Lung Ultrasound: The Emerging Role of Respiratory Therapists

Manjush Karthika, Duane Wong, Suresh G Nair, Lalitha V Pillai, and Chris Sara Mathew

Lung ultrasound is a point-of-care imaging tool that is routinely used in acute care medicine. Traditionally, radiology physicians were the primary practitioners of diagnostic ultrasound, but with the recognition of its importance in intensive care medicine, critical care physicians have also adopted this practice. Within the intensive care unit inter-professional team is the respiratory therapist, who participates actively in the care of ventilated patients. Their scope of responsibility is expanding with newer technologies being brought into clinical use on a regular basis. This review focuses on the scope and benefits of ultrasound training within respiratory care–related areas. *Key words: lung ultrasound; respiratory therapists; intensive care units*. [Respir Care 2019;64(2):217–229.

Introduction

The portable chest radiograph is a routine diagnostic tool used in the ICU setting to assess patient lung function. The routine use of bedside chest radiography is supported by longstanding data,[1] but there are studies that question its diagnostic impact and clinical efficacy.[2-4] Portable chest radiography has gradually appeared to be less useful, as noted in a large meta-analysis of randomized, controlled trials and observational studies.[5]

Computed tomography remains the accepted standard for all diagnostic and therapeutic procedures that require evaluation of lung function, whether for diagnostic purposes in pneumothorax, pneumonia, or pleural effusion, or for therapeutic purposes such as drainage of loculated or large effusions and for insertion of intercostal or pig-tail catheters. However, transporting a critically ill ICU patient with all of the accompanying monitoring equipment and emergency preparedness may not always be a practical option.[6]

The advancement of lung ultrasound (LUS) in recent years with better quality and spatial resolution has resulted in greater diagnostic accuracy.[7] Some of the advantages of

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LUS over chest radiograph and computed tomography include availability, portability, absence of radiation, real-time imaging, documentation, and reproducibility of findings. Over the last 20 years, LUS has become a prominent diagnostic tool for assessment and decision-making in care of the ventilated patient.

Technical Aspects of Lung Ultrasound

Ultrasound waves have frequencies higher than the upper limit of the human audible range, which is 2–20 KHz. Diagnostic ultrasound in medical science typically uses frequencies that range between 2 and 20MHz. Ultrasound waves are generated with piezoelectric crystals located in the head of the transducer or probe of the ultrasound machine.[8] When electrical energy is transmitted through the piezoelectric crystals in the transducer of the ultrasound machine, it deforms the crystals and ultrasound waves are generated. These ultrasound waves are then transmitted, attenuated, absorbed, reflected, refracted, and diffracted by the tissues or adjacent medium.[9] Although nearly all of the energy is reflected back, the difference in the acoustic impedance of various tissues changes the ultrasound signal strength. This provides information regarding the location and characteristics of tissues, and these data are processed into grayscale images, on which the technology of ultrasound is based.[10]

Another important area of interest is the effect of various tissues/media upon the transmission of ultrasound waves. The term echogenicity refers to the ability of a tissue or medium to produce echoes by transmitting ultrasound waves in the context of surrounding tissues.[11,12] When ultrasound waves pass through tissues with different echogenicity, the resultant images produced on the screen will differ in their contrast. Based on this, the images are categorized as hyperechoic (white on the screen), hypoechoic (gray on the screen), anechoic (black on the screen), and isoechoic (having echogenicity similar to that of a neighboring structure).

The generation and interpretation of ultrasound images vary from those of radiographic images because the energy sources differ widely. Modern ICU ultrasound machines are usually portable, lightweight, and have built-in memory to store images and videos.

To perform LUS, a high-frequency linear probe with a frequency of 5–12 MHz is optimal because it provides better resolution and less penetration (Fig. 1A). For these reasons, this probe is ideal for imaging superficial structures like the pleura or for identifying lung sliding, and it is also effective in ultrasound-guided vascular procedures. A low-frequency curvilinear probe with a frequency of 3–5 MHz is useful in the assessment of effusions, consolidated lung, and the diaphragm because of good penetration and large sector width (Fig. 1B). A phased-array transducer probe with a frequency of 3–4.5 MHz is also useful in LUS because the footprint can be placed easily in the intercostal spaces (Fig. 1C). These probes have a small footprint for fitting between the ribs to demonstrate all the signs of LUS, but the image clarity of the images is not as good compared to linear or curvilinear probes.[13]

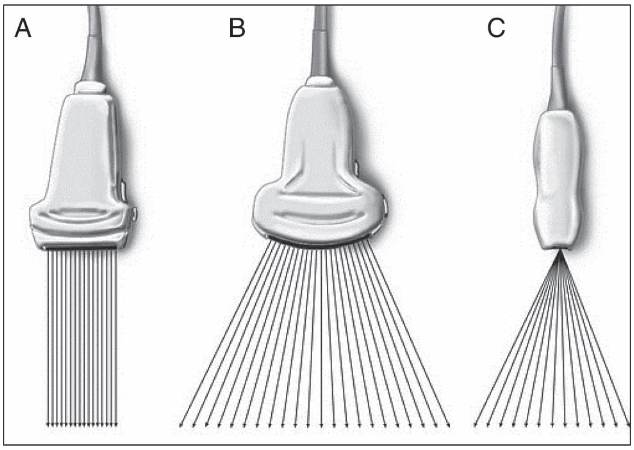

Fig. 1. Ultrasound probes commonly used in lung imaging. A: Linear array probe. B: Curved array probe. C: Phased array probe.

Even though most ultrasound machines have uniform functional features, there remains some variation in the designs of different manufacturers. Hence it is important to become acquainted with the modes and controls of the specific machine before scanning. The control panel of an ultrasound machine has various controls that are used to adjust the quality of recording images. The commonly used modes while performing LUS are B-mode and M-mode.

