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Original Research Article

Role of Ultrasonography in Diagnosis and Management of Acute Respiratory Failure- An Observational Study from a Tertiary Care Centre in India

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Abstract:

Background: Early and accurate diagnosis of acute respiratory failure leads to improved outcomes of patient management. It relies on reliable imaging modality, which is difficult in an emergency setting.3 Patients admitted in intensive care units are difficult to mobilize for modalities like CT thorax. Hence the importance of bedside ultrasonography in such scenario emerges. It is useful in diagnosis of pneumonia, pleural effusion, pneumothorax, interstitial lung disease etc.

Objective: To study the sensitivity and specificity of chest ultrasound in patients with acute respiratory failure

Methods: This was an observational study conducted in the Department of Pulmonary Medicine, Gauhati Medical College and Hospital from December 2022 to July 2023. Sixty one patients of acute respiratory failure were enrolled in the study and were evaluated with chest X ray, CT Thorax and chest ultrasonography.

Results: Out of the sixty one cases, twenty three patients were diagnosed as pleural effusion (38%), thirteen patients were diagnosed as consolidation (21%), five patients were diagnosed as pneumothorax (8%), eight patients were diagnosed as COPD (13%) and remaining twelve cases were diagnosed to be pulmonary oedema (20%). Overall sensitivity of USG in our study was found to be 86.8%. However, it was found to be least useful for COPD with sensitivity of 62.5%.

Conclusion: Chest ultrasonography with sensitivity of 85.2% is found to be a superior bed side imaging modality compared to standard chest radiography in identifying pleural effusion, pneumothorax, consolidation, pulmonary oedema and COPD. It is also very useful in differentiating an effusion from pleural thickening or consolidation.

Keywords: USG- ultrasound, ARF- acute respiratory failure, COPD-chronic obstructive pulmonary disease, ICU-intensive care unit, CT- computed tomography, GOLD- Global Initiative for Chronic Obstructive Lung Disease.

Introduction

Acute respiratory failure (ARF) is frequently encountered in medical practice which is often life threatening and can have multiple underlying aetiologies. [1] Early and accurate diagnosis of the underlying cause significantly improves patient outcomes and has a substantial impact on patient management and financial burden. [2]

However, early diagnosis necessitates a reliable imaging modality, which is difficult to obtain in an emergency setting.[1] In most instances, bed side portable chest X ray is done, but it is neither sensitive nor specific.[1] Moreover, critical patients of ICU are difficult to mobilize for advanced imaging modalities, such as computed tomography (CT) scan or ventilation-perfusion (V/Q) scan.[2] Additionally, repeated chest X rays result in a non-negligible amount of radiation exposure.[2] Data suggests that accurate diagnosis in ICU is difficult based on commonly available investigations. [2] Even under carefully controlled exposure conditions, more than 30% of the X ray films are considered to have suboptimal quality for interpretation. [8]

Lung ultrasound (USG) is a radiation-free, cost effective, rapid, and portable modality which allows real-time imaging of pulmonary structures. [1] In comparison to chest X ray, lung US may have higher sensitivity and similar specificity for

detection of pleural effusion, pneumonia, pneumothorax, and pulmonary oedema. [9] The Bedside Lung Ultrasound in Emergency (BLUE) protocol offers a standardized method for conducting lung ultrasound in the ICU. [1] This procedure can be completed within three minutes and has a diagnostic accuracy exceeding 90% for conditions such as asthma, chronic obstructive pulmonary disease, pneumonia, pneumothorax, pulmonary oedema, and pulmonary embolism. [9]

Lung US is particularly useful in identifying pleural fluid, which appears as either anechoic or hypoechoic relative to adjacent soft tissue. It can detect effusions as small as 20cc.11 It is considered superior to standard chest radiography in identifying pleural effusions and in differentiating pleural effusion from pleural thickening or lung consolidation. [2] Compared to chest CT, pleural ultrasonography demonstrates 93% sensitivity and specificity for identifying pleural effusion. [2]

Lung consolidation has an echogenicity on ultrasonography that is comparable to the density of tissue, particularly resembling the liver, a phenomenon known as sonographic hepatisation of the lung. [2] Within the consolidated lung, punctate and hyperechoic foci are often visible. [14] If these foci move in a respirophasic manner, which indicates the patency of the bronchus supplying that portion of the lung. [2] Demonstration of consolidation on lung USG strongly correlates with the results of CT chest. [15]

