"Pediatric chest: From x-ray to ultrasound. A pictorial review of 173 patients"

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Learning objectives

- To remember the sonographic appearance of normal chest.
- To become familiar with the images of various mediastinal and lung pathologies in children.
- To emphasize on key imaging features and on differential diagnosis.
- To correlate sonographic with radiographic findings.

Background

X-ray remains the modality of choice in the evaluation of pediatric chest. It is the first and most common imaging test, required in the emergency department.

Nevertheless, conventional radiography often causes diagnostic dilemmas needing further investigation. Until recently, Computed Tomography (CT) scan was the next step after conventional radiography; however pediatricians and radiologists hesitated to expose children to large amounts of radiation, as the risk of radiation induced cancer in children from CT is estimated to be as high as one in 500 [1]. Furthermore, Magnetic Resonance (MR) has not been established yet to be useful in the evaluation of lung pathology, so radiologists have to choose alternative, radiation free, imaging methods.

In the past, the role of chest ultrasound (cUS) was limited in the evaluation of the pleural space and the guidance of interventional procedures such as diagnostic or therapeutic thoracentesis and placement of thoracostomy tube. Nowadays, cUS can also be used in the evaluation of other pathologies of the lung and mediastinum especially in children where the immature bony skeleton serves as an acoustic window. So, cUS has become a complementary method in unclear cases where chest x-ray (CXR) seems inadequate to establish a diagnosis or whenever frequent follow-up is necessary. cUS examination must follow CXR so as to be able to focus on the pathology.

Chest US has multiple advantages comparing to other modalities:

- it can be performed at the bedside of the patient, especially in critically ill children
- it requires neither radiation exposure nor the administration of contrast agent
- radiologist can choose among different transducers (convex, linear, vector) and different access points on the child's chest, according to the age and body type, so as to improve diagnostic assessment
- it is a low cost modality and can easily be repeatable
- as for guided procedures US is accurate in finding the exact entrance point, thus avoiding repetitive efforts which irritate the patient and reducing complications like pneumothorax and large hematomas
- US is better than CXR in recognizing even small amounts of fluid. It can detect an effusion as less as 3-5 mL [2] and is more sensitive than both CXR and CT in characterizing the nature of the pleural fluid and early depicting complicated effusions [3]
- in the case of an opaque hemithorax on CXR, US can readily differentiate whether parenchymal disease, pleural disease or both is the cause [4]
- finally, in some cases US is more sensitive than supine CXR in the diagnosis of pneumothorax

The disadvantages of the method are:
- the multiple artifacts
- the inability to reconstruct images
- it is an operator dependent technology thus requires expert hands to reach a better diagnostic result
- difficult to use in open wounds and obesity.

Indications

The most common indication for cUS is an opaque hemithorax. US can be used for the detection and characterization of pleural effusions, as well as guidance of their management. Concerning lung parenchyma US offers frequent follow up of pneumonias in children, while color Doppler contributes in early depiction of complicated cases, such as necrotic areas and abscess formation. Taking advantage of all technical tools provided from the machine, like M-mode, the presence of pneumothorax can be confirmed and the diaphragmatic motion can be evaluated. Finally, the cUS complementary role in the evaluation of anterior and posterior mediastinum should be noted.

Findings and procedure details
During the last four years, 173 consecutive children had a cUS, in our department. All patients had an abnormal CXR (contralateral lung opacity, mediastinum widening, paravertebral mass, elevated hemidiaphragm, pneumothorax).

Different transducers were used, according to the size of the patient and the structure being examined. A high frequency linear transducer 17-5MHz, a small footprint 8-5MHz curved array and a convex 5-2MHz were mostly used, with the latter for the assessment of deeper lesions or in obese children. Intercostal approaches were used for the evaluation of pleural space and lung parenchyma. Images through the suprasternal and supraclavicular spaces were taken to examine superior anterior mediastinum, whereas liver and spleen served as acoustic windows for the inferior thoracic cavity. Posterior mediastinum was also assessed by paraspinal approach. Diaphragmatic motion was evaluated using intercostal and subxyphoid approaches.

