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Chest Ultrasonography vs. Chest X-rays for Diagnosing Pleural Effusion in Intensive Care Unit Patients

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Abstract

Background and objectives: The early detection of pleural effusion in intensive care unit patients is important since the pleura is vital for proper respiratory function. This study evaluates the accuracy of ultrasonography in early diagnosis of pleural effusion in intensive care unit patients, comparing it to chest X-rays, a less invasive and expensive alternative.

Methods: A cross-sectional comparative study design included 338 patients from March to September 2023 at three intensive care units: the emergency hospital, the Azadi Teaching Hospital, and the heart center. These patients underwent chest ultrasonography and X-ray examinations to detect pleural effusion Both imaging modalities' diagnostic accuracy, sensitivity, specificity, and predictive values were evaluated. P value <0.05 is regarded as statistically significant.

Results: The findings indicated that chest ultrasonography had a high level of sensitivity and specificity of up to 97% and 99.7% respectively with overall accuracy of 93.2%. A sensitivity and specificity of up to 90.1%, and 97.9% respectively, with an overall accuracy of 97%, were obtained from the chest X-rays. Ultrasound has higher positive and negative predictive values compared to chest X-rays, with a positive and negative predictive value of 96% and 99.7% respectively. In all cases, the statistical analysis results showed no significant difference in the diagnostic capabilities of ultrasonography and X-rays.

Conclusions: The findings demonstrate that ultrasound is a reliable tool with a kappa value of 0.738 for detecting pleural effusion at the bedside.

Keywords: Pleural effusion, Ultrasonography, X-rays.

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Introduction

The pleura consists of two serosal membranes: the visceral pleura, which surrounds the lungs, and the parietal pleura, which lines the inner chest wall. These membranes facilitate seamless movement during respiration. The transition between the two membranes takes place at the pulmonary hilum, where the reflection covers the hilum and continues to the diaphragm, forming the triangle ligament. Both membranes are composed of a layer of mesothelial cells that are upheld by fibro-elastic connective tissue. The connective tissue of the visceral pleura is a component of the peripheral interstitial fiber network and includes blood vessels and lymphatic branches. The pleura receives blood supply from the systemic circulation.[1] The pleura and pleural cavity are vital for lung function, like the importance of the pericardium and pericardial cavity for the heart. Pleural disorders are a prevalent concern in clinical settings, representing 25% of consults in pulmonary units. Chest radiography is usually the initial imaging modality employed to examine pleural illnesses. Approximately 200-500 mL of pleural fluid is needed to be detectable by chest X-ray. Smaller amounts may not be visible on a chest X-ray, and larger amounts may cause visible changes in the lung fields. Ultrasound (US), computed tomography (CT), and magnetic resonance imaging (MRI) can be used depending on the patient and clinical issues where Ultrasound (US) is used for assessing pleural effusions and guiding procedures, while computed tomography (CT) provides detailed cross-sectional images for evaluating pleural abnormalities. Magnetic resonance imaging (MRI) offers additional information on pleural masses, invasion of adjacent structures, and complications in pleural diseases.[1] Pleural effusion is the buildup of fluid in the area around the lungs, commonly triggered by illnesses such as congestive heart failure, bacterial pneumonia, malignancy, and pulmonary embolism. Diagnosing this disorder might be challenging due to its symptoms resembling those of other conditions. Doctors utilize imaging methods such as chest X-rays, point-of-care ultrasonography, and computed tomography scans to precisely identify pleural effusion.[1] Although point-of-care ultrasonography is highly accurate, it is not frequently utilized as the main diagnostic method, as most physicians depend on chest X-rays.[2] Transthoracic lung ultrasonography (LUS) has become a significant diagnostic tool in intensive care settings over the last 15 years, particularly for patients with acute respiratory failure requiring mechanical ventilation. Its success is attributed to its minimally intrusive nature, repeatability, and simplicity.[2] Mastering transthoracic LUS simply requires a brief training period. Transthoracic lung ultrasound (LUS) is critical in guiding therapeutic decisions including bronchoscopy, chest tube installation, PEEP titration, and others in around 50% of cases requiring treatments. Utilizing scoring methods such as the "LUS score" in the early stages can aid in forecasting patient outcomes in the Intensive Care Unit (ICU). Lung ultrasonography (LUS) provides precise pictures of the lungs, showing anomalies such as consolidations and effusions, which enhance the patient's clinical evaluation.[3] Mechanical ventilation is essential for individuals in critical care settings experiencing respiratory failure. It is utilized when natural breathing is inadequate to support life or gas transfer. Chest X-rays are frequently utilized in intensive care units, despite the disadvantage of radiation exposure. Lung ultrasonography is becoming a viable option for identifying lung diseases directly at the patient's bedside. It helps diagnose pleural effusion and assists with invasive operations. Chest ultrasonography is used for diagnosing and treating illnesses

