Paediatr Croat. 2013;57:227-34
IZVORNI ZNANSTVENI RAD / *ORIGINAL SCIENTIFIC PAPER*
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Pneumonias in children – comparison of lung ultrasonography findings with chest X-rays

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The aim of the study was to compare lung ultrasonography with chest X-ray findings in children with clinical suspicion of pneumonia and to investigate the accuracy of lung ultrasonography and its value in patient management and in reducing the number of chest X-rays. This prospective study included 52 patients (2 months to 15 years of age), with suspected pneumonia and clinically indicated chest X-rays. In each patient, chest X-rays and prior to it lung ultrasonography examination were performed and their findings compared. Some patients also had follow-up lung ultrasonography and chest X-ray examinations compared. Each hemithorax was evaluated and compared separately. For lung ultrasonography examinations, a combined transthoracic-transabdominal approach was used. The ultrasonography characteristics of pneumonia were determined. Also, the impact of lung ultrasonography on the patient management was analyzed. Comparison between chest X-ray and lung ultrasonography findings was performed in 134 hemithoraces. Fifty-four of them were negative for pneumonia. In the rest of 80 hemithoraces, lung ultrasonography showed a pneumonia-positive finding, while chest X-ray were positive in 74 hemithoraces. In 11 of 43 (25.6%) children with pneumonia-positive finding, new information gained from sonography affected the course of therapy. Ultrasonography finding of pneumonia was presented with subpleural consolidation (100%), air bronchogram (92.5%), interstitial/alveolar-interstitial edema (79%), pleural thickening and irregularity (46%), pleural effusion (41%), and fluid bronchogram (7.5%). In conclusion, lung ultrasonography might become an important part of the standard diagnostic protocol in the evaluation of pneumonias in children and reduce the number of chest X-ray.

Keywords: ultrasonography; chest X-ray; pneumonia; infant; child; adolescent

INTRODUCTION

Current understanding of radiological diagnostics involves continuous balancing between the potential harmful effects of diagnostic procedures based on X-rays and their potential benefits (1). This is especially highlighted in pediatric radiology, given that for the same dose of ionizing radiation the risk of developing carcinoma is 10-15 times greater in a one-year-old child compared to an adult (2). Despite that, there is a trend of increasing the number of diagnostic procedures based on X-rays in children's hospitals (3).

Community-acquired pneumonia in the pediatric population is common, with 40 cases *per* 1000 children under 5 years of age, diagnosed annually in Europe and North America (4). Due to its frequency, and occasionally severe and complicated clinical course, it presents a very important segment of daily clinical practice with a common need of chest X-ray (CXR) (4, 5).

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Primljeno/Received: 1. 7. 2012., Prihvaćeno/Accepted: 3. 12. 2012.

Although lung ultrasonography (LUS) in children has already been recognized as a potentially useful diagnostic modality, it is not, at present, frequently used in detection and follow-up of respiratory diseases. There have been just a few studies dealing with the use of LUS in this field (6-12).

Therefore, the aim of this study was to compare LUS with CXR findings in children with clinical suspicion of pneumonia, to evaluate diagnostic accuracy of LUS as well as its impact on the patient management, and to assess its potential to reduce the number of CXRs.

MATERIALS AND METHODS

Normal lung ultrasonography findings

When using the trans-thoracic approach, closest to the ultrasound probe is the subcutaneous fatty tissue, and then the intercostal muscles and fascia. Underneath these soft tissue structures are the ribs, which are visualized as hyperechogenic structures with an acoustic shadow. The pleura is presented as a smooth, echogenic line, up to 0.5 mm thick (8). The "lung sliding" sign needs to be included in pleural evaluation, and represents sliding of the visceral pleura over the parietal pleura (13). The absence of this sign is the main ultrasonography (US) criterion of pneumothorax (14).

Underneath the pleura, the presence of air within the lungs disables visualization of the lung parenchyma. However, horizontal artifacts resulting from the high acoustic impedance between the visceral pleura and the lung parenchyma are seen and are called A lines, i.e. parallel echogenic lines below the pleural line and equally distanced from one another (15, 16) (Figure 1A).

If the US examination of the lung bases is performed using the trans-diaphragmatic approach, with the liver or spleen forming the acoustic window, it is normally based on the acoustic phenomenon of "mirror image", which is supra-diaphragmatic projection of the liver or spleen (17) (Figure 1B).

