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Thoracic ultrasound in viral infections☆

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KEYWORDS
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Abstract Ultrasonography has proven useful in the study of many pulmonary diseases that affect the subpleural regions. This article reviews the current evidence regarding the role of ultrasonography in the diagnosis and management of viral lung infections. It describes the examination technique and the main ultrasonographic findings for different viruses that can affect the lungs.

PALABRAS CLAVE
Ecografía torácica;
Infección vírica;
Neumonía

Ecografía torácica de las infecciones víricas

Resumen La ecografía ha demostrado ser una técnica útil en el estudio de múltiples patologías pulmonares que afectan a las regiones subpleurales. En el presente trabajo, revisaremos el conocimiento actual del papel de la ecografía en el diagnóstico y manejo de las infecciones víricas pulmonares. Se describirá el método de exploración de los pacientes y cuáles han sido los principales hallazgos ecográficos descritos en los diferentes virus que pueden afectar al pulmón.

Introduction

Ultrasound is a technique that has proven to be useful in multiple chest pathologies.[1] All those pathologies that affect the periphery of the lung and show contact with the costal pleura will be potentially visible on ultrasound. Numerous studies have confirmed that thoracic ultrasound findings are very well correlated with those of computed tomography (CT), even in those pathologies that do not present with subpleural consolidations as the main finding,[2–4] even being able to determine their severity.[5]

Community-acquired pneumonia in adults is a common, life-threatening condition, with a high rate of hospitalisation,[6] and it is the leading cause of mortality attributable to infectious diseases in western countries.

Viruses were the cause of 200 million pneumonias in the world before the SARS-CoV-2 pandemic, half of them in children and the rest in adults.[7] In children, viral pneumonias are frequently caused by respiratory syncytial virus, rhinovirus, human metapneumovirus, human bocavirus and parainfluenza virus, and viral

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Table 1 Viruses causing community-acquired pneumonia in children and adults.

Respiratory syncytial virus
Rhinovirus
Influenza A, B and C viruses
Human metapneumovirus
Parainfluenza virus types 1, 2, 3 and 4
Human bocavirus[a]
Coronavirus types 229E, OC43, NL63, HKU1, SARS-COV-1 and SARS-COV-2
Adenovirus
Enterovirus
Varicella-zoster virus
Hantavirus
Parechovirus
Epstein-Barr virus
Human herpesvirus 6 and 7
Herpes simplex virus
Mimivirus
Cytomegalovirus[b]
Measles[b]

Adapted from Ruuskanen et al.[7].
[a] Predominantly in children.
[b] Predominantly in developing countries.

co-infections are common. Up to a third of children can have co-infections with viruses and bacteria. In adults, bacteria are the most common causative agent of pneumonia in adults, although up to a third of pneumonia cases are secondary to viruses such as influenza viruses, rhinoviruses and coronaviruses.[7] Table 1 summarises the main viruses that cause pneumonia in children and adults.

The pandemic that is currently affecting the entire world population has forced us to change our lifestyle and professional habits, even altering the functioning of radiology services.[8,9] Conventional radiography and CT have emerged as the most widely used techniques in the diagnosis and management of patients with SARS-CoV-2 infection and with the diagnosis of COVID-19.[10] Ultrasound can have a very interesting role in this pathology, and in this article we will review the publications regarding this technique in viral lung infections not caused by the SARS-CoV-2 virus (Table 2).

Ultrasound examination technique

Like many other types of examination, thoracic ultrasound should be systematic and always follow the same protocol. In cases of suspected bacterial pneumonia, the examination could begin with an approach guided by the patient's symptoms. These should indicate a point or a painful area in a hemithorax and begin the exploration in that place. However, in the case of viral pneumonia, the involvement can be extensive, diffuse and bilateral, so it is important to explore as much of the pleuropulmonary surface as possible. For this purpose, a completely intercostal approach should be insisted on, since this will avoid overlapping of the ribs and increase the accessible areas of lung parenchyma (Table 3).

