Zagazig University Medical Journal
www.zumj.journals.ekb.eg

https://doi.org/10.21608/zumj.2024.279736.3287 Volume 30, Issue 9.1, December. 2024, Supplement Issue

Manuscript ID ZUMJ-2403-3287
DOI 10.21608/zumj.2024.279736.3287

Original Article

Early Diagnosis of Pneumothorax in Intensive Care Units with thoracic Ultrasonography

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Submit Date 27-03-2024
Revise Date 02-04-2024
Accept Date 04-04-2024

ABSTRACT

Background: Pneumothorax is a prevalent critical condition in the intensive care unit, which ranges according to its clinical manifestations from asymptomatic to life-threatening, so early detection is essential. This study aims to evaluate the diagnostic role of chest ultrasonography (U/S) in identifying pneumothorax in ICUs patients.This cross-sectional study was performed in ICUs at Zagazig University Hospitals. The study included thirty critically ill cases admitted to ICUs from January to December 2023.Using Sony LOGIQ P7 < made in Korea. All studied populations had the following: Detailed history taking from patients or relatives, clinical examination, laboratory investigations and radiological evaluation, including chest x-ray, chest U/S and CT chest. **Results:** The most common U/S findings in pneumothorax on the first day of admission were lung point (63.3%), absent lung sliding presented (20%) and barcode sign (13.3%), while lung pulse could be detected in only one case (3.3%). On the third day, follow-up of the study, 30% of pneumothorax cases showed complete resolution, while on the seventh day, it reached 60%. Chest ultrasound showed good agreement with CT chest (kappa = 0.723); it could detect 23 positive cases out of 27 confirmed with CT and exclude two negative cases out of three truly negative confirmed by CT Chest. Chest x-ray revealed specificity, sensitivity, PPV, NPV and accuracy of 33.3, 40.7, 84.6, 5.9 and 40%; Chest U/S showed specificity, sensitivity, PPV, NPV, and accuracy of 66.7, 85.2, 95.8, 33.3, and 83.3%. **Conclusion:** Thoracic U/S is considered the appropriate imaging modality for detecting pneumothorax in ICU patients, as it is simple, portable, affordable, bedside, safe, and has higher sensitivity than chest X-rays. Among sonographic findings, the Lung point sign has the highest sensitivity, specificity and overall accuracy in the detection of pneumothorax.

Keywords: Pneumothorax, Intensive care units, Chest Ultrasound

INTRODUCTION

Pneumothorax (PNX) is described as an accumulation of air in the pleural cavities. Pneumothorax is widely classified as either spontaneous or traumatic. In healthy people, spontaneous PNX happens without any trauma. There are two types of spontaneous PNX: primary and secondary. Primary spontaneous PNX happens in the absence of any preexisting lung disease. Secondary spontaneous PNX occurs among cases with preexisting lung disease [1]. Physicians consider bedside chest ultrasonography to be a unique use for detecting PNX. Although sonography is an old method, the belief that U/S does not travel through the air for long hindered its use in evaluating lung illness. Only in the past ten years has it proven that chest U/S is beneficial for the bedside assessment of PNX, pulmonary edema and consolidations, along with previously documented

uses, such as the detection of pleural effusion and tumors [2]
The barotrauma continues to be one of the leading causes of PNX in critically ill individuals in the ICU. An early PNX diagnosis is crucial because it can develop into a tense one [3].
Computed tomography (CT) remained the most accurate diagnostic method for most chest diseases. However, for critically ill cases, obtaining a chest CT scan could be challenging. The usage of chest U/S has been growing and is preferable as it is bedside, portable, easy and with no radiation hazards (safe for pregnancy and newborn) [4].The present work aims to assess the diagnostic role of chest U/S in identifying pneumothorax in ICUs patients.

