Review Article

Applications of Ultrasonography in Respiratory Intensive Care

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Abstract

Emerging evidence suggests that ultrasonography of lung is a fast, inexpensive, widely available bed-side diagnostic tool which is useful for quick and early diagnosis of respiratory diseases. It is useful in the differential diagnosis of pulmonary infiltrates and has good accuracy in identifying consolidation and alveolar-interstitial syndrome. This technique can also be useful in the immediate evaluation of patients with dyspnoea or acute respiratory failure in the respiratory intensive care unit and helps in monitoring treatment response. Ultrasonography of lung has also been found to be useful in the diagnosis of pulmonary embolism, traumatic lung contusion and lung consolidation as well. There is a need for developing specific guidelines for establishing the standards of training and education regarding lung ultrasonography in India.

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Key words: Acoustic power, Ultrasound, Respiratory diseases.

Introduction

Ultrasound is a form of inaudible sound energy used for diagnostic purposes at a frequency range of 2-20 MHz. The ultrasound pulse is generated by piezoelectric crystals in the transducer of the device, generating waves that are transmitted, attenuated, and reflected by the tissues. Although nearly all of the energy is reflected back, the difference in acoustic impedance among tissues changes the ultrasound signal strength; this provides information regarding the location and characteristics of tissues, which are processed into gray scale images, on which ultrasound technology is based.[1]

Although ultrasonography is conventionally performed by radiologists, several studies have evaluated the use of ultrasound by non-specialists, including emergency room physicians, intensivists, and pulmonologists.[2-7] The advantage of lung ultrasound is that it is a bed-side tool, which can be applied immediately, and its findings can be correlated with clinical diagnosis.[3] Furthermore, lung ultrasound is especially attractive also for the evaluation of critically ill patients (Table 1).[1-3, 8-10]

Table 1. Advantages of ultrasound in respiratory diseases, both in emergency and routine diagnosis[1-3,8-10]

Easy to learn
Fast, non-invasive and easily reproducible
Portability: bed-side evaluation eliminates the need for transporting the patient and the risk thereof
Widely available
No exposure to radiation
Good accuracy
Aids in establishing the diagnosis and in monitoring the response to treatment
Low cost

Previous studies have shown that lung ultrasound should be essentially simple and more focused on critically ill patients. The objective of this review article is to evaluate the clinical use and widely acceptability of ultrasound in intensive respiratory care unit by pulmonologist.[2, 8, 11]

One important limitation of ultrasound waves has been the barrier of air, which is a poor conductor of ultrasound waves. As such, ultrasonography of lung was long considered impossible.[8, 12] This limitation was responsible for under-utilisation of this revolutionary technology in respiratory diseases. However, large number of studies have changed this view and have demonstrated that ultrasonography of lung is useful in the diagnostic evaluation of critically ill patients,[1-4, 9,11] more so after pulmonologists started using this technique by themselves.[9, 12]

Ultrasonography of lung is based on the principle that every acute disease reduces lung aeration, changing the lung surface and generating distinct, predictable patterns. This allows the diagnosis of various conditions and the monitoring of therapeutic interventions (Figure 1).[2, 8, 10]

For the purpose of thorough and complete ultrasonography, chest has been divided into three parts (anterior, lateral and posterior) and six zones (1, 2, 3, 4, 5, and 6). Anterior part contains zones 1 and 2 and is separated by the line close to nipple. Lateral part contains zone 3 and 4 and is separated by anterior

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and posterior axillary lines. Posterior part contains zone 5 and 6 and is separated by posterior axillary line and vertebral column (Figure 1).

Figure 1. Clinical photograph showing anterior and lateral part of the chest surface anatomy showing zones 1-4.

Linear probe have frequency of 5-10 MHz is very useful for thin superficial structure, pleura, and underlying tissue. Thin curvy linear probe having frequency of 3-5 MHz is used in case of thick and deeper chest wall.

Recent Advances in the Use of Ultrasonography in Respiratory Intensive Care Unit

Ten standardised signs have been developed which allow the precise localisation of lung surface, the definition of a normal lung surface and of the main disorders like pleural effusion, lung consolidation, interstitial syndrome and pneumothorax. Ultrasonography of lung allows appropriate diagnosis of several acute conditions. The bed-side lung ultrasound in an emergency (BLUE)[13] protocol is a standardised approach to an acute respiratory failure using ultrasonography of lung. The fluid administration limited by lung sonography (FALLS)[14] protocol which describes haemodynamic management of acute circulatory failure using the ultrasonography of lung.

