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Lung Ultrasonography for the Diagnosis of Severe Neonatal Pneumonia

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BACKGROUND: Lung ultrasonography is useful for the diagnosis of pneumonia in children and adults. This study investigated the lung ultrasound findings in severe neonatal pneumonia.

METHODS: From September 2012 to October 2013, 80 neonates admitted to Bayi Children's Hospital, affiliated with the Beijing Military General Hospital, were divided into two groups: 40 neonates with severe pneumonia according to their medical history, clinical manifestations, and chest radiograph findings and 40 neonates with no lung disease (control group). All subjects underwent bedside lung ultrasound examination in a quiet state. A single expert physician performed all ultrasound examinations. Findings of pleural line abnormalities, B lines, lung consolidation, air bronchograms, bilateral white lung, interstitial syndrome, lung sliding, and lung pulse were compared between the groups.

RESULTS: The lung ultrasound findings associated with infectious pneumonia included large areas of lung consolidation with irregular margins and air bronchograms, pleural line abnormalities, and interstitial syndrome. A large area of lung consolidation with irregular margins had 100% sensitivity and 100% specificity for the diagnosis of neonatal pneumonia.

CONCLUSIONS: Lung ultrasonography is a reliable tool for diagnosing neonatal pneumonia. It is suitable for routine use in the neonatal ICU and may eventually replace chest radiography and CT scanning.

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Neonatal pneumonia, especially severe infectious pneumonia, of the newborn is the most common infectious disease in neonates and is a significant cause of neonatal death. Neonatal pneumonia is reported to be the primary reason for neonatal respiratory failure and the first or second most common cause of hospitalization and death in developing countries.[1-3] Timely and accurate diagnosis is important to enable efficient treatment and improve the prognosis of patients with neonatal pneumonia. In the past, diagnosis of neonatal pneumonia depended on chest radiographic findings. Increasing awareness and advancement of ultrasound technology has led to the routine use of ultrasonography for diagnosing infectious pneumonia in both children and adults,[4-8] but ultrasonography is still not commonly used for diagnosing neonatal pneumonia. The aim of this study was to evaluate the accuracy of lung ultrasound findings for diagnosing severe neonatal pneumonia.

Materials and Methods

The institutional review board of the General Hospital of Beijing Military Command approved the study protocol (number 2011-LC-Ped-01). From September 2012 to October 2013, 80 neonates were enrolled in this study. All subjects were admitted to the Department of Neonatology & NICU of Bayi Children's Hospital, affiliated with the Beijing Military General Hospital, which has one of the largest neonatal wards in the world with 350 beds. A total of 8,877 neonates were admitted to the ward during the study period.

Patients

The patients were a nonconsecutive convenience sample of neonates with neonatal pneumonia as diagnosed by their clinical team according to the criteria described next. All lung ultrasound examinations were performed by a single examiner blinded to the diagnosis.

The patients were divided into two groups. The pneumonia group comprised 40 neonates, including 15 with congenital pneumonia (diagnosed within 24 h after birth), 18 with postnatal pneumonia (diagnosed 12.7 ± 3.3 days after birth), and seven with ventilator-associated pneumonia (diagnosed 7.1 ± 1.9 days after beginning mechanical ventilation). Neonatal pneumonia was diagnosed by the clinical staff according to following criteria: (1) presence of cough, fever, or dyspnea; (2) fine moist rales on auscultation; (3) significantly increased or decreased WBC count, increased neutrophils or ratio of immature/total neutrophils, high erythrocyte sedimentation rate, or high C-reactive protein level; and (4) patchy, blurred shadows with uneven density in the lung fields on chest radiograph. Patients were excluded if there was no definite evidence of infection or if they had serious complications such as pulmonary hemorrhage or pneumothorax that might affect lung ultrasound findings. The control group comprised 40 neonates with no pulmonary disease who were hospitalized for noninfectious jaundice, premature birth, or other nonpulmonary conditions. The control group patients did not undergo chest radiographic examination.

Lung Ultrasonography

A high-frequency linear 9- to 12-MHz probe (GE Voluson E8/E6; GE Healthcare) was used for ultrasound examinations. While in a quiet state, neonates were positioned in the supine, lateral, or prone position. Findings were recorded in each of three areas of each lung field, divided by the anterior and posterior axillary lines. Both lungs were scanned with the probe held parallel to the ribs.

Statistical Analysis

Data analyses were performed with SPSS for Windows, version 16.0 (IBM) software. Abnormal ultrasound findings were compared between the two study groups by Fisher exact test, and the specificity and sensitivity of the findings for diagnosing neonatal pneumonia were calculated.

