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REVIEW

Lung ultrasound in pediatric radiology - cons

Paolo Tomà [1]

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Abstract

In the 1990s, intensivists suggested a new type of sonography: lung ultrasound, based on artefacts that receive information even from physical acoustic phenomena not directly convertible into images of the human body. They compared the artefacts from the lung zones with no acoustic window with various computed tomography (CT) patterns. They used and still use US as a tool to evaluate patients bedside, i.e. monitoring of lung recruitment. They included Lung ultrasound in what was termed POCUS (Point-of-Care Ultrasound). Lung ultrasound has been progressively extended to paediatrics in general. The most appealing novelty has been the diagnosis of pneumothorax. Lung ultrasound was developed as a support tool for critical patients. Extrapolation with mass diffusion, in the absence of appropriate training, has led to misunderstandings and dangerous therapeutic diagnostic drifts.

Keywords Children · Lung · Review · Ultrasound

Introduction

Application of lung ultrasound in everyday clinical practice has gone through several phases during the last 50 years. Some of the first papers highlighting Lung ultrasound potentials in detecting cases of pneumonia were published in the 1970s [1].

The pioneers

The first articles dealt with the study of the thorax in all its components, from the mediastinum to the diaphragm. A Medline query of articles from January 1975 to December 1985 (“thorax”[MeSH Terms] OR “thorax”[All Fields] OR “chest”[All Fields]) AND (“ultrasonography”[MeSH Terms] OR “ultrasonography”[All Fields] OR “sonography”[All Fields])) NOT (“echocardiography”[MeSH Terms] OR “echocardiography”[All Fields]) AND (“1975/01/01”[PDAT]: “1985/12/31”[PDAT]) identifies 75 publications. The authors had already identified the limits and indications that would have been set for many years thereafter. Air and bones were insurmountable obstacles; the study of the lesions was possible only in the presence of an acoustic window, such as the thymus [2, 3]. In 1975, Skolnick et al. [4] described the artefacts from acoustic reverberations, such as echogenic lines that arise at regular intervals from the surface between tissue and air that act as a strong reflector (presently referred to as A-lines). According to Avruch and Cooperberg [5], tiny columns of fluid between gas and air bubbles were responsible for the formation of ring-down artefacts, described as vertical sharply defined structures that do not decrease their brightness with depth (presently the B-lines). The latter were considered findings related to a resonance effect when US beam stroked a group of air bubbles.

The stable period

In the second half of the 1980s, Avni first published the diagnosis by US of hyaline membrane disease, emphasizing that retrohepatic ring-down artefact in newborns was pathognomonic for hyaline membrane disease and allowed an immediate diagnosis. The persistence of the pattern could be a useful criterion for the prognosis evaluation [6]. We have been using this sign since 1992 [7], but without actually understanding its potential.

A PubMed query of articles from January 1986 to December 1995 ((“thorax”[MeSH Terms] OR “thorax”[All Fields] OR “chest”[All Fields]) AND (“ultrasonography”[MeSH Terms]

✉ Paolo Tomà
paolo.toma@opbg.net

[1] Ospedale pediatrico Bambino Gesù, IRCCS, Piazza S. Onofrio 4, 00165 Rome, Italy

OR “ultrasonography”[All Fields] OR “sonography”[All Fields])) NOT (“echocardiography”[MeSH Terms] OR “echocardiography”[All Fields]) AND ((“1986/01/01”[PDAT]: “1995/12/31”[PDAT]) AND (“infant”[MeSH Terms] OR “child”[MeSH Terms] OR “adolescent”[MeSH Terms])) detected 52 publications concerning chest sonography in children.

