Original article

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Stethoscope vs. ultrasound probe - which is more reliable in children with suspected pneumonia?

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Objective. To compare lung ultrasound (LUS) with auscultation findings in children with clinical suspicion of pneumonia. **Patients and methods**. A prospective study including 95 patients (age: from 2 months to 17.5 years; mean age: 5.1 y, SD 4.5 y) with referral diagnosis of suspected pneumonia. In all patients LUS and auscultatory examinations were performed within an hour. These findings were compared separately in each hemithorax. The radiologist performing LUS was blinded to the patient's clinical information. Positive auscultatory findings included: crackles and/or abnormal breath sounds (decreased, asymmetric, absent, or bronchial). For LUS examinations a combined transthoracic – transabdominal approach was used. A pneumonia-positive LUS finding included subpleural consolidation with air-bronchogram, or an adjacent area of interstitial edema. For each subpleural consolidation the cranio-caudal (CC) diameter was measured, and 95% confidence intervals (CI) of the sizes of subpleural consolidations for positive and negative auscultatory findings were compared. The p-value between LUS and auscultation was calculated using McNemar's test. **Results**. LUS and auscultation showed pneumonia-positive findings in 98 and 64 hemithoraces, i.e. in 67 and 45 patients respectively. In positive auscultatory findings the CI for CC diameters of subpleural consolidations ranged from 32.46 to 54.14 mm, and in negative auscultatory findings the CI was between 16.52 and 29.83 mm, which showed a statistically significant difference. McNemar's test showed a statistically significant difference between LUS and auscultation. **Conclusions.** LUS showed positive findings in more hemithoraces than auscultation in children with suspected pneumonia. A cranio-caudal size of subpleural consolidation of less than 30 mm significantly reduces the possibility of auscultatory detection.

Introduction

Lung ultrasound (LUS) has recently been recognized as an even more reliable imaging modality in detection and follow-up of pneumonia than chest X-ray (CXR), both in children and adults, and even to some extent rivaling computed tomography (CT) (1-11). However, it still cannot be claimed that it is a widely acknowledged imaging tool in everyday clinical practice. On the other hand, the stethoscope has been a broadly accepted diagnostic tool of every single medical student and doctor since the early 19th century, and represents a symbol of the medical profession.

Among a growing number of studies comparing LUS primarily with CXR, but also CT findings, we found only one comparing LUS and auscultatory findings, which was performed in adult patients with acute respiratory distress syndrome, and not a single one considering the pediatric population (12).

Therefore, the aim of this study was to compare LUS and auscultatory findings in children with a referral diagnosis of pneumonia.

Patients and methods

A prospective study was carried out at the Institute for Children and Adolescents Health Care of Vojvodina, Novi Sad, Serbia, in association with the Pediatric Emergency Department and Radiology Department, from 01 November 2012 to 30 May 2013. It included 95 outpatients with referral diagnosis of suspected pneumonia [59 males and 36 females; aged 2 months - 17.5 years, mean age 5.1 y (SD=4.5 y)] set at the Pediatric Emergency Department of the Institute. Inclusion criteria were as follows: 1) LUS and auscultatory examinations performed within an hour in the same child; 2) the availability of a pediatric radiologist (J.L.) with 7 years of experience in performing and interpreting LUS; 3) the radiologist performing LUS was blinded to all the patients' information, apart from the referral diagnosis (suspicion of pneumonia); 4) auscultatory examinations were performed by pediatricians (not pediatric residents); 5) only children with no former history of chronic lung disease (asthma, cystic fibrosis, bronchopulmonary dysplasia, etc.), immunosuppressive disorder, or malignant disease were included.

LUS examinations included both transthoracic (TT) and trans-abdominal (TA) approaches, using a linear probe of 9 MHz for TT, and a convex probe of 5 MHz for TA approach (Acuson S2000, Siemens, Erlangen, Germany). The average time needed for LUS examinations with standard deviation (SD) was calculated. The trans-thoracic approach comprised examination in supine and both lateral decubitus positions of the anterior (between the sternum and the anterior axillary line), lateral (between the anterior and posterior axillary lines) and posterior (between the posterior axillary line and the spine) lung areas, from the apex to the lung base. The US examination of each lung area consisted of longitudinal and transversal (intercostal) sections. The trans-abdominal approach included trans-hepatic and trans-splenic US scans in supine position to examine both lung bases. The US probe was angulated from the most anterior to the most posterior sections. A normal trans-abdominal US finding of the lung bases was presented with the acoustic phenomenon of "mirror image", which is a supra-diaphragmatic projection of liver or spleen (13).

