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REVIEW ARTICLE

Ultrasound and pleural pathology: a great ally

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ABSTRACT

Ultrasound has proven to be an effective, reliable, and economical technique for studying chest pathologies. It is an ideal technique for the study of pleural pathology, comprising liquid, solid, and air. Numerous studies have shown that pleural effusion can be detected, characterized, and quantified. It is also very useful in the diagnosis of pneumothorax in severe or traumatic patients, without the need to use other techniques that can delay diagnosis. In solid pleural pathology, it may play a role in screening and guiding biopsies. Finally, ultrasound is the technique of choice for guiding interventional procedures such as thoracocentesis and pleural biopsy.

Keywords: Chest ultrasound. Pneumothorax. Pleural effusion. Pleural ultrasound.

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INTRODUCTION

Ultrasound has proven to be an effective, reliable, and economical technique for studying chest pathologies[1,2]. Ultrasound is an ideal technique for populations susceptible to radiation, such as neonates, children, and pregnant women, as well as for bedridden patients[1,3]. On the other hand, it can be used in emergencies or as portable equipment in particular situations, including complex places or areas with few economic resources[3,4]. New advances in this technology have enabled new applications in studying lung diseases and in the diagnosis and treatment of pleural pathologies[2,5,6]. The pleura derives from the mesoderm and has visceral and parietal layers. The visceral layer covers the lungs, and the parietal layer covers the chest wall, mediastinum, and diaphragm. Its superficial nature, immediately below the thoracic, muscular, and bone walls, makes it susceptible to study by ultrasound. Conversely, the ability to be evaluated with ultrasound allows any interventional procedure to be performed using this guidance. This paper will review ultrasound's usefulness in studying liquid (pleural effusion), solid, and air (pneumothorax) pleural pathologies.

PLEURAL EFFUSION

Approximately 1.5 million people in the United States develop pleural effusion each year[7]. Ultrasound is an extremely sensitive technique for detecting pleural effusion, as it can detect pleural effusion from 5 ml[8]. In contrast, a chest X-ray in the posteroanterior projection needs more than 150 ml to detect pleural effusion. In patients in the supine position, posteroanterior radiography will only detect pleural effusion when it exceeds 500 ml[9]. The meta-analysis by Zaki et al.[10] showed that ultrasound is significantly more accurate than radiography in detecting pleural effusion. The sensitivity and specificity of ultrasound were 94.54% and 97.88%, respectively, compared to 67.68% and 85.30% for radiography. Ultrasound yields excellent results in detecting pleural effusion even when performed by less-trained personnel[10]. The highest detection rates of pleural effusion are obtained in supine or seated ultrasound[10]. Ultrasound is particularly useful when assessing subpulmonary and peridiaphragmatic pleural effusions, which are difficult to discover by conventional radiography or even by computed tomography (CT) (Fig. 1)[9]. Ultrasound distinguishes small volumes of pleural effusion from focal pleural thickening by a color Doppler signal. A Doppler-color signal will be identified inside the fluid in patients with small pleural effusions. This sign has a sensitivity of 89% and a specificity of 100%[11].

Ultrasound also allows a quantitative approximation of the volume of pleural effusion. Multiple formulas have been described for determining pleural effusion volumes depending on whether the examination is performed in a sitting or supine position (Tables 1 and 2)[12-18]. The two most straightforward formulas are, for patients in the supine position, multiplying the height of the fluid column in centimeters by an empirical factor of 90 to obtain the volume in millilitres,[19] and for patients in the prone position, multiplying the maximum distance