NORMAL ANATOMY - NORMAL CHEST US

Firstly, it has to be noted that sound cannot be transmitted through structures containing air, so aerated lung is normally not visualized under the pleura. Therefore the final sonogram on the screen is the result of multiple artifacts caused by air-tissue interfaces.

Starting with the long axis view, the anterior chest wall can be seen: the echogenic layer of subcutaneous fat superficially, followed by the hypoechoic layers of intercostal muscles and their thin echogenic fascia planes. The superior rib is sited on the left and the inferior rib on the right part of the image, producing intense posterior acoustic shadowing. About 0.5cm below and between the two ribs, a thick echogenic line will be seen. This is the pleural line, which represents the two layers of the pleura, the outer parietal and the inner visceral layer. The two ribs can be imagined as being the wings and the pleural line the body of a bat, so this image would be called the bat sign. The pleural line, on real-time US, moves with respiration horizontally and that in fact is the visceral layer moving along with the lung, while the surrounding chest wall and parietal pleura are still or move in an opposite direction to the lung, so this is called the lung sliding Fig. 1 on page 8 [5]. While the patient breaths, white vertical lines can be seen coming down the pleura deep into the lung. These are comet-tail reverberation artifacts created by the acoustic interface of the pleura with the aerated lung and they represent B lines Fig. 2 on page 9(a) or Z lines Fig. 2 on page 9(b).

In M-mode scanning the image of the normal lung sliding is known as the seashore sign Fig. 2 on page 9(b), [6].

PNEUMOTHORAX
Another artifact often seen in normal sonograms and in sonograms with pneumothorax, is the A lines. These are curved or horizontal echogenic lines parallel to the pleural line and at a distance equal to that of the pleural line from the skin [7]. They indicate subpleural air (physiologic or pathologic) which completely reflects the ultrasound beam. They are reverberation artifacts of the pleural line. A lines without B lines and no lung sliding, on real time US, are highly suggestive of pneumothorax Fig. 3 on page 9(a). M-mode in pneumothorax confirms the absence of lung sliding by producing multiple straight lines (non-moving artifacts from chest wall, pleural line and lung). This is the stratosphere sign Fig. 3 on page 9(b) [8].

There is a point, during respiration on the real time US, where normal lung adheres to the parietal pleura in a patient with pneumothorax. The meaning of this is that an area without lung sliding or B lines "meets" another area where lung sliding is seen. This is called the lung point and its presence is a hallmark for pneumothorax Fig. 3 on page 9(c) [9].

LUNG PARENCHYMA

In lung consolidations, air is replaced by fluid, leading to a good US transmission if there is a direct contact of the lesion with pleural surface [10].

Pneumonia follows 4 stages: The congestion, red hepatization, grey hepatization and resolution. Typical US image of pneumonia is a liver-like appearance of the parenchyma [11], during the second and third stage, when its surface resembles that of liver Fig. 4 on page 11(a).

Linear, branching or dot-like echogenic structures are often visible within consolidation and represent air bronchograms. They can sometimes have an intrinsic movement on real time US which is called dynamic air bronchogram and rules out atelectasis [12].

Several linear or branching hypoechoic structures may often be seen within consolidated lung representing bronchi filled with fluid or mucus and called sonographic fluid bronchograms. They do not have visible walls in contrast to the normal small vessels traversing the solid appearing pneumonia Fig. 5 on page 11.

Color Doppler demonstrates normal pulmonary vascular flow and preserved linear branching configuration in both pneumonia and atelectasis, even though vessels in atelectatic lung will have a more crowded and parallel appearance due to loss of pulmonary volume [4] Fig. 6 on page 12 (a,b,d,e).

