



Thoracic ultrasound: Potential new tool for physiotherapists in respiratory management. A narrative review^{☆,☆☆}



Aymeric Le Neindre^{a,*}, Silvia Mongodi^{b,c}, François Philippart^a, Bélaïd Bouhemad^{d,e}

^a Intensive Care Unit and Department of Critical Care Medicine, Groupe Hospitalier Paris Saint-Joseph, Paris, France

^b Department of Clinical-Surgical, Diagnostic and Pediatric Sciences, University of Pavia, Pavia, Italy

^c Department of Anesthesia and Intensive Care, Fondazione IRCCS Policlinico S Matteo, Pavia, Italy

^d Department of Anesthesia and Surgical Intensive Care Unit, C.H.U. de Dijon, Dijon, France

^e Faculty of Medicine, University of Burgundy, Dijon, France

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ABSTRACT

The use of diagnostic ultrasound by physiotherapists is not a new concept; it is frequently performed in musculoskeletal physiotherapy. Physiotherapists currently lack accurate, reliable, sensitive, and valid measurements for the assessment of the indications and effectiveness of chest physiotherapy. Thoracic ultrasound may be a promising tool for the physiotherapist and could be routinely performed at patients' bedsides to provide real-time and accurate information on the status of pleura, lungs, and diaphragm; this would allow for assessment of lung aeration from interstitial syndrome to lung consolidation with much better accuracy than chest x-rays or auscultation. Diaphragm excursion and contractility may also be assessed by ultrasound. This narrative review refers to lung and diaphragm ultrasound semiology and describes how physiotherapists could use this tool in their clinical decision-making processes in various cases of respiratory disorders. The use of thoracic ultrasound semiology alongside typical examinations may allow for the guiding, monitoring, and evaluating of chest physiotherapy treatments. Thoracic ultrasound is a potential new tool for physiotherapists.

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1. Introduction

The use of diagnostic ultrasound by physiotherapists is not a new concept [1]; it is frequently performed in musculoskeletal physiotherapy. Diagnostic ultrasound is noninvasive, is ionization-free, and can be performed rapidly at the patient's bedside for assessment and monitoring. The use of ultrasound for lung examination is increasingly gaining wide acceptance in emergency and critical care medicine [2,3]. A recent narrative review by Leech et al [4] notes that physiotherapists typically use pulmonary auscultation and chest x-rays to assess and monitor their interventions. However, based on previous studies regarding auscultation, Leech et al [4] report a low interrater reliability and a low accuracy for identifying pleural effusion, alveolar consolidation, and alveolar interstitial syndrome (61%, 36%, and 55%, respectively). Those authors also highlight the fact that chest x-ray sensitivity and specificity are low at detecting pleural effusion (42% and 89%, respectively), interstitial syndrome (53% and 90%, respectively), and lung consolidation (53% and 90%, respectively) [4]. Finally, chest x-rays are not necessarily performed during a physiotherapist's intervention, which could yield

inaccurate information about lung status. Thus, the limits of auscultation and chest x-rays are well described: the real effectiveness of chest physiotherapy is probably underestimated or overestimated, leading to excessive or inadequate treatment [4]. Thus, physiotherapists currently lack accurate, reliable, sensitive, and valid measurements for patient monitoring and assessments of the indications and effectiveness of chest physiotherapy [5]. The use of lung ultrasound (LUS) examination by physiotherapists to evaluate lung status in real time offers new insights [6]. The assessment of diaphragm function is another promising application of ultrasound, particularly in intensive care units (ICUs) during weaning from mechanical ventilation [7]. Leech et al [4] discuss the benefits for critical care physiotherapists of implementing LUS in their clinical practices and briefly propose applications in certain clinical situations. For example, LUS could be used to differentiate pleural effusion from lung collapse in the case of chest x-ray opacity. In this situation, LUS allowing a physiotherapist to know if a lung is recruitable or not could have the potential to influence physiotherapy treatment.

The objective of this narrative review is to detail the development of LUS for physiotherapists. This review refers to lung and diaphragm ultrasound semiology, and how thoracic ultrasound should be used at the patient's bedside for lung and diaphragm assessment. This review explores the literature and the LUS experiences of the authors to describe how physiotherapists may use this potential new tool in their clinical decision-making process.

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* Corresponding author. Tel.: +33 6 72 04 10 01.

E-mail address: aymeric.leneindre@gmail.com (A. Le Neindre).

2. Basics of LUS

2.1. Examination protocol

A simple machine with a microconvex probe (with a frequency of 2–4 MHz) is sufficient for performing a LUS examination. To explore the entire thorax, it is necessary to define examination areas. Two lines delimit the axillary space: the anterior and posterior axillary lines [8]. These lines define areas of investigation for each hemithorax—anterior, lateral, and posterior—each of which is divided into upper and lower parts. Each hemithorax includes 6 examination areas [2,8]. The locations of the liver and spleen allow for the identification of the right and left diaphragm cupolas, which separate the thoracic and abdominal compartments [2,9]. The probe explores the intercostal spaces, which form acoustic windows. The baseline examination uses a longitudinal view but can also use a transverse view [2]. By following this procedure, the physiotherapist can explore the entire pleura–pulmonary complex. Lung ultrasonography has 2 modes [8]: B mode (brightness, real-time), which allows for a 2-dimensional view, and M mode (motion), which allows for the visualization of structure motion as a function of time.