Each US finding of subpleural consolidation, with or without air-bronchogram, as well as consolidation with the adjacent area of B lines (vertically oriented "comet-tail" artifacts arising from the pleural line, reaching the edge of the screen, erasing the A lines, and moving with lung sliding) was considered as pneumonia-positive. According to the current literature, these findings included children in the study with US features of both bacterial and viral pneumonia (14, 15). Positive auscultatory findings included: crackles and/or abnormal breath sounds (decreased, asymmetric, absent, or bronchial). Auscultatory and LUS findings were compared separately in each hemithorax. Moreover, US findings were compared with CT and video-assisted thoracoscopy (VATS) in two children.

Ethics statement

The Ethical Committee approved the research and informed consent was obtained

from the parents of each examined child, as well as from the older children and adolescents themselves.

Statistical analysis

Each subpleural consolidation had the cranio-caudal (CC) diameter measured by ultrasound, and 95% confidence intervals (CI) of the sizes of subpleural consolidations for auscultatory positive and auscultatory negative findings were compared. In hemithoraces with two or more subpleural consolidations, the largest was used for calculation of CI. McNemar's test was performed using IBM SPSS statistics for Windows software, version 21.0 (Inc., Chicago, IL, USA), with calculation of the P-value between the two diagnostic modalities (LUS and auscultation). A P-value below 0.05 was considered as statistically significant.

Results

Out of 95 children (i.e. 190 hemithoraces) included in the study, LUS and auscultation showed pneumonia-positive findings in 98 and 64 hemithoraces, i.e. in 67 and 45 patients respectively. There were no hemithoraces with an auscultatory positive and LUS negative finding of pneumonia (Table 1, Figure 1). In one patient, pneumonia was revealed using the trans-hepatic approach only, and proved afterwards by CXR (Figure 2).

Pleural effusion was detected by ultrasound in 14 hemithoraces. In two hemithoraces, LUS findings completely matched the VATS finding (Figure 3). In one child with CT performed within 24 hours after LUS, and before VATS, necrotizing pneumonia and pleural effusion initially detected by LUS were confirmed by CT examination (Figure 4). However, in the same patient, LUS detected loculated pleural effusion with multiple fibrin strands, indicating organization of the effusion, whilst CT did not recognize them.

In the group of patients with positive auscultatory findings, the CI for CC diameters of subpleural consolidations ranged from 32.46 mm to 54.14 mm, and in patients with negative auscultatory findings, the CI was between 16.52 mm and 29.83 mm, which showed a statistically significant difference, based on the absence of the overlap between the two CIs.

The two-tailed P-value between LUS and auscultation, calculated with McNemar's test, was less than 0.0001, which, by conventional criteria, is considered to be extremely statistically significant. The average time of LUS examination was 5.7 minutes (SD 1.63).

Table 1 Distribution of the number of hemithoraces with and without pneumonia diagnosed by ultrasound and auscultation

Ultrasound	Auscultation		Total
	Positive	Negative	
Positive	64	34	98
Negative	0	92	92
Total	64	126	190

