Role of Pleural Manometry and Transthoracic Ultrasonography to Predict Entrapped Lung

Shaimaa Magdy Abo Youssef[1],Ahmed Abd Elsadek Mohamed [1],Diaa Eldin Abdelazeem Amin *2*, Nashwa Ahmed Amin [1],
Department of Chest Diseases[1] , Benha University, Egypt,
, Chest Hospital of Military Kobri Al-kobba *Egypt2*.

Abstract: Unexpandable lung is a complication by which the lung does not expand to the chest wall with pleural space drainage. Which will result in adverse events or intervention failure if not well recognized prior to the intervention.

Aim of the work: This study aimed to assess the role of pleural manometry and transthoracic ultrasonography in predicting abnormal lung expansion during pleural drainage.

Patients and Methods: this was a prospective observational analytical study involving 50 patients that aims to predict abnormal lung expansion during pleural drainage using pleural manometry and transthoracic ultrasound.

***Results*:** Regarding pleural manometry (pleural elastance), all patients in the entrapped lung group (100%) had pleural elastance >14.5cm H2o/L, while, in the non-entrapped lung group, all patients (100%) had pleural elastance ≤14.5cm H2o/L. Regarding ultrasonography, pleural thickening > 0.5 cm was found in all patients with entrapped lung (100%) and 50% of patients with non-entrapped lung with statistically significant difference. In the entrapped lung group, 20%, 35% and 45% of patients had simple, complex non-septated and complex septated pleural effusion, respectively, while in the non-entrapped lung group 63.35%,33.33% and 3.32% of patients had simple, complex non-septated and complex septated effusion, respectively, with statistically significant difference (p-value 0.0005).

***Conclusion*:** Pleural manometry and transthoracic ultrasound can guide decision-making regarding the timing of pleural interventions and management of cases with entrapped lung.

Keywords: pleural effusion, pleural manometry, transthoracic ultrasonography, entrapped lung.

Introduction:

The pleural effusion is caused by different etiologies ranging from relatively harmless viral pleuritis to congestive heart failure or cancer. There are two major etiologies for unexpandable lung, either a sequel of fibrinous pleuritis or an active pleural disease (lung entrapment). The presence of remote pleural inflammation resulting in mature fibrous membrane overlying the visceral pleura preventing full expansion of the lung is usually described as (trapped lung). Trapped lung typically presents with chronicity, stability with no clue of active pleural disease. The presence of active pleural process known as malignant pleural effusions and inflammatory pleural diseases described nowadays as lung entrapment (1).

Pleural manometry (PM) is helpful in the assessment of an unexpandable lung. PM can detect abnormal lung expansion during thoracocentesis (2).

PM is usually done during pleurocentesis and is helpful for detection of unexpandable lung and with the application of pleural manometry, cases of unexpandable lung can be accurately diagnosed and pleurodesis success can be predicted (2).

The usage of transthoracic ultrasound has been increasingly used to aid in the diagnosis and management of pleural effusion (3).

Aim of the work:

This study aimed to assess the role of pleural manometry and transthoracic ultrasonography in predicting abnormal lung expansion during pleural drainage.

Patients and Methods:

Study Design:

This study adopts a prospective, observational and analytical design aimed at predicting abnormal lung expansion subsequent to pleural drainage, employing pleural manometry and transthoracic ultrasound techniques. A total of 50 patients are recruited for this investigation, with data collection taking place at Benha University Hospital and Kobry El Koba Chest Hospital in Cairo. The study duration spans from April 2022 to April 2023.

Ethical approval was obtained from Ethical Committee in the Faculty of Medicine, Benha University (Institutional Research Board IRB) (Study No. MS-17-9-2022).

Patients were subjected to the following after informed consent:

1. History taking and clinical examination.
2. CXR and HRCT
3. Transthoracic ultrasound examination before and after pleural fluid drainage.

Key parameters assessed during the ultrasound examination included:

Characterization of the pleural effusion (e.g., free-flowing, complex septated, complex nonseptated), Measurement of effusion depth and volume, Assessment of lung expansion, Assessment of pleural thickening, Detection of underlying lung pathology (e.g., lung mass, consolidation, atelectasis), Comparison of pre- and post-drainage ultrasound findings to evaluate of the effectiveness of the drainage procedure in achieving lung re-expansion and resolution of pleural effusion abnormalities.