Results

General Study Group Information

The perinatal clinical characteristics of the two study groups are shown in Table 1.

Normal Lung Ultrasound Appearance

The ultrasound appearance of normal lung is black. The pleural line appears as a smooth echogenic line that exhibits respirophasic movement (Video 1). A lines are present as a series of echogenic parallel lines equidistant from one another below the pleural line (Fig 1). B lines, which can be seen in healthy, term newborns, are echogenic vertically oriented lines that start at the pleural line and reach the lower edge of the image (Video 2). In the control group, B lines were found in 12 healthy infants.[9-11]

Ultrasound Findings in Patients With Pneumonia

The main ultrasound findings of pneumonia are as follows:

1. Pleural line abnormalities: disappearance, irregularity, disruption, and coarse appearance

TABLE 1] General Clinical Information

Group	Male (Female) Sex	Gestational Age, wk	Premature	Term	Birth Weight, g	Vaginal Delivery	Cesarean Delivery
Pneumonia (n = 40)	22 (18)	28-39 plus 3 d	16	24	1,275-4,000	22	19
Control (n = 40)	21 (19)	27-40 plus 2 d	15	25	950-3,950	24	16

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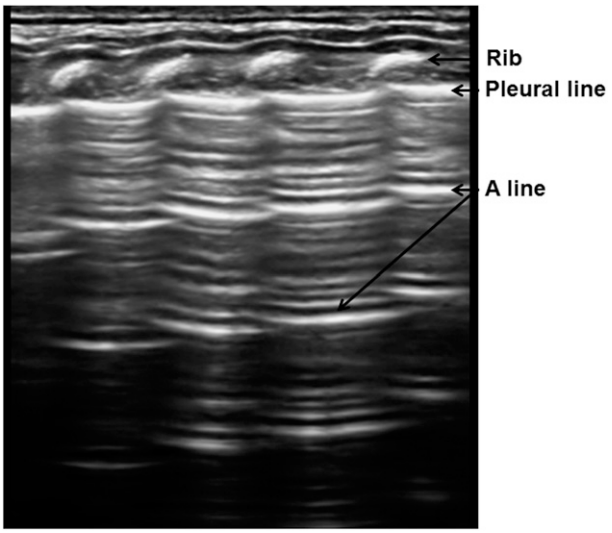

Figure 1 – *Normal lung ultrasound findings in a neonate (gestational age, 37 wk plus 4 d; birth weight, 2,970 g) admitted to the hospital 3 d after birth because of pathologic jaundice. The pleural line and A line are smooth, clear, and parallel to each other, and there are no B lines or comet tails.*

2. Lung consolidation: hepatization of the subpleural lung tissues determined by air or fluid bronchograms (Figs 2-4)
3. Interstitial syndrome: the presence of more than three B lines, or areas of white lung, in every examined area
4. Disappearance of lung sliding
5. Lung pulse: replacement of lung sliding by pulsation that is synchronized with the heart rate (Video 3).[11-14]

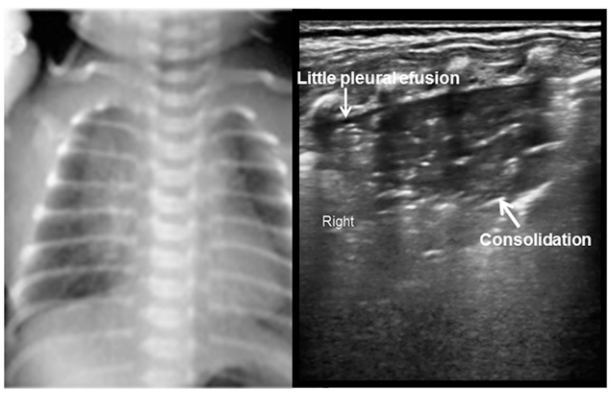

Figure 2 – *Lung ultrasound findings of pneumonia in a neonate (gestational age, 37 wk; cesarean section delivery; birth weight, 3,700 g) delivered 29 h after rupture of the membranes with no birth asphyxia. The infant had signs of respiratory distress, fever, WBC count of 30 × 10⁹/L, 81% neutrophils, platelet count of 67 × 10⁹/L, and C-reactive protein level of 39 mg/L. Lung ultrasound showed irregular areas of lung consolidation with air bronchograms in large parts of the right lung, disappearance of the pleural line and A line, a small pleural effusion, disappearance of lung sliding, and presence of a lung pulse. Chest radiography confirmed the diagnosis of pneumonia, which was more severe on the right side.*

The detailed lung ultrasound findings of pneumonia are shown in Table 2.