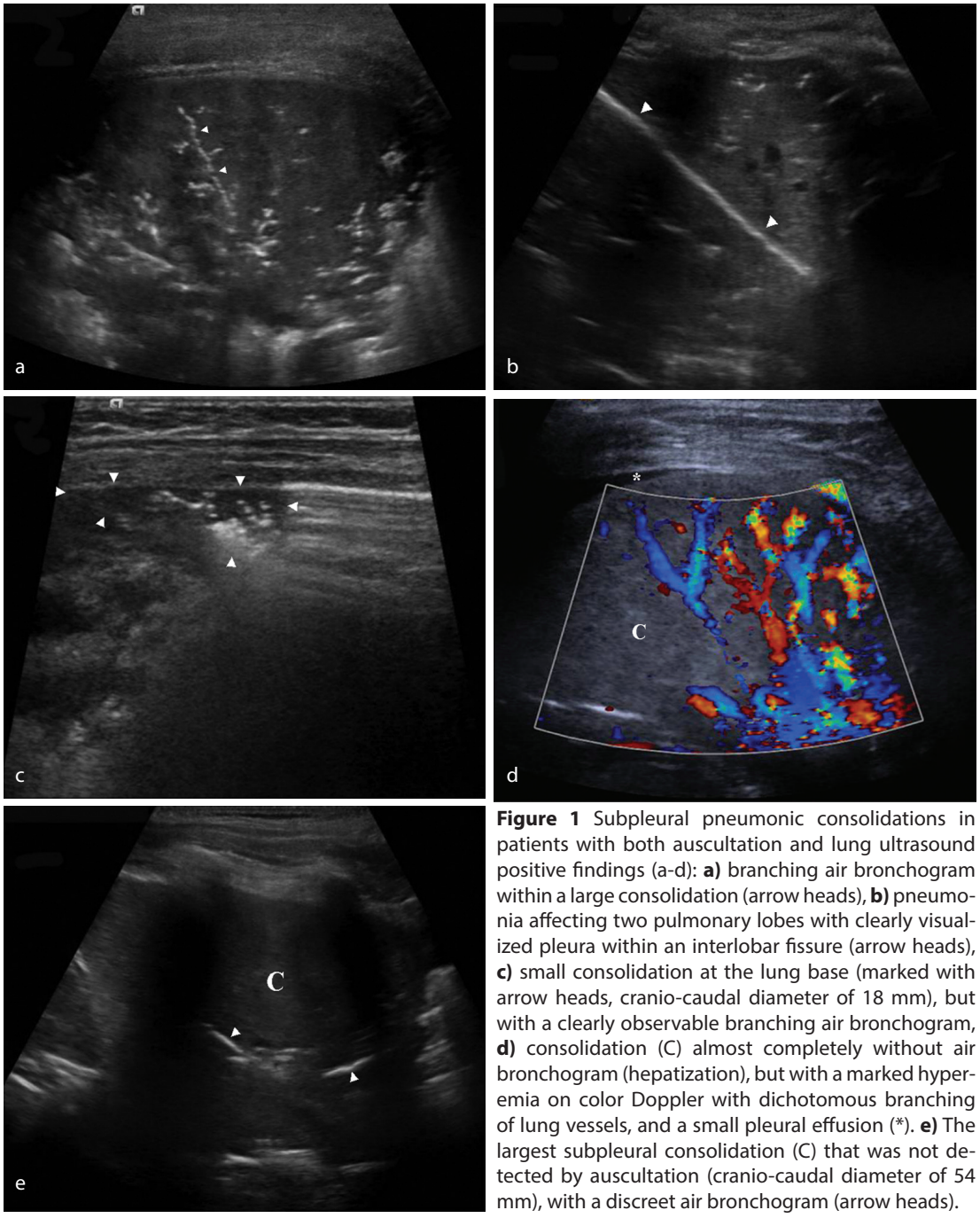

Figure 1 Subpleural pneumonic consolidations in patients with both auscultation and lung ultrasound positive findings (a-d): **a)** branching air bronchogram within a large consolidation (arrow heads), **b)** pneumonia affecting two pulmonary lobes with clearly visualized pleura within an interlobar fissure (arrow heads), **c)** small consolidation at the lung base (marked with arrow heads, cranio-caudal diameter of 18 mm), but with a clearly observable branching air bronchogram, **d)** consolidation (C) almost completely without air bronchogram (hepatization), but with a marked hyperemia on color Doppler with dichotomous branching of lung vessels, and a small pleural effusion (*). **e)** The largest subpleural consolidation (C) that was not detected by auscultation (cranio-caudal diameter of 54 mm), with a discreet air bronchogram (arrow heads).