4. Measurement of the pleural pressure changes using pleural manometry during pleural fluid drainage concurrent with pleural fluid drainage. This procedure was done by placing the catheter in the effusion during drainage.

The level where the catheter was inserted marks zero point (zero pressure) of the water column.

During drainage procedure, continuous monitoring of pleural pressure was performed to assess changes in intrapleural pressure as fluid is removed from the pleural space to ascertain whether the lung will expand normally, partially (lung entrapment), or not at all (trapped lung)

To prevent a sudden drop in Ppl, pleural pressure should be measured every 50–100 cc.

The pleural elastance was determined at the conclusion of the procedure (cmH2O/L) = change in pressure/change in volume, which is defined as the decrease in pleural fluid pressure in cmH2O following the removal of a 500 ml of pleural fluid as a result of thoracocentesis.

Pleural manometry serves as an adjunctive tool to optimize pleural drainage procedures, guide therapeutic interventions, and identify patients at risk of entrapped lung or inadequate lung expansion.

5. Thoracocentesis and Pleural fluid analysis were done.

6. Lastly guiding further diagnostic and therapeutic interventions like thoracoscopy, US guided Pleural biopsy or Abram's needle biopsy.

By using these interventions, we could take biopsy and reach accurate diagnosis.

all data were collected and statistically analyzed

Results: Patients were categorized into two groups: Entrapped Lung Group (Non-Expandable Lung)) and the Non-Entrapped Lung Group (Expandable Lung) according to pleural elastance > 14.5 cmH2O/L 0r <14.5 cm H2O/L respectively **(4)**

The study included 50 patients in two groups with no statistically significant differences regarding age, sex, or smoking index.

Table 1: Demographic data of the studied patients.

	Entrapped lung group	***Non-Entrapped lung group***	***P value***	***Statistically significant***
	N=20	***N=30***		
Age				
Mean± SD	40±15.74	49.9±18.16	0.0524	N. S
Range (Min-Max)	19-74	21-80		
Gender				
Male	15(75%)	20(66.67%)	0.5287	N. S
Female	5(25%)	10(33.33%)		
Smoking Index (Netti)				
Nonsmoker	6(30%)	15(50%)	0.4408	N. S
Mild	2(10%)	4(13.33%)		
Moderate	3(15%)	3(10%)		
Sever	3(15%)	1(3.32%)		
Heavy	6(30%)	7(23.35%)		
Statistical test used: Tow sample T-test & Chi-square test				
p-value≤0.05 considered statistically significant (95% confidence interval).				

Similarly, parameters such as side and volume of effusion in chest X-ray, side, volume, and type of radiological findings in HRCT showed non significant difference.

Table 2: Radiological findings (Chest Xray - HRCT) among the studied patients.

Radiological findings in chest Xray	***Entrapped lung group N=20***	***Non-Entrapped lung group N=30***	***P value***	***Statistically significant***
side of effusion in chest x ray				
Right	13(65%)	15(50%)	0.2952	N. S
Left	7(35%)	15(50%)		
volume of effusion in CXR				
Mild	2(10%)	2(6.67%)	0.3658	N. S
Moderate	14(70%)	17(56.67%)		
Massive	4(20%)	11(36.66%)		
Radiological findings in HRCT	***Entrapped lung group N=20***	***Non-Entrapped lung group N=30***	***P value***	***Statistically Significant***
Side				
Right	13(65%)	15(50%)	0.2952	N. S
Left	7(35%)	15(50%)		
Volume				
Mild	2(10%)	2(6.67%)	0.3658	N. S
Moderate	14(40%)	17(56.67%)		
Massive	4(20%)	11(36.66%)		
Type				
Simple	10(50%)	25(83.33%)	0.117	N. S
Encysted	10(50%)	5(16.67%)		
underlying lung pathology				
Pneumonia	5(25%)	3(10%)	0.196	N. S
lung collapse	5(25%)	21(70%)		
Emphysema	4(20%)	3(10%)		
lung nodules ± pleural thickening	6(30%)	3(10%)		
Statistical test used: Chi-square test				
p-value≤0.05 considered statistically significant (95% confidence interval).				