The Sensitivity and Specificity of Lung Consolidation for the Diagnosis of Neonatal Pneumonia

Lung consolidation may be observed in a number of respiratory diseases, including respiratory distress syndrome and atelectasis, but a large area of lung consolidation with irregular margins is only observed in neonatal pneumonia.[4-7,12-20] According to the ultrasound findings of this study, large areas of lung consolidation with irregular margins were 100% sensitive and 100% specific for the diagnosis of severe neonatal pneumonia.

Discussion

Lung ultrasonography has been described as a versatile tool for the diagnosis of many pulmonary diseases[4-7,10-21] and has been used for diagnosing community-acquired pneumonia in children and adults.[4-8] In this study, we evaluated the usefulness of lung ultrasonography for diagnosing neonatal pneumonia on the basis of the diagnostic standard for infectious pneumonia in both children and adults. The lung ultrasound findings of neonatal pneumonia showed large areas of consolidation with irregular margins and air bronchograms, pleural line abnormalities, and interstitial syndrome. The large areas of lung consolidation with irregular margins had 100% sensitivity and 100% specificity for the diagnosis of neonatal pneumonia.

Lung consolidation with air bronchograms is one of the most important ultrasound findings in neonatal pneumonia, but this may also occur in other lung diseases such as respiratory distress syndrome and atelectasis.[10-16] According to the results of the present study and the literature,[4-7,12] lung consolidation in neonatal pneumonia has the following ultrasound characteristics: (1) a large area of consolidation; (2) hypoechoic areas of varying size and shape in the same pulmonary field; (3) irregular margins around the area of consolidation; and (4) dynamic air bronchograms, which are branching echogenic structures with centrifugal movement observed during breathing. In this study, dynamic air bronchograms were observed in 21 of the 40 cases of neonatal pneumonia (52.5%). Pleural line abnormalities and interstitial syndrome are common, but nonspecific ultrasound findings in neonatal pneumonia and are related to both the inflammatory reaction and the degree of inflammatory exudate. In severe cases, there may also be pleural effusion. All these signs can also be

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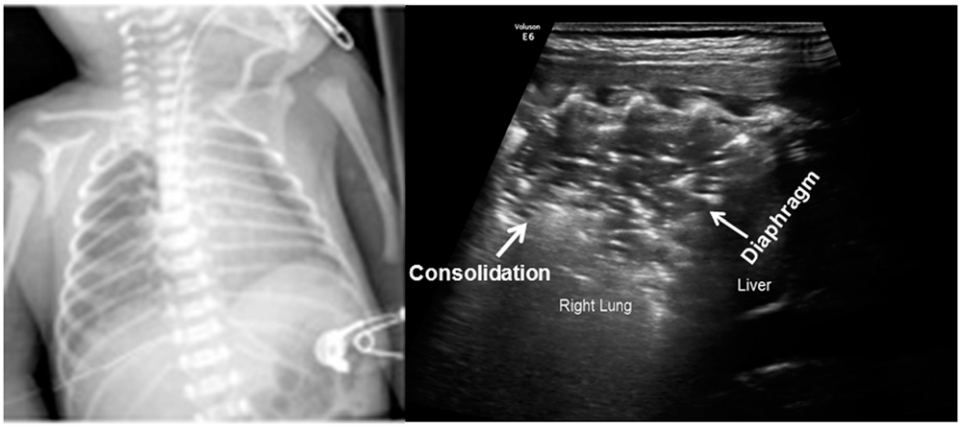

Figure 3 – *Lung ultrasound findings of pneumonia in a neonate (gestational age, 31 wk plus 1 d; vaginal delivery; birth weight, 1,550 g) delivered 47 h after rupture of the membranes with meconium-stained amniotic fluid. The infant had signs of respiratory distress, hypothermia, WBC count of 19.8 × 10⁹/L, 87% neutrophils, and platelet count of 87 × 10⁹/L. The patient was mechanically ventilated, and blood cultures grew* Klebsiella pneumoniae. *Lung ultrasound showed irregular areas of lung consolidation with air bronchograms in large parts of the right lower lung, disappearance of the pleural line and A line, disappearance of lung sliding, and presence of a lung pulse. Chest radiography showed high-density shadows in the right lower lung.*

found in other lung diseases, such as respiratory distress syndrome and transient tachypnea of the newborn.[13,18-22] In the present study, disappearance of lung sliding was observed in 30 cases (75%) of neonatal pneumonia, and a lung pulse was observed in 12 cases (30%). A lung pulse may also be observed in severe respiratory distress syndrome[11] and obstructive atelectasis in unventilated lungs, where the severity is associated with the severity of atelectasis.[11,16] The usefulness of all these signs for diagnosing neonatal pneumonia requires further study, but lung ultrasonography is never performed in isolation. The combination of typical lung ultrasound findings and typical clinical findings are diagnostic of pneumonia. Respiratory distress syndrome and transient tachypnea of the newborn may have some lung ultrasound findings that are also found in pneumonia, but their clinical presentations differ from pneumonia.[12,14,15,23]