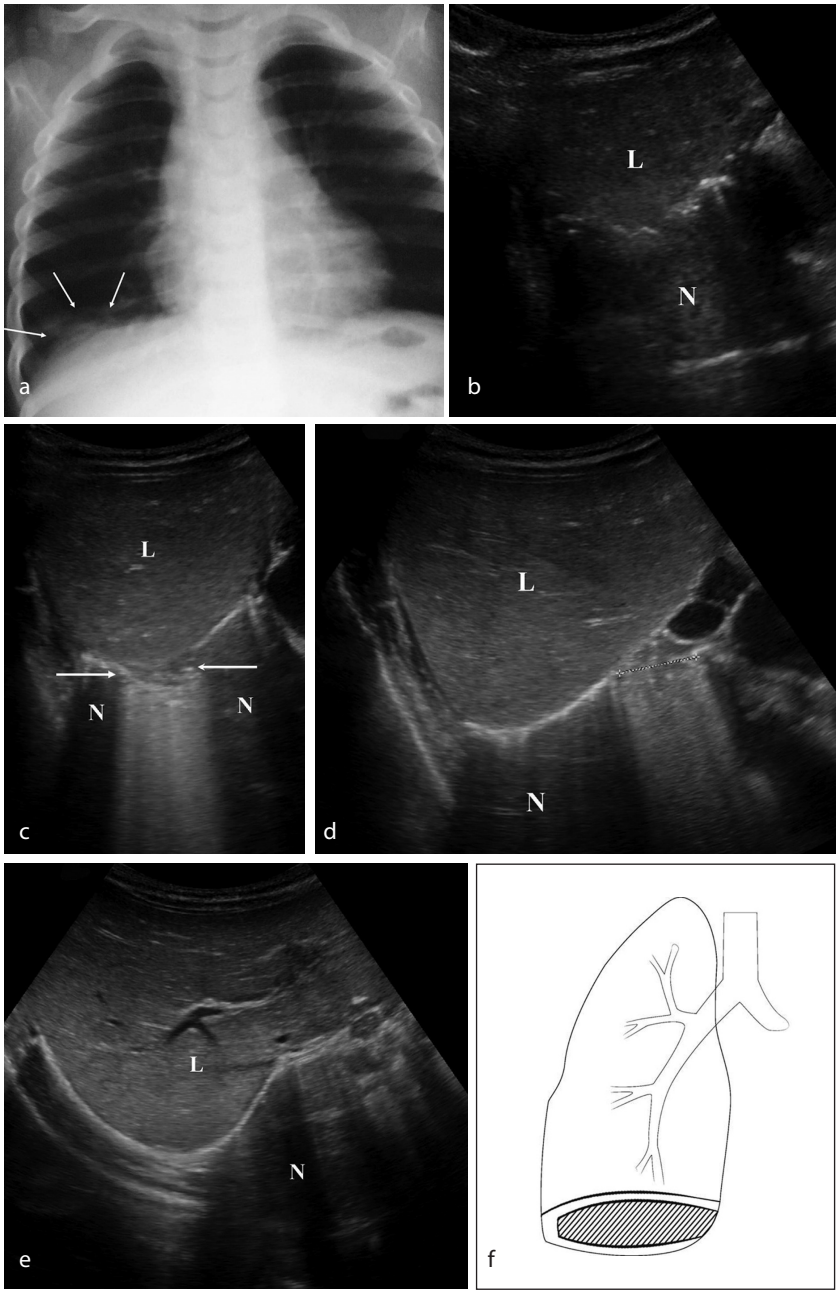

Figure 2 a) Chest X-ray showing a pulmonary consolidation within the right lung base (arrows). This consolidation went unmarked using a trans-thoracic lung ultrasound approach before CXR. However, trans-hepatic examination of the right lung base (**b - e**), from the most anterior (**b**) to the most posterior (**e**) section detected this pulmonary pathology. Images **b** and **e** show a normal ultrasound pattern of the "mirror image" phenomenon (N), while in the middle sections of the right lung base there are lung consolidations marked with arrows (**c**) and asterisks (**d**), with a discreet air-bronchogram. Note the normal lung ultrasound pattern adjacent to them (N), especially important laterally, because pneumonia does not abut on the lateral pleural surface which is accessible by a low trans-thoracic approach. L - liver. **f)** Scheme of the right lung with an area within the lung base (marked with oblique lines), which is only accessible to visualization by ultrasound when using the trans-hepatic approach. This area is not in contact with either anterior, or lateral, or posterior pleura, which is mandatory for trans-thoracic visualization, but only with basal pleura.