2.2. Normal lung ultrasonography

Ultrasound is not transmitted through well-aerated lungs [2]. Lung ultrasound is partially based on the analysis of generated air artifacts, and the LUS of a normal lung (aerated) is characterized by the presence of the bat sign, pleural sliding, and A lines [2,3]. Only the pleura is visible, and its movement (ie, pleural sliding) is typically evident. The A lines are reverberation artifacts from this pleural line [2,3] (Fig. 1A).

2.3. Alveolar-interstitial syndrome

B lines are vertical artifacts originating from the pleural line; they erase A lines and reach the edge of the screen. B lines are generated by the presence of air mixed with water, which causes a mismatch of the acoustic impedance [10]. Edematous interlobular septa in contact with air-filled alveoli generate multiple and well-defined B lines (Fig. 1B): this is known as *interstitial syndrome* (see Video S1 in the online supporting information). When alveoli are partially filled with fluid, the B lines become confluent and alveolar-interstitial syndrome is present [10,11].

The presence of multiple and diffuse B lines is characteristic of alveolar-interstitial syndrome [2,3]. Investigations are typically performed at the anterior and lateral thoracic areas. A *positive region* is defined by the presence of 3 or more B lines in a longitudinal plane between 2 ribs, and a positive examination result suggests the presence of 2 or more positive regions. The number of B lines is correlated with the loss of aeration and is not specific. Unilateral and focal B lines are associated with pneumonia, atelectasis, and pulmonary contusions. Bilateral and diffuse B lines are associated with pulmonary edema and acute respiratory distress syndrome. A gain or a loss in lung aeration induced by positive-end expiratory pressure [12], dialysis [13], or antibiotics [14] can be assessed semiquantitatively using LUS by monitoring the number of B lines present.

2.4. Lung consolidation

Lung consolidation may have a variety of causes, including pneumonia, pulmonary embolism, lung cancer and metastasis, compressive or obstructive atelectasis, and pulmonary contusion [8]. Lung consolidation appears as a tissue-like structure with irregular deep margins contacting the aerated lung or regular deep margins when the entire lobe is involved [8,15] (Fig. 1D, E). The presence of air bronchograms, fluid bronchograms (see Video S2 in the online supporting information), and vascular patterns can be observed within the consolidation [8,15]. Lung ultrasound may be helpful in determining the type of consolidation [8].

Pneumonia is defined by the presence of subpleural consolidation [16], which can be hemilobar with irregular deep margins or lobar with regular deep margins [15]. This tissue-like structure contains air bronchograms, which can be static and/or dynamic (see Video S3 in the online supporting information) [16], but fluid bronchograms may also be present, which indicate fluid-filled airways [17–19]. Tree-like vascularities may also be observed within the consolidation. Color Doppler ultrasound allows for the differentiation of tree-like vascularities and fluid bronchograms (Fig. 1E) [17,20].

Atelectasis ultrasound findings are characterized by a tissue-like pattern, abolished lung sliding, and static air bronchograms [21] (see Video S4 in the online supporting information). As with chest x-rays, the ipsilateral attraction of mediastinum structures can also be observed. The presence of a dynamic air bronchogram rules out atelectasis [22]. This bronchogram is associated with nonretractile consolidation and indicates the absence of airway congestion [22]. At an early stage preceding total aeration loss, atelectasis appears as A lines or possibly B lines, and lung sliding is replaced by lung pulsations synchronized with cardiac activity, which is known as the lung pulse [23].

2.5. Pleural effusion

Pleural effusion appears as dependent and anechoic (ie, free of echoes) structures [8]. Pleural effusion occurs between the diaphragm and the pleura, and conducts ultrasounds, allowing for deeper structures to be visualized, such as the thoracic aorta [2]. In M mode, pleural effusion is characterized by the sinusoid sign (Fig. 1C) [3,8].

The type of pleural effusion (ie, transudate or exudate) cannot be determined with certainty only using ultrasound examination, but some ultrasound patterns are characteristic of their nature. Transudates are always anechoic, whereas exudates are echoic and loculated [24].

Several procedures allow the pleural effusion volume to be estimated. Most methods measure the pleural liquid depth at the posterior lung base (ie, the posterior liquid depth) [25–28]. The patient is examined in the supine position, and the ultrasound probe is placed in the posteroinferior area in the transverse view. The maximum distance between the parietal and visceral pleura (posterior liquid depth) is measured 3 cm above the inferior pole of the lung at the end of expiration. A different method can more accurately assess the pleural effusion volume [29]. In this method, the patient is also examined in the supine position, and the ultrasound probe is slipped between the patient's back and the mattress. Each paravertebral intercostal space in the hemithorax is explored using a transverse view (Fig. 2). Examination begins from the upper portion to the lower portion of the thorax. As soon as pleural effusion is detected, a landmark is drawn on the patient's skin; this is the upper limit of the pleural effusion. Another landmark is drawn at the last intercostal space where pleural effusion is detected; this is the lower limit of the pleural effusion. The paravertebral length (Lus, cm) is measured between these 2 points. The cross-sectional area of the pleural effusion (Aus) is measured at the middle of the Lus using a transverse view at the end of expiration. The pleural effusion volume (V; in milliliters) is estimated using the following formula: $V \text{ (mL)} = \text{Lus (cm)} \times \text{Aus (cm}^2\text{)}$.

