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Original Research Article

A COMPARATIVE STUDY OF THE DIAGNOSTIC ACCURACY OF ULTRASONOGRAM IN PNEUMOTHORAX WITH COMPUTED TOMOGRAPHY OF CHEST

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Abstract
Background: Thoracic cavity injuries account for 20-25% of mortalities in traumatic events and are the second leading cause of death in pediatric trauma. **Aim:** The study aims to estimate the diagnostic accuracy of transthoracic ultrasonograms in pneumothorax compared to thoracic computed tomography. **Materials and Methods:**The study was a cross-sectional study conducted in the Department of Radio-diagnosis, Government Tirunelveli Medical College, a tertiary care hospital, for two years (2019-2021). Two hundred fifty patients were selected based on the inclusion and exclusion criteria admitted with significant risk for developing pneumothorax. **Result:** The age of the patients studied was in the range of 14 and 85 years, with a mean age of 39 years. Most of the study population was 21-40 years. Pneumothorax is quantified based on the location of the lung point. It is minimal when the lung point is identified as medial to the midclavicular line and moderate when identified at the midaxillary or posterior axillary line. Absent lung sliding has a high negative predictive value for pneumothorax. The lung point is identified in 63, and lung pulse is present in 3 cases. The barcode sign has high specificity and negative predictive value, and the transthoracic ultrasonogram is accurate. There is a good correlation of pneumothorax quantification between the chest computed tomography and the transthoracic ultrasonogram with a p-value <0.0001. **Conclusion:** With computed tomography of the chest as the criterion standard, transthoracic ultrasonogram has higher sensitivity and specificity for diagnosing pneumothorax.

INTRODUCTION

Thoracic cavity injuries account for 20-25% of mortalities in traumatic events and are the second leading cause of death in pediatric trauma.[1] However, prompt diagnosis and treatment could prevent many of these deaths. Less than 10% of blunt chest injuries and only 15-30 % of penetrating chest injuries require operative intervention. Most patients who sustain thoracic trauma can be treated by simple emergency room (ER) procedures.[2]One of the most common and easily treated thoracic injuries is pneumothorax, the collection of air between the parietal and visceral pleura.[3]The collapsed lung may develop as a complication of trapped air. Pneumothorax can develop spontaneously in patients with risk factors. However, it is seen in blunt or penetrating trauma mostly. Early detection of such injuries is critically important because it can significantly decrease the mortality rate and the resultant burden.

A combination of clinical examination and chest radiography often detects pneumothorax. But subtle pneumothorax may be difficult to detect in the trauma setting for various reasons. In a trauma patient, chest radiographs usually obtained are anteroposterior images with the patient in a supine position.[4] Radiographs obtained with the patient upright are more sensitive. Still, most trauma patients cannot be upright due to cervical spine injuries, hemodynamic instability, immobilization of orthopaedic injuries, ongoing resuscitation, or decreased level of consciousness.A Thoracic CT scan is considered the gold standard investigation for diagnosing and determining the size of the pneumothorax.[5] It is neither practical nor feasible to perform this cross-sectional imaging examination in all trauma patients for concerns such as radiation exposure, cost, and transport of unstable high-risk patients.

Chest ultrasonography has gained momentum recently as a portable, inexpensive, safe, and fast alternative for radiography in detecting traumatic intrathoracic injuries.[6] However, it largely depends on the operator's experience and expertise.Its results are unreliable in identifying parenchymal injuries. Chest US can be a reliable alternative to CT, especially in critical care and emergency management situations.Therefore, the study aims to estimate the diagnostic accuracy of transthoracic ultrasonograms in pneumothorax compared to thoracic computed tomography.

MATERIALS AND METHODS

The study was a cross-sectional study conducted in the Department of Radio-diagnosis, Government Tirunelveli Medical College, a tertiary care hospital, for two years (2019-2021).Two hundred fifty patients were selected based on the inclusion and exclusion criteria admitted with significant risk for developing pneumothorax.

