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ORIGINAL ARTICLE

Usefulness of Lung Ultrasound in the Diagnosis of Community-acquired Pneumonia in Children

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Key Words
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Background: Pneumonia is a life-threatening disease in children. With the current lack of universal diagnostic criteria, the diagnosis is usually made on clinical manifestations and findings from chest radiographs. Ultrasonography has recently been applied to the detection of pulmonary diseases. However, few data have been published showing its effectiveness in detecting pneumonia in children. The objective of this study was to determine the power of lung ultrasonography (LUS) for the diagnosis of pneumonia in children.
Methods: This retrospective study was carried out by reviewing medical records. Patients admitted to a pediatric ward with a diagnosis of pneumonia from June 1, 2010 to December 31, 2012 were enrolled in this study. Personal information, laboratory data, characteristics on LUS scan, and the results of chest radiography and LUS were collected. We compared the detection rate of pneumonia by chest radiography and LUS. LUS scans were followed up in 23 patients during the progression of their disease.
Results: A total of 163 patients was enrolled. Chest radiography was able to detect pneumonia in 152 patients, whereas LUS detected pneumonia in 159 patients. In LUS, the positive rates of the comet-tail sign, air bronchograms, fluid bronchograms, vascular pattern within the consolidation, and pleural effusion were 50.9%, 93.7%, 20.1%, and 28.9%, respectively. During follow

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up, the average size of the pneumonia patch in 23 patients decreased from 10.9 ± 8.7 cm^2 to 5.5 ± 8.2 cm^2, and finally to 2 ± 1.9 cm^2 on Day 1, Days 3—5 and Days 7—14, respectively.
Conclusion: LUS is a sensitive diagnostic tool with which to identify pneumonia in children. It is also useful in following up the progress of pneumonia. We suggest that LUS is a complementary tool to chest radiography in the diagnosis of pneumonia in children and that the follow up of pneumonia by LUS can reduce the exposure of children to ionizing radiation.

1. Introduction

Pneumonia is a major health threat worldwide and causes more deaths in children than AIDS, malaria, and measles.[1] In Taiwan, pneumonia is the 5th leading cause of death with a mortality rate of 24.8/10,000 people[2] and accounts for more than 0.65 million outpatient visits in medical settings each year; 50% of these patients are children.[3] In Taiwan, more than 70,000 children are admitted to hospital annually.[4] The lack of a worldwide consensus guideline for pneumonia means that the diagnosis is usually based on clinical signs and symptoms such as fever, cough, dyspnea, history-taking, and physical examination. The diagnosis of pneumonia is usually a new infiltrate seen on a chest radiograph. However, ionizing radiation may expose children to an increased risk of gene mutations and the development of cancer.[5] As an alternative, LUS has increasingly been used to detect pneumonia in children.[5,6] In many clinical settings, especially emergency departments and intensive care units,[7—9] LUS has been widely used as the primary diagnostic tool to detect pneumothorax, pulmonary consolidations, pleural effusion, acute respiratory distress syndrome, and pulmonary edema due to its ease of operation, provision of real-time images, and no risk of exposure to ionizing radiation.[8] Multiple studies have shown LUS imaging to be more accurate than chest radiography in some respiratory diseases in adults, such as pneumothorax, alveolar interstitial syndrome, pleural effusion, and pneumonia.[10—12] However, few studies have investigated the use of LUS in the diagnosis of pneumonia in children.[5,6,13] In our opinion, the small body size of young pediatric patients means that it is easier to detect pneumonia or other abnormalities with LUS. The purpose of this study was to demonstrate the characteristics of pneumonia in children on LUS and to evaluate the diagnostic power of LUS for pneumonia by comparison with conventional chest radiography.