METHODS

This cross-sectional study was performed in ICUs at Zagazig University Hospitals from January to December 2023. Using Sony LOGIQ P7 < made in Korea. Four hundred and two cases were admitted to the ICUs during the period of the study; 33 of them were suspected to have pneumothorax during their stay in ICU, 3 of them died before completing the study period, and 30 completed. Informed consent has been obtained from all individuals involved in this investigation. This study was approved by the Institutional Review Board (IRB) on the twenty-fifth of December 2022. The research was conducted under the World Medical Association's Code of Ethics (Helsinki Declaration) for human research.
Cases with the following characteristics were included: age >18 years, clinical suspicion by sudden respiratory and or cardiac deterioration of patients without apparent cause. Furthermore, cases with a high risk of pneumothorax (mechanically ventilated patients, after fiber optic bronchoscope, after insertion of CV lines).
Changes in respiratory function in a severely ill patient, including new or increasing hypoxia and tachycardia. PNX can be identified by hypotension, reduced breath sounds on the affected side, tracheal deviation away from the affected side, surgical emphysema, a reduction in tidal volume with pressure-controlled ventilation or an elevated airway pressure (peak or plateau) with volume-controlled ventilation. Cases with the following characteristics were excluded: those with unstable vital signs, in need of emerging intervention (e.g., intubating, arrest), surgical emphysema, after thoracentesis, and road traffic accident (RTA) patients.
All study population had the following: Detailed history taking from patients, relatives or ICU attendees (personal, present, and history, history of accidental pneumothorax or presence of risk factors for pneumothorax and Positive family history of pneumothorax). Clinical examination, laboratory and biochemical investigations on admission (Complete Blood picture, liver and Kidney function tests, serum electrolytes, and ABG).
Radiological evaluation using X-ray chest on admission is routinely done for detection of the cause of admission and if there is any chest disease, lung opacities, hyperinflation or effusion.
On the first day, third, and seventh day of admission for all patients during admission. Chest U/S was done on cases that could remain stable in the supine and sitting positions in the chest cavity's posterior, lateral and anterior portions. U/S was carried out exclusively in the supine position in the individuals unable to sit, and anterolateral areas were assessed.
A 3-5 MHz convex transducer is used for chest U/S to observe deeper lung tissues. A high-frequency linear array probe (5-12 MHz) helps view the chest wall, pleura, and lung peripheral parenchyma. Transversal, longitudinal and oblique-array probes must be placed throughout the rib spaces to evaluate the chest comprehensively. These probes should be placed along the med clavicular, parasternal, anterior axillary, medial, and posterior lines, moving from top to bottom in the ventral-dorsal direction. When the case can be mobilized, probes should be implanted along the paravertebral and interscapular lines. The upper clavicular approach allows assessing the lung apices and brachial plexus, whereas the anterior mediastinal tissues can be evaluated via the upper sternum [5].
Pneumothorax findings in ultrasonography:
Lung sliding:
PNX is characterized by air between the parietal and visceral pleura, preventing visibility of the visceral pleura. Lung sliding is eliminated in PNX and if it is partial, it is halted at the point where pleural tissue separates; this location is well characterized in U/S imaging and is referred to as the "lung point" [6].
Lung point
The 'lung-point sign' appears near the edge of PNX. It is caused by the sliding lung sporadically coming into contact with the chest wall upon inhalation, which helps identify the exact size of PNX. The chest U/S defines the degree of PNX by seeing and mapping lung sites on the chest wall, indicating the right treatment strategy. When modest patches of anterior PNX are present, lung points appear along the anterior parasternal line, sometimes invisible on

CXR. The assessment for PNX must concentrate on the non-dependent areas where it tends to arise.

Lung pulse

Caused by transmission of heart beats through a consolidated motionless lung. This sign is very useful to differentiate PNX from other conditions characterized by the absence of horizontal pleural motion. PNX is characterized by absence of lung pulse at LUS because the intrapleural air does not allow transmission of both horizontal and vertical movements to parietal pleura. So, visualization of lung pulse roles out PNX.

"M-mode," which emphasizes a distinguishing barcode feature.

The resulting M-mode tracing in PNX will only show one pattern of parallel horizontal lines below and above the pleural line, indicating a lack of mobility. This design mimics a 'barcode' and is nicknamed the 'stratosphere sign.'

