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Use of lung ultrasound for the diagnosis and treatment of pleural effusion

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Abstract. – Pleural effusion affects gas exchange, hemodynamic stability, and respiratory movement, thereby increasing the failure rate of intensive care unit discharge and mortality. Therefore, it is especially important to diagnose pleural effusion quickly to make the appropriate treatment decisions. The present review discusses the role of ultrasound in the diagnosis and puncture/drainage of pleural effusions and highlights the importance of lung ultrasound techniques in this patient population.

We searched on PubMed, Embase, and Cochrane Library databases for articles from establishment to October 2022 using the following keywords: "lung ultrasound", "pulmonary ultrasound", "pleural effusion", "ultrasound-guided" and "thoracentesis".

Lung ultrasound not only helps clinicians visualize pleural effusion but also to identify its different types and assess pleural effusion volume. It is also very important for thoracentesis, not only to increase safety and reduce life-threatening complications, but also to monitor the amount of fluid after drainage of pleural effusion.

Lung ultrasound is a simple, noninvasive bedside technique with good sensitivity and specificity for the diagnosis and treatment of pleural effusions.

Key Words:
Lung ultrasound, Pleural effusion, Thoracentesis.

Introduction

Pleural effusion is a pathological accumulation of fluid in the pleural cavity and is very commonly encountered in the clinic. In a healthy state, the production and absorption of pleural fluid is balanced. Pleural effusion represents a disturbance in this balance, possibly due to increased output and decreased reabsorption. Low plasma osmolarity, increased pulmonary capillary pressure, increased permeability, lymphatic obstruction, and decreased negative intrathoracic pressure are pathophysiological factors that contribute to the clinical relevance and salient features of pleural effusions[1]. The presentation of pleural effusion depends largely on the presence of underlying disease. Congestive heart failure is the most common cause of heart failure. The most common symptom of pleural effusion is dyspnea, the severity of which is related only to the volume of the effusion[2]. Some patients also present with a dry cough, which can be interpreted as a sign of pleural inflammation or lung compression due to a large amount of fluid collection[2]. Pleural effusion can also significantly impair the sleep quality of those affected[3]. In addition, pleural effusion affects gas exchange, hemodynamic stability, and respiratory movement, thereby increasing the failure rate of intensive care unit discharge and mortality[4,5]. Therefore, it is extremely important to diagnose pleural effusion quickly to make the appropriate treatment decisions.

Lung ultrasound has the advantages of safety, non-invasiveness, and accuracy, and can help clinicians quickly identify pleural effusion(s) and identify the different types of effusions (e.g., exudative, leaky, and hemorrhagic)[6]. In addition, lung ultrasound helps clinicians improve safety and reduce life-threatening complications during thoracentesis and drainage while dynamically monitoring the amount of fluid in the chest cavity and determining the timing of extubation. Therefore, pulmonary ultrasonography plays an important role in diagnosis. The present narrative review summarizes the current knowledge base regarding ultrasound and pleural effusion and chest drainage, with a focus on the impact of ultrasound on

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the diagnosis, volume assessment, and drainage techniques for pleural effusions.

Diagnosis of Pleural Effusion

Physical examination (percussion and auscultation) can be used in the clinic to diagnose pleural effusion. Loss of breath sounds on auscultation, solid sounds on percussion, and decreased palpable fibrillation on speech are all indicative of pleural effusion. The diagnostic accuracy of physical examination to detect pleural effusion is highly dependent on the size of the effusion and is unlikely to detect an effusion <300 ml. If the effusion volume is large, shortness of breath may occur. Pleural friction sounds can be heard during the initial stages of parapneumonic pleural effusion. Therefore, physical examination can be challenging in critically ill patients due to the presence of multiple factors that can alter sound propagation within the pleural cavity, such as mechanical ventilation, body position, obesity, subcutaneous emphysema, and patient noncooperation. Therefore, the sensitivity and specificity of physical examination for the diagnosis of pleural effusion are relatively low compared to those of radiography and computed tomography (CT)[7].