Although there are no clear differences between convex or linear transducers, it will be preferable to use one of the second as they have higher resolution for superficial structures and, in these patients, the object of study will be the pleuropulmonary line. However, if a linear transducer is not available or the person to be studied is obese, it can be done with convex transducers.

Another important point is the exploration of the posterior basal regions, since they are areas frequently affected by some viral and bacterial pneumonias, especially those related to aspiration phenomena. For this, it will be necessary to modify the position of the patient and perform the examination in the lateral decubitus position in those who are bedridden. In patients who can tolerate sitting, it can be very useful to perform the ultrasound in this position, as this allows all quadrants to be explored.

Finally, the importance of performing the procedure in a regulated manner must be emphasised, especially in those individuals in whom it is intended to repeat the ultrasound examination with the idea of controlling the infectious pathology. Registering the fundamental findings in each exploration quadrant allows them to be categorised and algorithms applied that will give us an idea of the evolution of the process.[11]

Application of ultrasound in viral lung infections

The specific application of thoracic ultrasound in the study of viral pneumonias has not been widely covered in the scientific literature. There are few studies in this regard and most correspond to case descriptions. We will review some of them to understand the ultrasound findings described.

In the work by Zhang et al.,[12] 11 cases with infection by the H7N9 virus, which causes avian influenza, were reviewed. Six of these patients developed acute respiratory distress syndrome and the remaining five cases were less severe. They sonographically monitored all of them with thoracic ultrasound, taking 12 reference areas. The ultrasound findings were graded in each quadrant and a total value was obtained by adding each of the areas explored. The sum of these values showed a very good correlation with the oxygenation values of the patients and with the clinical progression. According to these authors, ultrasound was a very useful tool in patient monitoring, since it allowed a daily study without the need to expose patients to radiation. In addition, ultrasound allowed the diagnosis of complications in treatment with positive oxygen pressures such as pneumothorax, which are a source of worsening of hypoxaemia in these types of patients. In H7N9 virus infection, ultrasound allowed for evaluating the clinical course of a patient with a very good correlation with CT findings, which, according to Shen et al., could be a good tool in the management of this disease together with CT and radiography.[13] In the work by Tsai et al.,[14] the ultrasound findings of two patients admitted for avian influenza were analysed, which were similar to those previously described: in one of them, bacterial pneumonia was successfully diagnosed as a complication of lung involvement by the H7N9 virus.[14] One of the patients died and the autopsy findings indicated the presence of interstitial infiltrates and pulmonary congestion that would appear as isolated or confluent B lines and white lung on ultrasound, as well as small subpleural haemorrhages corresponding to small subpleural consolidative foci. As in other studies, in

Table 2 Frequency of the causative agents of community-acquired pneumonia.

Causative agent	Studies designed to detect	
	PCR for viruses	PCR for atypical viruses and germs[a]
Streptococcus pneumoniae	37.1	33.0
Haemophilus influenzae	7.2	8.6
Haemophilus (other)	0.1	0.1
Moraxella catarrhalis	2.2	2.4
Staphylococcus aureus	4.7	3.9
Streptococcus pyogenes	0	0.4
Streptococcus (other)	0.1	0.7
Neisseria meningitidis	0.002	0.0
Klebsiella	1.6	0.7
Enterobacter	0	0.0
Enterobacteriaceae (other)	2.8	2.7
Pseudomonas	4.5	0.8
Gram-negative (other or unspecified)	0.5	1.8
Anaerobic bacteria	0	0.1
Other bacteria	5.7	0.3
Mycobacteria	0.03	1.8
Pneumocystis	0.1	0.2
Other fungi	0.02	0
Nocardia	0.03	0.04
Mycoplasma pneumoniae	3.7	8.9
Chlamydophila pneumoniae	1.4	2.9
Chlamydophila (other)	0.2	0.2
Legionella	3.3	6.2
Coxiella	0.5	0.3
Influenza A virus	4.7	3.4
Influenza B virus	0.3	1.1
Influenza A or B virus	1.2	9.2
Parainfluenza virus	0.8	4.6
Respiratory syncytial virus	1.5	4.7
Rhinovirus	4.1	11.5
Human metapneumovirus	0.4	4.1
Coronavirus	0.3	3.2
Bocavirus	0	0.04
Herpes simplex virus	0	0.1
Cytomegalovirus	0.02	0
Adenovirus	0.3	2.2
Chickenpox	0	0
Virus (other or unspecified)	9.6	0.6
Viral/bacterial coinfection	9.7	5.9