B-mode, or brightness mode, is the basic mode of ultrasound imaging; it is also known as grayscale or 2-dimensional imaging, which refers to the standard black-and-white image obtained on the ultrasound monitor (Fig. 2A). M-mode, or motion mode, is used to visualize targets that are physically moving or to assess the movement of structures over time. The motion occurring in a 1-dimensional plane is displayed on the vertical axis, and time is displayed on the horizontal axis (Fig. 2B). The M-mode images are obtained by placing the cursor over the moving object on the B-mode image and activating the M-mode function. M-mode is very useful in the evaluation of cardiac valves and fetal heart activity. When speaking in terms of LUS, M-mode helps the clinician assess the respiratory variability of the inferior cava and, most importantly, identify pneumothorax.[14] The lung and pleural structures are assessed using B-mode, whereas pleural movement is assessed with M-mode.[15]

Currently there are no recommendations regarding the superiority of any specific mode for lung assessment. A specific mode or probe can be selected upon the lung

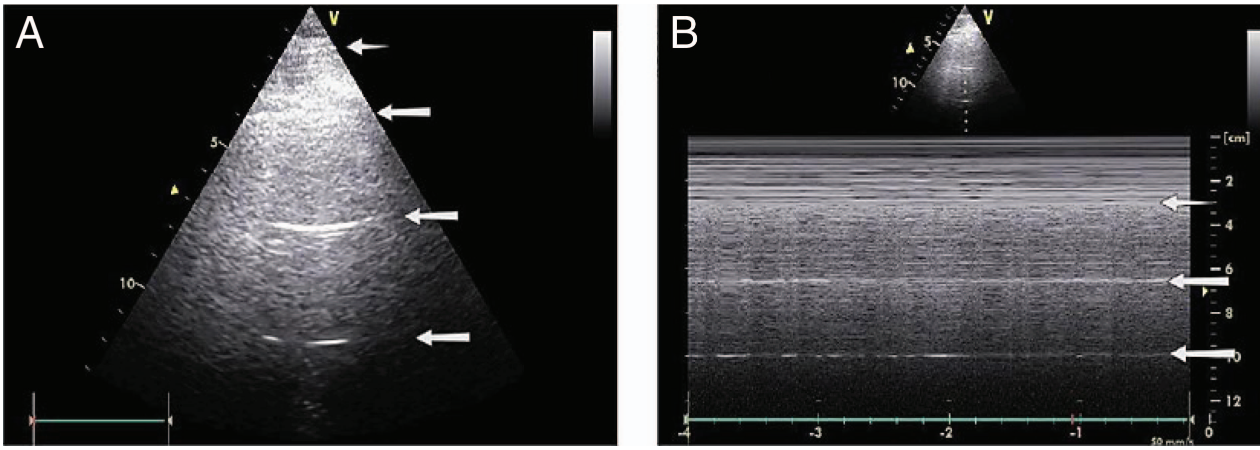

Fig. 2. Normal lung imaging, using B-mode and M-mode. A: B-mode illustrates A-lines. The A-lines or horizontal lines arising from the pleural line (arrow) are separated by regular intervals that are equal to the distance between the skin and the pleural line. B: M-mode shows the pleural line. Under the pleural line is the seashore sign (sandy pattern) due to the lung dynamics and pleural sliding. The horizontal lines are A-lines, separated by regular intervals (arrows). From Reference 110, with permission.

findings and clinician's discretion, with optimal settings recommended for lung imaging.[16,17]

Clinical Applications of Lung Ultrasound

As an imaging technique, LUS is easy to learn and simple to perform, and it has clear clinical utility in acute care medicine. Perhaps because bedside LUS in acute care is an essential technique for better patient outcomes, it required a pioneer from intensive care medicine, Dr Daniel Lichtenstein, to develop and implement this concept. LUS, a focused application of acute-care ultrasonography, helps clinicians rapidly diagnose and formulate immediate therapeutic plans related to lung disorders and pathologies. The LUS examination consists of 12 imaging zones, 6 on each side of thorax. The upper and basal part of each hemithorax is divided into anterior, lateral, and posterior zones, defined by the anterior and posterior axillary lines (Fig. 3).[18] To master this imaging technique, one should have a clear understanding of the 7 principles and 10 basic signs of LUS, along with the required skills.

Following are the 7 principles of LUS, as described by Dr Lichtenstein in his work in 2004,[19] with an update on the seventh principle:[20]

(1) A simple, unsophisticated ultrasound machine is adequate to perform LUS.
(2) Artifacts are generated in the thorax because gas and fluids have opposite locations or are mingled by pathologic processes.
(3) The lung is the most voluminous organ in the body with an extensive surface area (about 1,500 cm^2). Thus, precise areas need to be defined.
(4) All lung signs arise from the pleural line.

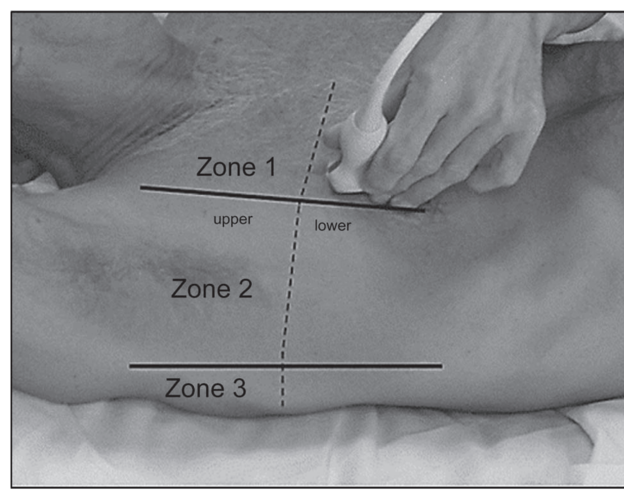

Fig. 3. Zones of lung ultrasound imaging. From Reference 18, with permission.