Whether a pleural effusion is unilateral or bilateral is usually determined using chest radiography in the clinic. In a standard posteroanterior chest radiograph, blunting of the rib-diaphragm angle and blunting of the heart-diaphragm angle are observed when pleural effusion accumulates to > 200 mL and > 500 mL, respectively[8]. However, upright chest X-ray can miss a large number of effusions, including up to 10% of parapneumonic pleural effusions[9]. Postural limitations and the coexistence of solid lung lesions may lead to poor quality chest X-ray imaging, which may affect the diagnosis of pleural effusion and limit further application of chest X-ray.

Chest computed tomography (CT) is the standard diagnostic modality for pleural effusion. However, its limitations include its inability to distinguish small pleural effusions from pleural thickening while exposing the patient to approximately 7 mSv of ionizing radiation, which is equivalent to 350 chest X-rays[10]. Moreover, it is costly and requires the transfer of patients to the radiology department where the CT scanner is located, with the inherent risks of transporting critically ill patients.

Routine use of pleural ultrasound can help clinicians provide high-value management and reduce ancillary tests, including CT scans that expose patients to ionizing radiation, and reduce complications from thoracentesis. Compared with physical examinations and chest X-rays, bedside ultrasound is more sensitive in detecting pleural effusions and avoids many of the detrimental aspects of CT. In addition, bedside ultrasonography can be used to assess the volume and characteristics of pleural effusions, reveal possible underlying lesions, and guide treatment. The advantages of lung ultrasound include the ability to acquire and interpret images at the bedside and the immediate integration of findings into clinical decision making. Several studies have reported that the diagnostic accuracy of ultrasound for detecting pleural effusion is higher than that of chest radiography[11-13]. The physiological amount of pleural effusion that can be detected using lung ultrasound is 5 ml, although a minimum volume of 20 ml is more reliable, and ultrasound is 100% sensitive to effusion when the volume is > 100 ml[11-13]. In a prospective study of critically ill patients with acute respiratory distress syndrome, the diagnostic accuracy of ultrasound for pleural effusion (93%) was higher than that of auscultation (61%) and anteroposterior chest radiography (47%), using chest CT as the reference standard[13]. Ultrasonography is characterized by its high sensitivity and accuracy in identifying and localizing pleural effusions. It is widely used to locate and quantify pleural effusions because it is simple, safe, and highly accepted by patients[14]. The International Consensus of Lung Ultrasound Experts states that, for the examination of pleural effusion, lung ultrasound is more accurate than supine chest X-ray and its accuracy is consistent with that of CT examination[15]. Moreover, lung ultrasound can be used to identify the nature of pleural effusion and exclude coexisting lung diseases such as pneumothorax, atelectasis, pulmonary solids, and interstitial syndrome(s)[16].

Ultrasound Assessment of Pleural Effusion Volume

The amount of pleural effusion and alteration to gas exchange are important factors in deciding whether to drain the effusion. In the case of small effusions, the benefits of surgery should be weighed against the risk for complications[17].

Several ultrasound methods have been proposed for estimating the volume of fluid accumulation[18-22]. Vignon et al[18] measured the interpleural distance (the distance between the visceral and mural pleura, or the distance between the lung and the posterior chest wall) and compared the maximum distance with the drainage volume at the apical and basal lung bases. The authors found a strong correlation between the interpleural distance and drainage volume. In addition, an interpleural distance > 45 mm or left chest base > 50 mm predicted a pleural effusion volume >8 00 ml. Roch et al[19] conducted a study involving 44 patients receiving mechanical ventilation to assess the accuracy of lung ultrasound in predicting pleural effusions > 500 ml. The interpleural distance measured by ultrasound at the base of the lung or at the fifth rib space was correlated with the volume of drainage. In addition, the predicted volume at the base of the lung > 5 cm was > 500 ml. Usta et al[20] measured the maximum distance between the mid-height of the diaphragm and seated visceral pleura (D) in spontaneously breathing patients after cardiac surgery. They also found a strong correlation between D and the expired volume and derived the following equation: V (ml) = 16 × D (mm). Balik et al[21] measured the maximum maximal interpleural distance (Sep) at the end of expiration at the base of the lung in 81 mechanically ventilated patients and found a good correlation between pleural volume and Sep and suggested the following equation to quantify pleural volume: V (ml) = 20 × Sep (mm).