The viruses responsible for community-acquired pneumonia appear in bold, as well as the percentage of cases for each of them. Adapted from: Shoar S, Musher DM. Aetiology of community-acquired pneumonia in adults: a systematic review. Pneumonia. 2020;12:11-23.

[a] The term atypical germs refers in these studies to *Mycoplasma, Clamydophila, Legionella* and/or *Coxiella*.

the patient whose lung involvement improved, the ultrasound showed a good correlation with the clinical course.

Along the same lines, Rossetti et al.[15] published the ultrasound findings of pulmonary involvement by the H1N1 virus in a 20-month-old boy with lymphoblastic leukaemia. According to these authors, the ultrasound findings preceded those found later on an anteroposterior radiograph. The ultrasound findings described in H1N1 virus infection are common to those described in other viral infections: small subpleural consolidations (<0.5 cm) and/or solitary or confluent B lines.[16] During the 2009 pandemic of influenza caused by the H1N1 virus, the study by Tsung et al.[17] demonstrated that ultrasound is capable of distinguishing between pneumonia caused by the virus, by bacteria or by the coexistence of both diseases, with a concordance between observers of 0.82, which is higher than that published in conventional radiology studies (kappa index of 0.51).[17] These same authors point out that ultrasound can be useful during epidemics or pandemics as a tool for therapeutic decision-making in patients with suspected viral infection.[17] In another article, Testa A et al.[18] demonstrated the usefulness of ultrasound in the diagnosis of H1N1 virus

Table 3 Summary table with the main articles published on thoracic ultrasound and viral pneumonia with the most relevant conclusions.

Study	Virus	Number of patients	Other techniques	Results	Main conclusions
Biagi C, et al. BMC Pulm Med. 2018	Bronchiolitis	87 patients (children)	Chest X-ray	Ultrasound: S: 100% Sp: 83.9% X-ray S: 95% Sp: 87% k = 0.93 (ultrasound)	Ultrasound is more accurate than chest X-ray. Good agreement between observers
Caiulo V, et al. Eur J Pediatr. 2011	Bronchiolitis	52 patients (children)	Chest X-ray	Ultrasound: S: 90.4% X-ray S: 73.1%	Ultrasound better than X-ray. It does not use radiation. It reveals findings not visible on x-ray It should be a routine technique in bronchiolitis
Testa A, et al. Crit Care. 2012	H1N1	98 patients	Chest X-ray Chest CT scan (in some cases)	Ultrasound: S: 94.1% Sp: 84.8% PPV: 86.5% NPV: 93.3%	Effective tool in the diagnosis of H1N1 infection in the emergency room. It detects cases with normal X-ray
Tsai N, et al. Crit Ultrasound J. 2014	H7N9	2 patients	Chest X-ray		Correlation with evolution and pathological anatomy. Usefulness of ultrasound in ICU
Tsung J, et al. Crit Ultrasound J. 2012	H1N1	20 patients	Chest X-ray	k = 0.82 (distinguishing viral from bacterial pneumonia)	Ultrasound distinguishes viral and bacterial pneumonias
Varshney T, et al. Emerg Med J. 2016	Bronchiolitis, asthma, pneumonia	94 patients (children)		Bronchiolitis: S: 46% Sp: 72.7% Pneumonia: S: 100% Sp: 61.1% k = 0.68 (novice and expert sonographers)	Asthma does not present ultrasound alterations. Good correlation between novice and expert sonographers. Ultrasound distinguishes asthma and pneumonia
Zhang Y, et al. Virol J. 2015	H7N9	11 patients			Ultrasound allows monitoring of patients with distress secondary to viral infection

k: kappa index of agreement; NPV: negative predictive value; PPV: positive predictive value; S: sensitivity; Sp: specificity.