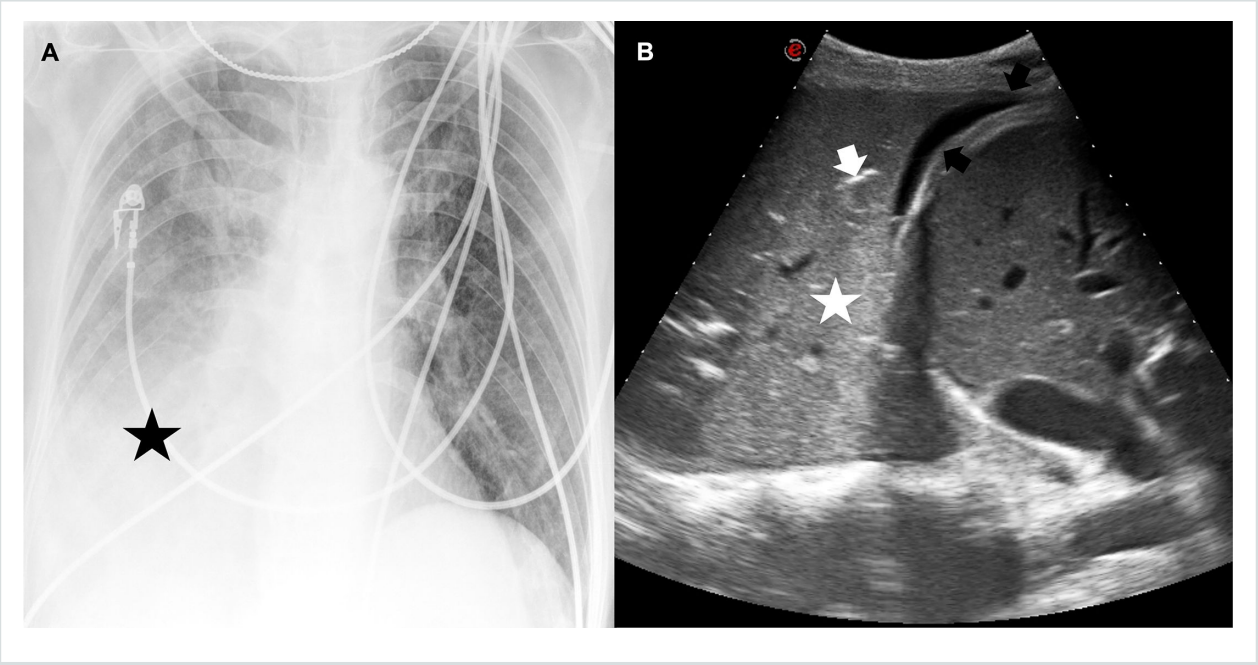

Figure 1. A: chest X-ray showing increased density in the right hemithorax (black star). In these cases, it is difficult to determine by chest X-ray whether it is pleural effusion or pulmonary consolidation. **B:** thoracic ultrasound showing extensive consolidation (white star) with an air bronchogram (white arrow) and minimal subpulmonary pleural effusion (black arrows).

between the two pleural sheets in millimeters by an empirical factor of 20 to obtain the volume in milliliters[15]. However, in most cases, a qualitative assessment of the effusion and the presence of associated atelectasis are sufficient[9]. However, Hassan et al.[20] showed that the formula involving the multiplication of the sum of the distances between the basal portion of the collapsed lung and the diaphragm and the maximum height of the pleural effusion (both in centimeters) by an empirical factor of 70 was the most accurate for determining the volume of a pleural effusion with 83% accuracy.

Ultrasound cannot determine the nature of a pleural effusion. Different etiologies may manifest with the same ultrasound characteristics, e.g., a hemothorax, empyema, or metastatic effusion may manifest as echogenic fluids, while pleural transudates usually present as anechogenic fluids. On the other hand, the presence of septa, regular or nodular pleural thickening, and the demonstration of septa inside the effusion suggest an exudate (Fig. 2)[21]. Ultrasound is the most sensitive technique in detecting septa inside a pleural effusion[9]. The presence of septa is not indicative of any pathology, as it can be identified in various conditions such as empyema, evolved hemothorax, parapneumonic effusion, and malignant effusion. The study by Yang et al.[21] suggested that ultrasound could differentiate between a pleural exudate and a pleural transudate.

Table 1. Formulas for determining pleural effusion volumes

Formula	Paper
LSF (cm^2) × U (cm) × 0.89 = E (ml)	Lorenz et al. (1988)
QSF (cm^2) × H (cm) × 0.66 = E (ml)	Kelbel et al. (1990)
LH (cm) × 90 = E (ml) correlation coefficient $r = 0.68$	Goecke and Schwerk (1990)
LH (cm) + SH (cm) × 70 = E (ml) correlation coefficient $r = 0.87$	Goecke and Schwerk (1990)
D (mm) × 47.6–837 = E (ml)	Eibenberger et al. (1994)

D: thickness of effusion layer in the supine position; E: effusion volume; H: effusion height; LH: lateral height of effusion in the sitting position, LSF: median of planes of longitudinal sections through the effusion in 6 positions; QSF: horizontal plane through the effusion; SH: median subpulmonary height of effusion in the sitting position; U: circumference of the hemithorax.