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such as pleural effusion, pneumonia, and lung cancer.[4] A study stated that ultrasound proves to be a method for diagnosing effusion, offering more precise results compared to chest X-rays.[5] The increased sensitivity of ultrasound allows for the detection of effusions as tiny as 20 mL, surpassing the capabilities of X-ray imaging.[5] Examining patients in a position enhances the accuracy of effusion measurement since fluid tends to gather in the part of the body.[5] Moreover, ultrasonography plays a role in identifying structures, which is vital for minimizing potential organ damage during invasive procedures.[5] This research aims to evaluate the accuracy of two imaging methods for identifying different types of pleural effusions in intensive care patients across three distinct clinical settings.

Patients and Methods

A cross-sectional comparative study was conducted involving 338 patients, aged between 16 and 83 who were admitted to three medical facilities: The ICU at the emergency hospital, the ICU at the Azadi Teaching Hospital, and the ICU at the heart center. From March to September 2023 these patients underwent chest ultrasonography and X-ray examinations to detect the presence of pleural effusion. False positives occurred when pleural effusion was mistakenly identified during diagnosis while true positives indicated detection of effusion. A follow-up period of three to five days post-initial diagnosis was carried out to validate the accuracy of the diagnoses of pleural effusion. Both ultrasonography and X-ray procedures were repeated during this follow-up period. The study excluded individuals under 12 years old. Detailed imaging results were documented in a predefined questionnaire, for analysis. Ultrasound bedside examinations on patients in three distinct locations were performed by a trained physician using the GE Vivid IQ ultrasound equipment equipped with a dual probe. The deliberate choice of utilizing a phased array and convex probe was made to ensure superior spatial resolution and range, both crucial for bedside examinations. A convex phased array probe was placed vertically along certain anatomical lines on both sides for the inspection. These lines were the mid-clavicular line, the anterior axillary line, and the posterior axillary line. Key findings were evaluated in everyone during the exam. The observations focused on monitoring pleural sliding, which is the usual movement of the two pleural surfaces as they interact during breathing. A line, known as horizontal reverberation or transducer reverberation, reflects the pleural line in the deep. The existence of A-lines is considered a normal observation. B-lines are characterized as vertical reverberation that appears as ring-down artifacts. As fluid buildup increased, it became challenging to distinguish separate B-lines. Pleural effusion, characterized by fluid showing an anechoic appearance in the posterior of the lung, was also examined during the test. The SIEMENS portable X-ray machine was used in the study because it could identify patient effusions at three different sites. The imaging procedure involved placing a film under the patient's back, which was challenging, particularly with obese patients or when the tube separated from the ventilator owing to patient movement. Once the X-ray technician captured the image, the film was promptly removed from the patient's back and transported to the radiology department for processing. Written consent was obtained from the patients; the Kurdistan Higher Council of Medical Specialties approved this study (number 38) on 4th January 2023. The research employed T-tests to compare the effectiveness of ultrasound and X-ray procedures, in detecting pleural effusion. The study focused on assessing the efficacy of lung ultrasound and chest X-rays (CXR) in diagnosing pleural effusion by evaluating