The BLUE Protocol

The BLUE protocol makes exclusive use of lung and venous ultrasound. It is based on profiles, which consider signs combined with topographic distributions. *Bat sign* is the most important sign in ultrasonography of lung and is a pleural line that corresponds to the surface of the lung. *Lung pulse*[10] is a sign of complete atelectasis, with a characteristic pulsation of the lung according to the heart-beat. *Attendant sign of atelectasis* is a relatively common condition in the intensive care unit (ICU), and characterised by the following features: (i) change in the imaging location in the heart; (ii) abolition of the dynamic movement of the diaphragm; and (iii) change in the imaging location of the diaphragm, which is raised by the least 2 cm (in the supine position).[8, 10, 11, 15]

A-line sign (Figure 2) corresponds to complete absence of B-lines and lung rockets (group of comet tail artifacts due to mobility during respiration) and is useful in detecting pneumothorax. *B-lines* are vertical lines that always arise from the pleural line and spread uninterrupted up to the edge of the screen. These are also called *comet-tail artifacts* (Figure 3). Their presence rules out abnormalities, like pneumothorax.

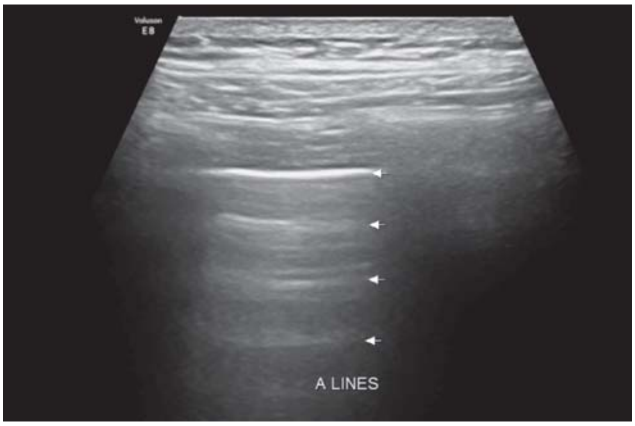

Figure 2. Ultrasonography of the lung showing A-line sign corresponding to complete absence of B-lines and lung rockets and is useful in the diagnosis of pneumothorax.

Figure 3. Ultrasonography of the lung showing lung rockets, a group of comet-tail artifacts. Their presence rules out pneumothorax.

Characteristic signs seen on lung ultrasonography are useful for diagnosing different pathological changes in the lung (Table 2; Figures 4 A & B, 5 A & B and 6 A & B).

The FALLS Protocol

The FALLS protocol uses the potential of the B-lines to indicate pulmonary oedema at the initial silent step, allowing haemodynamic management in acute circulatory failure. At the anterior chest wall, when a pulmonary artery occlusion pressure of 18 mmHg is reached during fluid therapy, B-lines replace the A-lines.

Ultrasonography of the lung has the main advantages of being useful as an immediate bed-side

Table 2. Characteristic signs on lung ultrasound

Sign	Diseases	Ultrasonography Findings
Seashore sign[8, 11] (Figure 4 A & B)	Pneumothorax, complete atelectasis, pleural fibrosis and apnoea	M-mode ultrasonography is the preferred method for lung movement imaging, producing the characteristic "seashore sign"
Stratosphere sign[4, 6-8] (Figure 5 A & B)	Pneumothorax	Stratosphere sign is recognisable on time-motion US, where standard lung sliding disappears. It is particularly useful in the ICU, where pneumothorax is undetectable on chest radiography in 30%-40% of cases
Lung Point (Figure 6 A & B)	Pneumothorax	Lung point is best revealed in M-mode ultrasonography where the exact pathologic location of the pneumothorax can be detected and marked for drainage
Air bronchogram[8, 10, 15]	Pneumonitis, consolidation	Static air bronchogram is usually produced in atelectasis. Dynamic air bronchogram is produced in ventilated areas of the lung and is caused by the presence of air inside bronchi
Alveolar consolidation[8,15,16]	Pneumonitis, consolidation	In alveolar consolidation, ultrasonography of lung is characterised by a tissue-like pattern resembling that of liver. In severely ill ventilated patients these areas are usually found in the lower lobes. The size of the opacity can be evaluated using the consolidation index