2. Materials and methods

2.1. Patient selection

This retrospective study was conducted in Kaohsiung Medical University Hospital, Kaohsiung, Taiwan. We reviewed the medical records of patients who were admitted to the pediatric ward with a clinical diagnosis of pneumonia and who had both chest radiography and LUS examinations within 2 days. The diagnosis of pneumonia was in accordance with the British Thoracic Society guideline.[14] Community-acquired pneumonia in children can be clinically defined as the presence of signs and symptoms of pneumonia (such as fever, tachypnea, breathlessness, cough, wheeze, or chest pain) in a previously healthy child due to an infection acquired outside the hospital.[14]

A total of 316 patients were reviewed between January 1, 2010 and December 31, 2012. Of these, 153 patients were excluded due to congenital anomalies, undergoing chemotherapy or severe immunosuppression, >48 hours between LUS and radiography, unavailability of chest radiography results, unavailability of LUS results, or diagnosis other than pneumonia. The remaining 163 children were included in this study. History-taking, physical examination, laboratory tests (including complete blood count and level of C-reactive protein), chest radiography, LUS, and measurement of vital signs were performed for each patient. The final diagnosis was made by pediatricians based on clinical presentations. The protocol was approved by the Institutional Review Boards of the University Medical Center (KMUHIRB-20120062).

2.2. Chest radiography

Chest radiography was performed on every patient on the day of admission. Posterior—anterior chest radiography was performed on patients who were able to stand, whereas posterior—anterior radiography in the supine position was performed if the patients were unable to maintain a standing position. The film was initially read by the radiologist on duty and later confirmed by a second radiologist. The radiologists were both blind to the patients' clinical presentation and ultrasound findings.

2.3. Lung ultrasound

The thoracic wall consists of skin, subcutaneous tissue, muscles, and the ribs. On longitudinal scans the pleura appear as a horizontal line (the pleural line), which moves during breathing. Beyond the pleural line, the air in the lung further impedes visualization of the normal lung parenchyma. However, the large change in echogenicity results in horizontal artifacts called A-lines. A-lines are parallel lines and can be seen below the pleural line in an ultrasound scan of a normal lung. When the fluid content in the lung increases, B-lines are generated. B-lines are vertical, hyperechoic artifacts originating from pleural line and extending to the edge of the image. B-lines are also called the comet-tail sign and are commonly seen in lung

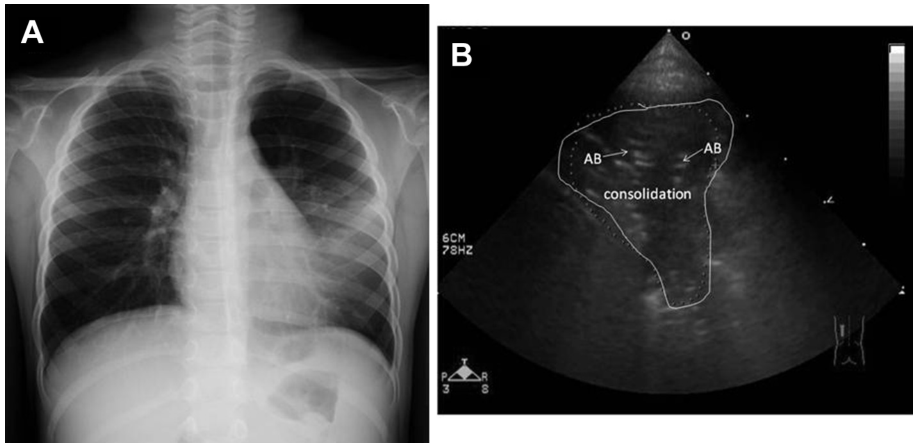

Figure 1 A 10-year-old boy suffered from fever, cough, and mild dyspnea, suggesting pneumonia. (A) Radiograph showing left lingular and lower lobe consolidation. (B) Lung ultrasound scan showing left lower lobe consolidation, i.e., an irregular hypoechogenic area with air bronchograms (AB). The size of the pneumonic infiltrates was 5.96 cm^2.

edema.[15] An air bronchogram is a hyperechoic round image seen when air is trapped in the bronchioles (Figure 1).When fluid fills the bronchioles, a tubular-shaped hypoechoic image called a fluid bronchogram can be seen.

LUS was conducted by experienced pediatric pulmonologists using a 5 MHz convex probe (Sono57500, Philips, Bothell, WA, USA). Each hemithorax was divided into three parts: anterior, lateral, and posterior. The anterior part extended from the parasternal to the anterior axillary line; the lateral part was defined as the area between the anterior and the posterior axillary line; and the area from the posterior axillary line to the paravertebral line was defined as the posterior part. Each part can be subdivided into upper and lower halves. The probe was placed perpendicular, oblique, and parallel to the rib in the anterior, lateral, and posterior thorax and every intercostal space was examined in detail.[16] Patients were in the supine position during scanning of the anterior thorax; they were in the lateral decubitus position during scanning of the lateral and posterior thorax. Both sides of the lung were examined. The most common ultrasound findings associated with pneumonia were collected, including: (1) hypoechoic areas of varying size and shape; (2) air bronchograms; (3) fluid bronchograms; (4) comet-tail artifacts (B-lines); (5) a vascular pattern within the consolidation; and (6) pleural effusion. The impression of pneumonia based on LUS was made by any of the characteristics of air bronchograms, fluid bronchograms, vascular pattern within the consolidation, or pleural effusion.[17]