The new wave

In the 1990s, no radiologist would have thought that Daniel Lichtenstein’s findings would have caused such radical changes in chest imaging. Lichtenstein is the founder of the Le Cercle des Echographistes d’Urgence et de Réanimation Francophones (CEURF, Group of French-speaking ultrasound users in emergency and resuscitation services), which aims to develop critical care US. The group defines it as a holistic approach, based on simple units (grey scale), one universal microconvex probe for whole body, and an approach centred on the main vital organ, the lung. Lichtenstein suggested a new type of sonography, Lung ultrasound, based on artefacts that receive information even from the physical acoustic phenomena not directly convertible into images of the human body [8–11]. He compared the artefacts from the lung zones with no acoustic window with various CT patterns. The experience from the adult critical care unit was translated into the neonatal intensive care unit and paediatric emergency unit by Copetti and Catarossi, two intensivists of northeast Italy who were followers of Lichtenstein’s ideas [12, 13]. They reevaluated the classic US pattern in which the essential requirement for using US was the presence of an open acoustic window, such as in consolidation and atelectasis [14]. They included Lung ultrasound within the Point-of-Care Ultrasound (POCUS). The next step was the enthusiastic acceptance of the new method, especially by clinicians, who emphasized the role of Lung ultrasound as an “all-in-one” approach, often rejecting integration with conventional imaging. Lung ultrasound is considered, by a widespread current of thought, a new imaging procedure in itself, and not a complement to the clinic, although it is also based on non-morphological data.

Since that period, according to Lichtenstein [15], there was a real explosion of the number of publications on this topic. A PubMed query focused on Lung ultrasound in neonatal respiratory distress assessment retrieved 375 articles over the past decade. Regarding the diagnosis of pneumonia, Pereda et al. [16], using the keywords paediatric age (<18 years), lung ultrasound, and pneumonia, found 1,475 studies published before July 2014. The metanalysis of Balk et al. [17] focused on the keywords paediatric age, lung ultrasound and pneumonia counted 784 articles published before August 2017.

Current status

Paradoxically, lung ultrasound provides better results with old machines without a lag phase between acquisition and reconstruction and with natural (“unfiltered”) views. In fact, harmonics and compound filters remove lung artefacts [18].

A- and B-lines

The main innovation is the old ring-down artefacts renamed B-lines [5]. Visualization of B-lines may vary by changing the technical adjustments, machines and probes [19]. They depend on transducer type, shape, size, frequency, focus, imaging techniques, e.g. tissue harmonic imaging, pre- and post-processing, etc. Advanced techniques, such as compound filters, should be turned off whenever possible. Lichtenstein [20] tried a new classification and remains rigid about his position, which is that (a) three B-lines between two ribs are called septal rockets, expressing thickened subpleural septa, and (b) twofold, up to 10- to 12-fold artefacts are called glass rockets, the equivalent of CT ground-glass opacities, indicating a severe interstitial syndrome. However, these interpretations are not sufficient to explain daily clinical practice. B-lines are evident during expiration in the incompletely expanded posterior basal segments of the healthy newborns/infants. Martelius et al. [21], using CT as the reference standard, suggests that B-lines are highly nonspecific in children and cannot be used as a sign of the pathological processes of lung parenchyma. This is partially true because, especially in the neonatal intensive care unit (NICU), they are significant but are visible in both expiration and inspiration. Soldati et al. [22] emphasized that B-lines are signals due to pathological modifications (such as oedema or interstitial lung disease) or to functional states (as partial atelectasis) that alter the alveolar volume and arrangement in the plane immediately below the pleura.

Consolidation/atelectasis

Kim et al. [23, 24] described the sonographic pattern of atelectasis the air bronchogram detected may become crowded and run parallel. They also defined the different patterns of the parapneumonic effusions: simple (with or without debris), complicated (septated or multiloculated fluid collection), fibrothorax (very thick, echogenic rinds of pleural plaque). Enriquez et al. [25] emphasised the role of colour Doppler to differentiate vessels from fluid bronchograms, identifying normal pulmonary arteries by their characteristic polyphasic (mainly quadriphasic) pattern depicted with spectral Doppler. The goal was to distinguish pneumonia from pleural effusion or tumours. They also classified lung consolidation into three groups: well-vascularized pneumonia, poorly vascularized pneumonia without necrotic areas and poorly vascularized pneumonia with necrotic areas. Copetti and Cattarossi [14] had the idea of combining Lichtenstein's systematic approach implemented for intensive care [20] with the research of anything really visible in children through an acoustic window: Theoretically, the majority of consolidations or atelectasis were evident. Therefore, in their opinion, chest radiography had become obsolete [26, 27].