Pathologic lung ultrasonography findings

Extension of the parenchymal disease to the pleura enables forming of an acoustic window and transmission of the ultrasound beam using either trans-thoracic or trans-diaphragmatic approach. The absence of alveolar air in the lung periphery is visualized in the form of hypoechogenic area, which represents subpleural consolidation (18, 19). Multiple branching of echogenic linear structures within the consolidation corresponds to the sonographic air bronchogram (18) (Figure 2A, B). A dynamic air bronchogram represents the centrifugal movement of hyperechogenic echoes (air) through the bronchioles when breathing (20). Sonographic fluid bronchogram is visualized as anechoic tubular structures, representing fluid-filled airways (6, 18) (Figure 2C). Color Doppler can be used to distinguish vessels within the lung consolidation and fluid bronchogram. The advantage of the LUS examination is that it allows for visualization of even small abscess formation, which is defined as a rounded, anechoic area containing fluid or air, without central color Doppler flow (9, 10, 12) (Figure 3A, B).

Another US form of the pathologic finding is presented with vertically oriented "comet-tail" artifacts in the lungs, called B lines. They are hyperechogenic, clearly defined, extending from the pleural line to the bottom of the screen, erasing the A lines and moving with "lung sliding". B lines result from the accumulation of fluid in the subpleural interlobular septa surrounded by air (21, 22). Their presence excludes pneumothorax as a diagnosis (15). On the basis of their compactness and distance, the interstitial edema (IE) and alveolar-interstitial edema (AIE) can be differentiated (21) (Figure 4A, B).

Pleural thickening is most frequently related to scarring, fibrosis, empyema, and pleuritis (23). In the area affected by pneumonic lung consolidation, the pleural line is less echogenic and lung sliding is reduced or absent (7).

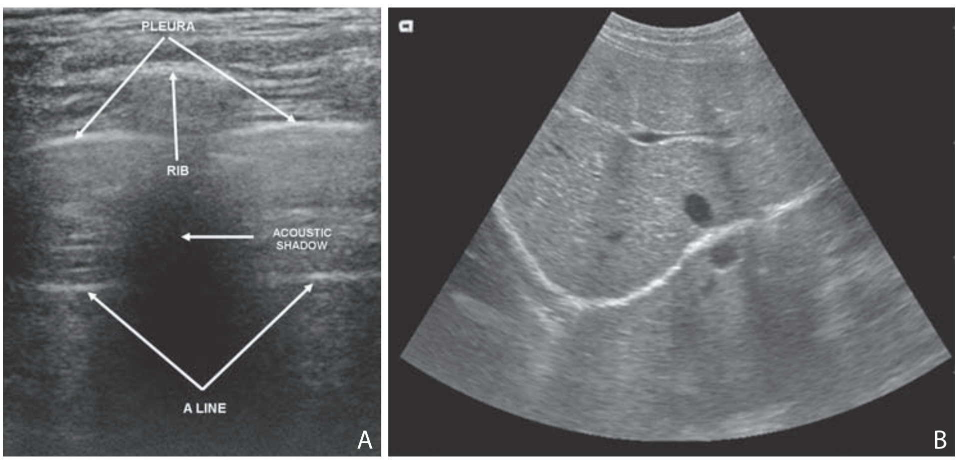

FIGURE 1. Normal lung ultrasonographic finding using the trans-thoracic approach in longitudinal section (A), and using the trans-hepatic approach – "mirror image" phenomenon (B).