(5) LUS is largely based on the analysis of artifacts generated, and previously this was addressed as an issue to indicate the infeasibility of LUS.
(6) The lung is a vital organ and hence lung signs arising from the pleural line are dynamic.
(7) A majority of acute, life-threatening lung disorders abut the pleural line, explaining the potential of LUS. Almost all life-threatening disorders, even those that may be less prominent in other tests, will show an extensive location with LUS, such as a pneumothorax, which can be small but still visible in a reasonably large projection.[20]

LUS necessitates the understanding of the following 10 basic signs for interpreting underlying normal and ab-

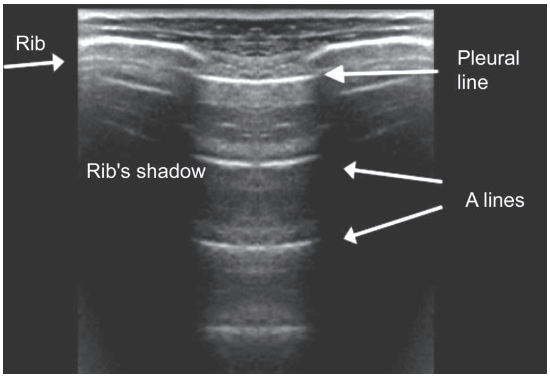

Fig. 4. Normal lung ultrasound image (B-mode) with the bat-wing sign and A-lines. From Reference 108, with permission.

normal lung conditions.[13,21,22] These signs have been assessed in various studies and have diagnostic accuracies ranging from 90–100%, which makes LUS a reasonable choice for the accepted bedside standard.[23]

For any ultrasound image obtained, a baseline image is required to correlate normal with abnormal. Similarly, the baseline normal image obtained during LUS is the pleural line/bat-wing sign. This baseline image is obtained in B-mode during initial lung screening. The pleural line lies 0.5 cm below the adjacent upper and lower rib shadows, yielding the appearance of a bat wing, with the ribs as the wings (Fig. 4). All LUS signs arise from the pleural line except for subcutaneous emphysema, where air under the skin will abolish the properties of ultrasound waves.

The second sign is the A-line or A-profile, which is a static sign seen in B-mode. Some of the ultrasound waves will bounce back and forth between the pleura and the transducer, generating reverberation artifacts called A-lines. These fundamental, hyperechoic, reverberation artifacts of pleural lines are seen normally and are confirmatory for the presence of physiological or free air in thorax (Fig. 4).

Lung sliding is the third sign, and it is normal and dynamic in nature and is seen in B-mode at the same level of pleural line (Fig. 5, left). The parietal and visceral pleura are normally closely adhered with a minimal amount of fluid (< 50 mL in healthy subjects) between them, allowing them to slide over one another during breathing. This appears as a backward and forward movement of the pleura. Lung sliding is synchronized with breathing, as the lungs descend toward the abdomen on inspiration. Lung sliding reflects the normal physiological movement of the lung toward the chest wall. This corresponds to the seashore sign in M-mode, which reflects the relation between lung sliding and superficial tissues (Fig. 5, right).

The fourth sign is the quad sign: it is an abnormal static LUS sign seen in B-mode, and it indicates the presence of a pleural effusion and is limited by 4 regular borders (Fig. 6A). The cephalic and caudal borders of a pleural effusion

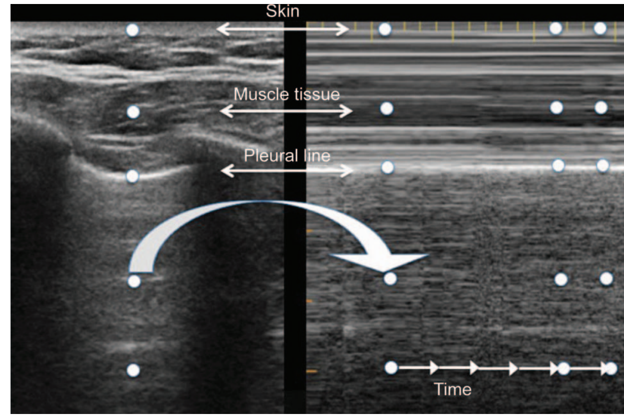

Fig. 5. Normal lung sliding image in B-mode (left) and the resultant normal seashore sign in M-mode (right). From Reference 108, with permission.

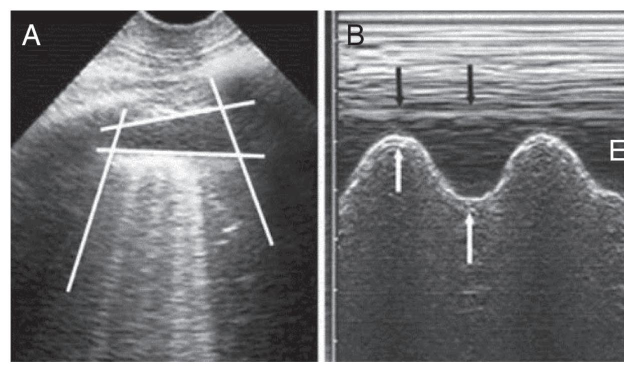

Fig. 6. Quad sign in B-mode and sinusoid sign in M-mode suggestive of pleural effusion. A: Below the pleural line, the regular line that is roughly parallel to the pleural line is the lung line, indicating the visceral pleura. This line, together with the pleural line and the shadow of the ribs, displays the quad sign. B: M-mode shows a movement of the lung line (white arrows) toward the pleural line (black arrows) on inspiration; the sinusoid sign, indicating a free pleural effusion and a viscosity enabling the use of a small-caliber needle if thoracentesis is envisaged. E = expiration. From Reference 21, with permission.

are formed by the ribs at the top and the parietal and visceral pleura at the bottom. The deep boundary of the collection is regular, roughly parallel to the pleural line, and is called the lung line (ie, visceral pleura). If the image is obtained by excluding the diaphragm, the pleural effusion will appear as rectangular (ie, the quad sign), and in case of a significant effusion with the diaphragm visible, the basal lung can be seen floating in the irregular image of the effusion.