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factors such as sensitivity, specificity, positive predictive value (PPV) negative predictive value (NPV), and accuracy. In this setup, true positive instances refer to patients confirmed to have pleural effusion. Conversely, false positives occur when individuals without pleural effusion are mistakenly identified by clinical examination as having the condition. True negatives indicate cases where individuals without the ailment are correctly identified as not having it. False negatives on the other hand involve individuals with effusion being inaccurately classified as healthy. Sensitivity or the true positive rate represents the likelihood of obtaining a positive test outcome when an individual is indeed positive, for the condition. It measures how effectively the test can identify those who are truly affected. Specificity, also known as the rate, denotes the probability of receiving a negative test result when an individual does not have the condition. This metric assesses how well the test can accurately identify those who are not affected by the ailment. A follow-up period of three to five days post-initial diagnosis was carried out to validate the accuracy of the diagnoses of pleural effusion. Both ultrasonography and X-ray procedures were repeated on all initially admitted cases during this follow-up period.

Results

A total of 338 patients had their initial chest ultrasonography followed by an x-ray; of these, 263 patients did not have pleural effusions and 75 cases had pleural effusions. Within the cases, there were 70 positive diagnoses categorized as follows: 11 severe bilateral, 16 moderate bilateral, 24 mild bilateral, and 19 minimum unilateral pleural effusion cases. Each category had eight results: three for severe bilateral cases, three for moderate bilateral cases, one for mild bilateral cases, and one for minimum unilateral cases. Additionally, there were five outcomes, across different categories; one severe bilateral case, two moderate bilateral cases one mild bilateral case, and one minimum unilateral case as outlined in Table (1).

Table (1): Diagnostic performance of the Chest ultrasonography (U/S) findings in the diagnosis of pleural effusion (bilateral and unilateral) among intensive care unit patients.

Total Patients (N=338)	Patients with Pleural Effusion (N=75)	Patients without Pleural Effusion (N=263)
	(TP= 70) (FP= 5)	(TN= 255) (FN= 8)
	Bilateral (N=51)	
	Unilateral (N=19)	

Category of Pleural Effusion	Sensitivity	Specificity	PPV	NPV	Accuracy
Overall (All Categories)	0.897	0.981	0.933	0.970	0.932
Severe Bilateral	0.786	0.997	0.917	0.991	0.965
Moderate Bilateral	0.842	0.994	0.889	0.991	0.976
Mild Bilateral	0.960	0.997	0.960	0.997	0.982
Minimum Unilateral	0.950	0.997	0.950	0.997	0.976

PPV: Positive predictive value; NPV: Negative predictive value

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The test consistently proves its ability to detect effusion regardless of severity levels, as illustrated in Table (1). Sensitivity ranges from 78.6% to 96%, across all categories, showcasing its effectiveness in identifying patients with effusion. The test displays specificity levels between 99.4% and 99.7%, indicating its precision in recognizing patients without effusion. Positive predictive values (PPV) range from 88.9% to 96%, showing the reliability of predictions. Negative predictive values (NPV) typically fall between 99.1% and 99.7%, underscoring the test's accuracy in excluding patients without effusion. With an accuracy rate of 93.2%, the test exhibits a level of precision in diagnosing outcomes, emphasizing its significance in effusion detection, and contributing insights for informed clinical decision-making. As shown in Table (2), A total of 338 patients, 62 tested positive and 276 tested negative on chest X-rays. Among the cases, there were 55 results distributed across different levels of severity, including 11 for total opacity of the field, 16 for the opacity of the costophrenic angle, 24 for blunting of the costophrenic angle, and 4 for no opacity seen in the lung field. Each category had 6 negatives: 2 for total opacity of the lung field, 2 for opacity of the costophrenic angle, 1 for blunting of the costophrenic angle, and 1 for no opacity seen in the lung field. Additionally, there were positives reported in each category with a count of 7: one each for total opacity of the Lung Field, and seven cases distributed among opacity levels and lung field observations.

Table (2): Diagnostic performance of the Chest X-ray findings in the diagnosis of pleural effusion (bilateral and unilateral) among intensive care unit patients.