Patients admitted with significant risk for developing pneumothorax as patients with thoracic trauma and patients who underwent thoracic procedures, thoracocentesis or central venous catheter insertion were included. Hemodynamically unstable patients, patients with tension pneumothorax (diagnosed with chest radiograph), patients with chest tubes placed before imaging, patients lost to ultrasound examination, pregnant patients, and pediatric patients were excluded.

After obtaining approval from the institutional ethical committee, patients fulfilling the inclusion and exclusion criteria are included. Informed consent was obtained before subjecting the patient to this study.All examinations (transthoracic ultrasonogram and computed chest tomography) are performed with the patient supine.

The patients are subjected to ultrasound examination. Ultrasound examinations were done with Sonoscape S18 and Mindray with a 7-MHz linear or 3.5-MHz convex probe. Every lung field is first examined in the longitudinal plane, from the second intercostal space to the diaphragm through the anterior and lateral chest wall. This is followed by examination from the sternum to the mid-axillary line transversely through the intercostal spaces.

The pleural line is identified in B-mode, and lung sliding and comet tail artifact (B-lines) were checked during respiration. When lung sliding and comet tail artifact were not seen, pneumothorax was suspected, and the US was switched to M-mode seeking for seashore sign. When the seashore sign cannot be seen, and instead, a barcode sign is viewed in the same location with absent lung sliding and absent comet tail artifact, a diagnosis of pneumothorax is provisionally made.

When lung pulse is detected on M-mode at the site of absent lung sliding and absent comet tail artifact, pneumothorax is ruled out.The patients are subsequently subjected to CT examination within 2 hours. Those patients with negative US for pneumothorax but significant risk for pneumothorax are also subjected to CT scans. CT examination is done with the 16-slice spiral CT scanning unit (Alexion and Aquilion Lightning Model TSX 035A, Toshiba Medical Systems Corporation, Japan).

The study data were presented as percentages and the number of cases. The categorical data were analysed with Pearson Chi-square tests. The sensitivity, specificity, positive predictive value, negative predictive value and diagnostic accuracy were calculated for each outcome variable, including absent lung sliding, absent B-lines, lung point, absent lung pulse and barcode sign on M-mode. Correlation between the quantification of pneumothorax on transthoracic ultrasonogram and computed tomography were assessed. Significance was defined by P-values less than 0.05 using a two-tailed test. Data analysis was performed using IBM-SPSS version 21.0 (IBM-SPSS Science Inc., Chicago, IL).

RESULTS

The age of the patients studied was in the range of 14 and 85 years, with a mean age of 39 years. Most of the study population was 21-40 years.

4 of the 500 hemithoraces could not be assessed due to diffuse subcutaneous emphysema. Excluding these 4 cases, lung sliding was absent in 96 of the 496 hemithoraces.

With the exclusion of 4 cases that could not be assessed, B-lines were absent in 96 of the 496 lung fields assessed sonographically. Multiple B-lines were seen in 3 cases of ARDS, pulmonary contusion and consolidation.

Lung point was identified in 63 lung fields to midclavicular, anterior axillary, midaxillary and posterior axillary lines.

Absent lung pulse was seen in 493 of the 496 lung fields assessed sonographically, excluding the 4 cases that could not be evaluated due to diffuse subcutaneous emphysema.

On M-mode, the seashore sign was demonstrated in 400 lung fields, the barcode sign in 79 lung fields, the sinusoid sign in 14 lung fields with pleural effusion/ hemothorax, and lung pulse in 3 cases of consolidation and lung mass.

Four of the 500 hemithoraces assessed could not be evaluated sonographically due to diffuse subcutaneous emphysema.Seventy-six pneumothoraces have been diagnosed with transthoracic ultrasonogram.

The gold-standard imaging modality in diagnosing pneumothorax is the computed tomography of the chest which gives a definitive determination of the presence or absence of pneumothorax and its cause. Pneumothorax has been diagnosed with CT chest in 83 of the 500 hemithoraces.