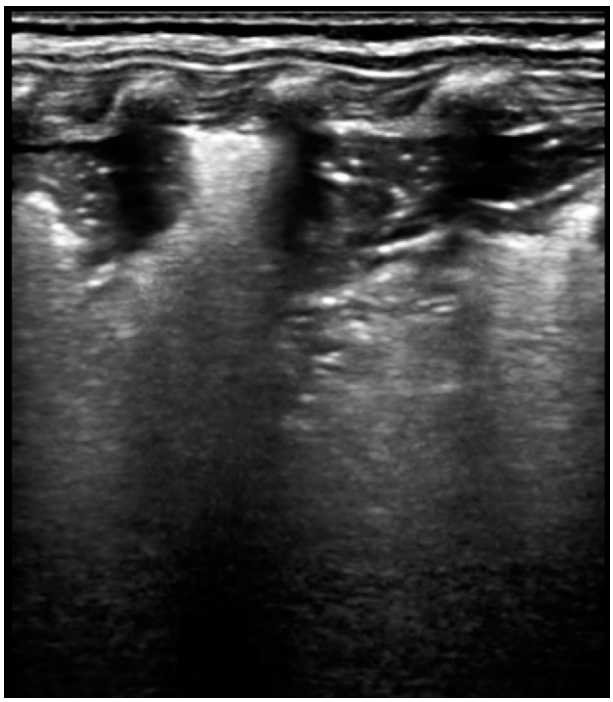

Figure 4 – *Lung ultrasound findings of pneumonia in a neonate (gestational age, 38 wk; birth weight, 4,000 g) who was admitted to the hospital with signs of respiratory distress and a 3-d history of fever. Pneumonia was diagnosed in this patient based on dense moist rales on chest auscultation, routine blood test results, and chest radiographic findings. Lung ultrasound showed two large areas of lung consolidation with irregular margins and heterogeneous echogenicity and disappearance of the pleural line and A line.*

This study has some limitations. It was based on a nonconsecutive convenience sample that may not be fully representative of all cases or findings of severe neonatal pneumonia. The study only included patients with severe pneumonia based on clinical criteria and does not report the lung ultrasound findings in patients with mild pneumonia, which will require further study. All ultrasound examinations were performed by a single expert examiner, so the results may not apply in the hands of a less-experienced examiner. Physicians performing lung ultrasonography should be properly trained and have adequate experience before this procedure is routinely used in neonatal ICUs. No chest radiographs were performed in the control group, although it is a reasonable assumption that the results would have been normal. It would be ethically indefensible to have performed chest radiography for comparison purposes in the control group. There was no measurement of intraobserver or interobserver variability of the

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TABLE 2] Occurrence Rate of Several Common Ultrasound Signs of Pneumonia

Ultrasound Sign	Pneumonia (n = 40)	Control Group (n = 40)	*P* Value
Lung consolidation[a]	40 (100)	0 (0)	< .001
Dynamic air bronchograms	21 (52.5)	0 (0)	< .001
Pleural line abnormalities[b]	36 (90)	0 (0)	< .001
Pleural effusion	8 (20)	0 (0)	< .001
Interstitial syndrome	40 (100)	0 (0)	< .001
Disappearance of lung sliding	30 (75)	0 (0)	< .001
Lung pulse	12 (30)	0 (0)	< .001

Data are presented as No. (%).
[a]Meaning a large consolidated area with irregular, serrated margins.
[b]Meaning disappearance, irregularity, disruption, coarse appearance, etc.

ultrasound findings. This requires further study given that lung ultrasonography has the potential for major application in neonatal medicine.

In summary, this study demonstrates that lung ultrasonography is useful for the diagnosis of neonatal pneumonia. Ultrasonography is accurate, inexpensive, and easy to perform at the bedside, making it especially suitable for neonates, who are difficult to transport to the radiology department. Lung ultrasonography may also be useful for guiding life-saving therapies in emergency situations. Most importantly, ultrasonography does not expose the patient to radiation, in contrast to radiography and CT imaging, which carry a risk of DNA damage and are, therefore, associated with an increased risk of cancer.[24,25] Bedside lung ultrasound examination is both feasible and convenient in the neonatal ward and may eventually replace chest radiography and CT scanning.

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Additional information: The Videos can be found in the Supplemental Materials section of the online article.

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