Continuous variables are expressed as mean $\pm$ standard deviation (SD) values. Categorical variables are expressed as numbers and percentages. All statistical analysis was performed with JMP 9.0.0 software (SAS Institute Inc., Cary, NC, USA)

3. Results

Table 1 summarizes the demographic information for the patients. All 163 patients were Taiwanese and 91 (55.8%) were boys. Their mean age was 73.2 $\pm$ 47.6 months. The average hospital stay was 7.4 $\pm$ 6.3 days and 27 patients were transferred to the pediatric intensive care unit due to their critical condition.

Table 1 summarizes the sonographic characteristics of all the patients with positive LUS findings. Of the 159 patients, 95 (59.7%) had pneumonia consolidation located on the right side of the lung, 48 (30.2%) on the left, and 16 (10.1%) on both sides. The comet-tail sign was seen in 81 (50.9%) patients. One hundred and forty-nine (93.7%) patients had a positive air bronchogram and 32 (20.1%) had a positive fluid bronchogram on the LUS scan. Forty-six (28.9%) had a vascular pattern within the consolidation and 43 (27.0%) patients had pleural effusion.

Of the 163 patients with pneumonia, chest radiography was able to detect 151 (92.6%), whereas LUS detected 159

Table 1 Characteristics of patients and findings on lung ultrasonography (n = 163).

Patient characteristics		
Sex		
Male	91 (55.8)	
Female	72 (44.2)	
Age (mo)	73.2 $\pm$ 47.6	
Weight (kg)	23.8 $\pm$ 14.0	
Height (cm)	115.5 $\pm$ 22.5	
Length of hospital stay (d)	7.4 $\pm$ 6.3	
Positive PICU stay	27 (16.6)	
Characteristic findings on lung ultrasonography		
Location		
Right	95 (59.7)	
Left	48 (30.2)	
Both sides	16 (10.1)	
	Positive	*Negative*
Comet sign	81 (50.9)	78 (49.1)
Air bronchogram	149 (93.7)	10 (6.3)
Fluid bronchogram	32 (20.1)	127 (79.9)
Vascular pattern	46 (28.9)	113 (71.1)
Pleural effusion	43 (27.0)	116 (73.0)

Data are presented as mean $\pm$ standard deviation or n (%).
PICU = pediatric intensive care unit.

Table 2 Findings of lung ultrasonography and chest radiography.

		Chest radiography		Total
		Negative	Positive	
Lung ultrasonography	Negative	0	4	4
	Positive	12	147	159
	Total	12	151	163

(97.5%). Twelve (7.4%) patients showed no pneumonia consolidation on chest radiography, but lesions representing pneumonia were found on LUS. Four (2.5%) patients with negative pneumonia findings on LUS were found to be positive on chest radiography. Table 2 gives the details of the chest radiography and LUS findings. The detection rate for chest radiography and LUS were 0.93 and 0.98, respectively.

LUS follow up was also performed on 23 patients on Day 1, Days 3–5, and Days 7–14. The results showed the decreasing size of the pneumonia patch from 10.9 ± 8.7 cm^2 to 5.5 ± 4.8 cm^2, and finally to 2 ± 1.9 cm^2 (Figure 2).

4. Discussion

The diagnosis of pneumonia, once thought to be accomplished by physical examination, history-taking, and specific findings on auscultation, has recently relied more on imaging. Chest radiography has been widely used for the diagnosis of pneumonia because of its convenience and ease of access. However, some studies have shown substantial variability in the interpretation of chest radiographs[18] as well as the risk of the development of cancer after radiation exposure in early life.[19] Although the lung is not an ideal target for ultrasonography, once fluid or solid material has accumulated in the lung it can more easily be visualized on an ultrasound scan.[10] Some studies have focused on the use of LUS in the diagnosis and follow up of community-acquired pneumonia in adults.[6,13,20–22] Reissig et al reported the first prospective study in adults of the diagnosis of community-acquired pneumonia using LUS with an excellent sensitivity of 94% and specificity of 98%. In our study, the detection of pneumonia using LUS was better (97.5%) than with chest radiography (92.6%).[20] The small body size of young children may have allowed LUS to detect pneumonia more readily than radiography.