Pneumothorax is quantified based on the location of the lung point. Pneumothorax is minimal when the lung point is identified as medial to the midclavicular line. Lung point at midclavicular or anterior axillary line indicates small pneumothorax. Identification of lung point at midaxillary or posterior axillary line indicates moderate pneumothorax. The lung point is not identified in large pneumothorax due to passive lung collapse [Table 1].

Table 1: Demographic data of the study

		Frequency	Percentage
Lung sliding	Absent	96	19.2%
	Present	400	80%
	Could not be assessed due to the presence of subcutaneous emphysema	4	0.8%
B-lines	Absent	96	19.2%
	Multiple	3	0.6%
	Present	397	79.4%
	Could not be assessed due to the presence of subcutaneous emphysema	4	0.8%
Lung point	Absent	420	84%
	Medial to the midclavicular line	2	0.4%
	Midclavicular line	24	4.8%
	Anterior axillary line	12	2.4%
	Midaxillary line	19	3.8%
	Posterior axillary line	6	1.2%
	Not identified	9	1.8%
	Could not be assessed due to the presence of subcutaneous emphysema	8	1.6%
Lung pulse	Absent	493	98.6%
	Present	3	0.6%
	Could not be assessed due to the presence of subcutaneous emphysema	4	0.8%
M-mode	Seashore sign	400	80%
	Barcode sign	79	15.8%
	Sinusoid sign	14	2.8%
	Lung pulse	3	0.6%
	Could not be assessed due to the presence of subcutaneous emphysema	4	0.8%
Presence of pneumothorax USG	Present	76	15.2%
	Absent	420	84%
	Could not be assessed due to the presence of subcutaneous emphysema	4	0.8%
Presence of pneumothorax	Present	83	16.6%
	Absent	417	83.4%
Quantification USG	Minimal	2	2.6%
	Small	36	47.4%
	Moderate	25	32.9%
	Large	9	11.8%
	Could not be assessed due to the presence of subcutaneous emphysema	4	5.3%
Quantification CT	Minimal	6	7.2%
	Small	34	41%
	Moderate	30	36.1%
	Large	13	15.7%

Among the 96 lung fields with absent lung sliding, 76 were sonographically diagnosed as pneumothorax with one false-positive case. The other 20 lung fields with absent lung sliding were seen in consolidation and passive atelectasis cases due to moderate to massive pleural effusion/hemothorax and lung mass. Thus, absent lung sliding has a high negative predictive value for pneumothorax.

76 of the 96 lung fields with absent B-lines were sonographically diagnosed as pneumothorax, including one false-positive case. The other 20 lung fields with absent B-lines were seen in consolidation and passive atelectasis cases due to moderate to massive pleural effusion/hemothorax and lung mass. Absent B-lines havea high negative predictive value for pneumothorax.

Among the 76 lung fields diagnosed sonographically as pneumothorax, lung point was identified in 63, including a false positive case. 9 of the 13 lung fields where lung point was not identified were due to lung collapse in large pneumothorax. Lung point could not be assessed in 4 lung fields, diagnosed sonographically as pneumothorax, due to subcutaneous emphysema. Statistical analysis done with the exclusion of 4 cases that could not be evaluated sonographically showed high specificity of lung point in diagnosing pneumothorax.

Lung pulse was present in 3 cases of consolidation and lung mass and absent in all cases diagnosed as pneumothorax. Absent lung pulse has the highest sensitivity and negative predictive value of 100% in diagnosing pneumothorax but the lowest specificity of 0.72%.
A Barcode sign was demonstrated in 76 of the 76 pneumothoraces diagnosed on transthoracic ultrasonogram, including one false-positive case. It was also demonstrated in 3 cases with absent lung sliding, such as consolidation and atelectasis. Barcode sign has high specificity and negative predictive value in diagnosing pneumothorax.
75 of the 83 pneumothoraces have been diagnosed with transthoracic ultrasonogram, with one false-positive case showing giant emphysematous bulla on computed chest tomography.Eight false-negative cases with minimal pneumothorax or that could not be evaluated due to subcutaneous emphysema. The overall diagnostic accuracy of transthoracic ultrasonogram in diagnosing pneumothorax is 98.2% [Table 2, 3].