Chest infection (traditional approach)

Opinions on whether to do chest radiography are the most diverse [28–32]. Additionally, radiologic terminology is confounding [29, 33, 34]. Comparing selected studies on the agreement for paediatric chest radiographs has kappa<0.6 [33]. Reported sensitivities range from 71% to 87% and specificities from 90% to 98%. The low accuracy is a greater problem perhaps than the low radiant dose. Despite these limits and recommendations, respiratory tract infections remain the most common indication for thoracic imaging [35]. The main problem for clinicians is that, even though the guidelines promote a clinical diagnosis, the signs and symptoms of lower respiratory tract infections are relatively nonspecific [33, 36, 37]. Lung ultrasound has been shown to be even more reliable than auscultation in detecting paediatric airspace disease, especially for lesions <30 mm [36]. Nevertheless, it does not mean that Lung ultrasound can replace auscultation in everyday diagnostic practice.

Lung ultrasound and community-acquired pneumonia

The diagnostic elements, unfortunately, went beyond the direct visualization of a lung without air and crowding of vessels and bronchi. In different ways, the various authors also included sub-centimetre echogenic areas, focal B-lines and pleural line abnormalities. The pleural line is an artefact generated by differences in the acoustic impedance of two adjacent tissues. According to Lichtenstein, a thickened, irregular pleural line corresponds to trace consolidations, but it is also typical of interstitial syndrome and is present in newborns with respiratory distress syndrome [38]. The attempt to automate the diagnosis by metaphors created a series of contradictions that have weakened the technique that had an intrinsic validity of support. It was probably better to link the interpretation to the knowledge of physics and anatomy without pretending to teach a complex matter in a few hours. However, there is a wide range of parenchymal findings depending on the phase of the pneumonia evolution, such as confluent B-lines, subpleural hypoechoic areas without air bronchogram (hepatization) or with adjacent B-lines, and subpleural hypoechoic areas smaller than 5 mm. Crowding of vessels and bronchi, which separates atelectasis from consolidation, is quite rarely seen. Lichtenstein et al. [39] distinguishes atelectasis from consolidation: A positive "dynamic air bronchogram" with centrifugal progression of the air bronchogram signal in inspiration suggests alveolar consolidation instead of bronchial occlusion with subsequent lung collapse and atelectasis, reporting specificity of 94%, positive predictive value (PPV) of 97%, sensitivity of 61% and negative predictive value (NPV) of 43%. However, their study only refers to resorptive atelectasis in patients mechanically ventilated. They also describe the abolished lung sliding associated with lung pulse. These signs are detectable also in atelectasis caused by foreign bodies. Much more difficult is the differential diagnosis for infectious disease in acute patients because they often coexist. Fluid bronchograms are also common inside consolidations. Two main meta-analyses seem to conclude that Lung ultrasound has a good accuracy, sensitivity of 96% (95% confidence interval [CI] 94–97%), specificity of 93% (95 CI: 90–96%), and positive and negative likelihood ratios of 15.3 (95% CI: 6.6–35.3) and 0.06 (95% CI:0.03–0.11), respectively [16, 17]. The same authors recognized the limits of the articles included in the meta-analysis (the same limits are also evident in the new studies). In general, the articles on the topic present several biases: selection bias, index test bias, reference test bias, incorporation bias, spectrum bias, reader bias, etc. [26, 27, 40–43]. The meta-analysis of Balk et al. [17] reports 12 studies including 1,510 patients. Lung ultrasound has a sensitivity of 95.5% (95% confidence interval 93.6–97.1) and specificity of 95.3% (91.1–98.3%). Out of the 12 articles, 4 are the same reported by Pereda et al. [16]. Balk et al. [17] highlighted the same biases by adding interesting considerations. The most worrying point is the attempt to perform the differential diagnosis on the nature of the pathogenic microorganisms [44–46]. Small hypoechoic areas, misinterpreted as consolidation and, consequently, as a sign of bacterial infection in infants and false interstitial pneumonia (defined by the presence of B-lines), represent the most serious intrinsic errors [26, 27, 42]. The subpleural hypoechoic areas are almost always focal zones of subsegmental atelectasis and not consolidations [34]. If the authors considered those areas consolidations (i.e. bacterial pneumonia), as it can be deduced from the conclusions, they administered antibiotic unnecessarily. The pattern of bronchiolitis described by Caiulo et al. [47] shows small hypoechoic areas as a sign associated with compact B-lines and pleural line abnormalities. These signs are compatible with the pathological pattern of infections in the first two years of life. B-lines and pleural anomalies are likely to be related to interstitial oedema and underinflation. A recent article reports a moderate inter-rater agreement of Lung ultrasound in the diagnosis of pneumonia [48]. The kappa values relative to the individual signs are: B-lines 0.59, pleural effusion 0.44, consolidation 0.46, composite for pneumonia 0.58. In Gravel's study, the median length of time to perform Lung ultrasound study was 9 min, while Pereda et al. [16] reports 10 min. Gravel found a difference in reliability when lung POCUS was performed by expert sonographers versus inexperienced sonographers, with a moderate agreement among the experts and a fair agreement among the less experienced.