2.6. Pneumothorax

Three signs define pneumothorax: the presence of A lines (ie, gas is present between the 2 pleural layers), the absence of pleural sliding, and the presence of lung point [30]. Lung point is visible in M mode and refers to the absence of any sliding or moving B lines at the physical locations where the transition into an area of sliding occurs. At this point, the lung contacts the wall during inspiration (ie, appearance of lung sliding) and does not contact the wall during expiration (ie, absence of lung sliding) [30] (see Video S5 in the online supporting information). The lung point represents the physical limit of pneumothorax [8]. B lines and lung pulse must be absent.

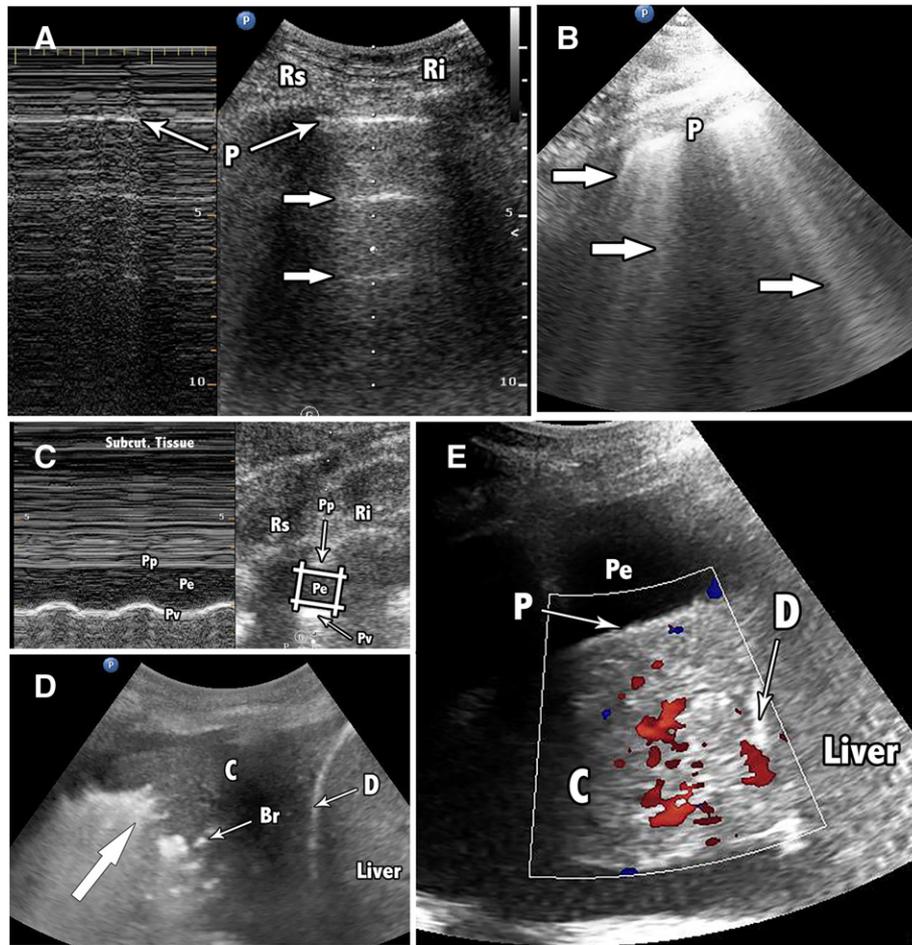


Fig. 1. Basic signs in LUS. A, Seashore sign (left, M mode): tissues above the pleural line are motionless and generate horizontal lines (sea). Below the pleural line, structures (ie, lung and Pv) are in motion and generate a sandy pattern. Bat sign (right, B mode): in the intercostal space, the shape of the Rs and Ri, and pleural line (ie, hyperechoic line) appear in the shape of a bat. A lines (right, B mode): horizontal repetition artifacts of the pleural line (big arrows) that indicate the presence of air. B, B lines: comet-tail artifacts (arrows) that arise from the pleural lines and erase A lines are nearly always long and always move with lung sliding. C, Sinusoid sign (left, M mode): during inspiration, the Pv moves toward the Pp; this sign indicates a free Pe. Quad sign (right, B mode): the Pvl, Pp, and shadows of the ribs form a quad; this sign indicates a Pe in an intercostal space. D, Shred sign (B mode): a deep boundary (arrow) with a shredded appearance indicates a partial lobar consolidation. Note the presence of a Br. E, Tissue-like sign (B mode): a tissue-like pattern arising from the pleural line (or Pv) of a complete lobar consolidation. Fluid-color sign: in color Doppler mode, the color sign highlights the presence of fluid in movement. Here, the fluid-color sign indicates the presence of a vascular pattern within the lung consolidation (ie, intrapulmonary shunt). P indicates pleural line; Rs, superior rib; Ri, inferior rib; Pp, parietal pleura; Pv, visceral pleura; Pe, pleural effusion; C, lung consolidation; D, diaphragm; Br, air bronchogram.

Thus, LUS is an accurate tool. The sensitivity and specificity of LUS compared with the criterion standard (ie, computed tomography [CT] and/or x-rays) average both 93% to detect alveolar-interstitial syndrome, 93% and 98% to detect pneumonia, 93% and 100% to detect atelectasis, 93% and 97% to detect pleural effusion, and 86% and 97% to detect pneumothorax, respectively (Table 1).