Table 2: Presence of pneumothorax – CT

		Presence of pneumothorax CT	
		Present	**Absent**
Lung sliding	Present	4	396
	Absent	75	21
B-lines	Present	4	396
	Absent	75	21
Lung point	Present	62	1
	Absent	17	416
Lung pulse	Present	0	3
	Absent	79	414
Barcode sign	Present	75	4
	Absent	4	413
Sonographic detection of pneumothorax	Detected	75	1
	Not detected	8	416

Table 3: Sensitivity and specificity of sonographic parameters

	Sensitivity	Specificity	PPV	NPV	Accuracy
Lung sliding	94.94%	94.96%	78.12%	99%	94.96%
B-lines	94.94%	94.96%	78.12%	99%	94.96%
Lung point	78.48%	99.76%	98.41%	96.07%	96.37%
Lung pulse	100%	0.72%	16.02%	100%	16.53%
Barcode sign	94.94%	99.04%	94.94%	99.04%	98.39%
Sonographic detection of pneumothorax	90.36%	99.76%	98.68%	98.11%	98.20%

There is a good correlation of pneumothorax quantification between the chest computed tomography and the transthoracic ultrasonogram with a p-value <0.0001 [Table 4].

Table 4: Quantification - USG * Quantification - CT Crosstabulation

Quantification USG	Minimal	Small	Moderate	Large	Total	P-value
Minimal	2	0	0	0	2	<0.0001
Small	0	33	3	0	36	
Moderate	0	0	23	1	24	
Large	0	0	0	9	9	
Could not be assessed due to the presence of subcutaneous emphysema	0	1	4	3	8	
Not identified	4	0	0	0	4	
Total	6	34	30	13	83	

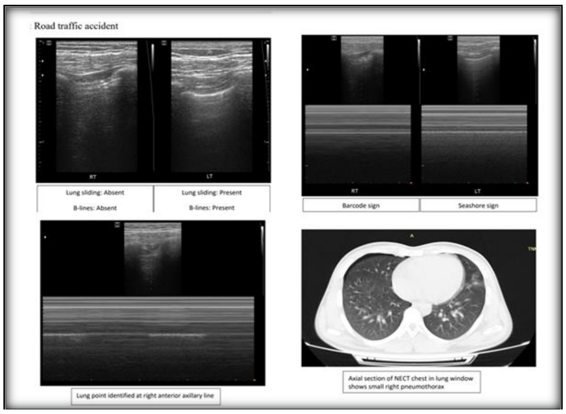

Figure1: A case of road traffic accident with right pneumothorax

DISCUSSION

This study has shown high sensitivity and specificity of transthoracic ultrasonograms measuring 90.36% and 99.76%, respectively, with positive and negative predictive values being 98.68% and 98.11% in diagnosing pneumothorax. In this study, one patient had false-positive, and 8 had false-negative results with ultrasonogram.
The diagnostic accuracy of ultrasonograms is affected by several factors, such as absent lung sliding, B-lines, lung point, lung pulse, subcutaneous emphysema, and minimal or loculated pneumothorax. Absent lung sliding can be seen in patients with poor respiratory reserve, consolidation,

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atelectasis, pulmonary fibrosis, pleural adhesions, phrenic nerve paralysis and acute respiratory distress syndrome. B-lines can sometimes be absent with no lung parenchymal abnormality, while multiple B-lines are always pathological. Lung point cannot always be identified, and lung pulse is absent in normal hemithorax. Examination limited to the second intercostal space can lead to false-negative results and necessitates a complete evaluation of the thorax.

Thus, absent lung sliding and absent B-lines had a high negative predictive value of 99.0% for pneumothorax in our study, with a low positive predictive value of 78.12%. Absent lung pulse had the highest sensitivity and negative predictive value of 100% in diagnosing pneumothorax at the expense of the lowest specificity of 0.72%. On M-mode, the barcode sign had high specificity and a negative predictive value of 99.04% in diagnosing pneumothorax.