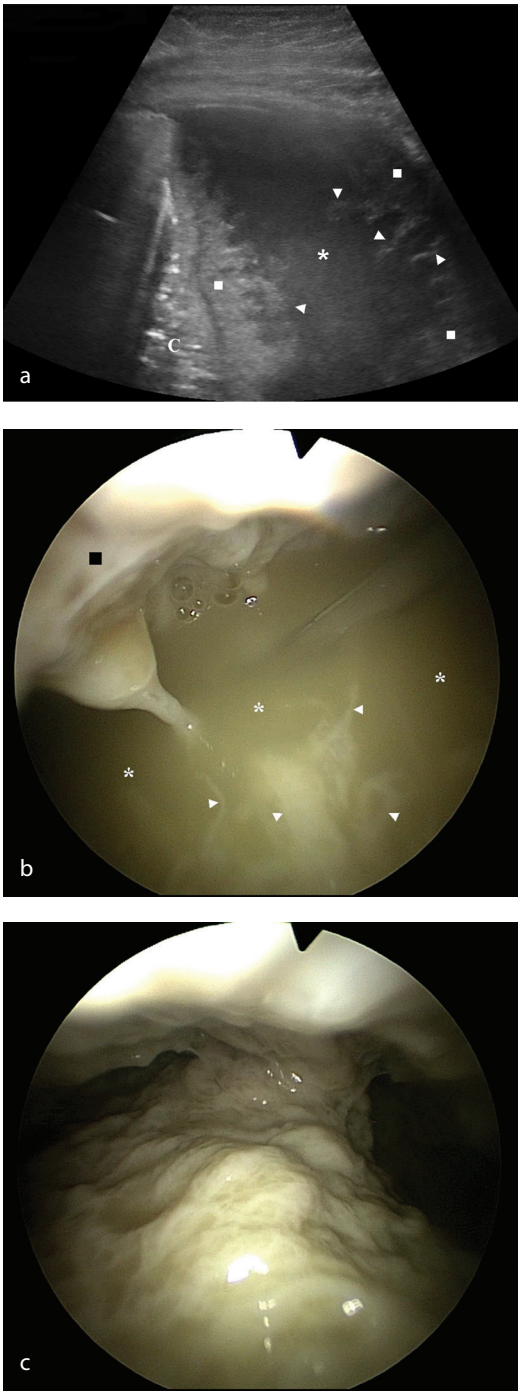

Figure 3 A 16-year old boy was provided with ambulatory care for 9 days and antibiotic therapy for a week. On admission he was dyspneic, febrile (38.7°C), and was coughing heavily, with oxygen saturation 91%-97%, and auscultatory finding of decreased breath sounds on the left. Lung ultrasound was performed on admission and video-assisted thoracoscopic surgery (VATS) the next day. There was a complete match of lung ultrasound **(a)** and VATS **(b)** findings of massive dense pleural effusion (*), with thick fibrin layers on both visceral and parietal pleural surfaces (□), and numerous fibrin filaments and strands floating within the pleural effusion (arrow heads). C - consolidation. **c)** VATS showing an extensive fibrinous coating of both visceral and parietal pleural surface after evacuation of the pleural effusion.