The fifth sign is the sinusoid sign, which is an abnormal dynamic LUS sign seen in M-mode, and it indicates the presence of a pleural effusion (Fig. 6B). This sign is displayed when the lung line moves toward the pleural line during inspiration. The sinusoid sign is obtained when the M-mode is activated by keeping the cursor in the center of

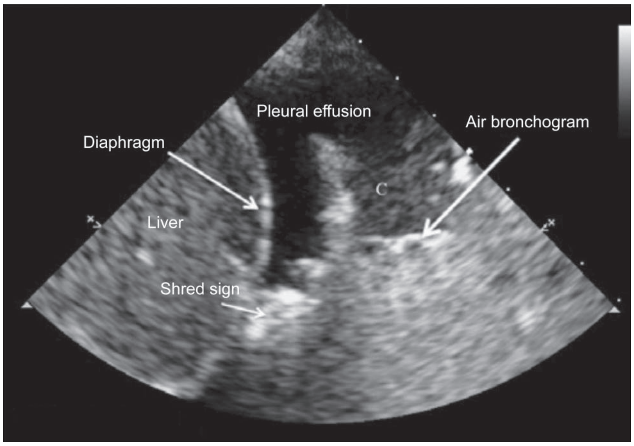

Fig. 7. Tissue-like sign and shred sign in B-mode, suggestive of consolidation. C = consolidated lung. From Reference 108, with permission.

the field with a large amount of pleural fluid as seen in B-mode. A sinusoid sign reinforces the clinician's findings that a pleural effusion is present and that the pleural fluid is not necessarily compromising lung dynamics.

The sixth sign mentioned is the shred sign, which is an abnormal sign seen in the B-mode. The shred sign represents non-translobar consolidation in most cases. The shred sign is formed when the border between consolidated and aerated lung is irregular, forming the fractal line, which is fully opposed to the lung line. This is a suggestive sign of pneumonia.

The seventh sign is the tissue-like sign, an abnormal sign that is observed in B-mode when there is a translobar consolidation (Fig. 7). When the lung is excessively filled with fluid, its echogenicity bears a resemblance to the liver, which is also called hepatization of lung.

The eighth sign, and one of the most important, is the B-line/lung rocket/comet tail artifacts. B-lines are seen in B-mode, and they are hyperechoic, long, vertical lines that originate from the pleural line and traverse the entire ultrasound screen, down to the bottom of the screen, erasing the normal A-lines (Fig. 8). These artifacts result from the mingling of air in the alveoli and water in the interlobular septa, due to the marked difference in acoustic impedance. The sound waves reverberate back and forth between the septa (because of the juxtaposition of air and water), creating a line for each reverberation that combine to form B-lines. The presence of B-lines is highly suggestive of alevolar-interstitial syndromes and pulmonary edema. B-lines are also known as lung rockets or comet tail artifacts.

The ninth sign is absent lung sliding, which is an abnormal sign observed in the B-mode and is one of the 3 findings to confirm pneumothorax. The presence of air in the pleural space prevents the visualization of visceral pleura, and lung sliding will not be seen. To observe absent lung sliding, 2 adjacent ribs should be identified with

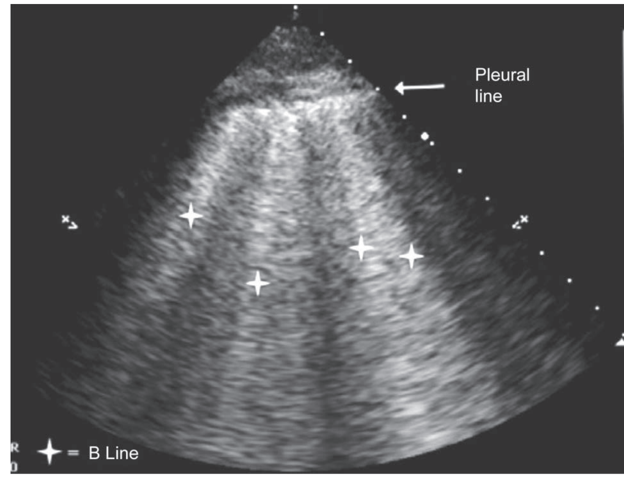

Fig. 8. B-lines/lung rockets/comet tail artifacts in B-mode, suggestive of alveolar interstitial syndrome/pulmonary edema. From Reference 108, with permission.