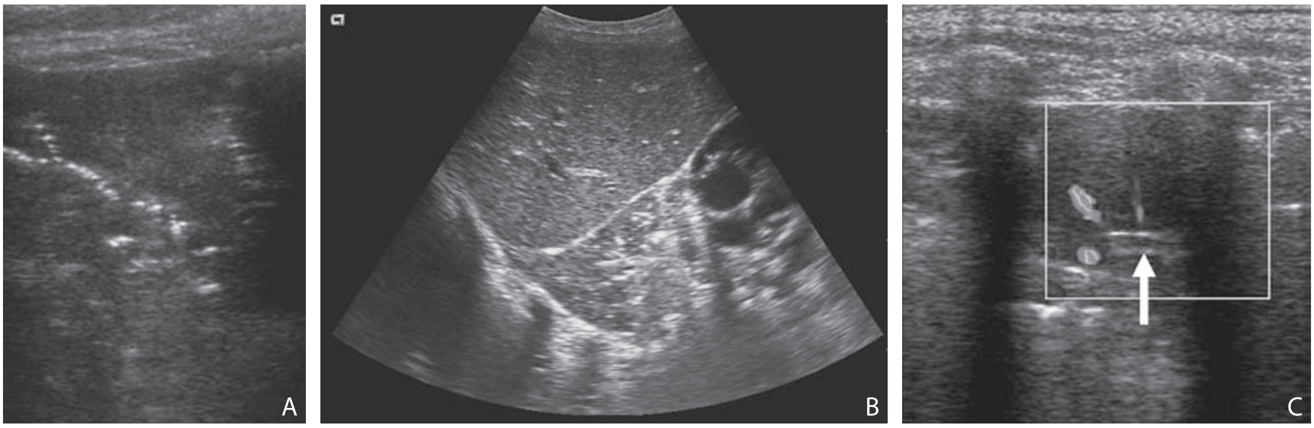

FIGURE 2. Dichotomous branching of the peripheral bronchi within the subpleural consolidation, corresponding to the air bronchogram: trans-thoracic approach (A); trans-hepatic approach (B); fluid bronchogram (arrow), with no apparent Doppler signal in it (C).

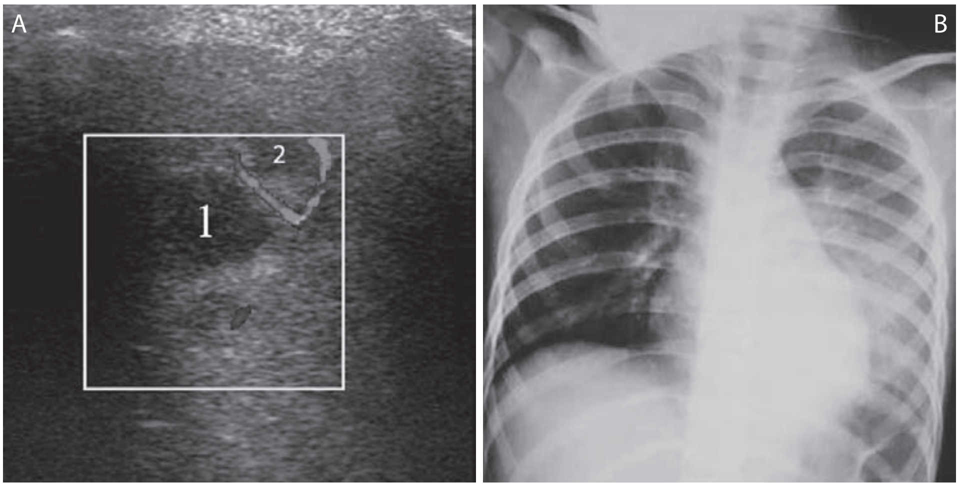

FIGURE 3. Two clearly delineated anechoic rounded areas without central color Doppler flow, consistent with two abscess formations (marked with 1 and 2), both with diameter of less than 10 mm (A); corresponding CXR of the same child with a massive left-sided pneumonia and no visible abscess (B).

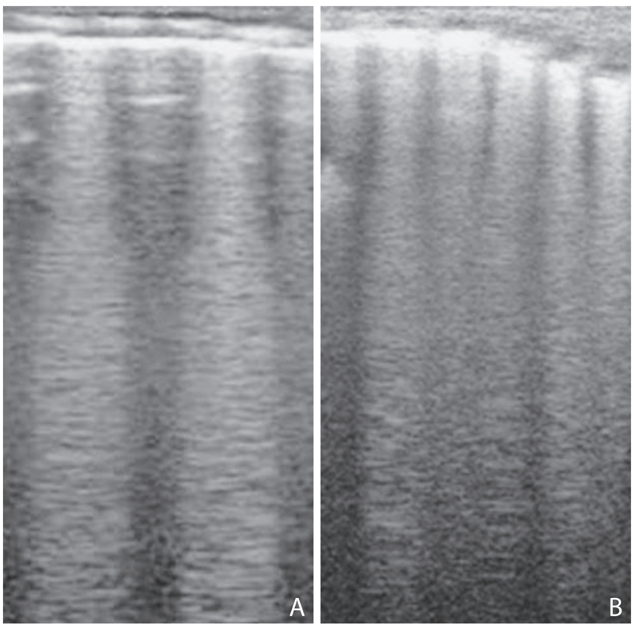

FIGURE 4. Interstitial edema: B lines combined with "spared areas" of normal lung ultrasonographic pattern (A), and alveolar-interstitial edema as a compact pattern of B lines (B).

