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Fluid volume as a predictor of pneumothorax after ultrasound-guided thoracocentesis

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ABSTRACT

Background and Objective: Pneumothorax, the accumulation of air between pleural layers, may occur spontaneously, post-traumatically, or iatrogenically after thoracocentesis. Although ultrasound guidance reduces its incidence, complications remain, particularly with large fluid volumes. Evidence on the link between aspirated volume and pneumothorax risk is conflicting. This study investigated the frequency of pneumothorax after ultrasound-guided thoracocentesis and its association with fluid volumes ≤1,000 ml and >1,000 ml in patients with pleural effusion.

Methods: A cross-sectional study was conducted at Memon Medical Institute Hospital, Karachi, from February to August 2024. A total of 266 patients, aged 20–60 years, with pleural effusion undergoing ultrasound-guided thoracocentesis were included and divided into Group A (≤1,000 ml) and Group B (>1,000 ml), with Group B subdivided into B1 (1,000-1,500 ml) and B2 (>1,500 ml). Data were analyzed using the Statistical Package for Social Sciences, and the association between fluid volume and pneumothorax was assessed using the chi-square test ($p < 0.05$).

Results: The mean age of the patients was 49.55 ± 7.63 years. Pneumothorax occurred in 8.6% of patients, with 4.5% in Group A and 12.7% in Group B. Subgroup B1 and B2 had 6.9% and 19.6% cases. Males had a higher frequency (82.35%) than females (52.94%). Fluid aspiration ranged from 550 to 950 ml in Group A (mean 778.3 ± 160.8 ml) and 1,250–2,000 ml in Group B (mean 1,669.4 ± 253.9 ml). A significant association was found between fluid volume and pneumothorax ($p < 0.05$).

Conclusion: Pneumothorax after ultrasound-guided thoracocentesis was significantly associated with larger aspirated fluid volumes, particularly >1,500 ml. Caution is advised when removing high volumes to minimize the risk.

Keywords: Pneumothorax, thoracentesis, interventional ultrasonography, pleural effusion.

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Introduction

Pneumothorax is the accumulation of air between the parietal and visceral pleura.[1] It can be broadly categorized into spontaneous and post-traumatic types. Spontaneous pneumothorax is further classified into primary and secondary types.[2] Cigarette smoking is one of the most common risk factors attributed to the development of spontaneous pneumothorax.[3] Primary-spontaneous usually occurs in tall, lean individuals with male predominance.[4] Previous literature has established that primary spontaneous pneumothorax usually results from a bleb or bulla rupture.[4] Secondary spontaneous pneumothorax occurs in individuals with pre-existing pulmonary conditions that lead to respiratory compromise, such as chronic obstructive pulmonary disease.[5] Iatrogenic pneumothorax is one of the major contributors to the development of post-traumatic pneumothorax.[6] Various procedures lead to its development out of which thoracocentesis (aspiration of fluid from the pleural cavity, also known as thoracentesis or pleural tap) is one of the major contributors, as it is one of the commonest procedures to be performed.[7] In most cases, thoracocentesis is considered a simple, well-tolerated, and safe procedure. However, several factors can tip the scales towards the development of pneumothorax following thoracocentesis, including lack of ultrasound guidance, gauge of the needle used for aspiration, the experience of the operator, and the volume of fluid aspirated during the procedure.[8] It is very important to identify the causes and mechanisms of the development of pneumothorax during thoracocentesis, as it is a very common procedure performed in both outpatient and inpatient settings. The global prevalence of post-thoracocentesis pneumothorax has been reported to be around 13% to 19%. Although ultrasound guidance has reduced its prevalence, 15%–50% of these patients still require chest tube insertion, which carries a significant risk of complications, leading to undue mortality and morbidity.[7,8]

Many studies have established relationships with most causative agents. However, there is some contradiction in the literature when it comes to the effect of aspirated volume. Some studies suggest its role, while others negate this statement. This study will test the hypothesis that the frequency of pneumothorax in patients undergoing ultrasound-guided thoracocentesis varies with the volume of fluid aspirated. Suppose we can identify a positive relationship between the amount of aspirated fluid volume during thoracocentesis and the development of pneumothorax. In that case, we can safely develop a cut-off value that will help us to make it a part of our guidelines so that such a complication can be safely avoided. Therefore, the objectives of the current study were to determine the frequency of pneumothorax in patients undergoing ultrasound-guided thoracocentesis and to compare the frequency of pneumothorax with an aspirated fluid volume ≤ 1,000 ml and >1,000 ml, respectively.