Power Doppler confirms the quadriphasic pattern of normal pulmonary arteries Fig. 4 on page 11(b), Fig. 6 on page 12(c), which is a valuable information against lung sequestration or malignant lesions where predominant pulsatile diphasic low-velocity flow occurs [13].
Complicated cases consist of necrosis and abscess formation presenting characteristic sonographic features. Although contrast enhanced CT is very sensitive in demonstrating areas of liquefaction, US can also reveal tissue necrosis in early stages, not even suspected radiographically or clinically Fig. 7 on page 13.

Necrotizing pneumonia is a serious, potentially fatal complication of lobar pneumonia and is characterized by massive necrosis and liquefaction of the lung. The presence of peripheral hypoechoic spaces in consolidated lung appeared to be a specific sign for the diagnosis of necrotizing pneumonia [14]. In our series necrotizing pneumonia was noted as:

a) diffuse inhomogenous consolidation Fig. 8 on page 14

b) multiple peripheral hypoechoic areas complicated with air in the pleural space due to bronchopleural fistula Fig. 9 on page 15

c) peripheral and central hypoechoic areas Fig. 10 on page 16

d) multiple confluent necrotic areas within solid appearing pneumonia complicated with abscess formation Fig. 11 on page 16

e) multiple neighboring anechoic and hypoechoic spaces giving the consolidation a "honeycomb" appearance Fig. 12 on page 18

In all cases no vascularity was seen within hypoechoic spaces that lack a visible wall.

Lung abscesses may be formed as infections progress. They can have thin smooth contour or thick irregular walls and contain either fluid or air-fluid level Fig. 11 on page 16(d), Fig. 13 on page 18(b). US can play an important role in the frequent follow-up of these patients Fig. 13 on page 18 and US-guided aspiration may help in the diagnosis as well as the treatment [4].

US may play a complementary role in the diagnosis of congenital malformations. It is well known that congenital pulmonary airway malformations (CPAM) are often sonographically detected prenatally, but may also present later in life due to superimposed infection [2]. Then they can become visible on US as their cystic components are filled with fluid. When infected they can present with thick walls and peripheral hyperemia. They may have variable sizes and communicate with each other Fig. 14 on page 19.

PLEURAL SPACE

As for the pleural space, chest radiographs taken in the lateral decubitus position can pick up as little as 50ml of fluid, while at least 300ml of fluid must be present to become
obvious in erect films as blunted costophrenic angles. US is sensitive in detecting even small amounts of fluid not suspected from conventional radiography.

US is more specific in recognising complicated parapneumonic effusions earlier than both CXR and CT.

Parapneumonic effusion is a pleural fluid collection next to infected lung [3]. This may be simple and completely anechoic, treated conservatively with antibiotics and follow up is recommended.

Complicated effusions may have several appearances. They can have multiple internal echoes and even become echogenic. They may contain fibrin strands floating within the collection or attaching to one pleural surface. They can create septations traversing the pleural space or loculations preventing the free movement of pleural fluid. In late stages an empyema may occur, which is a loculated effusion with no change in shape in different x-ray planes. On US empyema appears as thickening of one or both pleural layers in combination with multiple fibrin septations and debris that may entrap the lung Fig. 15 on page 20, [3].

Treatment is different in loculated effusions needing pleural drainage with or without fibrinolytic agents in the pleural cavity.

Once a lung consolidation complicates with parapneumonic effusion in a child, frequent follow up is needed and US is the modality of choice in such cases Fig. 16 on page 20.

**DIAPHRAGM**

When an elevated hemidiaphragm in noted on a CXR, US can be the first method to reveal supra/or subdiaphragmatic masses, or hernias.

Diaphragmatic motion is well evaluated with M-mode. The transducer is located either in the low intercostal spaces, between midclavicular and midaxillary lines, for separate examination of each hemidiaphragm or at the subxyphoid space for comparative evaluation.