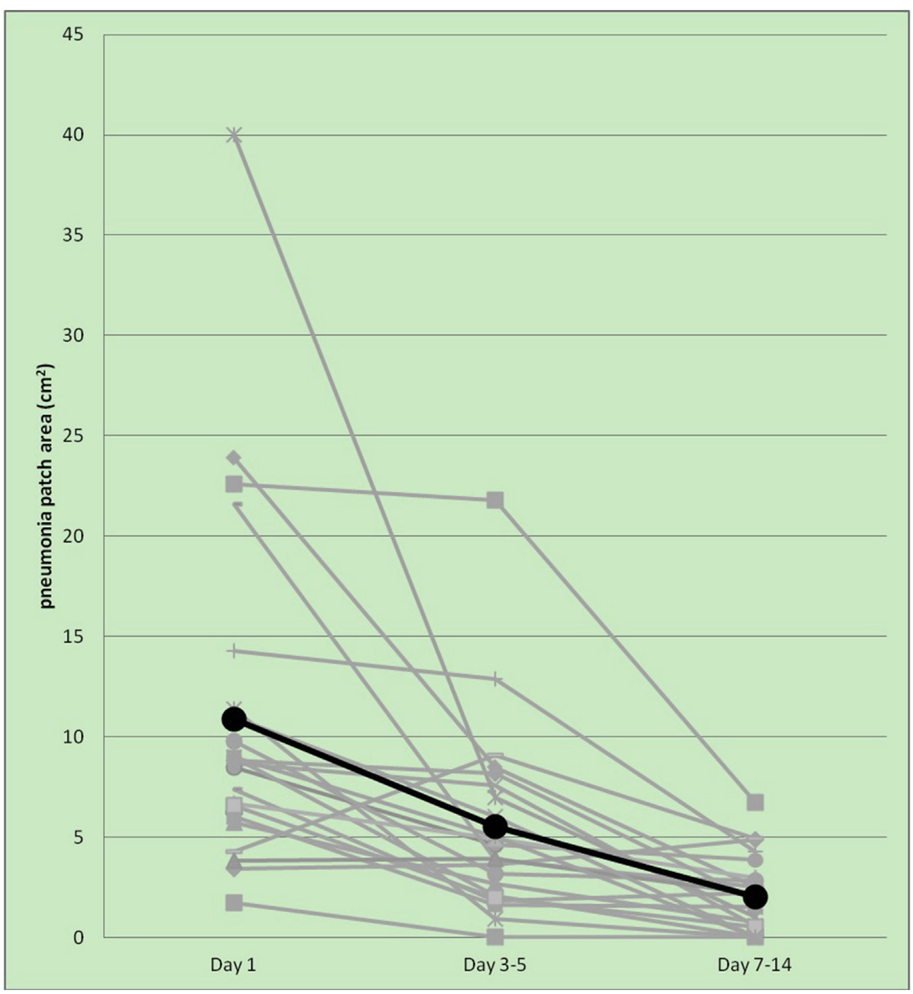

Figure 2 Area of pneumonia patches in 23 patients measured by lung ultrasonography. The bold line indicates the mean size of the pneumonia patches.

The sonographic sign of lung consolidation is a subpleural, echo-poor region with additional characteristics such as: (1) air bronchograms; (2) fluid bronchograms; (3) comet-tail reverberation artifacts at the far-field margin; and (4) a vascular pattern within the consolidation.[21,23] The positive rate of air bronchogram in patients with pneumonia ranged from 86.7% to 97% in previous studies.[20,21] Our study had similar results: 93.7% of our patients had air bronchogram(s) on LUS. The fluid bronchogram, which represents exudate-packed conducting airways, occurs less frequently than the air bronchogram. In adults, the positive rate of fluid bronchogram was reported to range from 0% to 8.1%.[20,21] However, in our study, the positive rate of fluid bronchogram was as high as 20.1%. This may be due to the fact that children have smaller conducting airways and the exudate obstructs the airways more easily, sometimes even collapsing the lung.