Definitions of abbreviations: US=Ultrasonography; ICU=Intensive care unit

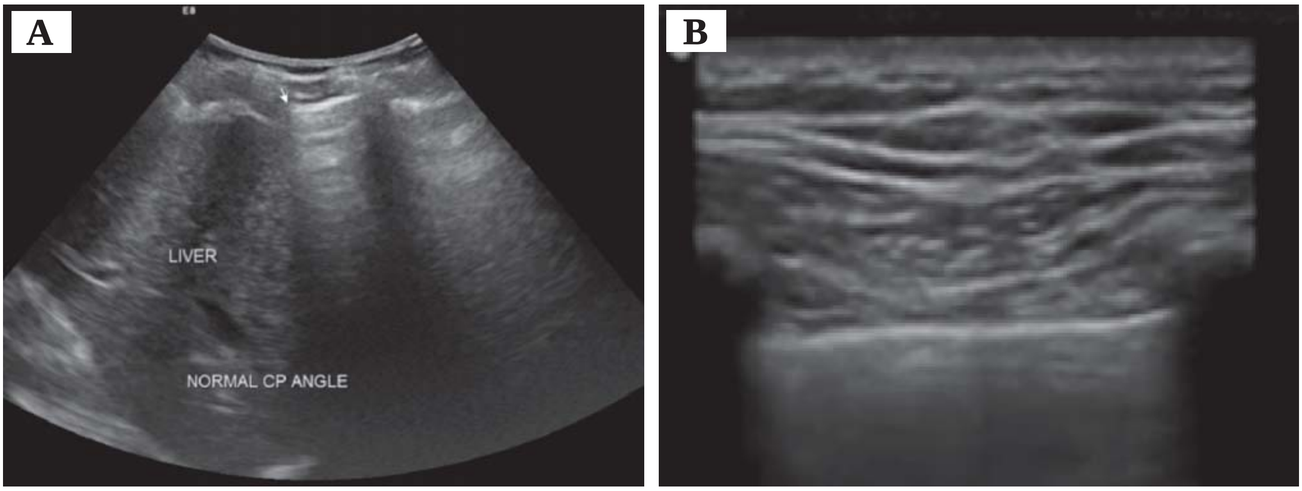

Figure 4. Ultrasonography showing (A) normal lung and (B) ***lung sliding, seashore sign.***

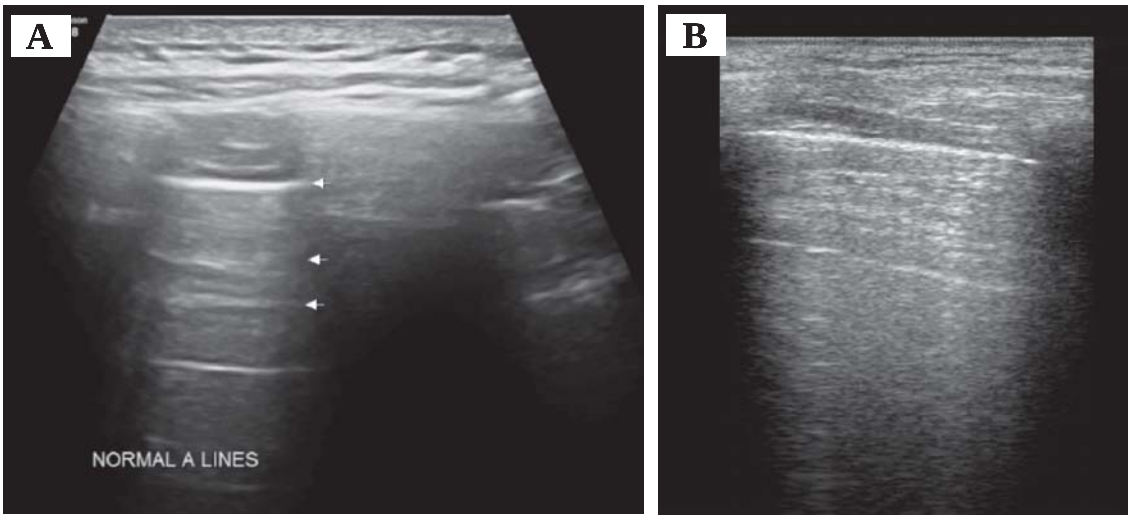

Figure 5. Ultrasonography showing (A) normal lung and (B) ***lung stratosphere sign.***