Lung USG plays an important role in pneumothorax also. [2] Presence of lung sliding and A-lines indicate normally aerated lung at the site where the probe is applied to the chest. [16] Identification of a lung point on lung USG yields 100% specificity for pneumothorax. [2] Pneumothorax can also be identified using M-mode USG, which exhibits a characteristic pattern known as the "barcode/ stratosphere sign." [17]

Lung USG surpasses chest radiography in sensitivity for detecting pneumothorax. [17] The addition of color Doppler US can enhance pneumo thorax detection, as the absence of a color signal from the lung is indicative of the air barrier created by the pneumothorax. [3] Lung USG is also highly sensitive and specific in distinguishing cardiogenic from non-cardiogenic causes of acute respiratory failure. Diagnosing acute pulmonary edema by detecting characteristic finding of B-lines has enabled in optimizing fluid replacement particularly if patient presents with shock. [2] Lung USG had a higher sensitivity and specificity for detecting pulmonary edema compared to chest X-ray, suggesting that it could be a valuable tool in the early diagnosis and management of acute respiratory distress. [2]

In COPD, the sensitivity of thoracic USG in the detection of emphysematous bullae is very low (18.18%), however presence of Multiple A and B-lines are significantly more common in patients of COPD belonging to GOLD group D. [2]

For these reasons, lung ultrasonography is gaining popularity in emergency care and in intensive care settings. Here we report our experience with lung USG in patients with acute respiratory failure.

Materials and Methods

This was a hospital based, single-centre, observational study conducted between December 2022 to July 2023 in the Department of Pulmonary Medicine, Gauhati Medical College and Hospital, a tertiary care hospital in Guwahati, Assam. Inclusion criteria were patients more than 18 years with acute respiratory failure due to various aetiologies. Patients were evaluated with detailed history and clinical examination, blood investigations which included complete blood count (CBC), C-reactive protein (CRP), renal function test (RFT), liver function test (LFT) and electrocardiogram (ECG). Arterial blood gas analysis was also done as baseline workup. Chest X ray and computed tomography of thorax were done. Bedside Thoracic ultrasound was conducted using “BLUE protocol” (FIGURE 1). The patients were treated as per institutional protocol for acute respiratory failure. The study was conducted according to the ethical principles established by the Declaration of Helsinki and Good Clinical Practice Guidelines and by the Indian Council of Medical Research.

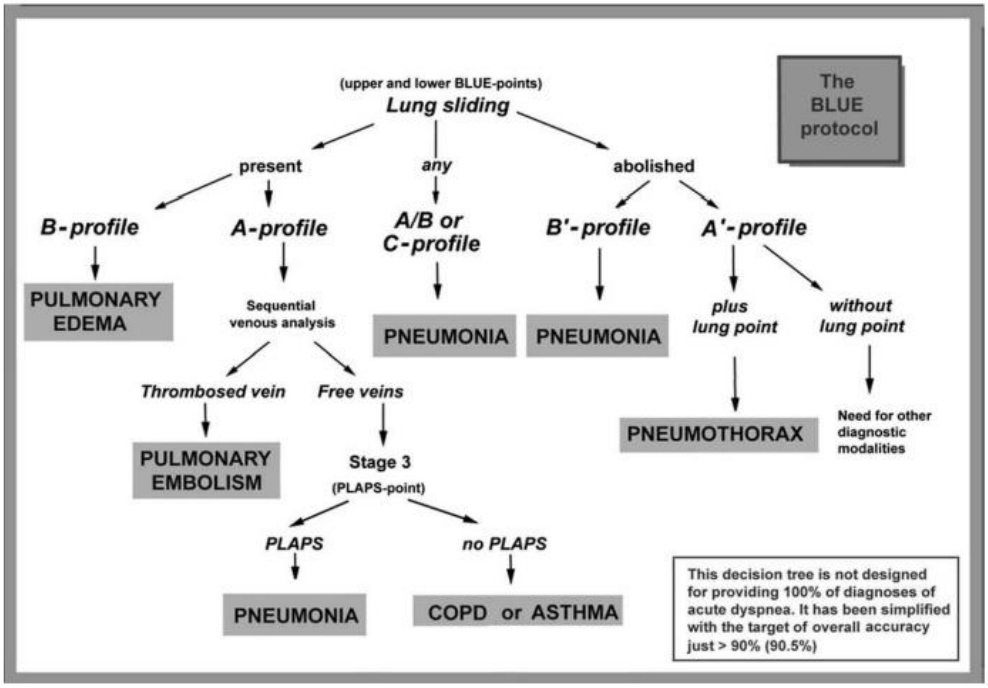

Figure 1: Blue Protocol

Our primary objective was to evaluate the sensitivity of lung ultrasound in diagnosing the etiology of acute respiratory failure. We analysed the data for baseline characteristics and true positivity and false positivity rate of lung ultrasound. Microsoft excel version 2022 was used for data analysis.