Total Patients (N=338)		Patients with Pleural Effusion (N=62)		Patients without Pleural Effusion (N=276)	
		(TP= 55) (FP= 7)		(TN= 270) (FN= 6)	
		Bilateral (N=51)			
		Unilateral (N= 4)			
Category of Pleural Effusion	Sensitivity	Specificity	PPV	NPV	Accuracy
Overall (All Categories)	0.901	0.979	0.887	0.982	0.970
Total Opacity of Lung Field	0.846	0.997	0.917	0.994	0.976
The opacity of Costophrenic Angle	0.889	0.994	0.889	0.994	0.976
Blunting of Costophrenic Angle	0.960	0.994	0.923	0.997	0.982
No Opacity was observed in the Lung Field	0.800	0.994	0.667	0.997	0.979

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Table (2) demonstrates the diagnostic accuracy of the evaluation of pleural effusion across different severity categories, yielding positive results. The diagnostic test exhibits a sensitivity of 90.1% and a specificity of 97.9%, indicating its precise detection of positive and negative cases. The positive predictive value (PPV) is 88.7%, and the negative predictive value (NPV) is 98.2%, demonstrating the test's reliability in generating precise outcomes. An impressive overall accuracy rate of 97% attests to the test's effectiveness. The test consistently provides judgment in specific categories. It has high sensitivity, specificity, PPV, NPV, and accuracy. The findings suggest that a diagnostic test is effective for diagnosing pleural effusion in different manifestations.

A two-sample t-test was conducted to compare the means of two independent groups using both imaging techniques, with a sample size of 338 for each group. We will use the t-test to ascertain whether there is a statistically significant disparity in the means.

Table (3): Comparison between mean initial ultrasound (U/S) and mean initial chest X-ray findings among critical care patients.

Variables	U/S Mean/SD	X-rays Mean/SD	p value
Overall Pleural Effusion			
Positive Cases For U/S (N= 75) For X-ray (N= 62)	0.2456/3.8248	0.2012/3.0403	0.076
Negative Cases for U/S (N= 263) For X-ray (N= 276)	0.7633/7.0271	0.7964/7.3414	0.0536

The findings presented in Table (3) show that upon analyzing the data, it was determined that there is no contrast between ultrasound and X-ray methods in identifying cases. The data does not conclusively establish a disparity between the ultrasound and X-ray categories for cases. When comparing ultrasound (U/S) and X-rays for cases, the t-test resulted in a t statistic close to 0.0536 with a degree of freedom of approximately 50.62. The absolute value of the t statistic (0.0536) falls below the value from the normal distribution (Z distribution) at a confidence level of 95% (±1.96). As per the outcomes of the t-test, there is no distinction between ultrasound and X-ray, with negative instances suggesting any variances are likely attributed to random fluctuation.

Discussion

In this cross-sectional comparative study, 338 patients were hospitalized for evaluations, at three distinct medical facilities: The ICU at the heart center, the ICU at the Azadi Teaching Hospital, and the ICU at the emergency hospital. The main objective of this study was to compare how accurate chest ultrasonography and chest X-rays are in detecting effusion. The results from ultrasonography indicated 263 cases and 75 positive cases with 70 of the findings correctly classified by severity. On the hand chest X-ray findings showed 62 cases and 276 negative cases with 55 of the positive cases accurately identified by severity. Based on our research outcomes, both chest ultrasonography and chest X-ray demonstrate abilities to recognize pleural effusion. Each imaging method presents its advantages as outlined in Tables One and Two which summarize diagnostic accuracy metrics such as sensitivity, specificity, positive predictive values (PPV) negative predictive values (NPV), and overall accuracy, for both modalities. After examining the accuracy of chest X-rays and chest ultrasonography using a two-sample t-test we found that there was no variance between the two methods in terms of their effectiveness. The results from the analysis as shown in Table (3) revealed

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no contrast between the two modalities for either positive or critical cases. This emphasizes the importance of considering both ultrasonography and X-ray as options for diagnosing effusion. Factors like availability, timeliness, and specific clinical needs may impact the choice between them.