On the other hand, more recent studies have shown that there is an overlap of ultrasound findings that only allows us to conclusively affirm the nature of a pleural effusion by ultrasound. Shkolnik et al.[22] demonstrated that finding an anechogenic effusion by ultrasound has a negative predictive value of 90% for the diagnosis of exudate. On the other hand, when the effusion is complex or complex septate, ultrasound has a positive predictive value of 90 and 96%, respectively, for the diagnosis of exudate.

Ultrasonography can determine the development of residual pleural thickening in patients with treated tuberculosis-related pleural effusion[23]. Malignant pleural effusion manifests more frequently as echogenic fluid, reflecting high cellularity, rather than anechogenic fluid. Malignant effusion is usually associated with pleural thickening. The presence of pleural nodules is the most specific sign of malignancy that can be identified on ultrasound examination of a pleural effusion[24]. The study by Qureshi et al.[25] revealed that ultrasound has a sensitivity of 73% and a specificity of 100% for diagnosing malignant pleural effusion[25]. However, pleural thickenings, which have a specificity of 95–100% for diagnosing malignant pleural effusion, are only found in 40% of cases; thus, their absence does not mean that the pleural effusion cannot be malignant[26]. The meta-analysis by Shiroshita et al.[27] showed that ultrasound conditions the need for repeated thoracocentesis or other examinations in patients with suspected malignant pleural effusion and nodulations on ultrasound, but it does not rule out the malignancy of a pleural effusion when these findings are absent[27]. Ultrasound contrast can help detect malignant pleural effusion (Fig. 3)[28]. Ultrasound has also helped assess the success of pleurodesis in managing malignant pleural effusion[26]. Hemothorax is easily diagnosed by ultrasound. Initially, it manifests as an anechogenic effusion. As time progresses, the spill will increase in echogenicity, and echogenic structures corresponding to clots appear within it[9]. The sensitivity of ultrasound to detect hemothorax in trauma patients is similar to that of conventional radiography, although with the advantage that ultrasound only requires 1 min to perform the evaluation, and radiography takes approximately 15 min[29].

SOLID PLEURAL PATHOLOGY

Multiple entities, both benign and malignant, can cause pleural thickening. Ultrasound is an excellent technique for detecting pleural

Table 2. Formulas for determining pleural effusion volumes

Roch et al. (2005)	PLD base > 5 cm corresponds to > 500 ml of pleural effusion	Sensitivity 83%
		Specificity 90%
		Little interobserver variability
Vignon et al. (2005)	Posterior effusion	Sensitivity: Right side 94%; Left side 100%
	Right side > 45 mm	
	Left side > 50 mm	
	Represents more than 800 ml	Specificity: Right side 76%; Left side 67%
Balik et al. (2006)	V (ml) = 20 × Sep (mm)	Correlation coefficient $r = 0.72$
Eibenberger et al. (1994)	Thickness of posterobasal effusion at the end of expiration	Correlation coefficient $r = 0.80$
	20 mm corresponds to 380 ± 130 ml	
	40 mm corresponds to 1000 ± 330 ml	

PLD: distance between lung and posterobasal chest wall at end-expiration; V: effusion volume; Sep: separation distance between lung and chest wall in the posterior axillary line basal.

effusion but is less sensitive for detecting small pleural thickenings[30]. When pleural nodules or thickenings are detected[24], ultrasound has a sensitivity of 73% and a specificity of 100% for determining the malignancy of a pleural effusion (Fig. 2)[25].

Inflammatory involvement of the pleura, particularly chronic processes, occurs with irregular thickening of the pleura, which may be accompanied by septate or nonseptate pleural effusion. These findings can be identified in tuberculous pleurisy, autoimmune polyserositis, and interstitial lung diseases[9]. Pleural fibrosis manifests as echogenic or hypoechogenic thickening that is easily distinguishable from effusion with conventional ultrasound or ultrasound contrast. Chronic pleural thickening usually occurs after an exudative pleural effusion, hemothorax, and empyema. Ultrasonographically, it manifests as hypoechogenic in the early phases and later shows mixed echogenicity, with or without calcifications[9]. Focal pleural thickening can be due to plaques from contact with asbestos and malignant pathology, and it may appear with coarse calcifications inside. Benign tumors of the pleura are sporadic (5% of all pleural tumors) (Fig. 4)[31]. Malignant pleural involvement is common and manifests itself in the form of irregular thickening of the pleura, which has a heterogeneous appearance and can infiltrate neighboring structures[9,32]. If metastatic pleural involvement is suspected, the diaphragmatic pleura should be evaluated, as it is the site where metastases are most frequently established. As malignant effusions are usually associated with pleural effusion, the diaphragmatic pleura can be explored from an intercostal space, taking advantage of the acoustic window that the fluid will offer[1].