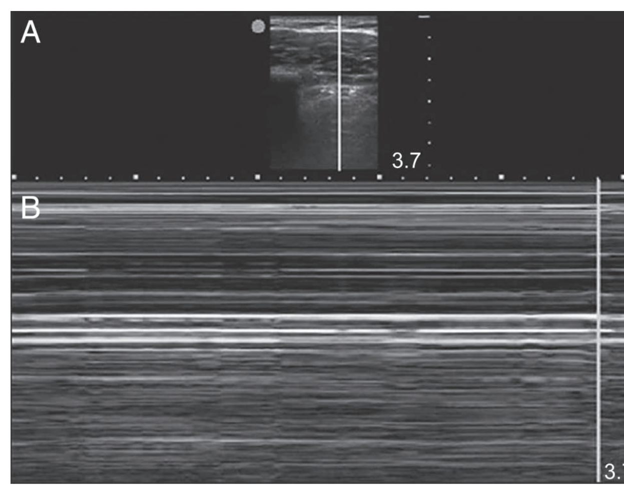

Fig. 9. Absent lung sliding image in B-mode A: and the resultant stratosphere sign/barcode sign in M-mode B:, suggestive of pneumothorax. From Reference 109, with permission.

the pleural line in between them. The typical back and forth movement of the pleural line with breathing will not be seen if there is any pleural involvement (pneumothorax, pleural effusion, pleurodesis) or lung involvement (pneumonectomy, pneumonia, lung intubation).[13] M-mode is also used to confirm absent lung sliding. The resultant M-mode image in a pneumothorax will only display 1 pattern of parallel horizontal lines above and below the pleural line, demonstrating the lack of movement. This pattern bears a resemblance to a barcode and is often termed as barcode sign or stratosphere sign (Fig. 9).[24,25]

The tenth sign is the lung point, which is an abnormal sign seen in the M-mode. Lung point is the point at which the 2 pleural layers rejoin one another (Fig. 10). Lung point is considered as confirmatory for pneumothorax, pro-

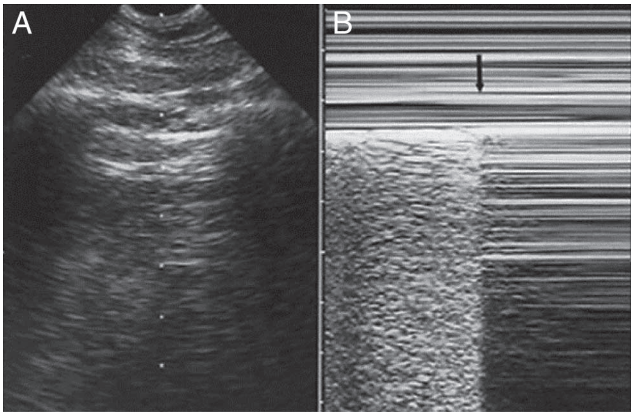

Fig. 10. Lung point, both in B-mode and M-mode, suggestive of pneumothorax. A: The pleural line just before the visceral pleura appears. B: The very moment the visceral pleura has touched the parietal pleural (arrow). This sign is called lung point; it can be seen along a line, but one point is sufficient for the diagnosis. From Reference 21, with permission.

vided lung sliding and B-lines are absent.[13] This point will be visible by activating the M-mode and keeping the probe in the area at which the sliding is appearing and disappearing. Lung point represents the meeting point where lung inflation and deflation take place.

A literature review has revealed that, apart from these diagnostic approaches in ICUs, LUS is also helpful in managing ventilated patients, from confirmation of endotracheal intubation to initiation of mechanical ventilation and prediction of weaning outcome.[26,27] The reduction of ventilator-related barotraumas through optimal PEEP and opening pressures are routinely practiced,[28] whereby LUS can be a useful imaging tool for quantifying lung volume during mechanical ventilation,[29] thereby preventing associated injuries.

It is necessary to mention some of the limitations of LUS, the most prominent being operator skill. This reinforces the fact that proper understanding and skills training in LUS is a prerequisite for reliable results.[30] LUS also has patient-dependent limitations because it is difficult to examine obese patients using LUS due of the thickness of their rib cage, the presence of subcutaneous emphysema, or large thoracic dressings, any of which can alter or impede the transmission of sound waves to the lung periphery. It is also important to mention that LUS cannot detect hyperinflated lung fields that result from an increase in intrathoracic pressures.[16] Another limitation is in the pediatric population, where LUS cannot address certain features, such as in a chest radiograph of a child presenting with respiratory distress, including hyperinflation and cardiac size and shape.[31] To be specific and comprehensive, a LUS assessment should take approximately 15 min, and with adequate knowledge and skills, clinicians can perform a lung examination more quickly.[16]

Lung Ultrasound by Non-Physicians

Although LUS requires only a short period of training, there remains considerable debate as to who should perform LUS.[32] Long regarded as a technique to be performed by a physician, some recent studies[33,34] suggest that the performance of LUS should be extended to other health care professionals, including physiotherapists and nurses.[33,34] There is a paucity of literature that reflects the role and exposure of respiratory therapists (RTs) in LUS; we also looked into related areas such as respiratory physiotherapy and nursing, with an emphasis on their experience with LUS.

In the only available study that focused on LUS training for RTs, the authors concluded that RTs trained in ultrasound are independently capable of performing LUS with an accuracy of $> 95\%$.[35] The authors designed a curriculum that covered both theory and practical applications of LUS. The theory portion was completed through lectures, internet resources, and self-study modules; the practical component was completed under direct supervision of an instructor. The authors demonstrated that upon completion of 10 supervised scans, $< 2\%$ of trainees required assistance with image acquisition, and $< 5\%$ of the images were interpreted incorrectly. Despite the fact that not all RTs had a chance to scan or diagnose pneumothorax because of fewer incidences, all of the RTs were able to independently identify normal images like A-lines or A-profiles, thereby meeting the exclusion criteria of pneumothorax. In a short review of the abovementioned study, the reviewer mentioned that LUS training can be done in a short period of time with appropriate theoretical knowledge and practical demonstrations. The review also identified further need of clinical outcomes data on LUS performed by RTs.[36]