One of the most valuable aspects of Lung ultrasound is the possibility to follow up the course of pneumonia in a completely safe way. It should therefore be considered in those patients with round pneumonia, collapse or persisting symptoms. Nevertheless, it is essential to keep in mind that Lung ultrasound findings often persist days or even weeks after all symptoms subside, which might lead to antibiotics overuse. Besides being the technique of choice to characterize pleural effusions, Lung ultrasound enables detection of the early stages of necrotizing pneumonia by revealing minor areas of necrosis, which cannot be seen on chest radiographs [23, 25]. Lung ultrasound could reduce the number of chest CT scans and chest radiographs in children with necrotizing pneumonia. A wide experience in paediatric radiology is necessary, given the difficulty in the differential diagnosis between abscess and cavitary necrosis. A typical pitfall is to interpret the fluid inside the abscess as a pleural effusion. Of course, chest CT should be employed in complicated cases and when the clinical course of the disease is not improving. Concerning the possible use of contrast-enhanced US (CEUS) [49], we know that the perfusion pattern of the consolidated lung on CEUS does not change the outcome [50]. The same should apply for CEUS. It is hard to see what US contrast adds beyond what may be visualised with Doppler US.

Neonatal lung diseases

Lung ultrasound may detect congenital lung malformations [43]. Lung ultrasound is becoming a useful tool in neonatal intensive care with a variety of patterns, including respiratory distress syndrome, transient tachypnea of the newborn, meconium aspiration syndrome, neonatal pneumonia, pneumothorax, and bronchopulmonary dysplasia. In 2007, Copetti and Cattarossi [12] described the Lung ultrasound pattern of transient tachypnea of the neonate. The following year he published the pattern of respiratory distress syndrome [13, 51]. The latter represents the summation of collapsed alveoli, transudation of fluid in the interstitium by increased capillary permeability and aerial distension of innumerable bronchioles, which have greater compliance compared to the surfactant-deficient lung. Consequently, B-lines are compact, diffuse and symmetrically distributed in both lungs: the Lung ultrasound white lung pattern. The pleural line is irregular and coarse. Multiple subpleural hypoechoic areas, generally small, are present mainly in the posterior and lateral scans [13]. In full-term newborns, the most common aeration disorder is transient tachypnea. The double lung point sign seems to be specific to this condition. All children show, at the first US examination, very compact B-lines in the lower lung areas, while in the upper areas B-lines are present but are not so compact [12]. Certainly, the more echogenic (white) appearance, the greater the alteration to the lung surface. A more recent article including the same authors [52] reports a PPV of 91.6% and an NPV of 97.1% for respiratory distress syndrome; a PPV of 96.5% and an NPV of 93.4% for transient tachypnea of the neonate. The authors also describe cases of transient without double lung point and emphasize the irregularity of the pleural line as a characterizing feature of the respiratory distress syndrome. However, integration with chest radiographs is still necessary, particularly for a panoramic view of the thorax, for lines, tubes, wires and air leak phenomena, leading to a combination rather than a contrast between chest radiographs and Lung ultrasound. Moreover, pneumomediastinum remains a challenging diagnosis for Lung ultrasound, as well as for interstitial emphysema [53, 54].