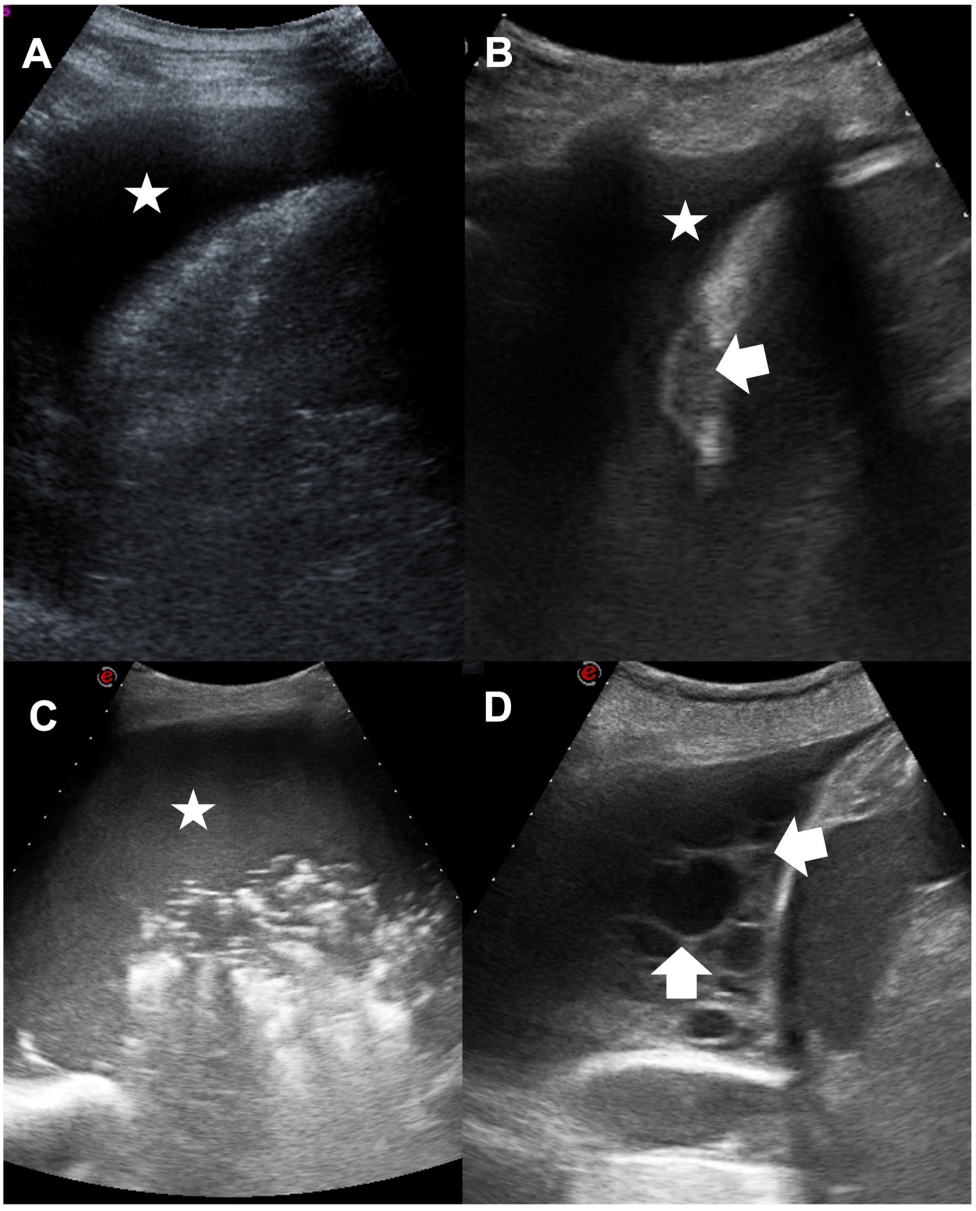

Figure 2. **A:** anechoic pleural effusion (white star). **B:** pleural effusion (white star) with a solid nodule in the diaphragmatic pleura (white arrow) in a patient with pleural metastases. **C:** complex pleural effusion with multiple internal echoes (white star) in a patient with pleural empyema. **D:** complex septate pleural effusion (white arrows) in a patient with pleural metastases.