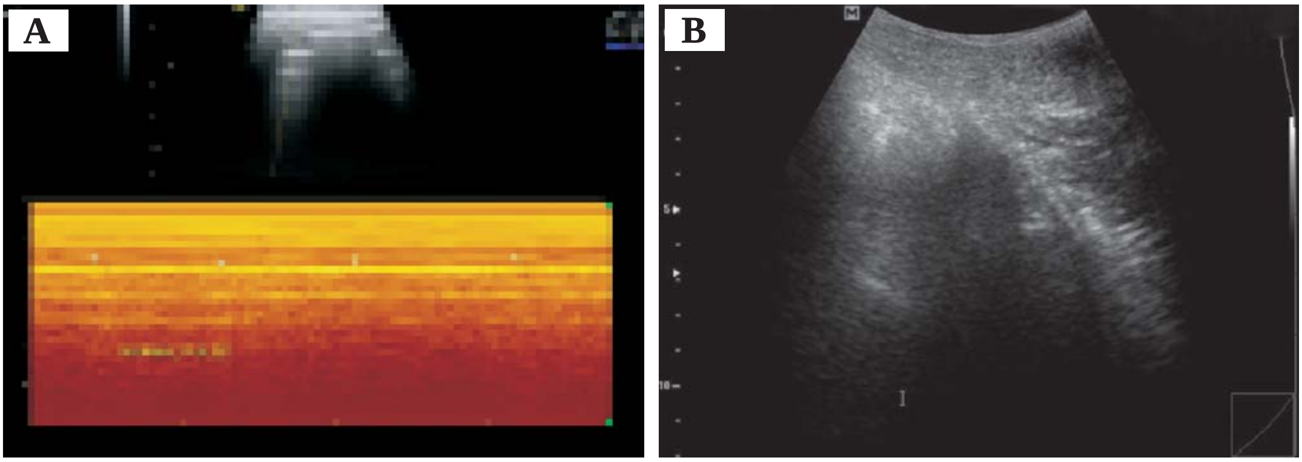

Figure 6. Ultrasonography showing (A) normal lung and (B) *lung point sign*.

diagnostic tool and being an imaging modality that does not cause exposure to ionising radiation.

Although the ultrasonography is considered as a separate and specialised field of investigation to be carried out by a specialist only, however, the ultrasonography of lungs and its clinical interpretation is probably the easiest one to be rapidly learnt by pulmonologists, internists and intensivists with proper training.[17] Unlike the other fields like heart, abdomen, obstetric applications, the normal lung pattern is same, wherever the probe is applied.

Ultrasound *Versus* Computed Tomography in the Intensive Care Unit

Over the last two decades, the use of ultrasonography of lung in critically ill patients has gained popularity, and has yielded good results. It helps in diagnosis of several abnormal conditions, including pneumothorax, consolidation, atelectasis, pleural effusion, and others.

Peris *et al*[17] evaluated the implementation of a protocol for routine lung ultrasonography in patients admitted to the ICU and found a reduction in the total number of chest radiographs and computed tomography (CT) investigations performed.

A prospective comparative study[18] evaluated the use of lung ultrasonography in acute respiratory distress syndrome (ARDS). The authors reported that bed-side lung ultrasonography was highly sensitive, specific, and reproducible for diagnosing the lung pathology in patients with ARDS and can be considered an attractive alternative to bedside chest radiography and thoracic CT.

Presently medical equipment manufacturer in India appears to be focusing much on developing diagnostic equipments for lung based on the advanced ultrasound technology. There is need of comparative studies for correlating the findings of ultrasound of a normal lung with their corresponding pulmonary function testing results so as to understand and quantify the impact of different pulmonary diseases with the help of ultrasonography of lung.

Conclusions

Lung ultrasonography is a modern, inexpensive and highly promising technique that needs to be explored further as a bed-side diagnostic tool. This technology may soon be widely used as a visual stethoscope not only in the ICU, but also in the outpatient and inpatient settings as well as in the emergency room. Further, it is also expected that suitable software applications is developed to help us to transmit images from ultrasound machines to smart phones for interpretation through software applications and inter-departmental review for achieving quick and accurate diagnosis. There is a need for developing specific guidelines for establishing the standards of training and education regarding lung ultrasonography in India.

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