Results:

Among sixty one patients enrolled in the study, thirty three (53%) were male and twenty eight (46%) were female. Twelve patients were between 18-30 years, twenty were between 31-50 years, twenty four were between 51-70 years and five were above 70 years of age.

Twenty three (38%) patients were diagnosed to have pleural effusion, thirteen (21%) had consolidation, five (8%) had pneumothorax eight (13%) had chronic obstructive pulmonary disease (COPD) and twelve (20%) had pulmonary edema **(Table 1)**

Table 1: Baseline characteristics:

Characteristics	Number (percentage) N=61 (100%)
Age (years)	
18-30	12 (19.7%)
31-50	20 (32.8%)
51-70	24 (39.3%)
>70	5 (8.2%)
Sex	
Male	33 (53%)
Female	28 (46%)
Etiology of acute respiratory failure	
Pleural effusion	23 (38%)
Consolidation	13 (21%)
Pneumothorax	5 (8%)
COPD	8 (13%)
Pulmonary edema	12 (20%)

A total of twenty three cases presented with pleural effusion out of which thirteen were female and ten were male. Ten patients had right sided, six had left sided and seven had bilateral pleural effusion. The sensitivity of ultrasonography in diagnosing pleural effusion was compared with bed side chest X ray and CT thorax. Ultrasonography was 100% sensitive in diagnosing pleural effusion. Among the thirteen patients presented with consolidation, eight were male and five were female. Right sided consolidation was found in eight cases, four had left sided consolidation and one patient had

bilateral consolidation. Bedside ultrasonography had 84.6% sensitivity in diagnosing consolidation compared with chest X ray and computed tomography. True positive were 84.6% and false negatives were 15.4% with ultrasonography.

Five patients with pneumothorax were enrolled. Three were female and 2 were male. Right sided pneumothorax was found in two cases and left sided pneumothorax was found in three cases. Sensitivity of bedside Ultrasonography in diagnosing pneumothorax was 80%. True positives and false negatives were 80% and 20% respectively. Eight patients with COPD were enrolled in this study. Seven were male and three were female. Bedside Ultrasonography had sensitivity of 62.5% in diagnosing COPD. True positives were 62.5% and false negatives were 37.5% with ultrasonography.

Among twelve patients who presented with pulmonary oedema, eight were female and four were male. Sensitivity of bedside ultrasonography in diagnosing pulmonary edema was found to be 75% with true positives being 75% and false negative being 25%.

Table 2: Sensitivity of bedside thoracic ultrasonography in different etiologies of acute respiratory failure

Etiology	Number	Ultrasonography		Sensitivity of USG
		TP	FN	
Pleural effusion	**23**	100%	0	100%
Consolidation	**13**	84.6%	15.4%	84.6%
Pneumothorax	**5**	80%	20%	80%
COPD	**8**	62.5%	37.5%	62.5%
Pulmonary edema	**12**	75%	25%	75%

Discussion

Numerous studies have compared the sensitivity and specificity of bedside ultrasonography to that of conventional imaging like chest X ray and computed tomography. The patients in our study had slight male preponderance and majority were in the age group of 51-70 years. Majority of the patients had pleural effusion followed by consolidation, pulmonary edema, COPD and Pneumothorax respectively.

Ultrasonography is very effective in diagnosis pleural effusion. In the study by Lichtenstein and Mezière (2008), the sensitivity and specificity of chest ultrasonography in detecting pleural effusion was 93% and 97% respectively. [2] Our study also has similar results. The sensitivity of ultrasonography was 100% in diagnosing pleural effusion in our study. Figure 2 depicts the USG finding of "quad sign" in pleural effusion. It is named for its appearance of four distinct areas or "quads" on the ultrasound image and indicates the presence of free-flowing pleural fluid. Here there is visualization of four distinct borders: Visceral Pleura, Parietal Pleura, Diaphragm and Lung Line. [23] This specific ultrasound finding is used to differentiate between pleural effusion and other causes of pleural abnormalities, such as pleural thickening shown in Figure 3. Pleural thickening is difficult to appreciate in bed side Chest X ray.