In one case study, the authors mentioned that the addition of LUS helped determine the diagnosis of pleural effusion in a symptomatic and deteriorating patient, after a chest radiograph and auscultation did not. Chest physiotherapy and bronchial hygiene therapies were tried initially, yet LUS aided in the diagnosis of pleural effusion and drainage of pleural fluid, thereby preventing intubation.[37] In a conference proceeding, 4-phase LUS training was used to train RTs to use the technique independently,[38] and still another review concluded that the superior sensitivity and specificity of LUS would help critical care clinicians reach an accurate, point-of-care diagnosis of respiratory disorders, enabling them to plan the need and determinants of respiratory care maneuvers.[33] Another narrative review also found that LUS could be an additional advantage alongside other assessment modalities to guide, monitor, and evaluate the effectiveness of chest physiotherapy.[39]

Literature reviews have demonstrated that nurse-performed LUS is also accurate in identifying cardiorespiratory derangements. In one study, the authors assessed nurse-performed LUS in diagnosing cardiogenic dyspnea, and they found a sensitivity and specificity of $> 95\%$.[40] The authors concluded that nurses with LUS training can accurately categorize patients with cardiogenic or non-cardiogenic dyspnea in emergency departments. Another study suggested that nurse-performed LUS may be a potentially useful alternative to the traditional physician-performed LUS. They observed good accuracy in diagnosing cardiogenic dyspnea and summarized that nurse-performed LUS, in combination with brain natriuretic peptide, is useful in ruling out dyspnea of cardiogenic origin.[41]

In contrast, another study that looked into the feasibility of paramedic-performed prehospital LUS found this approach to be nonsignificant because $> 50\%$ of the scanned images were deemed uninterpretable upon expert review.[42]

The Emerging Role of Respiratory Therapists

RTs possess the knowledge, skill, and ability to provide a wide range of diagnostic and therapeutic procedures to patients who require basic, advanced, and prolonged cardiopulmonary and related services. In addition, RTs are most advantageous in improving patient outcomes and thereby reducing morbidities.[43,44] An example of their advancement in professional practice is the presence of qualified RTs in therapeutically hybrid areas like extracorporeal life-support therapy.[45-47] It can be seen that ICUs around the world are implementing standard guidelines and protocols for mechanical ventilation, and this empowers RTs to be involved in ventilator management, including the selection of ventilator mode, determining the ventilation strategy, and participating in the decision to wean.[48,49] Many randomized, controlled studies have concluded that RT-driven mechanical ventilation protocols result in shorter weaning times, increased successful extubation rate, and ventilator-free days, as well as a reduction in overall morbidities.[50,51] An extended clinical role for RTs was demonstrated when a prospective LUS training study and subsequent review highlighted that RTs who are naïve in ultrasonography could be trained to perform LUS independently and competently, with a post-training accuracy of $> 95\%$.[34,35]

Because RTs are mainly involved in the care of acutely ill patients, we reviewed the scope of lung, diaphragmatic, and airway ultrasound in the following applied areas, where their expertise can be widely utilized.

Recognition of Pneumothorax

Of all the ventilator-associated complications, pneumothorax was found to be an independent predictor of mortality during mechanical ventilation.[52] Pneumothorax was also associated with a significant increase in morbidities such as increased length of ICU and hospital stay.[53] Pneumothorax is rarely seen in ventilated patients with normal lungs, and it is most often seen in patients with underlying respiratory pathology, such as obstructive airway diseases and ARDS.[54-56] The main causative factors are inappropriate PEEP and barotrauma.[54,57,58] Many of the clinical subjective and objective findings are nonspecific and are not considered to be reliable indicators of pneumothorax.[59] Imaging techniques remain the accepted standard for the recognition of pneumothorax.[60]

In the ICU, most patients are in a supine or semi-recumbent position, and anterior–posterior chest radiograph films are often obtained, limiting the reliability of chest radiographs.[61,62] Although computed tomography is considered to be the optimal choice, it is not always practical or safe to move a hemodynamically unstable, ventilated patient to the radiology department to exclude pneumothorax.[6] Hence, the practice of LUS for the diagnosis of pneumothorax has emerged as the method of choice with clinicians who can perform bedside ultrasonography.[63,64] Acute worsening of ventilated patients with cardiorespiratory compromise is a challenging scenario in ICU practice. The mnemonic DOPE is often used to identify the cause, where D stands for dislodgement of the endotracheal tube, O for obstruction of tube, P for pneumothorax, and E for equipment failure.[65] Of these 4 concerns, all except pneumothorax are recognizable and manageable at the bedside without much delay. It is understood that management of pneumothorax is often delayed due to the lack of prompt recognition. The ultrasound features of pneumothorax includes abolished lung sliding, absence of B-lines, absence of the lung pulse, and presence of the lung point.[66] The sequential assessment of pneumothorax starts with looking for the presence of lung sliding on the highest point of the anterior chest, which can exclude pneumothorax within seconds. If lung sliding is absent, then the presence of B-lines is checked to rule out pneumothorax. If there is no sliding and no B-lines, then the lung point should be sought, which confirms the presence of pneumothorax. Basic training with a 5-min online video showed a high accuracy in giving clinicians knowledge to exclude pneumothorax, and that this knowledge was retained for at least 6 months.[67]

RTs, being one of the primary practitioners of mechanical ventilation, play an important role in the identification and rectification of ventilator-related problems, and LUS may specifically facilitate their diagnostic skills in identifying pneumothorax.

Weaning from Mechanical Ventilation

Alternatively of interest for RTs is the utility of ultrasound in predicting weaning outcome. Weaning or liberation from mechanical ventilation is a complex, multifactorial process with a failure rate of approximately 20%.[68] Diaphragmatic ultrasound provides a direct and rapid assessment of diaphragmatic movement and function because it is a prime indicator of a patient's spontaneous efforts.