3. Basics of diaphragm ultrasound

3.1. Maximal diaphragm excursion

One method to assess diaphragm function using ultrasound is to measure its displacement. The most commonly used method involves an anterior subcostal approach between the anterior axillary line and the midclavicular line [31–35]. B mode is initially used to determine the best approach and select the exploration line. The liver and spleen serve as an acoustic window that allows the visualization of the diaphragm (ie, bright lines that border these organs; Fig. 3A). After the diaphragm is identified, excursion measurements are performed in M mode: the diaphragm moves toward the probe during inspiration and away from it during expiration. The distance between the end-

inspiration and end-expiration points defines the diaphragm excursion (Fig. 3A). The velocity of the diaphragm contraction can also be evaluated: $\text{velocity (cm/s)} = \text{excursion (cm)} / \text{inspiratory time (s)}$ [36]. Another method uses an intercostal approach (ie, longitudinal view; Fig. 3B; see Video S6 in the online supporting information). The probe is placed on the anterior axillary line, which allows for the visualization of the diaphragm cupola bordering the liver or spleen in B mode [37,38]. The presence of pleural effusion or atelectasis makes the diaphragm cupola easier to visualize [38]. The excursion measurement is performed in B mode. Landmarks are placed on the highest cupola area at the ends of expiration and inspiration. The distance between these 2 points is the diaphragm excursion. Normal values for this measurement are shown in Table 2. However, in practice, measuring the maximum diaphragm excursion during the maximum inspiratory effort seems to be the simplest method. A cutoff value less than 25 mm for maximum diaphragm excursion may help identify patients with and without severe diaphragm dysfunction [38].

3.2. Diaphragm thickening fraction

Ultrasound can also be used to assess the thickening capacity of the diaphragm. The inspiratory and expiratory diaphragm thicknesses (in

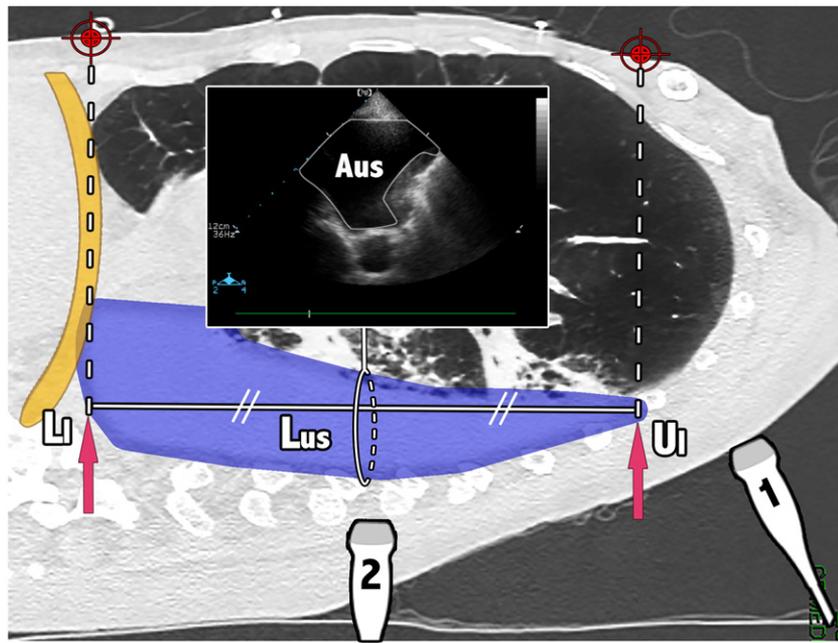


Fig. 2. Measure of pleural effusion volume with the multiplane ultrasound approach. The patient is in the supine position and the examination begins from the upper portion of the thorax (probe 1) toward the lower portion. Each paravertebral intercostal space in the hemithorax is explored using a transverse view. The upper limit of the pleural effusion is the first intercostal space where pleural effusion is detected (red arrow, U1); the lower limit is the last intercostal space where pleural effusion is detected. The paravertebral length (Lus; in centimeters) is measured between the 2 landmarks (red marks, opposite to the limits of pleural effusion drawn) of the patient's skin. The cross-sectional area of the pleural effusion (Aus) is measured at the middle of the Lus using a transverse view at the end of expiration (probe 2, left ultrasound image). The pleural effusion volume (V ; in milliliters) is estimated using the following formula: V (mL), Lus (cm) \times Aus (cm²). U1 indicates upper limit of the pleural effusion; L1, lower limit of the pleural effusion; Lus, paravertebral length; Aus, cross-sectional area of the pleural effusion.

millimeters) are measured in the zone of apposition of the diaphragm to the rib cage [39–42]. The probe is placed in an intercostal space between the midaxillary line and the anterior axillary line, 0.5 to 2 cm below the costodiaphragmatic sinus. In B mode, the diaphragm is observed as a structure made of 3 distinct layers: a nonechogenic central layer bordered by 2 echogenic layers (Fig. 3C; see Video S7 in the online supporting information) [39]: the pleural line (ie, external layer) and the peritoneum (ie, internal layer). The thickening fraction (TF) measurement is obtained in B mode using the following formula: TF (%) = [(end-inspiration thickness – end-expiration thickness)/(end-expiration thickness) \times 100]. Normal values for this measurement are presented in Table 2.