Patients and study design

A total of 52 patients with suspected pneumonia and clinically indicated CXR were enrolled in this prospective study (34 males and 18 females aged 2 months to 15 years, mean age 4 years, SD 4.4 years). All patients were referred to our tertiary health care regional children's hospital. Each child had a LUS examination performed initially at admission, followed by CXR within the next 30 minutes. Some children underwent clinically indicated follow-up CXR examinations, and LUS was also performed prior to each follow-up CXR. Forty-three patients had ultrasonographic and/or radiographic finding consistent with pneumonia. The criterion to determine the echographic diagnosis of pneumonia was the finding of subpleural lung consolidation with evidence of air bronchogram, or when the air bronchogram was absent, a finding of adjacent area of AIE. The diagnosis of pneumonia has not been changed during the course of the disease, and all patients responded to treatment with clinical improvement and resolution of infection. In the remaining nine children, both diagnostic modalities were negative and another localization of infection was subsequently detected.

The Ethics Committee of our institution approved the research, and informed consent was obtained from the parents of each studied, examined study child, as well as from older children and adolescents themselves.

All LUS examinations were performed by the same experienced pediatric radiologist who was not blinded for the patients' clinical information. CXRs were done in posterior-anterior (PA) projection, and reported by one of the other three experienced pediatric radiologists. They were aware of the clinical suspicion, but not of the LUS finding. In children with discrepancy of CXR and LUS findings, CXRs were interpreted once more by another pediatric radiologist from the department who was blinded for the previous CXR report and LUS finding. LUS examinations were performed with a 7.5 MHz linear probe and 5 MHz convex probe (Acuson X300, Siemens, Erlangen, Germany), using both the trans-thoracic and trans-abdominal approach. The trans-thoracic US approach was performed with linear probe and included 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 diaphragm. The trans-abdominal US was performed with convex probe and included the trans-hepatic and trans-splenic approach in supine position to examine both lung bases. Longitudinal and transverse (intercostal) sections were used in the trans-thoracic examinations of each lung area. Oblique transverse sections were mostly used for the trans-hepatic approach, whereas oblique longitudinal sections were used for the trans-splenic approach.

Pneumonia-positive LUS findings were analyzed with regard to the presence of the following: static air bronchogram, dynamic air bronchogram, fluid bronchogram, abscess formation, and IE/AIE. Color Doppler ultrasound was performed to distinguish pulmonary vessels from fluid bronchogram and to evaluate vascularity of the areas suspected of abscess. In each hemithorax, the pleura was also evaluated using LUS. Its thickness was measured in either lateral or posterior lung areas. The size of each subpleural consolidation visualized ultrasonographically was measured in cranio-caudal diameter. The characteristic LUS findings of pneumonia were determined.

CXR and LUS findings were compared in each hemithorax. This comparison included the number of registered foci of pneumonia by both diagnostic modalities, as well as the existence of abscess and pleural effusion.

The impact of LUS findings on the management of patients was analyzed.

In children with multiple fibrin strands within the pleural effusion, video-assisted thoracoscopy (VAT) was performed. The decision to proceed to surgery was based on patient assessment by a multidisciplinary clinical team. In two patients with VAT performed, operative findings were compared with imaging findings.

RESULTS

CXR and LUS findings were compared in 134 hemithoraces. In 54 of them, both diagnostic modalities showed pneumonia-negative finding. From the rest of 80 hemithoraces, 74 (92.5%) were reported as pneumonia-positive on CXR. Out of these 6 pneumonia-negative hemithoraces, in four children there was pneumonia reported on CXR in the opposite hemithorax. Another two children had a completely negative CXR finding. CXRs in these six patients were evaluated again by an experienced pediatric radiologist blinded for the previous report, and there was complete match in their reports. LUS presented a pneumonia-positive finding in all 80 hemithoraces.

The overall number of the foci of the disease detected by CXR and LUS was 80 and 96, respectively.