PNEUMOTHORAX

Ultrasound is a technique that has been widely used for the diagnosis of pneumothorax, particularly in patients with polytrauma or those admitted to intensive care units. Four ultrasound findings allow for the diagnosis of pneumothorax: absence

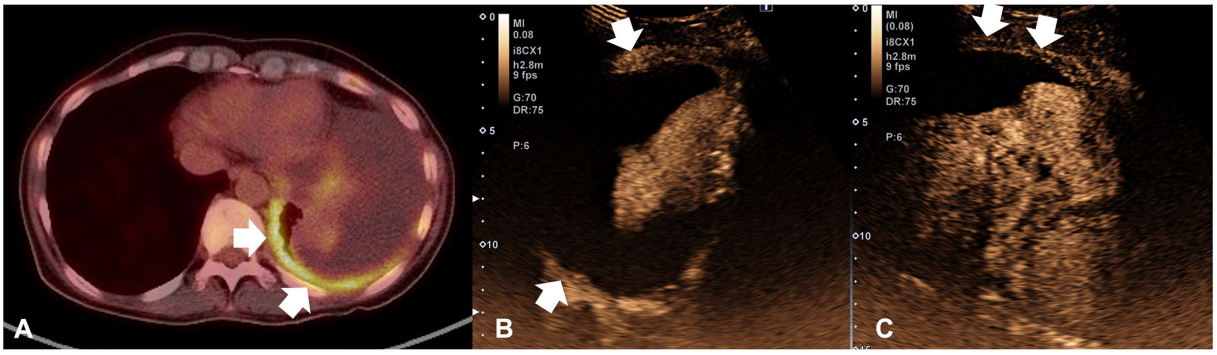

Figure 3. **A:** FDG PET/CT fusion image showing uptake in the parietal pleura (white arrows) in a patient with metastatic pleural involvement. **B:** contrast-enhanced ultrasound at 20 s, showing rapid uptake of circumferential pleural thickening (white arrows). **C:** contrast-enhanced ultrasound at 50 s, demonstrating early washout of pleural thickening (white arrows). Irregular pleural thickening with rapid uptake and early lavage suggests malignant pleural involvement.

CT: computed tomography; FDG: fluorodeoxyglucose; PET: positron emission tomography.