Another crucial thoracic artifact that can help with PNX diagnosis is an A-line. These are reverberation artifacts; they appear as horizontal hyperechoic lines repeated and spaced equally, reflecting off the pleura. The spacing between each A-line represents the distance between the parietal pleura and the skin surface. When 'B-lines' appear in a normal case, they expand from the pleural line and obliterate 'A-lines' as they radiate to the screen's edges. A case with PNX will have 'A-lines' but no 'B-lines.'. A-lines not diagnostic for PNX but presence of B-lines exclude presence of PNX.

The pleura moves rhythmically in time with the heart's rhythm, known as the "lung pulse." It is especially noticeable in areas of the lung along the pleural line, where the heart is. Heart vibrations are transferred to the lung pleura in an inadequately oxygenated lung, resulting in the "lung pulse."

CT chest was done for all patients on admission and discharge. The primary end-point of the study is the detection of pneumothorax. The study's secondary endpoints are discharge, hospital length of stay and survival rate.

Statistical Analysis: Data analyses were carried out with SPSS version 25. The means and standard deviations were used to display the quantitative data. Numerical and percentage data were used to display the categorical data. Chest CT was the reference standard for establishing the diagnostic indices for chest X-ray and US. The Kappa measure of agreement was used to analyze the agreement of X-ray and US with CT, and validity metrics were also evaluated for X-ray and U/S. Data with and without PNX were compared using an independent t-test for quantitative data and a Chi-square or Fisher's exact test for categorical data. Every statistical test was two-sided. $P<0.05$ were considered significant.

RESULTS

Table 1: show that the mean age of studied patients was (68.6±9.35) and ranged from 49-86 years. Male patients represent 56.7% of studied patients, while females represent 43.3%. About 33.3% of them were current smokers. Hypertension and DM were the most common comorbidities (53.3% and 46.6%, respectively). All patients with a history of risk factors for pneumothorax occurrence were intubated MCP (56.7%) or CV line insertion (43.3%) and only 10% of them had already had previous accidental pneumothorax.

Table 2: show that both barotrauma and CV line insertion were common etiologies for pneumothorax occurrence (46.7% and 36.6%, respectively) and only 6.7% account for spontaneous occurrence.

Table 3: show that the most common U/S findings in pneumothorax on the first day of admission was lung point (63.3%), while absent lung sliding presented in 20% and barcode sign (13.3%) of studied patients and lung pulse in one case (3.3%). On the third day of follow-up of studied patients, U/S findings have been changed; 30% of studied patients became resolved when managed according to ACCP Guidelines (conservative if stable asymptomatic patient, needle aspiration if large pneumothorax and stable patient or ICT insertion when needle aspiration fail or unstable patient) lung point appears in 33.3% and 10% with barcode sign, While on the seventh day of follow up 60% of studied patients became free, 16.7% had absent sliding, 10% with lung pulse (did not have PNX) and no patients with barcode sign .

Table 4: concerning the degree of agreement with CT chest, chest ultrasound showed good agreement (kappa = 0.723); it could detect 23 positive cases out of 27 cases confirmed with CT and exclude two negative cases out of three truly negative confirmed by CT.

Table 5: Chest x-ray revealed specificity, sensitivity, PPV, NPV and accuracy of 33.3, 40.7, 84.6, 5.9, and 40%. Chest U/S showed specificity, sensitivity, PPV, NPV, and accuracy of 66.7, 85.2, 95.8, 33.3 and 83.3% .

Table 6: Chest U/S showed a higher sensitivity and specificity of lung point in the detection of PNX (95.7% & 98.7%, respectively) than that for barcode sign or absent lung sliding, with an overall test accuracy of 93.3%, 78.6%, and 58.9%, respectively .

Table 7 : show that 30% of the studied patients died in ICU, and 70% were discharged, with a mean hospital stay of 9.5 ± 3.1 days; the length of hospital stay was substantially higher in cases with PNX, with a mean of 9.85 days versus 6.13 days in those without PNX .

Table (1): Basic characteristics of the studied patients.