During inspiration diaphragm descents, moving toward the ultrasound probe and appears as an upward slope on M-mode. In contrast, during expiration the diaphragm moves away from the probe and this is a downward slope on M-mode.

In diaphragmatic paralysis M-mode shows absent movement during quiet respiration and paradoxical movement-away from the transducer- when the patient sniffs [15] Fig. 17 on page 21.

**MEDIASTINUM**
Evaluation of anterior and posterior mediastinum is well established with US.

When mediastinum appears wider than expected on CXR, US can easily differentiate between a lung consolidation (mass, pneumonia, atelectasis) and a thymus gland Fig. 18 on page 22. Thymus gland may have variable appearances on CXR, some of them pathognomonic, others not. Its characteristic US appearance allows confident diagnosis making further imaging tests unnecessary [4].

US can give additional information concerning either the contour and shape of the thymus, or the location of the gland as in cases of retrocaval thymus Fig. 19 on page 24, where a part of the gland is situated between superior vena cava and great arteries [16].

Posterior mediastinal masses may occasionally mimic retrocardiac lung consolidations. US then can be useful in delineating the extrapulmonary location of the mass giving further information concerning the echotexture and specific sonographic signs for differential diagnosis Fig. 20 on page 23.

Images for this section:

![Image](image.png)

**Fig. 1:** Normal chest US in the long axis view of anterior chest wall. The Bat sign: The wings: superior rib to the left (sup rib), inferior rib to the right (inf rib), with intense posterior shadow. The body of the bat: pleural line between the two ribs and about 0.5cm below them. Black arrows indicate the lung sliding: the distinct horizontal movement of lung and visceral pleura against the parietal pleura during respiration. Chest wall anteriorly.
Fig. 2: (a) B-mode US in the long thoracic axis. Arrowheads indicate a B line: a vertical narrow based echogenic comet-tail artifact arising from the pleural line (red arrows) to the edge of the US screen. It is as echogenic as the pleural line. (b) In M-mode scanning the image of normal lung sliding with respiration is the seashore sign, where the "sea" is the non moving chest wall, the "foam" is the pleural line and the "shore" is the granular pattern of the normal sliding lung. Note also in the image above two short vertical comet tail artifacts (arrowheads). These are Z-lines. They are different from the B lines in that they are less echogenic than the pleural line and they don’t reach the edge of the screen. Both B and Z lines are normal findings and their absence can indicate the presence of pneumothorax.
**Fig. 3:** Pneumothorax. All images from the same patient. (a) B mode in the short axis view from anterior chest wall of a newborn with pneumothorax. Chest wall anteriorly (asterisks). The pleural line (red arrows), in this case of pneumothorax, is thinner and consists only of the parietal pleura. No lung sliding was seen on real time US. Yellow arrowheads point to the A lines- reverberation artifacts of the pleural line indicating the presence of subpleural air (in this case pathologic air of pneumothorax). They are parallel to the pleural line and at regular intervals. Compare them with the A lines of fig 2b where they were normal artifacts from physiologic air of the lung periphery. (b) M mode scanning: the entire image has been replaced by multiple straight lines and this is well known as the stratosphere sign. It reflects the non moving chest wall and pleura and the
absence of lung sliding. (c) US in the long axis view from the lateral chest wall. The left half of the image shows two vertical comet-tail artifacts (black asterisks) and presence of lung sliding, hallmarks of normal lung expansion. In the right half of the image there is pneumothorax with only some A lines and no lung sliding or vertical artifacts. The dashed line marks the lung point where normal lung interfaces with air of pneumothorax.