One LUS examination showed more extensive finding on the right lung base when using a trans-abdominal than trans-thoracic approach. In 33 (41%) pneumonia-positive hemithoraces, LUS detected pleural effusion, while it was visualized in 21 (26%) hemithoraces using CXR. Pleural drainage was required in two patients, based on both CXR and LUS findings. In 11 of 43 (25.6%) children with pneumonia-positive finding, new information provided by follow-up LUS examinations had an impact on the course of therapy. In two patients with small abscess formations detected, this finding caused prolongation of antibiotic therapy. There were no abscesses reported by use of CXR. Two patients had a prolonged course of antibiotic treatment because the follow-up LUS examination showed persistence of pneumonic consolidation, in contrast to the two CXRs that showed complete regression of pneumonia (Figure 5A, B). In three patients, antibiotic treatment was altered because of the appearance of small pleural effusion on follow-up examinations, which was not reported on follow-up CXR, or on initial LUS and CXR examinations. In two children, antibiotic therapy was changed because of alteration in ultrasonographically verified thickness of pleural effusion, which appeared more dense compared to the initially anechogenic, clear effusion. In two patients, the appearance of multiple fibrin strands within the pleural effusion influenced the decision to proceed to both diagnostic and therapeutic VAT, which subsequently confirmed the US findings.

In each pneumonia-positive hemithorax evaluated by LUS, one or more subpleural consolidations were visualized.

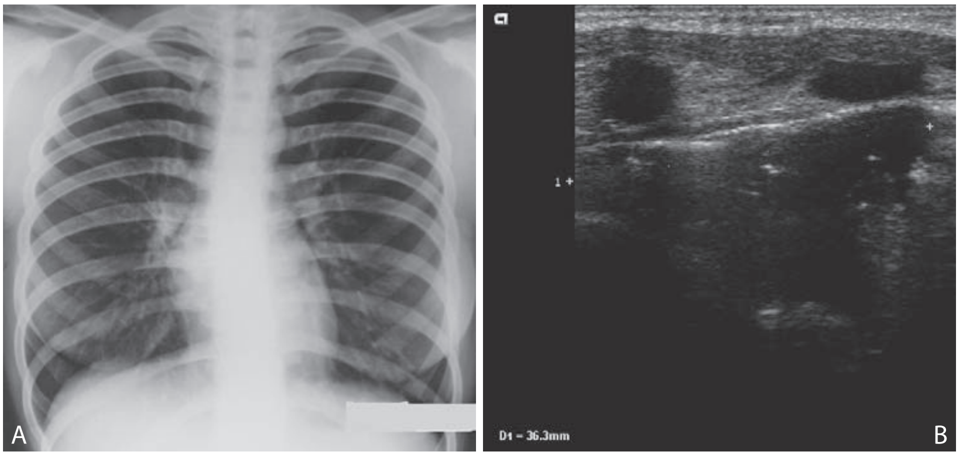

FIGURE 5. Follow-up chest X-ray in a child hospitalized for pneumonia, interpreted as normal (A); the same child 15 minutes before chest X-ray, parasternally and paracardially on the right side, lung ultrasonographic examination showed subpleural consolidation with the approximate cranio-caudal diameter of 36 mm (marked with asterix) (B).

Their mean size measured cranio-caudally was 30 mm (SD 16.5 mm). The characteristic LUS findings for pneumonia, apart from subpleural consolidation, were distributed by frequency as follows: air bronchogram (92.5%; static 70% and dynamic 22.5%), IE/AIE (79%), pleural thickening and irregularity (46%), pleural effusion (41%), and fluid bronchogram (7.5%).

DISCUSSION

Although LUS is the diagnostic modality known for over 30 years, it is not widely accepted, and not at present included in the guidelines for diagnosing pneumonia, both in adults and children. It is recommended only to confirm the presence of pleural effusion (24). Currently, the finding of consolidation on CXR appears to be the most reliable sign of pneumonia (25). Computed tomography (CT) has a high level of accuracy, but cannot be used as a first-line radiological examination due to the high exposure to ionizing radiation, availability, and cost (7, 26).