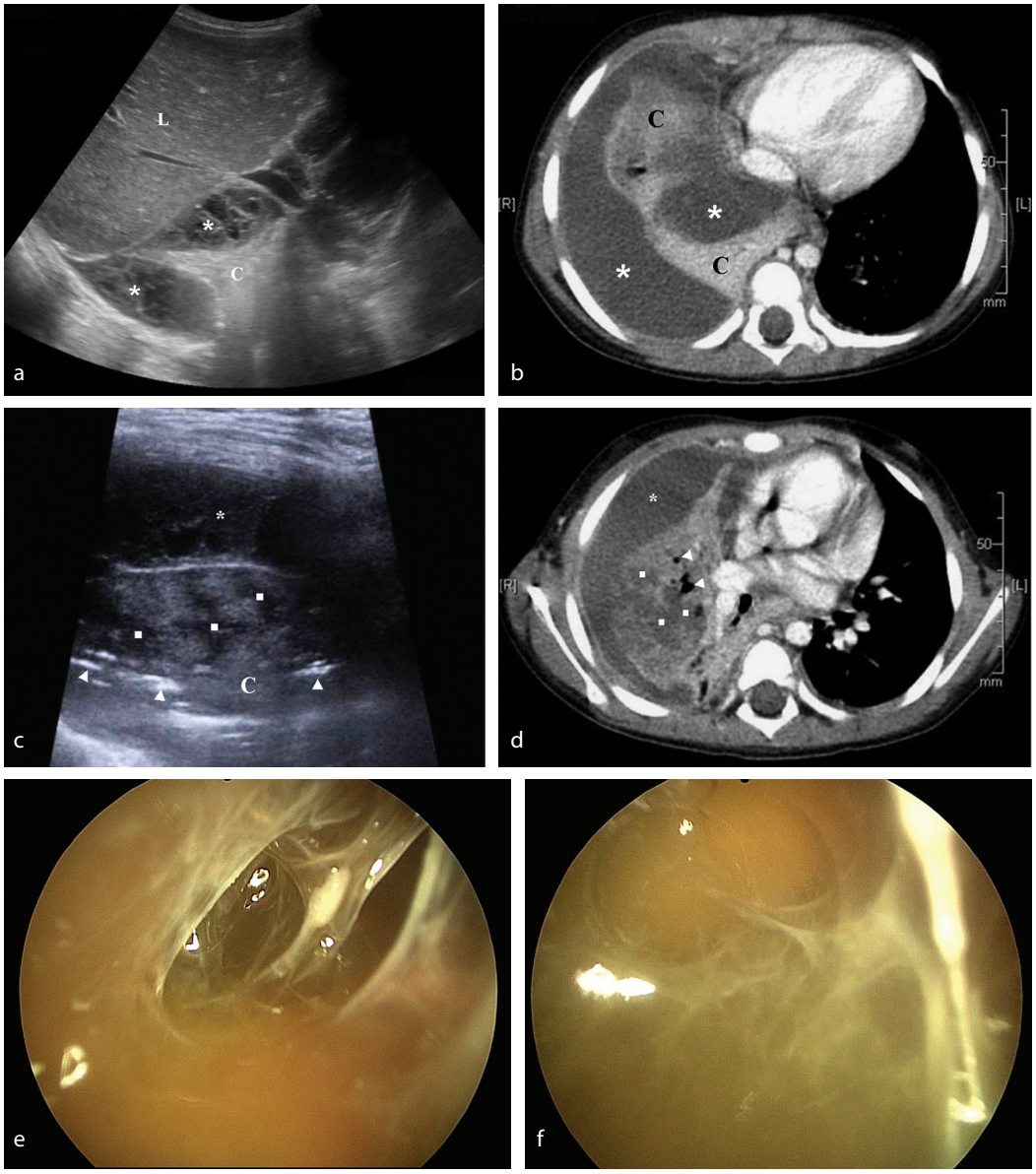

Figure 4 A 3-year old girl who was treated as an outpatient for 8 days by a local pediatrician, receiving antibiotic therapy for 5 days, was admitted to the Pediatric Emergency Department with tachypnea, tachycardia, and fever (38.3°C). Auscultation showed asymmetric breath sounds, and both early and late inspiratory crackles on the right. Lung ultrasound **(a, c)** and CT performed the next day **(b, d)** showed lung consolidations (C) with necrotic areas (□) and a small amount of air (arrow heads), as well as massive pleural effusion (*). However, lung ultrasound, unlike CT, detected numerous fibrin strands within the pleural effusion. L - liver. **e, f)** Video assisted thoracoscopy confirmed the ultrasound finding of multiple fibrin strands within the pleural space.

Discussion

Although LUS has been used for a shorter period of time than CT, and especially CXR, we cannot refer to it as a new diagnostic technique. It simply has not been as widely excepted as perhaps it should be. A large number of studies have already compared LUS with CXR, and proved its superiority in the evaluation of not only the pleural space, but also the lung parenchyma, especially in detecting pneumonia, both in adults and children (1-4, 6, 8, 9, 16-19). Only a few studies have compared LUS with CT findings, which is highly reasonable considering the ionizing radiation and consequent ethical issue (2, 4, 5, 7, 10, 11). However, we found only one study comparing LUS and auscultation findings, but not a single study comparing them in children with suspicion of pneumonia (12). In that one study, Lichtenstein et al. showed the higher diagnostic accuracy of LUS in comparison to auscultation and bedside CXR in detection of pleural effusion, alveolar consolidation and alveolar-interstitial syndrome (12). It is well known that the diagnosis of pneumonia simply by physical examination, history taking, and specific auscultatory findings is not reliable, even in expert hands (20). However, on the other hand, when there is a diagnostic modality such as LUS, which has still not been widely accepted, it is expected and understandable that clinicians are suspicious of positive US findings which they do not recognize using auscultation. This was the reason why we focused our study almost solely on a comparison of findings from an ultrasound probe and a stethoscope, in children with suspected pneumonia.