Diffuse comet-tail artifacts in LUS are a sign of alveolar interstitial syndrome. However, these artifacts are also present around an isolated alveolar consolidation.[24] The absence of a B-line could be useful in ruling out any opacity in chest radiography.[24] In our study, the positive rate of comet-tail artifacts around the pneumonia is 50.9%, which is similar to previously reported data in children (59%).[5] In the diagnosis of pneumonia by LUS, the consolidation is also accompanied by air bronchogram within the lesions; B-lines around them can increase the specificity of a diagnosis of pneumonia.[10] The disappearance of the B-lines or change in the pattern of multiple lines in the follow up by LUS is a sign of lung re-aeration.[25]

In adults, the field depth commonly found on LUS pre-settings is 16–18 cm,[15] whereas the pre-setting is 8 cm for children.[5] Because the chest wall is thinner in children than in adults and children have a relatively smaller lung mass, the penetration of the echo beam may be easier and so more parts of the lung can be examined. Moreover, the small lung mass of children may make consolidations extend to the pleura more easily. In our experience, setting the LUS between 5 cm and 10 cm is the most practicable to detect abnormal LUS findings in children.

In our study, LUS appeared to be a good diagnostic tool for the detection of pneumonia. The result is very close to that of Cortellaro et al,[7] who found a 98% sensitivity of LUS in an adult population. It is also in good accordance with other studies.[20,26] Gehmacher et al[26] found a positive rate of 88.8% in adult patients with pneumonia detected by LUS. Reissig et al[20] reported a 93.4% sensitivity for LUS in an adult population. In our study, the chest radiographs of 12 patients showed no obvious lesions, but these patients were found to have pneumonia patches on LUS. Chest radiography may fail to detect these lesions due to (1) their small size at the early stage of disease and (2) if the lesions are beyond the heart or mediastinum. An additional chest lateral radiograph may increase the detection rate for pneumonia. Four patients were negative for pneumonia on LUS, but showed a positive pneumonia patch on chest radiography. The reasons why LUS did not detect the pneumonia patch may be because the lesions were not large enough to extend to the pleura, or the lesions were located in areas difficult for the ultrasound beam to reach, such as the supraclavicular fossa, the axillary region, and the area shielded by the scapula.

LUS is also a useful tool in the follow up of patients with pneumonia and it could be used to estimate the pneumonia size semiquantitatively.[17,20,21,27] However, the true pneumonia size estimated by LUS was always underestimated as a result of distal multiple amplification artifacts or air inclusions.[21] Not only can the size of pneumonia be measured by LUS, but a decreased air bronchogram and the volume of pleural effusion compared with baseline can also indicate remission of the disease.[20] For these reasons, we can monitor the progress of the disease in patients and guide our treatment by repeating LUS within a few days.

Some limitations of this study should be noted. First, this is a retrospective study and the patients may not have accepted LUS and chest radiography on the same day. Although we tried to minimize this pitfall by only selecting patients in whom these examinations were performed within 48 hours, there are still some unavoidable consequences, such as the patient's pneumonia improving or worsening quickly, which may have introduced bias into this study. Second, the LUS findings are not specific for pneumonia and other diseases may have similar features. It is difficult to distinguish these features by LUS alone without any other information. However, this is not a problem in our clinical setting as all enrolled patients were previously healthy, free from underlying diseases, and diagnosed with community-acquired pneumonia by their presenting symptoms and signs. The role of LUS is to assist clinicians in acquiring imaging evidence to confirm the diagnosis of pneumonia, especially for patients in whom the chest radiograph is devoid of consolidation.

As with other ultrasound applications, LUS can be operator-dependent. The correct diagnosis cannot be made if the operator is insufficiently trained or inexperienced. Fortunately, the learning curve for LUS appears to be easier and faster than for other ultrasound applications.[28,29]

In conclusion, our study showed a high detection rate for LUS in identifying pneumonia in children. It also proved to be a promising tool for the follow up of patients with pneumonia. Patients can receive more frequent follow ups using LUS during treatment and more information can be made available to pediatricians for decision-making. We suggest that LUS is a complementary tool to chest radiography in the diagnosis of pneumonia in children and that the follow up of patients with pneumonia by LUS can reduce the exposure of children to ionizing radiation.

Conflicts of interest

All authors declare no conflicts of interest.

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