3.3. Diaphragm paralysis and diaphragm dysfunction

To summarize, diaphragm ultrasound provides qualitative and quantitative information regarding diaphragm function [36]. For diaphragm paralysis, the findings are clear: excursion and thickening of the diaphragm are not observed [9]. In unilateral paralysis, the negative pressure generated by the other hemidiaphragm during inspiration

causes the paralyzed portion to passively move cranially [36]; this paradoxical movement (ie, cranial inspiratory movement) can be observed in B mode. In the case of suspicion of diaphragm dysfunction, ultrasound findings are less straightforward [9,36]; normal values are widely distributed in the population (Table 2). However, diaphragm ultrasound may help in identifying the subpopulation of ICU patients at risk due to a low maximum diaphragm excursion (<25 mm) [38] or a low diaphragm TF (<20%) [41] (see Video S7 in the online supporting information).

4. Guiding chest physiotherapy with LUS

Chest physiotherapy aims to improve airway clearance, alveolar recruitment, and ventilation/perfusion matching [43]. It typically involves many techniques that are often used in combination [44], and the selection of interventions depends on the type of pulmonary dysfunction assessed. For example, in the case of retained airway secretions, airway clearance techniques may be used to promote secretions removal, reducing airway resistance, optimizing lung compliance, and decreasing work of breathing [43]. In the case of lung consolidations, chest physiotherapy aims to improve lung recruitment, compliance, and ventilation/perfusion matching. For example, positioning and hyperinflation may be used to reexpand atelectasis as they increase alveolar recruitment and lung perfusion [43,45]. Manual techniques are often associated with instrumental interventions such as noninvasive ventilation, intrapulmonary percussive ventilation, or endotracheal suction, and a physiotherapist must accurately evaluate a patient in order to select the most suitable intervention [43,45,46].

Lung ultrasound provides real-time and accurate information about the pleura, lung, and diaphragm statuses of the patient: this allows for the assessment of lung aeration, including interstitial syndrome to lung consolidation [8]. Each LUS pattern is related to a level of aeration as follows: normal with A lines indicates a well-aerated lung; B lines indicate alveolar-interstitial syndrome and increased extravascular lung water; and lung consolidation indicates total loss of aeration. Increases

Table 1
LUS diagnostic performances

Disease	Comparison	Sensitivity	Specificity
Lung consolidation [15]	CT	90%	98%
Diffuse alveolar-interstitial syndrome [10]	CT	93%	93%
Pneumonia [19]	X-ray/CT	93%	98%
Atelectasis [23]	X-ray	93%	100%
Pneumothorax [2]	CT	86%	97%
Pleural effusion			
Presence [3]	CT	93%	97%
Loculated [24]	CT	CT and LUS are similar in their abilities to detect loculations.	
Pleural adhesion [59]	Thoracoscopy	81%	96%

X-ray indicates chest radiography.

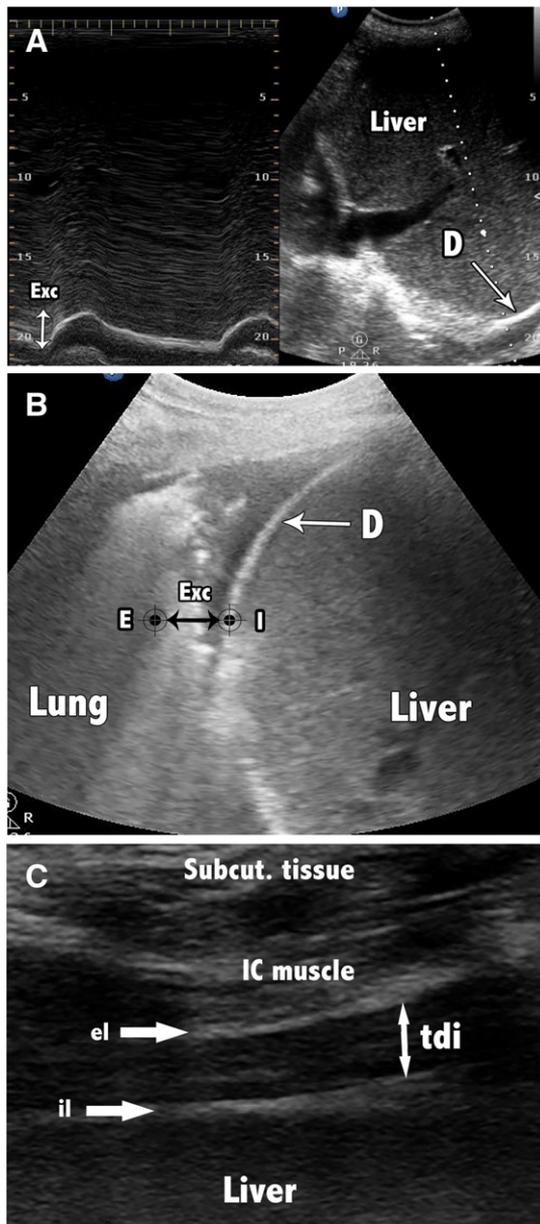


Fig. 3. Ultrasound evaluation of the diaphragm. A, Measure of the diaphragm Exc using the anterior subcostal approach (left: M mode; right: B mode). The liver provides an acoustic window. B, Measure of the diaphragm Exc using the IC approach on the anterior axillary line (B mode). The diaphragm is well defined due to pleural effusion and basal lung consolidation. C, Diaphragm zone of apposition in an IC space. D indicates diaphragm; Exc, excursion; E, expiration; I, inspiration; IC, intercostal; el, external layer (pleura); il, internal layer (peritoneum); tdi, diaphragm thickness.