Fig. 4: (a): solid appearing pneumonia (asterisks), dot-like and linear echogenicities represent air bronchograms. Diaphragm (red arrowhead), spleen (S). (b) Power Doppler signal from pneumonia suggests quadriphasic pattern from normal pulmonary artery.
**Fig. 5:** Air bronchograms. Different cases. (a) branching, tree-like. (b) dot like or linear echogenic structures. (c) in combination with fluid bronchograms (yellow arrows): hypoechoic branching structures with no distinct walls are bronchi filled with fluid. (d) a few air bubbles in the periphery of this necrotizing pneumonia. Less echogenic small vessel walls are apparent (arrowheads).
Fig. 6: Color Doppler in consolidated lung (a) Poorly vascularized pneumonia with no visible necrotic areas. Free movement of the pleural fluid produces color on Doppler US (arrow). (b) Well vascularised pneumonia with multiple normal branching vessels and (c) quadriphasic wave pattern. (d, e) different cases of atelectasis with multiple vessels having a crowded and parallel configuration, due to loss of the lung volume.
Fig. 7: CXR and US of a 7y.o boy with pneumonia. US reveals a small area of liquefaction (yellow circle) in the periphery of this solid appearing pneumonia (arrowheads: air bronchograms) not even suspected radiographically nor clinically.
Fig. 8: Necrotizing pneumonia presented as diffuse inhomogeneous consolidation containing multiple hypoechoic areas with blurred borders and no internal vascularity.
**Fig. 9:** (a) CXR of a 9 y.o girl with cough and fever: almost complete opacification of the left hemithorax. (b) Color Doppler US reveals peripheral hypoechoic areas (red arrows) with no internal vascularity and moderate pleural effusion. (c) a level above (b), air is seen in the pleural space (red arrows), proving that this necrotizing pneumonia is complicated with bronchopleural fistula (arrowheads: air bronchograms).

**Fig. 10:** Necrotizing pneumonia (a) multiple peripheral and central hypoechoic areas within consolidated lung (b) who could predict this excessive tissue necrosis only by looking this child's CXR?
Fig. 11: (a) Erect AP CXR: inhomogenous right middle and lower lung opacification (asterisks), cranially bordered by the minor fissure and caudally becoming more dense (arrows), obscuring the right hemidiaphragm. (b) Intercostal US from anterior chest wall at the level of the middle lung field: the area of asterisks in (a) corresponds to an heterogenous solid appearing pneumonia with internal confluent hypoechoic spaces due to necrosis. In the left half of the image two comet tail artifacts from non consolidated lung. (c) Lateral CXR of the same patient. The inferior portion of pneumonia in (a)
seems to have a lenticular shape in the lateral view (arrows) and is located in the middle lobe. (d) US anterior intercostal approach in a lower level than (b) reveals an oval, well demarcated, thin walled hypoechoic lesion with no internal vascularity (doppler is not included). Imaging findings compatible with abscess formation.

**Fig. 12:** (a) x ray with opacification of the left lower lobe and blunting of the left costophrenic angle. There is mild scoliosis to the right. (b) In US we recognise an advanced necrotizing pneumonia with areas of liquefaction and internal septations giving a honeycomb appearance. There is also mild pleural effusion with thickened visceral pleura (arrowhead).
**Fig. 13:** This is a case of a 9y.o child with a RUL pneumonia whose parents refused hospitalization. 5 days after being treated with oral antibiotics at home they returned without clinical improvement. (a) AP CXR shows an oval well circumscribed opacity in RUL in the place of preexisting lobar pneumonia. (b) US reveals a thick walled hypoechoic cavity with air in the non dependent portion which represents an air-fluid level. There was no consolidation around. CXR raises suspicion for abscess formation but cannot demonstrate the air-fluid level, at this time. (c, d) show gradual reduction of abscess dimensions until complete resolution (e).