Furthermore, this study evaluated the performance metrics for pleural elastance in predicting the presence of Entrapped Lung. The analysis in **table (3)** revealed:

Table 3: Pleural elastance and manometric Changes among the studied patients.

Pleural elastance and manometric	***Entrapped lung group***	***Non-Entrapped lung***	***P value***	***Statistically significant***

Changes		*Group*		
	N=20	*N=30*		
Pleural elastance				
PE≤14.5 cmH2O /L	0(0%)	30(100%)	<0.0011	Sig.
PE>14.5 cmH2O/L	20(100%)	0(0%)		
Volume	720.5±210.65	1118.33±434.28	0.952	N. S
Initial Pressure	27.45±2.04	27.87±1.76	0.4595	N. S
Closing Pressure	15.45±5.61	19.07±4.07	0.0186	Sig.
Change in Pressure	12±4.63	8.83±3.76	0.0154	Sig.
Statistical test used: Tow sample T-test & Chi-square test				
p-value≤0.05 considered statistically significant (95% confidence interval).				

Regarding pleural elastance, patients were categorized into entrapped lung group and non-entrapped lung group according to pleural elastance >14.5cm H2o/L and pleural elastance ≤14.5cm H2o/L, respectively.

Regarding the initial pressure of the pleural manometry during thoracocentesis there was no significant difference between two groups. But there was significant difference in closing pressure. In the entrapped lung group, the closing pressure of the pleural manometry during thoracocentesis was 15.45± 5.61 cmH2O and in the non-entrapped lung group was 19.07 ± 4.07 cmH2O. None of patients had negative initial pressure or rapid drop in pleural pressure (Trapped lung).

Regarding change in pressure of the pleural manometry during thoracocentesis in the entrapped lung group, the mean change in pressure was 12± 4.63 cmH2O and in the non-entrapped lung group was 8.83± 3.76 cmH2O, with statistically significant difference.

Table 4: Ultrasound findings among the studied patients.

Ultrasound Examination	*Entrapped lung group*	*Non-Entrapped lung group*	*P value*	*Statistically significant*
	N=20	*N=30*		
pleural thickening more than 0.5 cm				
No	0(0%)	15(50%)	0.0025	Sig.
Yes	20(100%)	15(50%)		
Amount of Effusion				
Minimal	0(0%)	0(0%)	0.4466	N. S
Mild	2(10%)	2(6.67%)		
Moderate	14(70%)	19(63.33%)		
Massive	3(15%)	6(20%)		

Extensive	1(5%)	3(10%)		
side of effusion				
Right	13(65%)	15(50%)	0.2952	N. S
Left	7(35%)	15(50%)		
US TYPE OF EFFUSION				
Simple	4(20%)	19(63.35%)	0.0005	Sig.
Complex Nonseptated	7(35%)	10(33.33%)		
Complex Septated	9(45%)	1(3.32%)		
Swirling Sign				
Negative	6(30%)	5(16.67%)	0.2846	N. S
Positive	14(70%)	25(83.33%)		
Underlying lung pathology				
C profile	5 (25%)	3 (10%)	0.168	N. S
A profile	4 (20%)	3 (10%)		
Statistical test used: Chi-square test				
p-value≤0.05 considered statistically significant (95% confidence interval).				

Regarding pleural thickening more than 0.5 cm in US findings, In the entrapped lung group all patients had pleural thickening more than 0.5 cm 100%, while the non-entrapped lung group 50% of patients had pleural thickening and the same percentage had no pleural thickening with statistically significant difference between two groups.

There was no statistically significant difference regarding the amount of pleural effusion in US, or the side of effusion.

Regarding US type of the pleural effusion, patients were categorized into (simple, complex non-septated and complex septated) with statistically significant difference between two groups.

Regarding the presence of Swirling sign in US, patients were categorized into positive and negative, with no statistically significant difference.

- Swirling sign: - multiple floating echogenic particles within the pleural fluid that moves in response to respiratory movement or heart beat during real-time ultrasound examination.

Pleural fluid color and clarity, AFB, Gram stain positivity, cytology findings, LDH, protein, and glucose levels did not show significant associations with the likelihood of having an entrapped lung. However, CXR assessment demonstrated a significant association

with lung expansion post-tapping, thoracoscopy or treatment suggesting its potential for assessment of lung expansion during a duration of 2 months.