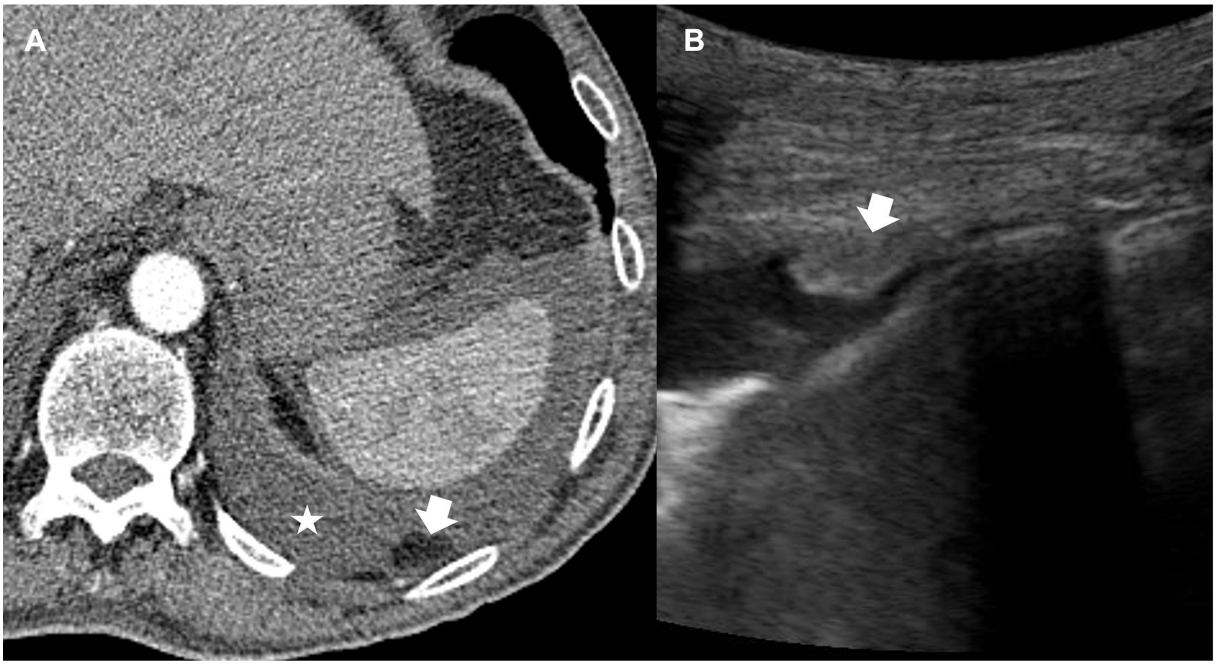

Figure 4. **A:** a pleural nodule of fat density corresponds to a lipoma in a patient with left pleural effusion. **B:** an ultrasound image of the same patient where the pleural lipoma is shown as a hyperechoic lesion dependent on the parietal pleura.

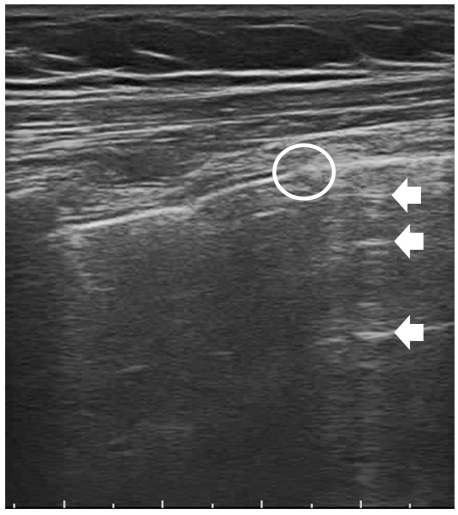

Figure 5. Lung point sign. The image shows a point where the characteristics of the pleuropulmonary line change (white circle). On the right, posterior linear reverberations (white arrows) produced by the pneumothorax can be seen.

of pleuropulmonary movement, absence of comet-tail artefacts or B-lines, absence of pulmonary pulse, and the presence of a lung point (Fig. 5)[33]. The absence of lung sliding is the most sensitive ultrasound marker for the diagnosis of pneumothorax, with a sensitivity and specificity of 87.2% (77.7–93.7%) and 99.4% (96.5–100%), respectively, and a diagnostic odds ratio of 556.74% (100.03-3098.7), while the sensitivity, specificity, and diagnostic odds ratio of the "lung point" sign were 82.1% (71.7–89.8%), 100% (97.6–100%), and 298 (58.893–1507.8), respectively[34].

Pleuropulmonary movement is the most used sign but can be altered in patients with pleural synechiae, surgical history, or COPD. The absence of visualization of B-lines or comet-tail artifacts does not always indicate pneumothorax and may also be found in patients with COPD. Ultrasound examination to detect or rule out pneumothorax takes only 2–7 min[35]. The meta-analysis by Chan et al.[36] showed that ultrasound is superior to supine chest X-ray, regardless of the operator, type of trauma, or type of transducer used. The risk of incorrectly diagnosing a pneumothorax after an ultrasound examination is 3.6%[36]. Conversely, the risk of failing to detect a post-traumatic pneumothorax with ultrasound, and therefore not taking appropriate therapeutic measures, is 4.2%. On the other hand, the risk of missing a pneumothorax using an anteroposterior chest X-ray is 18.6%[36]. The meta-analysis by Tian et al.[37], which analyzed studies published between 2000 and 2020, concluded that the sensitivity of ultrasound was 89% (95% confidence interval [CI] 86–91%), specificity was 96% (95% CI 95–97%), and the diagnostic odds ratio was 193.94 (59.009–637.40) at 95% CI[37].

In neonates, ultrasound has proven to be an excellent test for diagnosing pneumothorax since it does not use ionizing radiation and can be performed at the bedside. The meta-analysis by Dahmarde et al.[34] indicated that ultrasound has a sensitivity of 96.7% and a specificity of 100% for diagnosing pneumothorax in neonates. However, most reviews show that the results obtained may contain biases due to the operators' experience levels and the patient's context. Therefore, studies should be conducted to evaluate the time required and the learning curve for the diagnosis of pneumothorax by ultrasound and its usefulness in clinical contexts other than polytrauma or against upright posteroanterior chest X-ray[38].