Despite the wide acceptance of CXR as a diagnostic tool in children with suspected pneumonia, it has some very serious disadvantages. CXRs are very often of suboptimal quality, especially in infants and younger children, and there is a significant variation in inter- and intra-observer interpretation of the same CXR images, which very much depends on radiologist's experience (7). Also, CXR is not reliable in detecting small pleural effusions and its internal components (11, 27, 28). Although the effects of low-dose ionizing radiation are not entirely clarified, there are studies that point out the importance and influence of radiographic procedures on the likelihood of developing acute lymphoblastic leukemia (29, 30).

On the other hand, certain anatomical characteristics, such as a thinner thoracic wall, smaller width of the thorax, and smaller lung volume facilitate US imaging and ensure a very high quality visualization of the children's lungs compared to the adult population (8). LUS is not considered to be an examination of high inter- and intra-observer variability in the interpretation. *Bedetti et al*. have demonstrated this by showing how inexperienced doctors can learn to detect IE after 10 examinations, i.e. after only 30 minutes of training (31). Nevertheless, experience may play an important role in LUS examinations. An experienced pediatric radiologist often has a better technique and can perform this examination faster, which is extremely important in hospitals such as ours, where there are approximately 80 children being examined daily on a single US device. Also, one of the greatest advantages is the absence of ionizing radiation, as well as broad availability and possibility of performing bed-side examinations.

We examined each child using a technique of combined trans-thoracic and trans-abdominal approach, which has not yet been reported. Our pre-study experience revealed that, even though rarely, in some patients US finding on the lung bases is more precise and extensive when using a trans-diaphragmatic approach. In the present study, it was the case in one LUS examination.

Our study confirmed the superiority of LUS in visualization of small pleural effusions, in evaluating the thickness of pleural fluid and especially its internal components including fibrin strands, which may indicate early organization of an effusion (6, 10, 23, 32). VAT, which was performed in two patients, confirmed the US finding of multiple septated pleural effusion. Although small pleural effusions are not surgically important, their appearance as a new finding in follow-up LUS examinations was interpreted by the pulmonologist as aggravation and influenced the treatment of two patients in our study. Also, LUS enabled evaluation of the pleura, which was found focally thickened adjacent to subpleural consolidations in almost half of the hemithoraces with detected pneumonia. In our study, LUS also showed a potential to detect small pulmonary abscess formations, which conforms with the results of previous studies (9, 10), but their existence was not proven either by CT or surgery because clinicians in our hospital were aware that small abscess with a diameter of less than 10 mm might hardly be visualized using CT. Nevertheless, this US finding prolonged the course of antibiotics, which was clinically significant (33). LUS also showed a higher accuracy in detecting the foci of pneumonia, which has been previously reported in children only in the study by *Copetti and Cattarossi* (7). A potential reason for this might be the fact that standard CXR in PA projection gives a summation image resulting from superimposed normal and pathologically changed lung parenchyma. In contrast, US allows for examination along the circumference of the lung, which may differentiate between each of the affected parenchymal sections. This was especially important in two patients whose CXRs were reported as negative. Therefore, our study showed that LUS is not inferior to CXRs in identifying pneumonia, which is in line with recently published studies (34, 35).

New information gained from LUS in comparison to CXR affected the management of one-quarter of the patients included in our study. To our knowledge, similar study evaluating the clinical impact of LUS has been previously published in adults only (36).

Typical sonomorphological features in each hemithorax with detected pneumonia included a subpleural consolidation and in 92.5% of consolidations air bronchogram, which is in accordance with previous studies both in children and adults (7, 37, 38), except for dynamic air bronchogram observed in 22.5% of pneumonic consolidations, which is less than reported in the study by *Lichtenstein et al*. (20). We can only speculate about the reasons. The only US device we are working on does not belong to high-class devices that influence the image quality to a certain extent. We have also observed that detecting a dynamic air bronchogram might take more time than to record a static bronchogram only, which we, unfortunately, are often not able to afford in our everyday clinical practice, due to the large number of patients and only one US device available. B lines in the form of IE/AIE, as an expression of inflammatory edema, were observed adjacent to pneumonic consolidations in 79% of hemithoraces with pneumonia, which is in line with literature data in pediatric and adult population (7, 38). There is a significant discrepancy in previously published data in regard to the visualization of fluid bronchogram, which ranges from 0 to 100% (7, 9, 37). Fluid bronchograms are mostly described in postobstructive pneumonias, but also in severe inflammatory processes where the bronchi may contain mucus or secretions (6, 18). In our study, it was observed in 7.5% of consolidations. Each time fluid bronchogram was observed, it was distinguished from vessels using color Doppler.