or decreases in aeration cause a detectable change in the LUS pattern [8]. Lung ultrasound also describes the presence of a pleural effusion or a pneumothorax and provides a functional assessment of the diaphragm. These LUS performances may be useful for the physiotherapist and could guide the choice of techniques and parameters for chest physiotherapy [4]. However, to reliably assess the lung status, LUS examinations should be comprehensive (ie, both lungs and the 12 chest areas should be investigated). Thus, using comprehensive and repeated LUS examinations, the efficiency of chest physiotherapy can be monitored.

4.1. B lines

Multiple, homogeneous, and diffuse B lines are caused by pulmonary edema. In this case, the physiotherapist must first refer back to the

Table 2
Reference values in diaphragmatic ultrasound

Measures	Male	Female
Excursion (cm) [34]		
Quiet breathing	1.8 ± 0.3 (1.1-2.5)	1.6 ± 0.3 (1-2.2)
Deep breathing	7 ± 1.1 (4.7-9.2)	5.7 ± 1 (3.6-7.7)
Voluntary sniffing	2.9 ± 0.6 (1.8-4.4)	2.6 ± 0.5 (1.6-3.6)
Paralysis [38]	<0.25	
Velocity (cm/s) [64]		
Quiet breathing	1.3 ± 0.4	
Diaphragm thicknesses (cm) [42]		
Healthy subject	0.22-0.28	
Paralysis	<0.2	
TF [41]		
Healthy subject	28-96%	
Paralysis	<20%	

medical staff. Then, the physiotherapist may implement noninvasive ventilation in a seated patient [47] in combination with medical treatment (eg, diuretics). A reduction in the number of B lines is a good marker of treatment effectiveness [13,48].

Intensive care unit patients are commonly bedridden in a supine or semirecumbent position, and lung aeration disorders often occur as a result [49,50]. In these cases, B lines are found primarily in the most dependent parts of the lungs and are frequently associated with basal lung consolidations [50]; thus, body positioning and mobilization might be a suitable strategy to improve lung aeration [43,51].

In cases in which B lines are limited to one region of the examination, pneumonia, atelectasis, or a pulmonary contusion can be considered as possible diagnoses [8]. Well-defined B lines (see Video S1 in the online supporting information) are indicative of an interstitial disorder, for which there is not currently a recommended chest physiotherapy technique; physiotherapists may be monitoring the progression of the disorder. When confluent B lines are present, alveoli are partially filled by fluid [10]. Techniques aimed at improving ventilation and preventing lung consolidation should be considered and include positive expiratory pressure (PEP), body positioning, and mobilization [43,46,52]. Aerosolized treatments, such as β-agonists, that improve alveolar clearance may be useful for alveolar clearance [53] and could be followed by airway clearance techniques if retained secretions are present (refer to clinical examination).

4.2. Lung consolidation

At the patient's bedside, LUS performs much better than chest x-rays at diagnosing lung consolidation: the sensitivity and specificity of LUS average 90% and 98%, respectively [15], whereas those of chest x-rays average 68% and 95%, respectively [54]. Lung ultrasound characteristics thus allow physiotherapists to quickly distinguish between atelectasis and pneumonia (see above) and to implement a suitable therapeutic strategy.

Lobar or hemilobar lung consolidation with fluid bronchograms in mechanically ventilated patients (see Video S2 in the online supporting information) is treated using techniques that increase the expiratory flow rate (eg, huffing and exsufflator [43,46,52]) with adjustments to the ventilator settings. In a spontaneously breathing patient, techniques that aim to improve lung ventilation (eg, positioning and noninvasive ventilation) can be used; this should be followed by expiratory-flow-rate enhancement techniques to remove possible secretions. The replacement of fluid bronchograms by air bronchograms is a marker of efficiency; the secretion-filled airways (ie, fluid bronchogram) in the consolidation are cleared and replaced by air, leading to an air bronchogram in LUS. The presence of a dynamic air bronchogram in the consolidation in mechanically ventilated (see Video S3 in the online supporting information) or spontaneously breathing patients indicates a need to increase positive-end expiratory pressure in mechanically ventilated patients, PEP in spontaneously breathing patients, or

implement measures such as mobilization and body positioning to improve alveolar ventilation [43,46]. With LUS, the physiotherapist monitors the consolidation and evaluates the effectiveness of treatments [14]. Whatever the chest physiotherapy treatment indicated and chosen, the decrease of the consolidation size and the number of B lines, and the appearance of A lines are markers of efficiency [55]. The unfavorable evolution of pneumonia is defined by increases in the signs described above, which can lead to pulmonary abscesses or empyema [17,20].