Pneumothorax

The major US criterion for a diagnosis of pneumothorax is the absence of the lung sliding sign with a reported sensitivity of 95.3%, a specificity of 91%, an NPV of 100% and a PPV of 87% [55]. However, the absence of respiratory lung movements can also be noticed in patients with any type of hyperinflation, such as asthma, foreign body aspiration or severe emphysema [56]. It is also a finding in extensive pleuropneumonias. The lung point sign can be a useful parameter, showing a sensitivity of 66% and a specificity of 100% [57]. M-mode can be practical in detecting the presence or absence of lung sliding sign, especially for less experienced operators. In M-mode, the absence of motion results in a static pattern of horizontal lines (stratosphere sign), which replaces the seashore sign. In M-mode, superimposed short vertical scatter bands reveal transmission of normal cardiac pulsation, the lung pulse [58]. The absence of this sign further contributes to the diagnosis [15]. Lung ultrasound is also highly efficient in detecting complete re-expansion of the lungs after pneumothorax drainage [55]. Ianniello et al. [59] report an overall sensitivity of 77%. Analyzing the first 2 years of experience separately, sensitivity was 74% during the first year and 80.5% during the second (gold standard: CT). Specificity was 99.8%, PPV was 98.5%, NPV was 97% and accuracy was 97.2%. This study emphasizes a crucial point: The main drawback in the application of Lung ultrasound is the need for experience, particularly in the detection of pneumothorax. Press et al. [60] report a sensitivity of 18.7% after a 2-month training of helicopter emergency medical service providers. In general, mainly in newborns, Lung ultrasound accuracy is good, as it also allows to diagnose hydropneumothorax [61–63].

Pleural effusion with the collapsed lung can be observed at US cross section during the expiratory phase, while A-lines are evident at the same cross section in the inspiratory phase, appearing as the curtains closing, hence the name curtain sign [64].

Discussion

After the first phase of relative interest, radiologists have progressively abandoned the thoracic US. The improvement of conventional radiology with the introduction of digitalization, the quality of CT and also the use of magnetic resonance imaging have diverted the attention from the technique that provided the worst morphological quality. Over the years, US has become a tool for the physician who specializes in the care of critically ill patients. The intensivists and, in general, pediatric emergency medicine physicians, having only one technique available and considering the difficulties of interpreting bedside chest radiographs, were persuaded to expand the indications for sonography. Therefore, POCUS has become an integral part of emergency medicine practice. The approach includes cardiac examinations, intravascular volume assessment, abdominal examinations, assessment for skull fractures, vascular access, etc. [65, 66]. The habit of learning through a practical approach (similar to that of the pediatric or adult basic life support concepts) led to the development of semiotics based on simple signs in order to have an immediate approach acquired in a short time through metaphorical names based on an apparent relationship of similarity between the images. Unfortunately, US is a complex technique that involves knowledge and experience, as well as a global radiologic culture that includes the physical properties of the techniques. The diagnosis by US of pneumothorax is probably the technique of choice in emergency, but literature shows that it works best if the operators have been properly trained [59]. The contribution to the diagnosis of pneumonia is closely related to the sonographic/radiologic culture of the operators [17]. Lung ultrasound is a three-dimensional technique but covers about 70% of the lung surface, does not scan the central airways, does not evaluate hila and does not detect pathologies not adherent to the pleura. Therefore, it cannot be considered self-sufficient and all-in-one. Lung ultrasound allows a practical assessment that can hardly be measured in terms of accuracy. With good sense, it can complement the clinical approach. It can also add information, in terms of conspicuity, to the chest radiograph.

Another problem is the quality of the literature on the topic. Fewer than 10% of the articles on lung ultrasonography, in the last 10 years, have been published in radiologic journals. This has entailed nonspecialist peer review. As has been pointed out, the quality of the revisions in radiologic journals on topics concerning radiology is higher [67]. In my opinion, the pediatric radiologist can/must use Lung ultrasound in a proper way and within the context of radiologic science. The problems of managing appropriateness and the cost of investigations remain, since we evaluated that bedside US requires a medical time for the examination about three times longer. Lung ultrasound takes an average of about 10 min for a radiologist and about 30 min at bedside. We calculated that the cost of US bedside is about three times the cost of a similar scan within the department of radiology. From a clinical point of view, according to the literature and frequently observed in everyday experience, the highest risk is undoubtedly represented by a mono-modality malpractice with many false positives for bacterial pneumonia, with a considerable increase in antibiotic treatment, mainly caused by small hypoechoic areas not representing consolidation, but micro-atelectasis frequent in bronchiolitis and asthma. We should also consider the risk of false negatives if patterns characterized only by B-lines are interpreted as positively viral, while they can hide a consolidation that does not reach the pleura.