LUS has been used as a routine diagnostic procedure in our tertiary health care, regional children's hospital for seven years, and during this period it has served as a very reliable imaging method. We mostly use it in detecting pneumonia in children of all ages, and pulmonary diseases in preterm infants, as well as for their follow-up, which has been reported in three of our studies (18, 21, 22). The use of LUS in newborns was also reported by Copetti et al. (23, 24). On the basis of a number of studies showing the high sensitivity and specificity of LUS in detecting pneumonia, greater than CXR, as well as our substantial experience derived from everyday clinical practice, all patients with LUS positive findings are treated as having pneumonia.

Comparing the groups with positive and negative auscultatory findings with regard to the 95% CI of the CC diameter of lung consolidations, we determined that there is a 30 mm threshold size of the consolidation for auscultatory findings. This suggests that in 95% of auscultatory examinations it is not possible to determine the presence of the consolidation of lung parenchyma with a CC diameter less than 30 mm, which indicates the limited possibilities of physical diagnostics, predominantly in early pneumonic changes and those of smaller extent. McNemar's test showed a statistically significant difference in performance between LUS and auscultation.

We compared LUS with VATS and CT findings in only 2 children (1 VATS, 1 VATS and CT), and the match was almost perfect. In one child, LUS proved even more reliable in evaluating the internal components of pleural effusion in comparison to the CT, which was in concordance with the published data (5, 10, 11). This information had an important impact on the therapy, because a pediatric surgeon decided to perform VATS, instead of only placing a chest tube. In the second child, a 16-year old boy, information provided by US led directly to the VATS procedure, which was performed without a previous chest CT examination. LUS served here as an outstanding tool in avoiding the patient's exposure to a very

high effective dose of potentially harmful ionizing radiation.

We have already proposed the use of a combined, trans-abdominal and trans-thoracic approach (18, 21, 22). This was based on the observations made in our daily clinical practice, indicating that the TA approach can occasionally provide additional information about the extensiveness of pathological findings within the lung base. However, for the first time, in one child, we faced the situation where a positive US finding was detected using the trans-hepatic approach, whereas the TT approach showed a normal LUS pattern. The pathological finding within the right lung base was seen medially in its middle section when angulating the probe from the most anterior to the most posterior position. In entirely anterior and posterior sections of the right lung base, the US findings were normal, presenting with the acoustic phenomenon of "mirror image". The reason why these pulmonary changes were undetected by the TT approach is probably their position within the centre of the right lung base, not reaching the anterior, lateral, or posterior costal pleural surfaces (which would be mandatory for the trans-thoracic visualization), but only the basal pleura. This is the reason why the TT approach should be accompanied by the TA approach, although even recently published studies, both in children and adults, have reported only the TT approach as a sufficient LUS technique to diagnose pneumonia (1, 2, 16, 17). It is important to say that the low TT approach used in these studies is exactly the same as the TA approach with regard to the costo-phrenic angles, but should not be equated with regard to the lung base parenchyma, because using solely the TT technique would have resulted in one false-negative finding of pneumonia in our study, which is not negligible. This case of pneumonia was proved using CXR. The pathological US finding observed within the lung base by the TA approach only was completely resolved after antibiotics treatment. The regular use of the additional trans-abdominal US approach might increase the sensitivity of the LUS, which is already high. The implementation of the additional TA approach would decrease the delay, especially in the diagnosis of early stages of pneumonia in some patients, which is extremely important from the aspect of potential complications in children with pneumonia which is unrecognized at the time of the first LUS examination.

LUS imaging for the detection of pneumonia is highly reliable, but like most diagnostic tests, it is not perfect. It is very hard to strictly define a pneumonia-positive US finding, because there is a wide range of positive findings, depending on the stage of pneumonia caught at the time of examination. These findings may encompass the following: solely the areas of confluent B lines, subpleural consolidations, without an air bronchogram (so called hepatization), subpleural consolidations with adjacent areas of B lines, extremely small subpleural consolidations with sizes of less than 5 mm, and subpleural consolidation with an air-bronchogram as a most typical US finding (1-3, 14, 15, 25). It is also hard to distinguish bacterial pneumonic consolidation from subsegmental atelectasis due to viral pneumonia. Anyhow, we have to be aware that in some cases LUS findings are non-specific and have to be compared to and associated with clinical findings, so that we may determine the true etiology of pulmonary changes (21). Auscultation does, and will always have its place in diagnosing pulmonary diseases, especially those with a very limited or the still insufficiently explored role of LUS, such as acute bronchitis or bronchiolitis. Therefore, we propose the use of LUS whenever the physical finding is unclear, without exposing children to unnecessary CXRs.