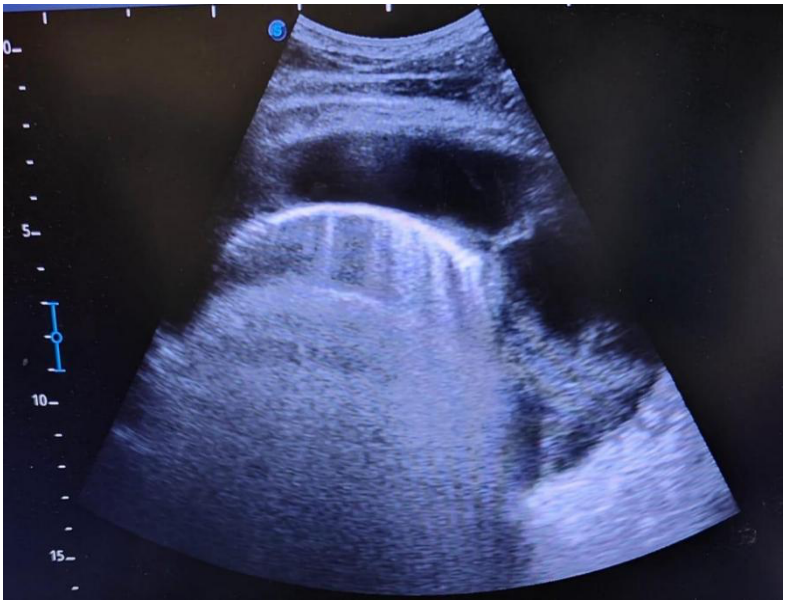

Figure 2: Ultrasonography image of quad sign seen in pleural effusion

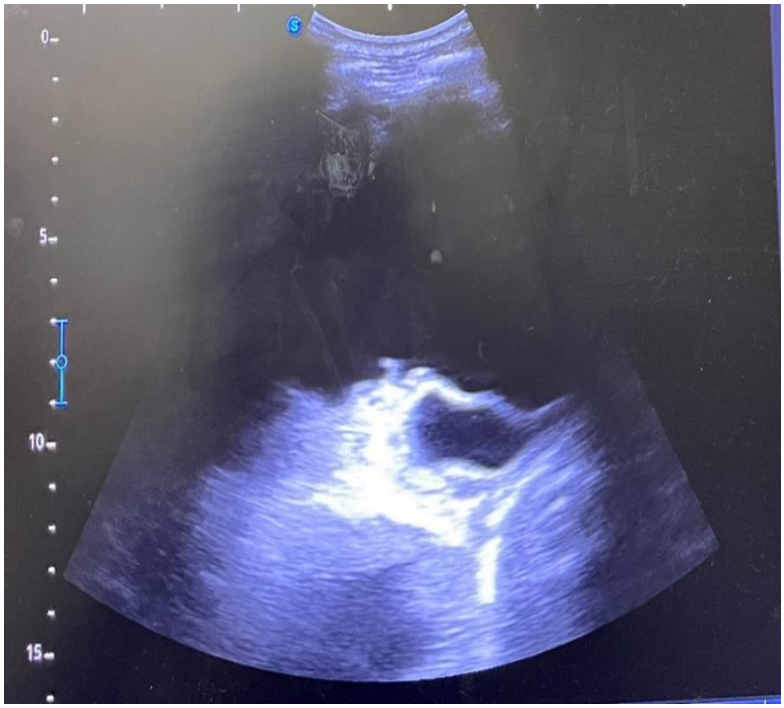

Figure 3: USG image of effusion with pleural thickening

USG is also helpful in identifying Septations and loculated pleural effusion (Figure 4) which cannot be determined in chest X ray. Septations appear as echogenic (bright) lines within the anechoic (dark) fluid, indicating fibrous strands dividing the fluid into pockets. [3] Loculations are areas where the fluid is trapped and does not freely flow, typically irregular in shape and often distributed in various parts of the pleural cavity. [24]