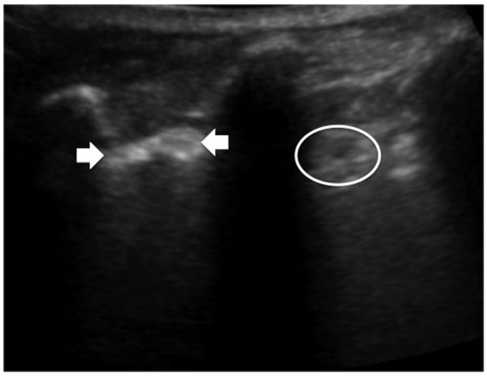

Figure 1 Viral pneumonia. Examination performed with a 4 MHz convex probe in the posteroinferior portion of the left hemithorax. Thickening of the pleuropulmonary line (between the white arrows) and a small subpleural consolidation (inside the ellipse) are identified.

involvement compared to conventional chest radiography, in patients who attended the emergency department. Ultrasound had a sensitivity of 94.1%, a specificity of 84.8%, a positive predictive value of 86.5%, and a negative predictive value of 93.3%.[18] In this study, ultrasound was able to diagnose patients with viral infection whose initial chest radiograph was normal. The false positives of the ultrasound in this series were attributed to the existence of previous interstitial pathology since they present similar ultrasound semiology (Fig. 1).

Childhood bronchiolitis is usually caused by viruses. Rarely is the use of radiological examinations indicated in its diagnosis or management, but, in daily clinical practice, anteroposterior chest radiographs may be used. The study by Caiulo et al.[19] demonstrated that ultrasound is superior to radiography in the diagnosis of bronchiolitis in children. In this study, ultrasound was able to detect alterations in 47 of 52 patients affected by bronchiolitis, while radiography only detected 38 cases. All the patients with a normal ultrasound had a radiograph without alterations, while in 9 cases with anodyne radiography, ultrasound alterations were detected. The authors also showed that ultrasound showed a very good correlation with clinical classifications of the severity of disease.[19] The most frequent findings in these patients were: subpleural consolidations (85%; multiple in 82% of the cases), white lung areas (65%) and abnormalities of the pleuropulmonary line (44%). Moreover, three patients with pleural effusion and one case of pneumothorax were detected by ultrasound, all of them not evident on the chest radiograph. The study by Biagi et al.[20] demonstrated that ultrasound had high sensitivity and specificity for the diagnosis of concomitant bacterial pneumonia in children with bronchiolitis (100% and 98.4%, respectively), greater than chest radiography (Fig. 2). In this study, the authors found a strong correlation between the presence of consolidations greater than 1 cm and the diagnosis of bacterial pneumonia concomitant to bronchiolitis ($r = 0.684$, $P < 0.0001$).[20] The diagnostic capacity of thoracic ultrasound is often questioned because it is considered explorer-dependent. The study by Varshney et al.[21] showed that there is a good correlation between the ultrasound findings found by expert and novice doctors with this technique. On the other hand,