The discussion gains depth by referencing the studies of Khalil and Zanobetti.[4,6] The author expresses concern about the use of chest X-rays in ventilated patients daily and supports using chest ultrasonography for its precise accuracy and portability. Compared to X-rays, ultrasound proves to be more accurate in detecting effusion. This finding implies that ultrasound should be an imaging tool in emergency rooms for diagnosing dyspnea. [4,6]

In a research study conducted by Corradi and colleagues in 2016, the main focus was, on assessing lung fluid buildup in patients on ventilation using lung ultrasound (V LUS) and quantitative lung ultrasound (Q LUS).[7] The results indicated that Q LUS exhibited correlations with capillary wedge pressure (PCWP) and extravascular lung water (EVLW) compared to V LUS. [7] Q LUS demonstrated accuracy in diagnosis and consistency between observers especially at elevated positive end-expiratory pressure (PEEP) levels.[7] Conversely, our study spanning three institutions compared the efficacy of chest ultrasound and chest X-rays in detecting pleural effusion in hospitalized patients. Both imaging methods successfully identified pleural effusion. Ultrasound detected a total of 263 cases correctly categorizing the severity of 75 instances. In contrast, chest X-ray findings identified 62 cases out of the 276 cases examined accurately grading the severity of 55 occurrences. The research by Corradi et al. Underscores the advantages of utilizing Q LUS over V LUS for detecting lung fluid accumulation, in ventilated patients particularly when dealing with PEEP levels. [7] Our comparison study, between chest ultrasonography and chest X-rays highlights the accuracy of both imaging methods, in detecting pleural effusion. Additionally, Stock's studies focus on technology showcasing the benefits of a portable ultrasound device in scenarios.[8] For individuals with heart failure, nurses conducted ultrasound assessments noted by Dalen offer evidence supporting the reliability and effectiveness of ultrasound examinations.[9] The research conducted by Volpicelli, and his team supports the idea that using bedside lung ultrasonography during emergency scenarios is beneficial and cost-efficient.[10] The results of this study indicate that ultrasound exhibited a sensitivity ranging from 78.6% to 96% and a specificity between 99.4% and 99.7% resulting in an accuracy of 93.2%. In comparison, chest X-rays showed a sensitivity of 90.1%, a specificity of 97.9%, and an overall accuracy of 97%. The statistical analysis revealed no variance in effectiveness between ultrasonography and X-ray for both positive and negative cases. The ultrasonography sensitivity levels found in this study, which ranged from 78.6% to 96%, are like those found in Abbasi's study on pneumothoraxes, which found a sensitivity of 86.4%.[11] Also, the specificity values we got from ultrasound in our study (ranging from 99.4% to 99.7%) seem to be higher than the specificity values Abbasi found for using both ultrasound and chest X-rays together (100%). It's worth noting that this research didn't delve deeply into factors related to time efficiency.[11] Moy investigation delved into utilizing CT imaging features for effusion classification.[12] While this work did not specifically focus on effusion categorization, it showcased the precision of ultrasound and X-ray indicating superior sensitivity and specificity when contrasted with Moy's emphasis, on CT imaging features.[12] Moy's research paper delves into enhancing agreement among observers through the utilization of CT imaging characteristics, an element not explored in this research.[12] This study offers perspectives by demonstrating the diagnostic precision of ultrasound and X-ray in thoracic imaging aligning with or surpassing the sensitivity and specificity levels documented in previous studies. The comparison suggests that different imaging methods could excel in domains emphasizing the importance of tailoring approaches to meet specific clinical needs in thoracic imaging.

Conclusions

Ultimately, the exploration confirms that chest ultrasonography is a good tool for early detecting pleural effusion, providing results like those of a chest X-ray. The comparison and review stress the importance of thorough statistical analysis and training to draw valid conclusions about the usefulness of different imaging techniques in diagnosing pleural effusion. Based on this study's findings, it is recommended that anesthesiologists and critical care specialists better diagnose patients with pleural effusion using ultrasonography rather than X-rays.

Conflict of interest

The authors have no conflict of interest to disclose.

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