Table 5: Lung expansion post drainage and treatment.

lung expansion post drainage and treatment.	***Entrapped lung group***	***Non-Entrapped lung Group***	***P value***	***Statistically significant***
	N=20	***N=30***		
CXR and Ultrasonography				
lung not fully expanded	9(45%)	0(0%)	<0.0015	Sig.
lung fully expanded	11(55%)	30(100%)		
Statistical test used: Chi-square test				
p-value≤0.05 considered statistically significant (95% confidence interval).				

Table 6: Complications & Final Diagnosis among the studied patients.

Complications & Final Diagnosis	***Entrapped lung Group***	***Non-Entrapped lung Group***	***P value***	***Statistically Significant***
	N=20	***N=30***		
Complications				
No complication	19(95%)	27(90%)	0.6856	N. S
Pneumothorax	0(0%)	1(3.33%)		
Infected wound	1(5%)	2(6.67%)		
Final Diagnosis				
Malignant PF (Mesothelioma, Mets)	4(20%)	15(50%)	0.9301	N. S
Effusion due to infectious cause (TB, Empyema)	15(75%)	13(43.33%)		
Post cardiac surgery effusion	1(5%)	2(6.67%)		
Statistical test used: Chi-square test				
p-value≤0.05 considered statistically significant (95% confidence interval).				

There was no significant difference in (complications & final diagnosis) between the study groups. As regard complications, one patient developed pneumothorax in non-entrapped lung group, one patient complicated by wound infection in entrapped lung group and two patients complicated by wound infection in non-entrapped lung group.

As regard final diagnosis, in entrapped lung group 4 patients had Malignant pleural effusion, 15 patients had Tuberculous pleural effusion and Empyema, and one patient had Post Cardiac surgery effusion.

While in non entrapped lung group, 15 patients had Malignant pleural effusion, 13 patients had TB and Empyema and 2 patients had Post Cardiac surgery effusion.

Discussion:

Currently, there are no methods to identify entrapped lung prior to pleural effusion drainage and so many patients require more than one procedure for definitive management. The current study focuses on a novel approach for identification of entrapped lung, using pre procedure transthoracic ultrasonography combined with the standard method of pleural manometry during thoracocentesis.

In this study patients were categorized into Entrapped and Non- Entrapped lung groups according to pleural elastance (pleural elastance ≤14.5cm H2o/L and pleural elastance >14.5cm H2o/L).

There was no statistically significant difference between two groups regarding volume of pleural fluid aspirated or initial pressure of the pleural manometry during thoracocentesis.

However, there was statistically significant difference as regard the closing pressure of pleural manometry during thoracocentesis, change in pressure, and pleural elastance. Regarding the closing pressure of the pleural manometry during thoracocentesis in the entrapped lung group, the mean the initial pressure was 15.45 ± 5.61 cmH2O and in the non-entrapped lung group was 19.07 ± 4.07 cmH2O (p-value 0.0186).

Regarding the change in pressure of the pleural manometry during thoracocentesis in the entrapped lung group, the mean change in pressure was 12 ± 4.63 cmH2O and in the non-entrapped lung group was 8.83 ± 3.76 cmH2O (p-value 0.0154).

In a study by **Patel et al., 2021,** changes in pressure in pleural manometry during thoracentesis were found to be significantly associated with the presence of Entrapped lung ($p < 0.05$) (5).

Similarly, **Zielinska-Krawczyk et al., 2018** reported a significant correlation between pleural elastance >14.5cm H2o/L and the likelihood of having Entrapped lung ($p < 0.01$) **(6).**

Feller- Kopman et al., 2009 study concluded that the measurement of pleural pressure aids to identify lung entrapment, allows for safe removal large effusion and is a helpful tool to select appropriate patients with malignant pleural effusion for pleurodesis (7).

Current findings regarding changes in pressure in pleural manometry during thoracentesis are similar to those reported by **Patel et al., 2021** indicating that this parameter could be a reliable predictor of Entrapped lung in our study population.