It is of clinical interest whether diaphragmatic ultrasound can predict successful weaning. In a prospective cohort, the authors used diaphragmatic ultrasound to assess mean diaphragmatic thickness (mean of daily assessed end-expiratory diaphragmatic thickness), diaphragmatic thickness fraction (thickness at end inspiration − thickness at end expiration/thickness at end expiration × 100), mean diaphragmatic excursion (average of diaphragmatic excursion during tidal breathing), and diaphragmatic dystrophy (diaphragmatic thickness < 2 mm). They observed that all of these variables were significantly decreased with the increased length and duration of mechanical ventilation, thereby concluding that diaphragmatic ultrasound is a sensitive tool for predicting weaning outcome.[69]

In another study, investigators examined ultrasound assessment of diaphragmatic movement and lung aeration, and they concluded that these techniques were superior for predicting the weaning process in comparison to the traditional indices related to blood gases and respiratory mechanics.[70] The loss of lung volume after extubation is a hallmark sign of extubation failure, leading to poor gas exchange, prolonged mechanical ventilation, and increased mortality and morbidity.[71] Lung aeration loss can be estimated using a validated score called the Lung Ultrasound Score. The LUS score of aeration is calculated for each given region of interest. Points are allocated according to the worst ultrasound pattern observed: normal aeration = 0, well separated B-lines = 1, coalescent B-lines = 2, and consolidation = 3 (Fig. 11).[26] A LUS score ranging between 0 and 36 was calculated as the sum of each region.[72] The authors concluded that the LUS score of aeration changes during a successful spontaneous breathing trial can accurately predict postextubation distress. They also concluded that a LUS score of < 13 predicts successful extubation, whereas a LUS score of > 17 is considered a threshold for postextubation distress and extubation failure. Because RT-driven weaning protocols are accepted globally, the addition of diaphragmatic ultrasound screening is likely to help in predicting successful weaning and extubation.

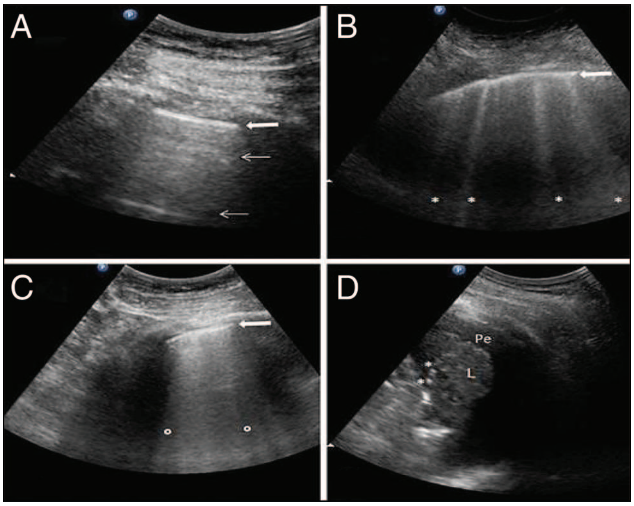

Fig. 11. Lung ultrasound patterns corresponding to progressive loss of aeration. A: Normal pattern with multiple horizontal A-lines. B: The pleural line is visible with separated B-lines, suggestive of moderate lung aeration loss. C: The pleural line is visible with coalescent B-lines arising from the pleural line, suggestive of severe in lung aeration loss. D: Transverse view of a consolidated lower lobe. From Reference 26, with permission.

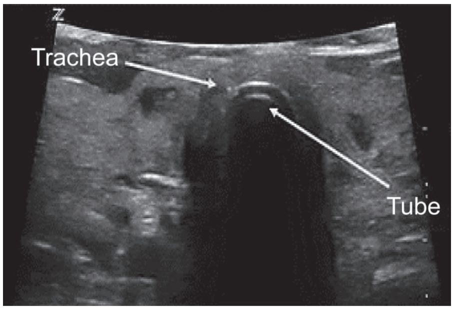

Fig. 12. Ultrasound image of endotracheal intubation, with semicircular hyperechogenicity. From Reference 83, with permission.

Airway Management

RTs participate as key members of airway management teams, where their expertise is appreciated from basic bag-valve-mask ventilation to advanced techniques related to difficult intubations. Airway imaging is a newer application of ultrasonography that is proven to lead to better patient outcome.[73-75] Airway ultrasound is useful in various areas of RTs' involvement in airway management, including confirmation of endotracheal tube placement,[75,76] prediction of difficult intubation,[77] prediction of pediatric endotracheal tube size and placement,[78,79] detection of subglottic stenosis,[80] prediction of postextubation stridor,[81] and confirmation of laryngeal mask airway position.[82] Ultrasound confirmation of endotracheal intubation is achieved by keeping the transducer at the level of the suprasternal notch in the transverse approach, where the shadow of the endotracheal tube is seen as semicircular hyperechoic lines in the trachea with an empty esophagus (Fig. 12).[83] Positioning the linear probe transversely over the cricothyroid membrane during the intubation process results in confirmatory reverberation artifacts, known as the bullet sign.[84] Similarly, esophageal intubation is detected by a double tract sign (Fig. 13), whereby the esoph-

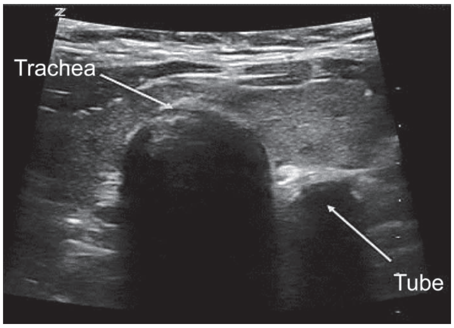

Fig. 13. Ultrasound image of esophageal intubation, with double tract sign. From Reference 83, with permission.

agus will be distended with the endotracheal tube inside. Both the tracheal and the esophageal tracts are seen in Figure 13, indicating esophageal intubation.[83]

A systematic review and meta-analysis concluded that trans-tracheal ultrasound confirms endotracheal intubation with superior sensitivity and specificity. The review also confirmed this technique's utility in emergency intubations as an initial assessment before the final confirmation with capnography.[85] Yet another recent prospective cohort concluded that airway ultrasound, end-tidal capnography, and a conventional clinical method of 5-point auscultation have comparable sensitivity and specificity in identifying tracheal or esophageal position of the endotracheal tube. The authors also confirmed the clinical importance of ultrasonographic assessment because the time difference in confirming endotracheal tube placement was observed to be significantly faster than the other 2 methods.[86] As advocates for patient safety during airway management, RTs could justify extending their scope of practice with airway ultrasound to enhance patient safety and reduce adverse events.

