CT confirmed the diagnosis of NP in all eight patients and *Streptococcus pneumoniae* was the etiological pathogen in seven patients. Pneumatocele was formed in all eight patients and pneumothorax was found in five patients. Surgical intervention of thoracotomy with decortication was necessary in five children due to broncho-pleural fistula and loculated empyema with lung entrapment. Sensitivity, specificity, and positive predictive value of this sonographic finding for the diagnosis of NP were 35%, 100%, and 100%, respectively. Another 14 children with severe pneumonia, of non-necrotizing type, were seen during this study period and all revealed negative sonographic feature of PHES in consolidated lung. The negative predictive value of this sonographic finding in children with severe lobar pneumonia was 48%. Correlation of the sonographic feature of PHES in children with NP is shown in Table I. No significant differences were noted regarding the demographic data, biochemical examinations, identified organisms from blood or pleural effusions and outcomes. Pneumothorax was seen more commonly in children who presented PHES in US, with a significant difference ($p<0.05$).

Discussion

Necrotizing pneumonia is a serious, potentially fatal complication of lobar pneumonia and is characterized by massive necrosis and liquification of lung tissues[1,2,5,6]. Pulmonary necrosis develops early in the course of the disease, and typical radiologic signs of cavitations will be evident on plain chest roentgenograms only later[1]. Although a chest CT scan is able to define a more specific pattern of segmental or lobar pulmonary liquification than conventional chest radiographs in children with NP[6], chest US can also reveal PHES representing pulmonary necrosis and provide another specific diagnostic method for this rapidly progressive condition, as in our study.

The presence of PHES in consolidated lung appears to be more specific for the diagnosis of NP in our study. It is important to increase the awareness of this specific finding through more published studies to make an earlier diagnosis possible. However, this specific sonographic finding was found in only eight (35%) patients in children with NP. Moreover, the sonographic feature of PHES was detected about 10 days after onset of fever in our study. The low detection rate of this specific finding may be attributed to the timing of the examination. Early performance of chest US may reveal consolidated lung without necrosis, while in late performance, air accumulation in the necrotic cavity may contribute to a more limited evaluation of consolidated lung, thus making the detection of necrotic areas less likely. Because of the low sensitivity, the absence of PHES in consolidated lung should not be sufficient to exclude a diagnosis of NP.

Table I. Comparison of Demographic Data, Clinical Characteristics, Complications and Outcomes for Children With Versus Without Peripheral Hypoechoic Spaces in Ultrasonography

	Necrotizing pneumonia with PHES (n=8)	Necrotizing pneumonia without PHES (n=15)		
	No. (%)	No. (%)	Total no. (%)	p value
Age (years)	3.6±1.1	4.9±1.8	4.3±1.1	0.24
Days of fever elapsed before detection	10.0±3.7	8.8±1.6	9.5±2.0	0.46
Lab examination				
WBC ($\times 10^9$/L)	24.2±6.5	23.3±4.5	23.7±2.7	0.50
Hb (g/dl)	9.5±1.0	8.8±0.6	9.1±0.6	0.26
Platelet ($\times 10^9$/L)	334.3±146.1	231.9±84.2	277.4±81.2	0.66
CRP (mg/L)	321.1±43.6	307.1±67.8	313.3±41.4	0.41
Pathogen				
Streptococcus pneumoniae	7 (88)	8 (53)	15 (65)	0.18
PRSP	4 (50)	3 (20)	7 (30)	0.39
Complications				
Cavitations	8 (100)	15 (100)	23 (100)	1.00
Broncho-pleural fistula	5 (63)	7 (47)	12 (52)	0.67
Pneumothorax	5 (63)	2 (13)	7 (30)	<0.05
Lung abscess	1 (13)	4 (27)	5 (22)	0.62
Outcomes				
Chest tube placement	8 (100)	10 (67)	18 (78)	0.12
Intensive management	5 (63)	8 (53)	13 (57)	1.00
Surgical intervention	5 (63)	7 (47)	12 (52)	0.67
Chest tube drainage (days)	12.8±4.4	13.4±4.6	13.1±3.1	0.84
Duration of fever (days)	16.5±5.0	14.3±2.8	15.3±2.7	0.15
Hospital stay (days)	22.0±6.2	23.9±5.7	23.1±4.1	0.78

PHES: Peripheral hypoechoic spaces. WBC: White blood cell. Hb: Hemoglobin. CRP: C-reactive protein. PRSP: Penicillin-resistant *Streptococcus pneumoniae*.

During the period analyzed, another 14 individuals with lobar pneumonia of non-necrotic type complicated by massive pleural effusion were seen, and all revealed negative sonographic feature of PHES in consolidated lung. Although the positive predictive value of this sonographic finding for the diagnosis of NP was 100% in our study, the negative predictive value of this sonographic finding in children with severe lobar pneumonia was 48%. Conversely, this means that 52% of patients with a negative sonographic feature of PHES were actually NP, and were mistakenly classified by this sonographic finding. It must be emphasized that using ultrasound as the main imaging technique to diagnose NP requires frequent and repeated studies to decrease the number of missed diagnoses of NP.

Bacterial pneumonia is the most common cause of lung consolidation in children; however, its appearance is nonspecific. Infarction, hemorrhage, vasculitis, lymphoma, and bronchoalveolar carcinoma can result in consolidation that appears similar to that of pneumonia on US. Furthermore, a necrotic area of pulmonary infarction may also be recognized on US as a peripheral wedge-shaped hypoechoic region[7,8]. In children with PHES in consolidated lung, the etiologies of this specific sonographic finding should include infections, fat embolism, and pulmonary infarction.

In children with NP, persistent pneumothorax, broncho-pleural fistula and lung entrapment are poor prognostic factors of medical treatment and usually lead to surgical interventions[9]. In our study, although there was no difference

in the clinical characteristics and outcomes for pneumonic patients who present with or without PHES, complication of pneumothorax is more frequently associated with this specific finding. Furthermore, almost two-thirds of children with PHES on US require surgical intervention of thoracotomy with decortication because of cavitary lung process with bronchopleural fistula complicated with pneumothorax. We believe that the sonographic features of peripheral cavitations seen as hypoechoic areas in consolidated lung may help in predicting severe parenchymal lung disease and high prevalence of pneumothorax, which may lead to further surgical interventions.

In conclusion, US can disclose a very heterogeneous appearance of consolidated lung with peripheral hypoechoic areas representing necrosis and may provide a rapid, non-radiating, diagnostic imaging method for detecting NP in childhood pneumonia. In pneumonic children with PHES in consolidated lung, the diagnosis of NP can be suggested with confidence. We strongly recommended chest ultrasound studies in all patients with consolidation to provide diagnostic and prognostic information, which may influence therapy in children with lobar pneumonia.

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