Conclusion

Lung US was developed as a support tool for critical patients. The extrapolation of this fast technique from intensive care, where it is used in close correlation with clinical data and resuscitation practices, to daily routine investigation of lung diseases, in the absence of appropriate training, has led to misunderstandings and dangerous therapeutic diagnostic drifts. What can be useful in intensive care in expert hands can cause damage in other contexts.

Compliance with ethical standards

Conflicts of interest None

References

1. Kangarloo H, Sukov R, Sample WF et al (1977) Ultrasonographic evaluation of juxtadiaphragmatic masses in children. Radiology 125:785–787
2. Haller JO, Schneider M, Kassner EG et al (1980) Sonographic evaluation of the chest in infants and children. AJR Am J Roentgenol 134:1019–1027
3. Garel L, Lallemand D (1982) The thorax. In: Kalifa G (ed) 448 Pediatric ultrasound. Vigot, Paris, pp 73–88
4. Skolnick ML, Meire HB, Lecky JW (1975) Common artifacts in ultrasound scanning. J Clin Ultrasound 3:273–280
5. Avruch L, Cooperberg PL (1985) The ring-down artifact. J Ultrasound Med 4:21–28
6. Avni EF, Braude P, Pardou A, Matos C (1990) Hyaline membrane disease in the newborn: diagnosis by ultrasound. Pediatr Radiol 20: 143–146