	Studied patients N=30
Age (years)	
Mean ± SD	68.6 ± 9.35
	49-86
Gender	N (%)
Male	17 (56.7%)
Female	13 (43.3%)
Smoking	
Current smoker	10 (33.3%)
Ex-smoker	1 (3.3%)
Non-smoker	19 (63.4%)
	Studied patients N=30
Comorbidities	
Free	1 (3.3%)
HTN	16 (53.3%)
DM	14 (46.6%)
IHD	6 (20.0%)
CKD	4 (13.3%)
CLD	2 (6.7%)
Malignancy	2 (6.7%)
Chest comorbidities	
COPD	4 (13.3%)
ILD	5 (16.7%)
Mass (malignant)	2 (6.7%)
History of accidental PNX	3 (10%)
Risk factors for PNX	
No risk factors	3 (10%)
Intubated MVP	14 (46.7%)
CV line insertion	11 (36.6%)
CT guided biopsy	2 (6.7%)

Table (2): Etiology of pneumothorax among the studied patients.

		Studied patients N=30	
		N	%
PNX etiology	**Barotrauma**	14	46.7
	CVline insertion	11	36.7
	Spontaneous	2	6.7
	Traumatic biopsy	3	10.0

Table (3): Chest U/S findings among the studied patients.

Variables		**Studied patients N=30**	
		N	%
US finding on first day	Lung point	19	63.3
	Barcode sign	4	13.3
	Absent lung sliding	6	20
	Presence of Lung pulse	1	3.3
US finding on 3rd day follow up	Resolved	9	30.0
	Lung point	10	33.3
	Barcode sign	3	10
	Absent sliding	6	20
	Presence of Lung pulse	2	6.7
US finding on 7th day follow up	Resolved	18	60
	Lung point	4	13.3
	Absent sliding	5	16.7
	Presence of Lung pulse	3	10

Table (4): Agreement between CT chest and chest U/S assessment among the studied patients.

			CT chest on first day of admission		**Total**
			PNX	**Not**	
U/S on first day of admission	PNX	N	23	1	24
		% Within US decision	95.8%	4.2%	
		% within CT decision	85.2%	33.3%	
	Not	N	4	2	6
		% within US decision	66.7%	33.3%	
		% within CT decision	14.8%	66.7%	
Total		N	27	3	30
Kappa agreement P-value			**0.723 0.02 S**		

S: P-value<0.05 is significant

Table (5): Validity data of chest U/S and chest X-ray in comparison to CT chest as predictors in detection of pneumothorax

	Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
US	85.2%	66.7%	95.8%	33.3%	83.3%
X-ray	40.7%	33.3%	84.6%	5.9%	40%

Table (6): Validity data of each chest U/S finding as a predictor in detection of pneumothorax.

	Sensitivity	**Specificity**	**PPV**	**NPV**	**Accuracy**
Lung point	95.7%	98.7%	95.8%	97.3%	93.3%
Barcode sign	79.3%	83.5%	84.6%	70.9%	78.6%
Absent sliding	75.4	72.3%	54.6	44.6%	58.9%

Table (7): Outcome, length of hospital stay and the relation between length of hospital stay among the studied patients with pneumothorax

			Studied patients N=30	
			N	%
Outcome		Died	9	30.0
		Discharged	21	70.0
Hospital stay (days)		Mean ± SD Range	9.5 ± 3.1 5-18	
	Confirmed N=27	**Not N=3**	**t-test**	
Length of hospital stay (days) Mean ± SD	9.85 ± 2.58	6.13 ± 1.11	**2.24**	**0.033 S**

S: P-value<0.05 is significant

DISCUSSION

Chest diagnostic imaging is vital for managing critically ill cases. Previously, direct viewing of the lung parenchyma was achieved using a chest X-ray and CT [7]. Chest X-rays are most commonly conducted on cases in the ICU while they are in the supine position. The X-ray beam is directed too close to the chest. Furthermore, if the X-ray beam is not directed tangentially on the mediastinal structures and diaphragm dome, accurately identifying the "silhouette sign" may be unattainable. For these reasons, diagnosis errors could result [7]. The CT scan correctly identifies most chest conditions, including PNX. It also provides a valuable guide for chest drainage in cases with abscess, localized PNX or emphysema. Nevertheless, this treatment necessitates transporting the case to a CT unit, which can be unsafe and necessitates both cardio-respiratory monitoring and medical care. The risk of prolonged exposure to ionizing radiation should not be disregarded while repeating assessments to explore further and follow up on a medical disorder [5].