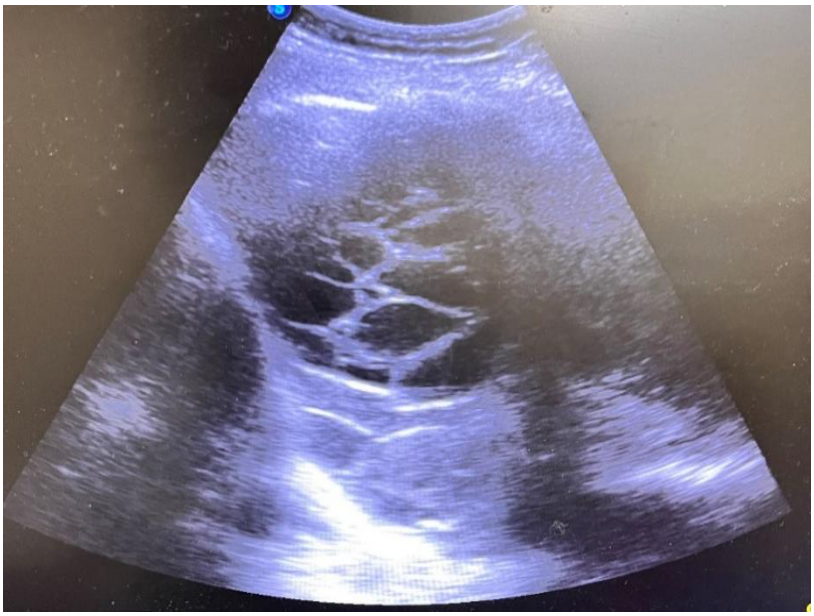

Figure 4: USG image of loculated effusion

Bourcier et al has reported the sensitivity of ultrasonography to be around 90% in detecting consolidation. In our study, USG had a sensitivity of 84.6% for diagnosis of lung consolidation. The phenomenon of "sonographic hepatisation" of lung as well as presence of air bronchogram is well documented indicative of consolidation and is corroborated by the findings of our study. (Figure 5)

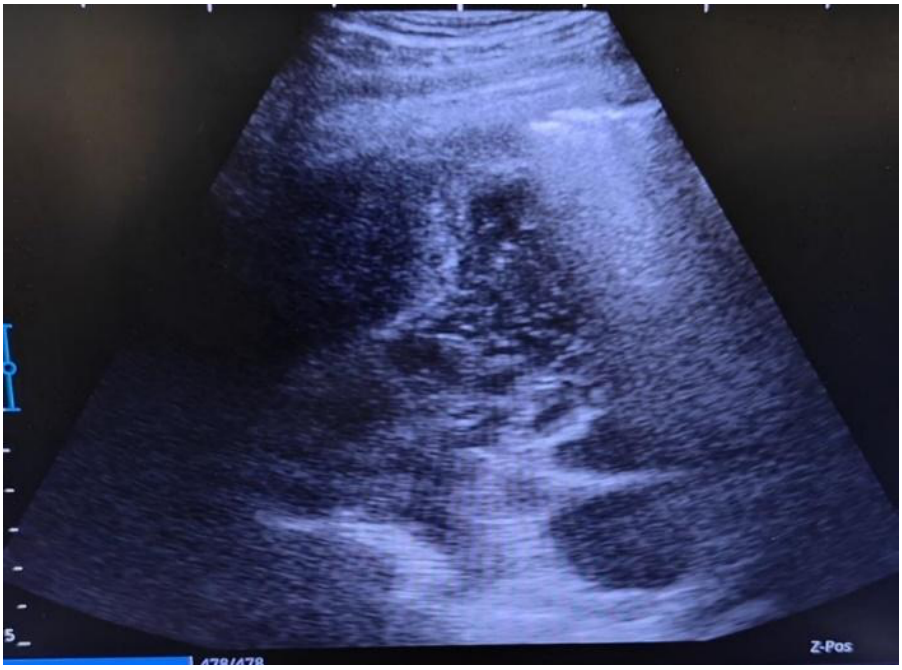

Figure 5: USG image of consolidation with air bronchogram

Various previous studies have noted a sensitivity of 92-100% in diagnosing pneumothorax. In pneumothorax, the pleural layers do not move synchronously with respiration because air in the pleural space prevents lung expansion and movement resulting in a uniform, static appearance on M-mode, resembling a barcode or stratosphere (Figure 6). In our study, the sensitivity of lung ultrasound in detecting pneumothorax was 80%, which is lower compared to the prior studies.