7. Tomà P, Lucigrai G (1992) Chest. In: Fariello G, Perale R, Perri G, Tomà P (eds) Paediatric ultrasound. Ambrosiana, Milan, 458 pp 163–174
8. Lichtenstein DA, Mezière GA (2008) Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest 134:117–125
9. Lichtenstein D, Mézière G, Biderman P et al (1997) The comet-tail artifact. An ultrasound sign of alveolar-interstitial syndrome. Am J Respir Crit Care Med 156:1640–1646
10. Lichtenstein D, Axler O (1993) Intensive use of general ultrasound in the intensive care unit. Prospective study of 150 consecutive patients. Intensive Care Med 19:353–355
11. Lichtenstein DA, Lascols N, Mezière G, Gepner A (2004) Ultrasound diagnosis of alveolar consolidation in the critically ill. Intensive Care Med 30:276–281
12. Copetti R, Cattarossi L (2007) The "double lung point": an ultrasound sign diagnostic of transient tachypnea of the newborn. Neonatology 91:203–209
13. Copetti R, Cattarossi L, Macagno F et al (2008) Lung ultrasound in respiratory distress syndrome: a useful tool for early diagnosis. Neonatology 94:52–59
14. Copetti R, Cattarossi L (2008) Ultrasound diagnosis of pneumonia in children. Radiol Med 113:190–198
15. Lichtenstein DA (2019) Current misconceptions in lung ultrasound: a short guide for experts. Chest 156:21–25
16. Pereda MA, Chavez MA, Hooper-Miele CC et al (2015) Lung ultrasound for the diagnosis of pneumonia in children: a meta-analysis. Pediatrics 135:714–722
17. Balk DS, Lee C, Schafer J et al (2018) Lung ultrasound compared to chest X-ray for diagnosis of pediatric pneumonia: a meta-analysis. Pediatr Pulmonol 53:1130–1139
18. Lichtenstein D, Malbrain ML (2015) Critical care ultrasound in cardiac arrest. Technological requirements for performing the SESAME-protocol — a holistic approach. Anaesthesiol Intensive Ther 47:471–481
19. Dietrich CF, Mathis G, Blaivas M et al (2016) Lung B-line artefacts and their use. J Thorac Dis 8:1356–1365
20. Lichtenstein DA, Malbrain ML (2017) Lung ultrasound in the critically ill (LUCI): a translational discipline. Anaesthesiol Intensive Ther 49:430–436
21. Martelius L, Heldt H, Lauerma K (2016) B-lines on pediatric lung sonography: comparison with computed tomography. J Ultrasound Med 35:153–157
22. Soldati G, Demi M, Inchingolo R et al (2016) On the physical basis of pulmonary sonographic interstitial syndrome. J Ultrasound Med 35:2075–2086
23. Kim OH, Kim WS, Kim MJ et al (2000) US in the diagnosis of pediatric chest diseases. Radiographics 20:653–671
24. Hansell DM, Bankier AA, MacMahon H et al (2008) Fleischner society: glossary of terms for thoracic imaging. Radiology 246: 697–722
25. Enriquez G, Aso C, Serres X (2008) Chest ultrasound. In: Lucaya Y, Strife JL (eds) Pediatric chest imaging, 2nd edn. Springer, Berlin Heidelberg New York
26. Ianniello S, Piccolo CL, Buquicchio GL et al (2016) First-line diagnosis of paediatric pneumonia in emergency: lung ultrasound (LUS) in addition to chest-X-ray (CXR) and its role in follow-up. Br J Radiol 89:20150998
27. Reali F, Sferrazza Papa GF, Carlucci P et al (2014) Can lung ultrasound replace chest radiography for the diagnosis of pneumonia in hospitalized children? Respiration 88:112–115
28. Harris M, Clark J, Coote N et al (2011) British Thoracic Society guidelines for the management of community acquired pneumonia in children: update 2011. Thorax 66(Suppl 2):ii1–i23
29. WHO (2001) Standardization of interpretation of chest radiographs for the diagnosis of pneumonia in children. In: World Health Organization: pneumonia vaccine trial investigators' group. Department of Vaccine and Biologics, Geneva
30. Swingler GH, Zwarenstein M (2009) Chest radiograph in acute respiratory infections. Cochrane Database Syst Rev https://doi.org/10.1002/14651858.CD001268.pub3
31. Franquet T (2001) Imaging of pneumonia: trends and algorithms. Eur Respir J 18:196–208
32. Bradley JS, Byington CL, Shah SS et al (2011) Executive summary: the management of community-acquired pneumonia in infants and children older than 3 months of age: clinical practice guidelines by the Pediatric Infectious Diseases Society and the Infectious Diseases Society of America. Clin Infect Dis 53:617–630
33. Andronikou S, Lambert E, Halton J et al (2017) Guidelines for the use of chest radiographs in community-acquired pneumonia in children and adolescents. Pediatr Radiol 47:1405–1411
34. Bramson RT, Griscom NT, Cleveland RH (2005) Interpretation of chest radiographs in infants with cough and fever. Radiology 236: 22–29
35. Donnelly LF (2005) Imaging in immunocompetent children who have pneumonia. Radiol Clin N Am 43:253–265
36. Lovrenski J, Petrovich S, Balj-Barbir S et al (2016) Stethoscope vs. ultrasound probe - which is more reliable in children with suspected pneumonia? Acta Med Acad 45:39–50
37. Florin TA (2018) Clinical examination not strongly associated with pneumonia diagnosis. J Pediatr 192:266–269
38. Volpicelli G, Elbarbary M, Blaivas M et al (2012) International evidence-based recommendations for point-of-care lung ultrasound. Intensive Care Med 38:577–591
39. Lichtenstein D, Mezière G, Seitz J (2009) The dynamic air bronchogram. A lung ultrasound sign of alveolar consolidation ruling out atelectasis. Chest 135:1421–1425
40. Stadler JAM, Andronikou S, Zar HJ (2017) Lung ultrasound for the diagnosis of community-acquired pneumonia in children. Pediatr Radiol 47:1412–1419
41. Urbankowska E, Krenke K, Drobczyński Ł et al (2015) Lung ultrasound in the diagnosis and monitoring of community acquired pneumonia in children. Respir Med 109:1207–1212
42. Jones BP, Tay ET, Elikashvili I et al (2016) Feasibility and safety of substituting lung ultrasonography for chest radiography when diagnosing pneumonia in children: a randomized controlled trial. Chest 150:131–138
43. Sardanelli F, Di Leo G (2009) Biostatistics for radiologists: planning, performing, and writing a radiologic study. Springer-Verlag, Milan
44. Virkki R, Juven T, Rikalainen H et al (2002) Differentiation of bacterial and viral pneumonia in children. Thorax 57:438–441
45. Korppi M, Kiekara O, Heiskanen-Kosma T, Soimakallio S (1993) Comparison of radiological findings and microbial aetiology of childhood pneumonia. Acta Paediatr 82:360–363
46. Donnelly LF, Klosterman LA (1998) The yield of CT of children who have complicated pneumonia and noncontributory chest radiography. AJR Am J Roentgenol 170:1627–1631
47. Caiulo VA, Gargani L, Caiulo S et al (2011) Lung ultrasound in bronchiolitis: comparison with chest X-ray. Eur J Pediatr 170: 1427–1433
48. Gravel CA, Monuteaux MC, Levy JA et al (2019) Interrater reliability of pediatric point-of-care lung ultrasound findings. Am J Emerg Med. https://doi.org/10.1016/j.ajem.2019.01.047
49. Deganello A, Rafailidis V, Sellars ME et al (2017) Intravenous and intracavitary use of contrast-enhanced ultrasound in the evaluation and management of complicated pediatric pneumonia. J Ultrasound Med 36:1943–1954
50. Jaffe A, Calder AD, Owens CM et al (2008) Role of routine computed tomography in paediatric pleural empyema. Thorax 63:897–902