The relative simplicity of bedside U/S evaluation and the accessibility of practical, affordable, portable instruments have made chest U/S a fascinating replacement choice in various circumstances, as it offers precise data that is therapeutic and diagnostically relevant [5].Various reports have studied the role of chest U/S in specific clinical circumstances of PNX, such as post-traumatic PNX [8], PNX in the ICU and post-operative PNX [9]; there were sporadic reports of spontaneous PNX [10].

This cross-sectional investigation was carried out in intensive care units at Zagazig University Hospitals on critically ill patients admitted with respiratory failure of different etiologies in whom there was a suspicious pneumothorax for suspicious PNX, demonstrated that the mean age of the studied group was (68.6±9.35) and range of 49-86 years. Male patients represent 56.7% of the studied group, females represent 43.3%, while .33.3%of the studied group were smokers. Hypertension and DM were the most common comorbidities (53.3% and 46.6%, respectively). All patients with a history of risk factors for pneumothorax occurrence as intubated MCP (46.7%) or CV line insertion (36.6%) and only 10% of them had already previous accidental pneumothorax .

Our results are in agreement with that reported by Archana et al. [11], who investigated the efficacy of chest U/S versus x-rays in the detection of pneumothorax among 79 patients with significant male prominence (76%), 55.7% of cases were with age <40 years. Also, Elgazzar et al. [12] studied 50 cases with an average age of 15 and 48 years and 70% male dominance. The majority of patients were diabetic (44%) and hypertensive (33%). Chen et al. [13] investigated the risk factors and PNX etiologies in 58% of cases with method-related PNX. Thoracentesis was the method that induced the most PNX (54%), followed by 40% with central vein/pulmonary artery catheterization (40%) and 23% with bronchoscopy/transbronchial lung biopsy.

This study revealed that barotrauma and CV line insertions were the most common etiologies for pneumothorax occurrence (46.7% and 36.6%, respectively), and only 6.7% accounts for spontaneous occurrence .

A study evaluated 1199 patients with pneumothorax admitted to Wolfsan Medical Center, England, found that 218 patients (18.2%) were diagnosed with primary pneumothorax, secondary type in 505 (42.1%), traumatic in 403 (33.6%) and iatrogenic in 73 (6.1%). The most common cause of secondary spontaneous pneumothorax was COPD, which occurred in 68% of this group of cases [14].

However, Elgazzar et al. [12] found that the most prevalent causes of PNX were road traffic accidents, spontaneous incidence, barotrauma, iatrogenic and traumatic causes (40%, 20%, 16%, 14%, and 10 %, respectively).This discrepancy in risk factors and related etiologies could be attributed to our inclusion criteria for the sample, as they were critically ill patients admitted to ICU with respiratory failure with clinical suspicion by sudden respiratory and or cardiac deterioration of patients without apparent cause. Also, the sample sizes were different.

This study showed that the most common U/S findings in pneumothorax were lung point (63.3%) and barcode sign (13.3%), while absent lung sliding presented in 20% of studied patients and lung pulse in one case (3.3%). On the third day of follow-up of the studied patients, U/S findings have been changed; 30% of studied patients became resolved, lung points appeared in 33.3% and 10% with barcode signs, while on the seventh day of follow-up, 60% of studied patients became free, 16.7% had absent sliding, 10% with lung pulse and no patients with barcode sign.

Consistent with our results, Archana and his colleagues [11] showed that out of 79 patients, 64 (81.1%) did not have the lung sliding or barcode signs, but 54.4% had the lung point sign. Also, Dulchavsky et al. [15] found that using U/S to rule out PNX had a true negative rate of 100% compared to chest radiography. Liechtenstein et al. [2] stated that the lung point is a particular marker of PNX, although it is not precise as it cannot be identified in severe PNX, whereas lung sliding has a 100% NPV. In prior research of 176 individuals, PNX was diagnosed in 53 (30%) by U/S and 40 (23%) by chest X-ray. On U/S, they discovered PNX by the absence of lung sliding signs [16].