Similarly, these results regarding pleural elastance align with those reported by **Zielinska-Krawczyk et al., 2018.**

Regarding ultrasonographic findings, there was significant difference in the presence of pleural thickening more than 0.5 cm; as presented in Table 4, in the entrapped lung group all patients had pleural thickening more than 0.5 cm

(100%), while in non-entrapped lung group 50% of patients had pleural thickening and the same percentage had no pleural thickening with statistically significant difference (p value 0.0025).

Similar to these results, the study by **Huggins et al., 2007** reported significant demonstrated abnormal visceral pleural thickness on HRCT in entrapped lung **(4).**

A study by **Light et al., 1980** reported significant associations between pleural thickening and trapped lung as apart of Entrapped lung group (8).

Regarding the type of effusion identified through ultrasound imaging there was significant associations between type of effusion and the likelihood of Entrapped lung. Specifically, a statistically significant p-value of 0.0005 was observed, indicating that the

distribution of simple, complex nonseptated, and complex septated effusions differs significantly between the two groups.

Similar to these results, **Faber & Krenke (2021)** reported significant associations between the complex septated type of effusion identified through ultrasound imaging and the likelihood of Entrapped lung ($p < 0.05$) **(9).**

Radiological assessment lung expansion by CXR and US, after drainage of pleural fluid and medical treatment, showed 55% of patients in Entrapped lung group had fully expanded lung while in 45% of patients, lungs were not fully expanded after 2 months duration. In non-entrapped lung group, 100% of patients had fully expanded lung with high statistical significant difference (p-value <0.0001).

In a study by Brueder et al., (2020), CXR assessment showed significant differences in lung expansion between patients with and without Entrapped lung ($p < 0.05$) (10)

Similarly, Laursen et al. (2021) reported a significant association between CXR findings before and after drainage and the likelihood of Entrapped lung ($p < 0.05$) (1)

As presented in Table 6, there was no significant difference in complications and final diagnosis between the study groups. As regard complications, one patient developed pneumothorax in non-entrapped lung group, two patients complicated by wound infection in non entrapped lung group, and one patient complicated by wound infection in entrapped lung group.

As regard final diagnosis, in entrapped lung group 4 patients had malignant pleural effusion, 15 patients had tuberculous pleural effusion and Empyema, and one patient had post cardiac surgery effusion.

While in non entrapped lung group, 15 patients had malignant pleural effusion, 13 patients had TB and Empyema and 2 patients had post cardiac surgery effusion.

In a study by Arnold et al. (2020), complications following pleural drainage did not significantly differ between patients with and without Entrapped lung ($p > 0.05$) (11).

Similarly, Banka et al. (2020) reported no significant associations between complications and the presence of Entrapped lung ($p > 0.05$) (12).

Additionally, Bibby et al. (2019) reported significant associations between the final diagnosis (MPE) and the presence of Entrapped lung ($p < 0.05$) (13).

Conclusion:

This study offers a clinical entity for the role of pleural manometry and transthoracic ultrasonography in pleural effusion cases using different parameters, aiding in early detection of entrapped lung. So, pleural manometry and transthoracic ultrasound can guide decision-making regarding timing of pleural interventions and management of cases with entrapped lung.

Abbreviations: PM: Pleural Manometry, US: Ultrasound, AFB: Acid Fast Bacilli, LDH: Lactate Dehydrogenase.