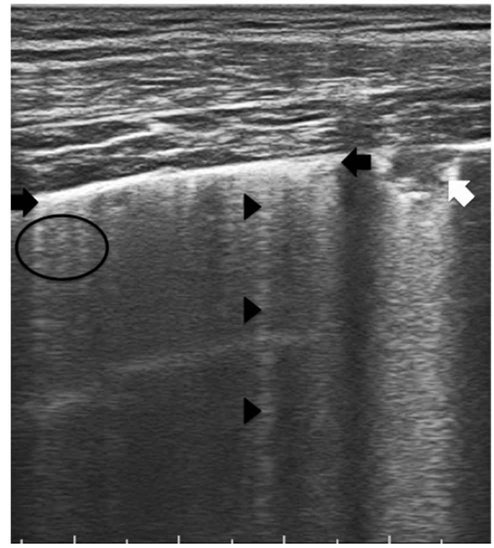

Figure 2 Patient with acute respiratory distress syndrome. Exploration performed with a 10 MHz linear probe in the anteroinferior part of the right hemithorax. The image shows a thickening of the pleuropulmonary line (between the black arrows), a small subpleural consolidation (white arrow), isolated B lines (arrow heads) and grouped B lines (inside the ellipse).

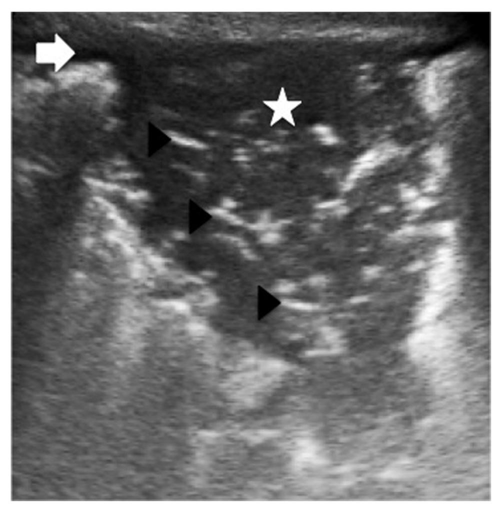

Figure 3 Bacterial pneumonia caused by *Streptococcus pneumoniae*. Examination performed with a 4 MHz convex probe in the posterolateral portion of the right hemithorax. Sublobar consolidation (star) with a homogeneous appearance and with serrated contours typical of bacterial pneumonias. Multiple air bronchograms can be observed inside (arrow heads), as well as a small pleural effusion adjacent to the consolidation (white arrow).

they demonstrated that ultrasound makes it possible to distinguish between exacerbation of asthma and viral and bacterial infections in paediatric patients with dyspnoea. The patients with asthma did not present any abnormality on ultrasound examination. However, the patients affected by an infection had three or more B lines per intercostal space, consolidations, pleural line irregularities and effusion. Thus, ultrasound is useful in bronchiolitis for diagnosis and follow-up, monitoring treatment, detecting patients who will need supplemental oxygen, and ruling out differential diagnoses with asthma or bacterial pneumonia[22] (Fig. 3).

Conclusions

Ultrasound has proven to be useful in the diagnosis of multiple viral infections with pulmonary involvement, both in epidemic and seasonal situations. It allows the detection of pulmonary involvement in patients with suspected viral infection. It can also distinguish between a viral and a bacterial infection. Finally, the ultrasound findings correlate with the clinical progression of the patient and allow an easy and precise monitoring of the disease.

On the other hand, the findings are not pathognomonic and coincide with other diseases such as respiratory distress or interstitial pathology, which can lead to the diagnosis of false positives.

Ultrasound is a simple technique, with a rapid learning curve for the diagnosis of widespread viral lung involvement that would allow imaging of lung involvement in the context of a viral pandemic.

Authorship

1 Person responsible for the integrity of the study: IV.
2 Study concept: IV.
3 Study design: IV.
4 Data collection: IV.
5 Data analysis and interpretation: IV.
6 Statistical processing: IV.
7 Literature search: IV.
8 Drafting of the article: IV.
9 Critical review of the manuscript with intellectually relevant contributions: IV.
10 Approval of the final version: IV.

Conflicts of interest

The author declares that he has no conflicts of interest.

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