Despite being detected in each pneumonia-positive hemithorax using LUS, consolidations of lung parenchyma can be visualized only when they extend to the pleura, which is probably the biggest disadvantage of this diagnostic modality and disables visualization of perihilar lesions (11). However, it has been reported that in adults, lung consolidations propagate to the pleura in 98.5% of cases (39). Because lung mass is smaller in children, extension to the pleura may be even more frequent (7). Another disadvantage would be the inability to detect air-filled cavities due to the artifacts that air creates on US.

There were some limitations to this study. The sample size was small and therefore, our results need to be validated by additional, more extensive studies. US examinations were performed by a single expert operator, and it is reasonable to hypothesize that similar results could not be immediately achieved by less experienced operators. Also, the LUS operator was not blinded for clinical presentation of the patients.

In conclusion, a new diagnostic information gained from sonography affected the management of every fourth patient in our study. Therefore, our results suggest that LUS might have a significant role in the diagnostic work-up of pneumonias in children. We also believe that clinical signs of pneumonia associated with positive LUS finding might in the majority of patients exclude the need to perform CXR.

NOVČANA POTPORA/*FUNDING*

Nema/*None*

ETIČKO ODOBRENJE/*ETHICAL APPROVAL*

Odobrenje Etičkog povjerenstva Medicinskog fakulteta Novi Sad/*Approval of the Ethics Review Committee of the Medical Faculty Novi Sad*

DOPRINOSI AUTORA/*DECLARATION OF AUTHORSHIP*

Lovrenski J. – study design, data collection, analysis, interpretation, writing, figures, literature search/*dizajn i pisanje rada, prikupljanje podataka, analiza, interpretacija nalaza, izrada slika, pretraživanje literature*
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Varga J. - data collection, analysis, literature search/*prikupljanje i analiza podataka, pretraživanje literature*

SUKOB INTERESA/*CONFLICT OF INTEREST*

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SAŽETAK

Pneumonije kod djece – usporedba nalaza ultrazvuka i rengenograma pluća

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Cilj studije je usporediti nalaz ultrazvuka pluća s rengenogramom pluća u djece s kliničkom sumnjom na pneumoniju, istražiti točnost ultrazvuka pluća, njegovu vrijednost u zbrinjavanju bolesnika i smanjenju broja rengenograma pluća. Prospektivno istraživanje obuhvatilo je 52-je bolesnika (od 2 mjeseca do 15 godina života) sa sumnjom na pneumoniju i klinički indiciranim rengenogramom pluća. Svakom bolesniku urađen je ultrazvuk pluća, potom rengenogram pluća i nalazi su uspoređeni. U nekih bolesnika usporedili smo i kontrolne ultrazvuke pluća i rengenograme pluća. Posebno je evaluiran i uspoređen nalaz na svakom hemitoraksu. Za ultrazvuk pluća primijenjen je kombinirani transtorakalno - transabdominalni pristup. Određene su ultrazvučne karakteristike pneumonije. Također je analiziran utjecaj na tretman bolesnika. Usporedba između nalaza rengenograma pluća i ultrazvuka pluća provedena je u 134 hemitoraksa. Pedeset i četiri su bili negativni na postojanje pneumonije. U ostalih osamdeset hemitoraksa ultrazvuk pluća je pokazao pozitivan nalaz na pneumoniju, dok je rengenogram pluća bio pozitivan u 74 hemitoraksa. U 11-ero od 43-je (25,6%) djece s pozitivnim pneumonijskim nalazom informacije koje je pružila ultrasonografija utjecale su na tijek terapije. Utrazvučni nalaz pneumonije bio je prezentiran ili na ultrazvučni nalaz pneumonije upućivali su: subpleuralne konsolidacije (100%), ultrazvučni zračni bronhogram (92,5%), intersticijski/alveolarno-intersticijski edem (79%), iregularnu i zadebljalu pleuru (46%), pleuralni izljev (41%) i ultrazvučni fluid bronhogram (7,5%). Ultrazvuk pluća bi mogao postati važan dio standardnog dijagnostičkog protokola u evaluaciji pneumonija u djece i smanjiti broj rengenograma pluća.

Ključne riječi: ultrasonografija; rengenogram pluća; pneumonija; novorođenče; djeca; adolescent