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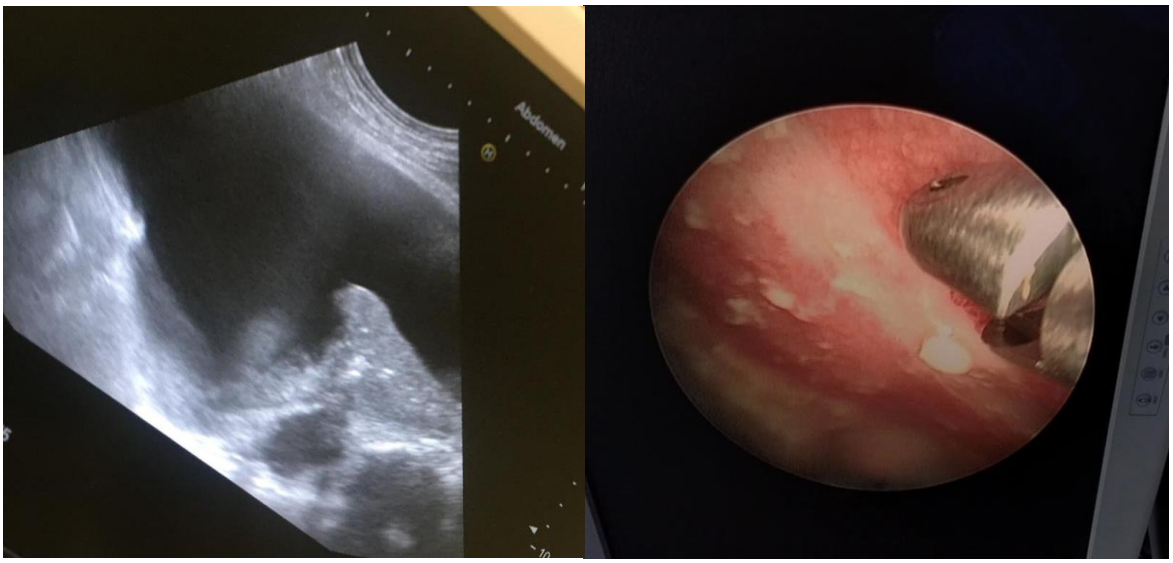

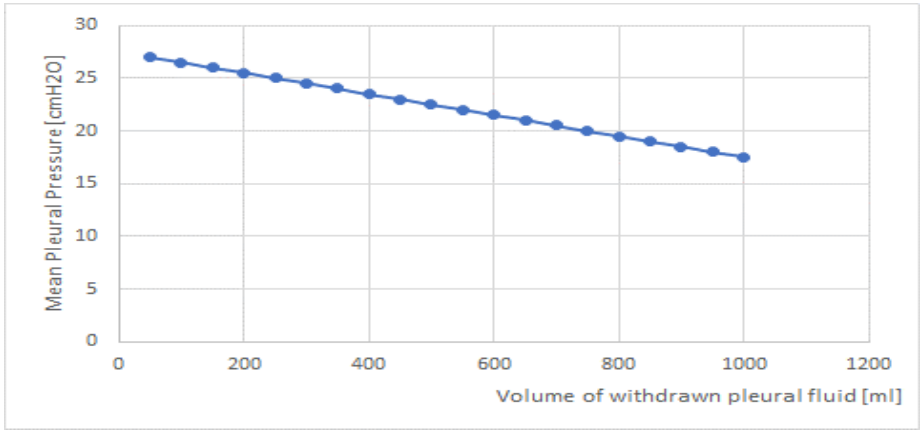

Figure 1: A case of TB pleural effusion. (Non Entrapped Lung)

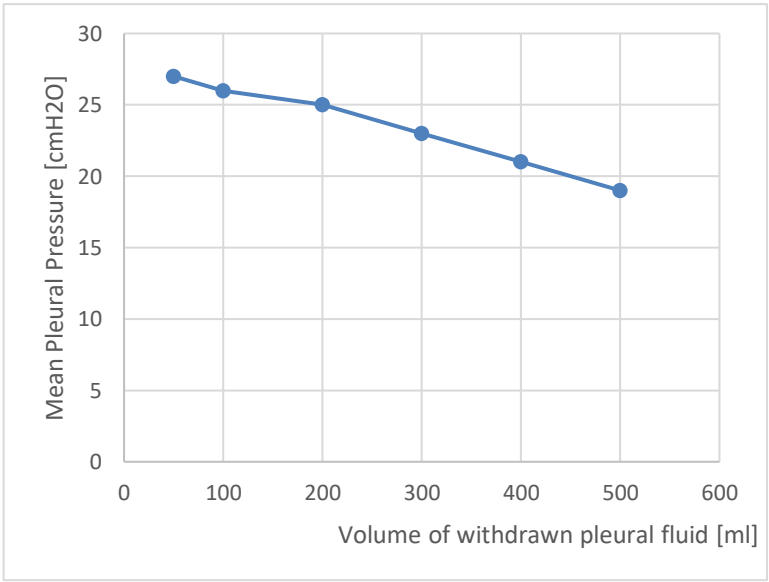

Figure 2: Chronic Empyema with Lung Entrapment