Identification of lung point had high specificity of 99.76% but low sensitivity of 78.48% in diagnosing pneumothorax. However, the lung point identified in pneumothorax should be differentiated from the physiological and pseudo lung points. Physiological lung point can be demonstrated in the left hemithorax at the mediastinal pleura, where the visceral pleura contacts the soft tissue of the mediastinum cyclically during inspiration. Identifying cardiac pulse in the no-lung region between two seashore signs differentiates the physiological lung point from the lung point in pneumothorax, where lung pulse is characteristically absent. The pseudo lung point is demonstrated in pulmonary contusion or consolidation at its junction with the adjacent normal aerated lung. A barcode sign is identified at the site of pulmonary contusion or consolidation with a seashore sign in the normal lung. Identifying an A-line at the same location as the barcode sign suggests pneumothorax, as A-lines are abolished in pulmonary contusion and consolidation.

There is a good correlation of pneumothorax quantification between the chest computed tomography and the transthoracic ultrasonogram with a P-value <0.0001. Thus, an ultrasonogram can aid in appropriate management with chest tube placement in large pneumothorax and periodic monitoring in patients with minimal pneumothorax, managed conservatively, without subjecting them to repeated dosesof ionizing radiation.

Our study results correspond to the opinion expressed in the literature that transthoracic ultrasonogram has higher sensitivity and specificity in diagnosing pneumothorax. However, the sensitivity of this study was greater than that in studies by Goodman et al.[7] Kirkpatrick et al.[8] Zhang et al.[9]Balesa et al.[10] and Bhoil et al.[11] 87.5%, 48.8%, 86.2%, 89% and 89.6% respectively, possibly because of large sample size in our study.

But, the sensitivity of this study was lower than the studies by Lichtenstein et al.[12] Rowan et al.[13] and Soldati et al.[14]is 95.3%, 100% and 92%, respectively, possibly due to the limitations of the small sample size and selection bias in these studies. Subcutaneous emphysema was an exclusion criterion in some studies, including that by Soldati et al.[14] When 4 cases with extensive subcutaneous emphysema that could not be assessed sonographically were excluded from our study, the study's sensitivity had improved to 94.94%.

The results of this study suggest that transthoracic ultrasonogram can serve as a reliable alternative to computed tomography of the chest for diagnosing pneumothorax with the advantages of being simple, portable and rapid, especially in critical care and emergency management situations,where the patients are at risk for mobilisation to the CT unit, and in pregnant and pediatric populations, who are at risk of exposure to ionizing radiation, the ability of ultrasonogram to quantify pneumothorax is of considerable utility as a chest tube can be placed in large pneumothorax detected sonographically before transferring the patient to another facility.

CONCLUSION

With computed tomography of the chest as the criterion standard, transthoracic ultrasonogram has higher sensitivity and specificity for diagnosing pneumothorax. It is a reliable tool for quantifying pneumothorax with good agreement with chest computed tomography, thus aiding the management. Transthoracic ultrasonogram also has the advantages of being simple, portable, rapid and with no risk of radiation exposure.

Transthoracic ultrasonogram can be a reliable alternative to CT in diagnosing pneumothorax, especially in critical care, emergency management situations, pregnancy and pediatric population, and peripheral centres lacking computed tomography facilities.

Limitations

There are some limitations in this study. The major limitation is that the study population included patients with a higher risk for developing pneumothorax and were symptomatic and did not include asymptomatic patients with the risk factors for pneumothorax. However, the criterion standard of computed tomography of the chest would not have been obtained for comparison otherwise, or the asymptomatic patients may need to be irradiated with CT, which can be unethical. The patients are subjected to computed tomography at least 10 minutes after the initial ultrasonogram examination but within 2 hours. This may allow the expansion of pneumothorax in some cases and can cause quantification errors between transthoracic ultrasonogram and computed tomography in some cases.

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