In cases of atelectasis, it is important to differentiate between obstructive and passive mechanisms [50,56]. There are primarily 3 causes of atelectasis: absorptive (eg, airway obstruction), compression of lung tissue (eg, positioning and pleural effusion), and surfactant dysfunction. Management of atelectasis differs according to the etiology [50,56]. The presence of a large pleural effusion in LUS is indicative of passive atelectasis related to lung compression. Thus, physiotherapist should first refer the patient to medical staff. If the patient's condition does not require the placement of a chest drain, the physiotherapist may help decrease the work of breathing and improve lung ventilation (eg, noninvasive ventilation) if required [43,46]. If there is an obstructive atelectasis caused by retained secretions (refer to clinical review), the implementation of lung recruitment techniques is indicated (eg, manual or ventilator hyperinflation, PEP, body positioning, and expiratory-flow-rate enhancement techniques) to promote secretion removal [43]. The resolution of obstructive atelectasis or an increase in aeration is characterized by the appearance of A lines or B lines, respectively (Fig. 4; see Video S4 in the online supporting information). These changes in the LUS pattern allow to assess the effectiveness of chest physiotherapy treatments [57,58].

4.3. Pleural effusion

Lung ultrasound is an excellent tool for pleural assessment and can help to locate effusion, estimate its volume, distinguish transudate from exudate, and detect loculations and the presence of pleural adhesions [59].

The quality and number of studies that assess the effectiveness of chest physiotherapy in pleural effusion are limited [60,61]. None of these studies provide precision regarding the nature of pleural effusion and the patient's condition. If the physiotherapist identifies a pleural effusion, it seems reasonable to address the patient and wait for medical or surgical treatment to be completed [62]. Then, the physiotherapist may help to implement supportive respiratory management if a chest drain is not required (see above).

Moreover, in cases of diaphragm dyskinesia induced by pleural effusion, physiotherapist may measure improvement by ultrasound assessing an increase in diaphragm function [63].

4.4. Diaphragm dysfunction

Diaphragm ultrasound could be a valuable tool for physiotherapists when evaluating diaphragm kinetics and strength in cases of difficult-to-wean ICU patients. It may also be helpful for the assessment of changes in diaphragm kinetics induced by inspiratory resistive loads [64] or the assessment of the effectiveness of inspiratory muscle training [65].

Diaphragm dysfunction is observed as dyskinesia (ie, a decrease in the maximum diaphragm excursion) or a decrease in the diaphragm TF. In ICU patients, diaphragm dysfunction frequently occurs (ie, incidence averages 60%), and the primary risk factors are sepsis and disease severity [66]. Mechanical ventilation is often cited as a cause of diaphragm dysfunction (ie, disuse atrophy). Mechanisms of diaphragm injuries are complex and not completely known. Phrenic nerve injuries after major surgical procedures (ie, cardiac and thoracic) [36] are also typically observed (see Video S7 in the online supporting information).

Regular monitoring of maximum diaphragm excursions or the diaphragm TFs via ultrasound allows for the monitoring of diaphragm recovery [41]. The regular monitoring of diaphragm function determines the evolving nature (ie, fast or slow) of diaphragm recovery and guides treatment strategies (eg, waiting for a fast resolution or pursuing a tracheotomy).

Diaphragm ultrasound could be of interest for some controversial issues related to diaphragm physiotherapy. Patients with chronic obstructive pulmonary disease have static and dynamic lung hyperinflation related to their disease severity (ie, degree of obstruction and severity of emphysema); this hyperinflation makes the diaphragm less efficient due to its unfavorable position [67]. The effectiveness of diaphragmatic breathing exercises for these patients is controversial. In patients with severe hyperinflation, a loss of mechanical efficiency in the respiratory muscles has been reported [68]. Conversely, in less severely affected patients, it appears that diaphragmatic breathing exercises improved the functional capacities of patients [69]. It is possible to measure the effects of diaphragmatic breathing exercises on the maximum diaphragm excursion and the diaphragm thickening ratio. Using ultrasound in this way, the physiotherapist could rationally adapt their rehabilitation programs for patients with chronic obstructive pulmonary disease (see Video S6 in the online supporting information) [70].

5. Limitations

First, lung disorders that do not reach the pleura cannot be assessed by ultrasound. Second, dressings, subcutaneous emphysema, and obesity are obstacles to using LUS. The use of inadequate probes or settings and noncompliance with examination conditions are also limitations [3]. Finally, LUS must be used alongside clinical evaluations and should not be the only outcome measure used in clinical practice. As suggested by Leech et al [4], LUS may be used to answer a focused clinical question. The results of using tools currently available (eg, clinical review, auscultation, and chest x-rays) allow the physiotherapist to form an initial diagnosis of patient's respiratory conditions. Then, the physiotherapist should perform LUS if his clinical hypothesis must be confirmed. The patient selection requiring LUS is helpful because nearly all mechanically ventilated patients have pathologic findings in LUS but not always with clinical significance [71]. In addition to clinical examinations, LUS may guide the choice of chest physiotherapy strategies and help to determine if the patient requires medical intervention and no chest physiotherapy (eg, pneumothorax and severe pleural effusion).

Finally, an appropriate level of training is necessary to implement LUS in clinical practice [2,4]. As highlighted by Leech et al, physiotherapists do not routinely use LUS for patient assessments. Standard training in LUS thus must be developed for physiotherapists.

6. Perspectives and research

For physiotherapists to perform LUS evaluations, they must possess extensive knowledge of anatomy, pulmonary physiopathology, and LUS semiology. Rigorous training and experience are required for LUS use [4]. Lung ultrasound is currently a diagnostic tool for intensivists, emergency physicians, and pulmonologists [8]. It is quite conceivable that a physiotherapist may use LUS to detect lung abnormalities and not to provide a medical diagnosis in order to select and reassess his/her physiotherapy treatments. The application of LUS in physiotherapy may cover all medical specialties that require chest physiotherapy.