51. Agrons GA, Courtney SE, Stocker JT, Markowitz RI (2005) Lung disease in premature neonates: radiologic-pathologic correlation. Radiographics 25:1047–1073
52. Vergine M, Copetti R, Brusa G, Cattarossi L (2014) Lung ultrasound accuracy in respiratory distress syndrome and transient tachypnea of the newborn. Neonatology 106:87–93
53. Lovrenski J (2012) Lung ultrasonography of pulmonary complications in preterm infants with respiratory distress syndrome. Ups J Med Sci 117:10–17
54. Tomà P, Owens CM (2013) Chest ultrasound in children: critical appraisal. Pediatr Radiol 43:1427–1434
55. Lichtenstein DA, Menu Y (1995) A bedside ultrasound sign ruling out pneumothorax in the critically ill: lung sliding. Chest 108:1345–1348
56. Lovrenski J, Vilotijević Dautović G, Lovrenski A (2019) Reduced or absent "lung sliding" - a novel lung ultrasound sign of pediatric foreign body aspiration. J Ultrasound Med. https://doi.org/10.1002/jum.14988
57. Lichtenstein D, Mezière G, Biderman P, Gepner A (2000) The "lung point": an ultrasound sign specific to pneumothorax. Intensive Care Med 26:1434–1440
58. Doerschug KC, Schmidt GA (2013) Intensive care ultrasound: III. Lung and pleural ultrasound for the intensivist. Ann Am Thorac Soc 10:708–712
59. Ianniello S, Di Giacomo V, Sessa B, Miele V (2014) First-line sonographic diagnosis of pneumothorax in major trauma: accuracy of e-FAST and comparison with multidetector computed tomography. Radiol Med 119:674–680
60. Press GM, Miller SK, Hassan IA et al (2014) Prospective evaluation of prehospital trauma ultrasound during aeromedical transport. J Emerg Med 47:638–645
61. Staub LJ, Biscaro RRM, Kaszubowski E, Maurici R (2018) Chest ultrasonography for the emergency diagnosis of traumatic pneumothorax and haemothorax: a systematic review and meta-analysis. Injury 49:457–466
62. Cattarossi L, Copetti R, Brusa G, Pintaldi S (2016) Lung ultrasound diagnostic accuracy in neonatal pneumothorax. Can Respir J 2016:6515069
63. Raimondi F, Rodriguez Fanjul J, Aversa S et al (2016) Lung ultrasound for diagnosing pneumothorax in the critically ill neonate. J Pediatr 175:74–78.e1
64. Targhetta R, Bourgeois JM, Chavagneux R et al (1992) Ultrasonographic approach to diagnosing hydropneumothorax. Chest 101:931–934
65. Khwaja A, Saade S, Rempell R (2019) Pediatric emergency medicine point of care ultrasound impact on radiology ultrasound volume. Pediatr Radiol 49:579–580
66. PoCUS Device Market Size, Share, Trends | Forecast Report 2025. https://www.psmarketresearch.com/market-analysis/pocus-device-market. Accessed 22 May 2019
67. Di Leo G, Sardanelli F (2016) Pitfalls of systematic reviews and meta-analyses. Radiology 279:652