![Fig. 13](image)

**Fig. 14:** A 48 days old full term neonate with reduced feeding, fever (up to 37.7 oC) and persistent vomiting for 5 days (a) AP CXR: Homogenous opacification (asterisks) of almost the entire right hemithorax, with well demarcated inferior borders and no mediastinal shift. (b) US: thick walled (arrowheads), oval hypoechoic lesion containing fine internal echoes in communication with a second smaller lesion (arrows). Infected congenital cystic adenomatous malformation (CCAM), pulmonary blastoma and abscess cavity were included in the differential diagnosis. (c) Color Doppler revealed only intense peripheral vascularity due to superimposed infection. 2 weeks after therapy with 3
different antibiotics there was only decrease in the perilesional vascularity. No change in shape or size was noted. The possibility of abscess was excluded. Histology revealed CCAM.

**Fig. 15:** Complicated pleural effusions (a) Floating fibrin strands (arrows) in the pleural cavity. (b) Fibrin bands (arrowheads) attaching the visceral pleura (p: pneumonia) (c) Multiple septations traversing the pleural space creating loculations (arrows). (L: liver, a: atelectatic lung) (d) Empyema (e): Completely loculated effusion containing pus. There is marked thickening of both pleural layers, multiple debris and septations, preventing free movement of fluid. (asterisks: debris)
**Fig. 16:** (a) 8y.o child with LLL consolidation and a small pleural effusion (p: pneumonia, asterisk: free pleural effusion). (b) mild thickening of both pleural layers, more obvious at the visceral layer (yellow arrow). There is some free fluid (asterisk) and a septated subpneumonic pleural effusion (p: pneumonia, s: subpneumonic effusion). (c) Day 5: the pleural space has been completely occupied by debris and septations restricting normal expansion of the lung. (d, e) Erect CXR and US at day 9. The left lower lung opacity on CXR corresponds to a loculated effusion and US reveals the pleural cavity filled with dense material (it was pus at thoracentesis) and consequent lung collapse (a:lung atelectasis, d: pus, asterisk: small amount of free fluid, s: spleen)
Fig. 17: Asymptomatic 13 year-old girl with elevated left hemidiaphragm on plain film (not available). (a) Chest MRI-coronal T2W, obtained for the evaluation of phrenic nerve along its course next to the mediastinum. Intact left hemidiaphragm. (b) Normal right diaphragmatic movement. (c) Sagittal US image of the left hemidiaphragm and M mode tracing show almost absent movement during quiet respiration and (d) paradoxical movement (movement away from the transducer) when the patient sniffs, findings indicating paralysis. INSP: inspiration, EXP: expiration
**Fig. 18:** A newborn child with a large dense opacification of the right hemithorax. It has smooth well demarcated lateral borders with no mediastinal shift. It is probably a large thymus gland. The characteristic US appearance of the thymus (asterisks) does not allow further investigation.

**Fig. 20:** (a) CXR of a child with a 20 days persistent right paracardiac opacity not corresponding to antibiotics. (b) US shows a well circumscribed paravertebral (s: spine) solid mass (arrowheads) containing microcalcifications (red arrows). (c) Internal vascularity (arrows) at color Doppler. Regarding to the age of the patient and the location
of the mass at the posterior mediastinum it was thought to be a neuroblastoma. (d, e) MRI confirmed US findings and gave additional information concerning the extent of the tumor. A neuroblastoma was diagnosed histologically.

Fig. 19: Incidental finding at the CXR: symmetrical widening of the superior mediastinum of a 8y.o girl(red arrows). US of the superior anterior mediastinum with a small footprint 8-5MHz curved array reveals continuation of the thymus gland (yellow asterisks) to a more posterior position (red asterisk) between the great vessels: the superior vena cava (SVC), the left brachiocephalic vein (LBV) and the aortic arch (Ao). MRI certified the retrocaval extension of the gland.
Conclusion

US is useful in the evaluation of many pediatric chest queries.

Apart from differential diagnosis, it contributes to avoid additional radiation exposure (multiple x-rays/CT) when frequent follow-up is required (pleural effusions, complicated pneumonias, pneumothorax).

It is a reliable method in the assessment of mediastinum and of diaphragmatic movement, thus replacing fluoroscopy.

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