Xirouchaki et al [71] assessed the influence of LUS on medical practices and observed a significant change in diagnoses and treatments compared to typical examinations. Because it is also a useful diagnostic tool in chest physiotherapy, LUS's influence on physiotherapist's clinical decision-making process should be evaluated.

Lung ultrasound may be used in clinical research for chest physiotherapy because it is accurate, reliable, and reproducible; it is also a suitable outcome for research on the impact of chest physiotherapy in lung

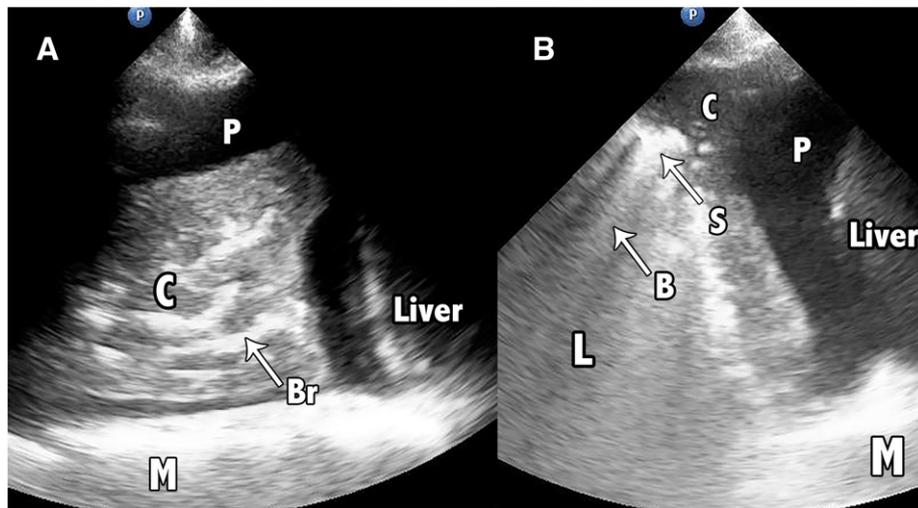


Fig. 4. Treatment of obstructive atelectasis with chest physiotherapy. A, Right lung obstructive atelectasis assessed with ultrasound before chest physiotherapy treatment. Note the presence of the tissue-like sign and a static Br. Lung consolidation provides an acoustic window that allows for the visualization of the mediastinum. B, Ultrasound assessment of the right lung during chest physiotherapy. Chest physiotherapy techniques include noninvasive ventilation and lateral decubitus. Note the emergence of B lines and the shred sign, the reduction of the tissue-like sign's size, and the disappearance of the Br. C indicates consolidation; Br, air bronchogram; M, mediastinum; B, B lines; L, lung; S, shred sign; P, pleural effusion.

eration disorders. For example, the use of a LUS score based on typical LUS patterns (eg, A lines, B lines, and consolidation) allows lung aeration to be quantified. These LUS scores have been well correlated with CT results [14] and can be used to monitor alveolar recruitment [12].

The previous literature in chest physiotherapy in ICU patients used outcomes with low accuracy to assess chest physiotherapy techniques (eg, sputum weight, chest x-rays, and pulmonary function) [72]. The diagnostic limitations of these outcomes make it difficult to conclude on the true effectiveness of chest physiotherapy [4]. This confirms the relevance of LUS use for research in chest physiotherapy.

In addition, LUS may help to identify the most suitable physiotherapy technique for various respiratory pathologies [4] in studies and in routine practice. For example, determining the techniques that should be used by the physiotherapist in the case of pneumonia is difficult and may include the techniques for bronchial secretions removal or PEP/noninvasive ventilation [46,52]. The selection of the appropriate treatment depends on clinical review and LUS findings (see the Lung consolidation section). Lung ultrasound may be helpful to answer clinical questions such as “Is only the major airway retaining secretions or is lung consolidation also present?” and can provide significantly higher accuracies than conventional examinations performed by the physiotherapist [4].

To summarize, LUS may be used as a tool in research and clinical practice to clarify the indications and effectiveness of chest physiotherapy for various respiratory diseases.

7. Conclusions

Diagnostic ultrasound performs significantly better than chest x-rays or auscultation at diagnosing lung deficiencies. Lung ultrasound provides relevant information about the lung and diaphragm statuses, which may indicate chest physiotherapy (eg, alveolar-interstitial syndrome and lung consolidation) or require the patient to be reviewed by the medical team (eg, pneumothorax and pleural effusion). Because the usual evaluation tools of physiotherapist (ie, clinical review, chest-x-ray, and auscultation) lack accuracy and reliability, implementing LUS semiology into the clinical decision-making process seems to be a promising opportunity. Physiotherapists should use LUS semiology to guide, monitor, and evaluate their chest physiotherapy treatments; however, this tool should always be used alongside clinical examination. Lung ultrasound may be an accurate outcome for research in chest physiotherapy, particularly to assess chest physiotherapy

techniques that aim to improve lung aeration. The training of physiotherapists will be an important issue in the future to ensure an appropriate use of this tool. This potential new tool for physiotherapists still requires significant development before being used commonly.

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