We did not use color Doppler in evaluation of pneumothorax, which could have improved diagnostic accuracy in this setting.

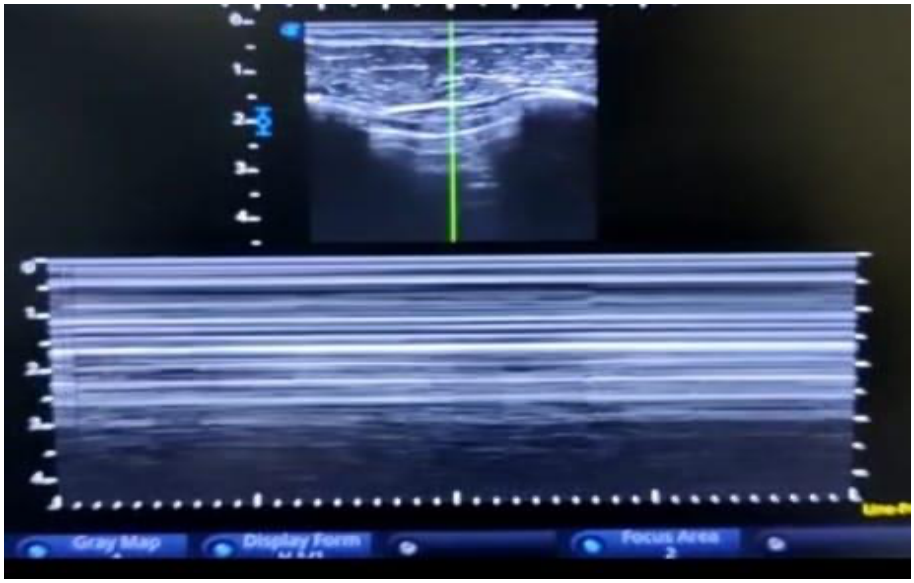

Figure 6: USG image of pneumothorax with stratosphere sign

The sensitivity of USG for diagnosing COPD was found to be 62.5% in our study, which is relatively low compared to other conditions. This finding aligns with the literature indicating that USG is less effective for diagnosing diseases like COPD that primarily involve changes in lung parenchyma and air trapping. [6] Despite this limitation, USG can still provide valuable information, particularly in identifying associated complications such as pneumothorax or pleural effusion in COPD patients. Our study has shown a sensitivity of 75% for diagnosing pulmonary edema by lung ultrasound. Previous studies, such as those by Picano et al have reported higher sensitivities (up to 85-90%. [6]The identification of B-lines or "comet-tail artifacts" (FIGURE 7) are crucial for

diagnosing pulmonary edema. B-lines are vertical, hyperechoic (bright), well-defined lines that arise from the pleural line and extend to the bottom of the ultrasound screen without fading. They move synchronously with lung sliding. [6] The slight discrepancy in sensitivity might be due to differences in operator experience and patient population. Our study confirms that bedside lung sonography can be a useful tool for detecting pulmonary edema, and help in differentiating between cardiogenic and non-cardiogenic causes of pulmonary edema.

Figure 7: USG image of B lines seen in pulmonary edema

Our study highlights various advantages of bedside lung ultrasonography, such as easy portability and bedside application, real time imaging and no risk of radiation exposure. [6] However, like any other imaging modality, ultrasonography also has some limitations. It is difficult to scan the posterior thoracic area in patients admitted in intensive care unit with life support devices, which may hinder access and proper positioning for imaging. [28] Ultrasonography is heavily operator dependent and requires advanced technical skill and clinical knowledge. [28] It can be time consuming compared to other conventional imaging modalities. A bedside ultrasonography may take up to 20 minutes, which can be less time efficient in emergency settings. [28]

Conclusion

This study reinforces the role of chest ultrasonography as a valuable diagnostic tool in the management of acute respiratory failure in ICU settings. With an overall sensitivity of 85.2%, chest ultrasonography is superior to standard chest radiography in identifying pleural effusion, lung consolidation, and pneumothorax, as well as in differentiating pleural effusion from pleural thickening or consolidation. However, its lower sensitivity for COPD and certain limitations, such as operator dependency and the time required for thorough examination, emphasize the need for a comprehensive diagnostic approach that potentially combines USG with other imaging modalities. The findings support the integration of USG into standard diagnostic protocols for ARF, enhancing patient care through rapid and accurate bedside imaging.

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