Anyone accessing the world of lung ultrasonography has to be aware of its limitations, such as the inability to detect pulmonary changes not abutting pleura, pathological findings within hilar regions, and air-filled lung abscesses. However, the current literature suggests that most consolidations (up to 98%) will contact the pleura and are US detectable (26). As with any other US application, operator competency is very important, and error may occur if the operator is not properly trained and experienced. In our study, all LUS examinations were performed by a pediatric radiologist very experienced in this field. This fact probably resulted in the very short average time needed for LUS examination (5.7 minutes). However, this time can be quite variable, depending on the age of the child (older child - larger thorax surface to examine), the child's cooperation during the exam, as well as the complexity of the finding (more complicated finding - longer exam and report).

This study has several limitations. In the course of our study the greatest problem was the lack of a gold standard for diagnosis of pneumonia. It was not feasible to prove all the LUS and auscultatory findings by CT, which is considered to be the diagnostic gold standard in this field, but it cannot be used on a regular basis for ethical reasons, namely due to the high exposure to ionizing radiation. This was the reason why we could not calculate the sensitivity and specificity of LUS and auscultation. The pediatric radiologist performing LUS was aware of the clinical referral diagnosis. However, the great majority of children sent to the Radiology Department of our hospital for LUS have a clinician's referral diagnosis of pneumonia, so it is very easy to work it out even when this information is not immediately accessible. Furthermore, each LUS was performed and interpreted by a single pediatric radiologist, which creates a bias in the research. However, in real life, we believe that each clinician would prefer to have a finding from an experienced operator rather than from someone who is still becoming familiar with the technique, which is the case with other pediatric radiologists from our department. The operator tried to preserve objectivity by not knowing anything else about the patient, except the referral diagnosis. It was not possible to define bacterial and viral pneumonias clearly (blood culture, when obtained, was negative due to antibiotic treatment before admission to our hospital, and serology for respiratory viruses, *Chlamydia* and *Mycoplasma pneumoniae* when performed were negative). However, no distinction between bacterial and viral pneumonia has been made in most articles dealing with this topic (1-3, 4, 6). In clinical practice, especially in underdeveloped countries, it is often virtually impossible to distinguish between bacterial and viral pneumonia, so antibiotic treatment is mostly empirical, based on the age and current epidemiological situation (27).

Conclusion

In conclusion, in children with clinically suspected pneumonia, lung ultrasound showed a positive finding in more hemithoraces than auscultation. A cranio-caudal size of a subpleural consolidation of less than 30 mm significantly reduced the possibility of auscultatory detection. The use of an additional trans-abdominal US approach, along with the standard trans-thoracic approach, is expected to result in a further increase of ultrasound sensitivity in diagnosing pneumonia, which is already high. Lung ultrasound is a reliable diagnostic tool, and should be implemented in everyday clinical practice whenever physical findings need to be complemented with imaging findings. Its application might to a certain extent exclude the need for imaging modalities based on

ionizing radiation, which would strongly support the Image Gently campaign.

What is already known on this topic

Lung ultrasound is an extremely valuable diagnostic tool in detecting pneumonia in children of all ages, with higher sensitivity and specificity than chest X-ray, shown by a number of studies. However, only one study in the published literature has compared lung ultrasound and auscultation findings, but not in pediatric patients with suspicion of pneumonia.

What this study adds

Our study shows more positive lung ultrasound findings compared to auscultation in children with suspected pneumonia, and establishes the threshold size of subpleural consolidations below which it is highly unlikely that pneumonia will be detected by auscultation. This is very important from the aspect of expectations from both diagnostic methods, and their reliability in everyday clinical practice. When the physical finding is unclear, lung ultrasound can provide valuable information for the clinician, without using ionizing radiation in children, supporting the "Image gently" campaign.

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Conflict of interest: The authors declare that they have no conflict of interest.

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