Ultrasound can also predict the volume of a pneumothorax and the need for treatment. Once a pneumothorax has been diagnosed with ultrasound, the sign of the lung spot and its location should be sought. This will allow for estimating the volume of the pneumothorax and the need for drainage[39]. A double lung point indicates that the pneumothorax is of minimal volume and that if respiratory failure is present, other causes should be sought[39].

ULTRASOUND-GUIDED PLEURAL INTERVENTIONAL PROCEDURES

Thoracentesis

Fluid collection by puncture of pleural effusion can be performed using ultrasound guidance. British guidelines recommend performing all thoracocentesis using ultrasound guidance[40]. One study showed that 15% of patients chose an inappropriate spot for thoracentesis when ultrasound explored the region[41]. In addition, ultrasound prevented accidental organ puncture in 10% of patients in this series[41]. The success rate of thoracentesis increases from 66% (when performed by physical examination and X-ray) to 90% when ultrasound is used as a guide[40].

Ultrasound-guided thoracocentesis can be performed in two ways: by marking or by direct guidance of the puncture. When marking, a safe spot is chosen using ultrasound, and then thoracocentesis is performed without any image guidance. This procedure is simple, but it is important to remember that when the patient is mobilized and changes the position in which it has been marked, the pleural effusion can also be displaced. Therefore, it is recommended that the procedure be performed immediately after marking. In the direct puncture-guided technique, the procedure is conducted by constantly visualizing the needle using ultrasound[10]. The systematic review by Wilcox et al.[42] showed no lower rate of pneumothorax if the procedure is performed after labeling or with continuous ultrasound guidance. A chest X-ray is not recommended after thoracentesis. It should only be performed when the patient exhibits symptoms postprocedure or if air has been aspirated during thoracentesis[43-46]. Performing thoracocentesis with a previous skin mark performed with ultrasound does not reduce the possibility of developing a postprocedure pneumothorax[42]. The American Thoracic Society, Society of Thoracic Surgeons, and Society of Thoracic Radiology Consensus on managing patients with pleural effusion and suspected malignancy recommend ultrasound-guided thoracocentesis[47].

Pleural biopsy

Pleural biopsy is essential in patients with focal or diffuse pleural thickening. This technique helps avoid more invasive procedures associated with more significant morbidity and mortality, such as thoracoscopy and thoracotomy. Image-guided pleural biopsy, either CT or ultrasound, has a sensitivity of 87% for malignancy, with a mortality of less than 1%, compared to 47% obtained with traditional pleural biopsy[30]. The most common complication is pneumothorax, which can occur in up to 20% of cases. However,

if there is pleural effusion and the lung is far from the biopsy area, the rate of pneumothorax significantly[30] decreases. If the pleural thickening is 5 mm or more and is in an approachable location, performing the biopsy with ultrasound guidance is recommended. When mesothelioma is suspected, biopsy with ultrasound guidance demonstrates a sensitivity of 94% and a specificity of 100%, with few complications[48]. This biopsy should be directed to the areas of most significant uptake if a positron emission tomography (PET)/CT scan has previously been performed[48].

Pleural drainage

The insertion of a pleural drainage tube has multiple indications. Ultrasound guidance during insertion of a pleural drainage tube is recommended in multiple guidelines because it minimizes the risk of malposition and injury to internal organs[49]. Ultrasound allows for the real-time assessment of the location of the catheter tip and checks the persistence of effusion or pneumothorax.

CONCLUSIONS

Ultrasound is a fundamental tool in the diagnosis and management of pleural pathologies. It facilitates the detection and quantification of pleural effusion, the assessment of pleural effusion suspected of malignancy, the diagnosis of pneumothorax, the evaluation of solid pleural lesions, and the guidance of percutaneous interventional procedures.

ETHICAL DISCLOSURES

Protection of humans and animals. The authors declare that no experiments involving humans or animals were conducted for this research.

Confidentiality, informed consent, and ethical approval. The authors have obtained approval from the Ethics Committee for the analysis of routinely obtained and anonymized clinical data, so informed consent was not necessary. Relevant guidelines were followed.

Declaration on the use of artificial intelligence. The authors declare that no generative artificial intelligence was used in the writing of this manuscript.

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