Competency and Training in Lung Ultrasound

A review of the literature shows that, although some researchers have attempted to standardize the essential skills to attain competency in LUS among ICU physicians, the duration of training needed remains unclear.[87,88]

It is also evident that the ultrasound training of mid-level providers and other non-physicians in developing countries is relatively inadequate. The utility, however, is growing,[89-91] and it is suggested that, if educated, non-physician professionals would be able to adopt ultrasonography into their clinical practice and would utilize it frequently.[92]

A significant difference is observed in the duration and methodology of LUS training programs that are currently available. It has been observed from a number of small studies and conference abstracts that LUS skills can be satisfactorily attained with anywhere from 2 h to 4 months of training, and with 20–80 supervised scans.[93-98]

Some authors have suggested the need for a minimum of 100 chest ultrasound procedures[99] to confirm competency, whereas others have emphasized a duration of LUS training for acceptable competency ranging from 30 min[94] to 7 months.[100] One study proposed performing several LUS examinations on a daily basis to help clinicians become competent in identifying pleural effusion, lung consolidation, and alveolar interstitial syndrome within 6 weeks.[16] However, the authors did not specify the number of scans required.

In a recent publication, a new scale, the Assessment of Competency in Thoracic Sonography, was introduced to assess the quality of point-of-care thoracic ultrasound performed by new learners. The authors concluded that the scale was effective in making valid judgments regarding the competency of novices in point-of-care thoracic ultrasound, and the majority of learning improvement occurred in their first 25–30 practice studies.[101]

Another publication on competency assessment of LUS was the LUS–Objective Structured Assessment of technical skills. The 26-element competency check includes 6 domains: indication for LUS examination, systematic approach, technical skills, recognition and differentiation of normal anatomy from pathology, documentation and reporting the examination, and diagnostic conclusion. The authors concluded that this assessment tool provides a relevant, valid, and feasible method to assess the competency of operators from diverse medical specialties.[102]

While there is a learning curve associated with the application of LUS, it is relatively short,[103] and the diagnostic yield of LUS largely depends on the performer's expertise.[104-106] A consensus process was aimed at unifying the approach and language of 6 major areas of LUS (ie, terminology, technology, technique, clinical outcomes, cost effectiveness, and future research) to obtain LUS effectiveness in various clinical settings, such as acute care areas, operating rooms, and out-patient clinics. They advocated LUS as a point-of-care tool, with training attained through the combination of theory and bedside mentoring.[107]

Because LUS is not routinely used by RTs in clinical practice, the level of training, the number of scans, and the duration of training required to achieve competency in LUS is unknown. Considering the vast scope of practice and intended positive outcomes, RTs can be utilized for performing LUS subsequent to adequate training and competency assessment. Hence, it is highly suggested that professional respiratory care bodies of various countries initiate training programs for LUS among RTs with competency certification.

Conclusion

It is apparent from this review that the potential role of RTs in imaging areas, specifically LUS, is vast but underutilized. The in-depth knowledge and skills possessed by

RTs, acquired throughout their academic and clinical careers, provide an ideal foundation for them to identify and manage any cardiorespiratory emergency. We are well acquainted with the range of RTs' responsibilities, and we therefore believe RTs should be trained in LUS. Acquiring this skill is a benchmark in current practice, and it may assist RTs in reducing adverse events in ventilated patients. Lung, diaphragmatic, and airway ultrasound appear to be closely related and promising tools for RTs' because they offer better diagnostic accuracy in resource- and time-limited settings. It also appears to be a clinical technology that is easily taught.

Foreseeing professional advancement and better patient outcomes, we recommend the inclusion of a comprehensive respiratory care–related ultrasound training module within the existing worldwide respiratory therapy curriculum. We also suggest a well-structured respiratory care protocol related to ultrasound training for working RTs, to augment their technical and clinical decision-making skills for safer practice.

Directions of Future Research

This review was aimed at exploring the potential for respiratory therapists to perform LUS, as well as diaphragmatic and airway ultrasound. However, there are substantial gaps identified from the current available literature regarding RTs' exposure to diagnostic ultrasound, although it clearly has an influence on respiratory care practices. Future research focusing on randomized, controlled, academic and clinical trials using diagnostic ultrasound as a part of a respiratory therapist's clinical practice is highly recommended. The need for prospective studies to explore training requirements for respiratory therapists to attain competency in lung, diaphragmatic and airway ultrasound is also suggested. Such studies may subsequently reflect the scope of inclusion of diagnostic ultrasound in respiratory care services. Conducting randomized clinical trials on patient outcomes is challenging, hence alternative methods of demonstrating efficacy, such as comparative accuracy and decision making studies, may also be explored.

We therefore emphasize that the wide clinical scope of diagnostic ultrasound, and the lack of its related literature in the respiratory care profession, as reflected in our review should be considered an eye opener for respiratory therapists to get involved in the training and subsequent practice of this imaging tool.

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