According to this study, ultrasound evaluation was useful for quantifying pleural effusion and deciding whether thoracentesis should be performed. Remérand et al[22] proposed a new technique for assessing pleural effusion volume. The inferior and superior intercostal spaces where pleural effusion was visible in a supine patient were identified, and the distance between these two points was drawn on the patient's skin to determine the paravertebral length of pleural effusion (LUS). The cross-sectional area of pleural effusion (AUS) was manually drawn at the midpoint of the LUS. The volume of pleural effusion was obtained by multiplying LUS and AUS. The authors reported a strong correlation between ultrasound measurements, drainage volume, and lung CT findings.

Nevertheless, the reliable estimation of effusion volume remains challenging for various reasons. First, ultrasound measurements are influenced by the size of the chest cavity. In taller patients with larger chest cavities, fluid volume is distributed over a larger area than in those with smaller chest cavities. This may lead to underestimation or overestimation of the amount of fluid in the pleural cavity. Second, the patient's position (i.e., upright, supine, or lateral) can affect fluid distribution. In addition, the position of the diaphragm (abdominal hypertension, phrenic nerve palsy, diaphragmatic hernia) can affect the measurement of pleural fluid. Third, in the presence of very large pleural fluid volumes, measurements may be influenced by fluid displacement due to lung collapse. In addition, it is not possible to visualize the entire portion of a very large pleural effusion. Fourth, the presence of pulmonary solidities can affect the shape of fluid accumulation. Fifth, the use of transverse or longitudinal scans, operator expertise, and ultrasound interpleural distances to measure inter- and intra-observer variability can also affect the results, estimated to be 6.7-12.8% and 4.8-11.1%, respectively[18]. Transverse scans tend to overestimate pleural fluid volume, leading to the need for a strict, standardized ultrasound protocol.

Assessment of Pleural Effusion Type

According to pathogenesis, pleural effusions can be divided into exudative and leaky (EPE and TPE, respectively) pleural effusions. The former is caused mainly by diseased pleural surfaces, such as pleural tuberculosis and cancer[23,24], while the latter is caused by systemic factors, such as congestive heart failure and cirrhosis, which affect the absorption and formation of pleural effusions[25]. Clinical diagnosis relies on biochemical examination of pleural effusion samples obtained by thoracentesis[26].

This study evaluated the diagnostic accuracy of lung ultrasound in differentiating the nature of exudate from exudate and found that some ultrasound features of pleural effusions (e.g., echogenicity, compartmentalization, and pleural thickening) were present at a high frequency in exudative pleural effusions. In addition, the frequency of these features is higher among patients diagnosed with pustular pleural effusion[27]. Despite the interest of some investigators, studies assessing the accuracy of lung ultrasound in determining the nature of pleural effusions remain scarce[28-29]. Yang et al[28] first used high-frequency, real-time ultrasonography to determine the nature of pleural effusions in 1992. The authors analyzed ultrasound images from 320 patients with pleural effusions and reported that all those with leaky effusions exhibited an anechoic appearance on ultrasonography (96/96) and that anechoic effusions could be either TPE or EPE (33.9%). In addition, complex internal echogenicity and pleural thickening tend to occur in EPE[29]. The echogenicity of pleural effusions can be homogeneous or heterogeneous, and leakiness is typically echogenic. Pleural effusions with compartmentalization or internal echogenicity are usually suggestive of exudation, which is more likely to be inferred if accompanied by pleural thickening and structural changes in the lungs. In addition, homogeneous echogenic effusion is usually typical of hemothorax[6].

Qureshi et al[30] evaluated the sensitivity and specificity of chest ultrasound for detecting malignant diseases in patients with pleural effusion. They found that ultrasound could differentiate between malignant and benign effusions (overall sensitivity, 79%; specificity, 100%). Malignancy was characterized by the thickness of the mural or visceral pleura, presence of visceral pleural nodules, and diaphragmatic abnormalities (thickness, presence of nodules, and laminar breakdown). Ultrasound scans can also reveal the presence of liver metastases.

In conclusion, the ultrasound characteristics of the effusion help distinguish the nature of the pleural volume based on internal echogenicity, homogeneity, and pleural thickness.