In this study, Concerning the degree of agreement with CT chest, chest ultrasound revealed good agreement (kappa = 0.723); it could detect 23 positive cases out of 27 cases confirmed with CT and exclude two negative cases out of three truly negative confirmed by CT chest.

Chest radiography had sensitivity, specificity, PPV, and NPV of 36, 100, 100, and 70%, respectively. Chest U/S showed specificity, sensitivity, PPV, NPV and accuracy of 66.7, 85.2, 95.8, 33.3, and 83.3% .

Elgazzar et al. [12] documented that X-ray revealed a low agreement with CT, whereas U/S indicated acceptable agreement with CT. Another 13 cases of PNX were identified during CT-guided biopsy; U/S was superior to chest radiography in PNX diagnosis with a sensitivity of 100% [17]. Compared to chest X-rays, U/S was more sensitive but not as sensitive as CT chest scans. False negative cases comprised those with loculated PNX, which was difficult for the U/S to detect, particularly near the lungs' apices where the U/S windows were insufficient [18]. Dente et al. [19] revealed that the time in which U/S was conducted impacted its accuracy.

Regarding U/S and X-ray compared to CT chest as predictors in the detection of chest pneumothorax, our findings agreed with a study held in Banha University hospitals that found that the overall accuracy of the chest X-ray was 45.2%. The chest U/S specificity, sensitivity and accuracy of 87.5, 81, and 82% respectively [12].

Another study showed that using CT scans as the gold standard, chest ultrasound demonstrated similar specificity to CXR (99.5 and 98.7%, respectively) and higher sensitivity than chest X-rays (48.8% vs. 20.9%). Even though CT scans remain the standard technique, U/S has been demonstrated to be more sensitive than chest X-rays in diagnosing occult traumatic PNX [20].

Several reports assessed the diagnostic utility of chest radiography compared with U/S for diagnosing PNX. Alrajab et al. [21] revealed a 78.6% pooled sensitivity and 98.4% specificity for U/S. Chest radiography had specificity and sensitivity of 99.3 and 39.8%, respectively, indicating that when compared to chest radiography, chest U/S may be more precise in identifying PNX. When a patient was in the supine position, the chest X-ray was less sensitive in identifying PNX than a chest US [5].

Sieber et al. [22] proved that pre-existing lung problems may make diagnosing a PNX with U/S difficult. These limiting circumstances are thought to have a more significant occurrence in interventional pulmonology than in emergency or ICU settings and the case with the missed PNX in that research represents one such uncommon false-negative incident. He had a minor trapped apical PNX, which thoracic U/S cannot easily identify.Also, the results documented a higher sensitivity and specificity of lung point in the detection of PNX (95.7% & 98.7%, respectively) than that for barcode sign or absent lung sliding, with an overall test accuracy of 93.3%, 78.6%, and 58.9% respectively .

A short investigation supports the premise that thoracic ultrasound is quick and straightforward to learn, as Monti et al., [23] non-clinician medical emergency staff can identify PNX using U/S with a sensitivity of 96% and a specificity of 100% after a short period of training that included presentations, short videos on the PNX signs to monitor U/S images, and a guide to the U/S.

This study found that 30% of cases died in the ICUs and 70% were discharged, with a mean hospital stay of 9.5 ± 3.1 days. The length of hospital stay was substantially higher in cases with PNX, with a mean of 9.85 days versus 6.13 days in those without PNX .

Chen et al. [13] proved that cases of procedure-related PNX fared better. Cases who develop PNX in the ICUs as a result of barotrauma or a complicating tension PNX are more likely to die.

CONCLUSION

Chest U/S is a bedside and safe imaging technique with higher sensitivity, specificity and accuracy than chest X-rays. Lung point signs in chest ultrasonography have the highest sensitivity, specificity and overall accuracy in the detection of pneumothorax.

No potential conflict of interest was reported by the authors.

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Citation

Nafae, R., Zake, L., Nasr, D., Zayed, N. Early Diagnosis of Pneumothorax in Intensive Care Units with Thoracic Ultrasonography. *Zagazig University Medical Journal*, 2024; (5029-5037): -. doi: 10.21608/zumj.2024.279736.3287