Ultrasound-Guided Thoracentesis

As suggested by Lichtenstein[31], any type of ultrasound device and probe can be used to scan the chest, although microconvex probes have several advantages in lung ultrasound. This transducer is a small ergonomic probe with good spatial resolution and range. Using intermediate frequency values, it enables visualization of the pleural line and pleural cavity. More importantly, its size enables the operator to explore the PLAPS point (defined as the intersection of the horizontal line at the level of the lower blue dot and vertical line at the posterior axillary line). In fact, the PLAPS point is where all free fluid collects in a supine patient; therefore, scanning this area provides more sensitive detection of pleural effusion in even smaller amounts. However, this type of probe is not always available. Other ultrasound probes (i.e., cardiac, abdominal, and vascular probes) have both advantages and limitations. The use of low-frequency phased-array probes enables better visualization of pleural effusion. The abdominal probe (convex probe) is ideal for thoracoalveolar characterization, pleural effusion assessment, and artifact assessment. However, it is usually bulky, and it may be difficult to explore PLAPS points. Cardiac probes (i.e., phased arrays) have been used successfully to detect pleural effusions but sometimes fail to clearly reveal pulmonary sliding[32]. A higher frequency vascular probe (i.e., line array probe) is ideal for pleural line and subpleural space evaluation. However, the use of this probe for the assessment of lung injury and pleural effusion is not ideal[33]. In the absence of a microconvex probe, Lichtenstein recommended the use of an abdominal probe, recognizing that the abdominal probe may be limited in areas that are difficult to access or in superficial resolution assessment (i.e., lung sliding assessment)[32]. This recommendation is fully consistent with international recommendations for bedside lung ultrasound[34]. Volpicelli et al[15] recommended the use of a microconvex probe as the first choice when assessing the volume of pleural effusion. However, when these probes are not available, a phased-array or convex probe is recommended. Ideally, the probe should be sufficiently small to be placed in the intercostal space with good spatial resolution and range. Convex probes offer these advantages for good visualization of the lungs and are widely used in several ultrasound devices[35].

Thoracentesis is a valuable diagnostic and therapeutic technique to both clarify the nature of pleural effusion and to drain large amounts of pleural fluid, thereby relieving symptoms of dyspnea[36]. Ultrasound guidance helps localize the puncture site and prevent complications. Diacon et al[37] compared ultrasound and physical examinations to determine the puncture site for thoracentesis. Compared with chest percussion, ultrasound increased the accuracy of site detection (presence/absence and thickness of pleural effusion) by 26% and prevented potential complications at 15% of clinically determined puncture sites. Wrightson et al[38] have confirmed the superiority of ultrasound in detecting the optimal puncture site and reducing complications (e.g., pneumothorax). As such, the British Thoracic Society guidelines for pleural disease 2010 concluded that “all pleural punctures should be guided by ultrasound”[39].

During thoracentesis, the patient can sit upright with the arm elevated, if possible, or supine with the arm behind the head. In this position, the effusion is reflected downward in the lower part of the chest, leading to an increase in the safety limit (depth of pleural effusion)[40]. Ultrasound-assisted thoracentesis uses "site marking" or "direct needle guidance" [38]. In the former method, the physician identifies the optimal site and marks it on the skin and then performs the procedure without the use of an ultrasound probe. However, changes in the patient's position can cause fluid redistribution; therefore, the puncture must be performed immediately after marking the site. In the latter method of puncture guidance, the correct position of the needle is visualized in real-time. For direct needle guidance, the correct position of the needle is visualized in real time and constantly monitored. Mayo et al[41] performed 232 ultrasound-guided thoracentesis procedures without real-time needle guidance and reported a very low complication rate (1.3%). Therefore, real-time ultrasound guidance of the puncture is not required when ultrasound is performed for accurate localization of the body surface. However, some experts suggest that ultrasound can be used before and after puncture to assess normal lung gliding and rule out pneumothorax[42].

Conclusions

Lung ultrasound is a simple, noninvasive bedside technique with good sensitivity and specificity for the diagnosis of pleural effusions. It is not only essential for visualizing effusions, but also helps to differentiate between pleural effusions of different types. The use of ultrasound to guide thoracentesis is advocated to improve the safety of this invasive procedure, especially in ventilated, intensive care unit patients or for small, localized effusions. In addition, lung ultrasound is essential to monitor the volume of the drained pleural effusion and determine when best to remove the drainage tube.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Ethical Approval

The study did not involve human participants and ethics approval is not applicable.

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