Methods

This cross-sectional study was conducted at the Department of Radiology, Memon Medical Institute Hospital Karachi from February 2024 to August 2024. Ethical approval was obtained from the Institutional Review Board Committee of Memon Medical Institute Hospital (Ref. No. IRB/MMIH/2024/05, dated: 14-02-2024). Informed written consent was obtained from the patients while the study was conducted strictly in accordance with the principles of the Declaration of Helsinki. The inclusion criteria were patients of any gender aged between 20 and 60 years, and patients with pleural effusion diagnosed on the basis of radiographs or ultrasound undergoing ultrasound-guided thoracocentesis. The exclusion criteria were patients already diagnosed with pneumothorax or hydro-pneumothorax before performing ultrasound-guided thoracocentesis, patients in whom the aspirated fluid volume was less than or equal to 50 ml, as such a small amount of aspirated fluid volume is usually for diagnostic purposes, and patients with underlying significant lung disease, as such patients are vulnerable to early development of pneumothorax. Using the OpenEpi, Version 3, open-source calculator with a 95% confidence interval, 80% power, and an anticipated population proportion of 18%,[9] the estimated sample size was 227. After accounting for a 10% dropout rate and potential incomplete or missing data entries, the required sample size was 266. Patients meeting the inclusion criteria were assessed by ultrasonography. Demographic details like the patient's age and gender were noted. Patients underwent thoracocentesis by an experienced consultant radiologist and then immediately followed by a chest radiograph in an erect position. Patients were assigned to two groups: Group A included patients with aspirated fluid volume ≤1,000 ml, and Group B included those with an aspirated fluid volume >1,000 ml. Group B was further subdivided into subgroups B1 (1,000 to 1,500 ml) and B2 (>1,500 ml). The details regarding the amount of fluid aspirated and to which it belongs, and the presence or absence of pneumothorax, were entered into the proformas. To ensure standardization in the sampling population, thoracentesis in all patients was done by one radiologist.

Statistical analysis

Statistical Package for Social Sciences version 22 was used for data entry and analysis. Qualitative variables were expressed as frequency and percentage, while quantitative variables were expressed as Mean ± SD. The association between pneumothorax and the volume of fluid aspirated was assessed using the chi-square test. A p-value of ≤0.05 was considered significant.

Results

Out of the 266 patients who underwent ultrasound-guided thoracocentesis in both outpatient and inpatient departments, 133 patients were assigned to group A and 133 patients to group B on the basis of inclusion criteria. Regarding gender distribution, 159 (59.77%) were males, and 107 (40.22%) were females. The age of the participants ranged from 20 to 60 years, while the mean age of the study participants was 49.55 ± 7.63 years. The gender-wise age distribution of the study participants is shown in Figure 1.

A total of 23 cases (8.64%) of pneumothorax were reported overall, with 6 cases in Group A and 17 cases in Group B. Within Group B, 5 cases were in Subgroup B1, and 12 cases were in Subgroup B2. The overall frequency of pneumothorax (Figure 2) following ultrasound-guided thoracocentesis was found to be 8.6%, with 4.5% in Group A and 12.7% in Group B. Specifically, the frequency was 6.9 % in Subgroup B1 and 19.6% in Subgroup B2, respectively. Among these 23 cases, 14 (82.35%) were males, and 9 (52.94%) were females. The details of pneumothorax cases are given in Table 1.

In group A, the range of fluid aspiration was between 550 and 950 ml, with a mean aspiration volume of 778.3 ± 160.8 ml. Likewise, in group B, the range of fluid aspiration was

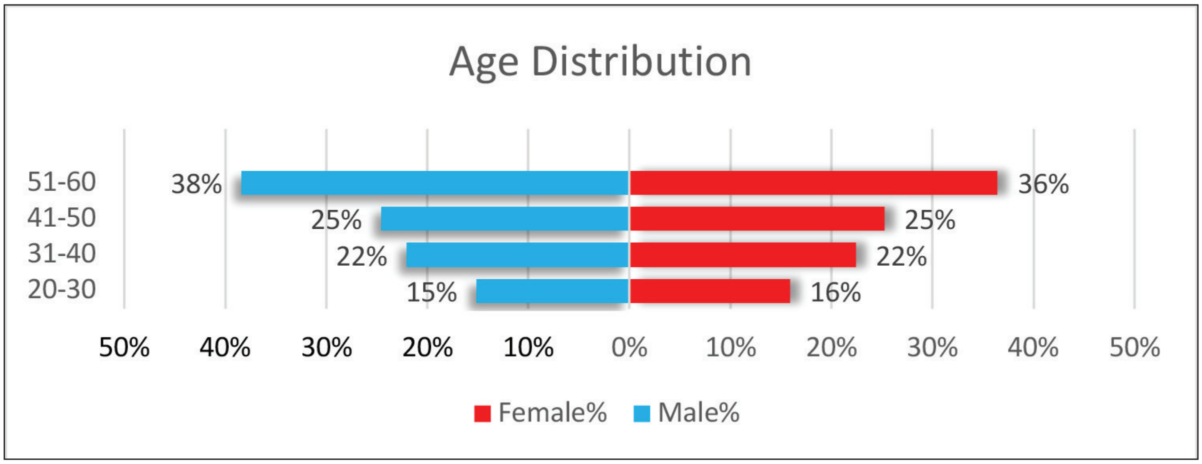

Figure 1. *Age distribution of study participants.*

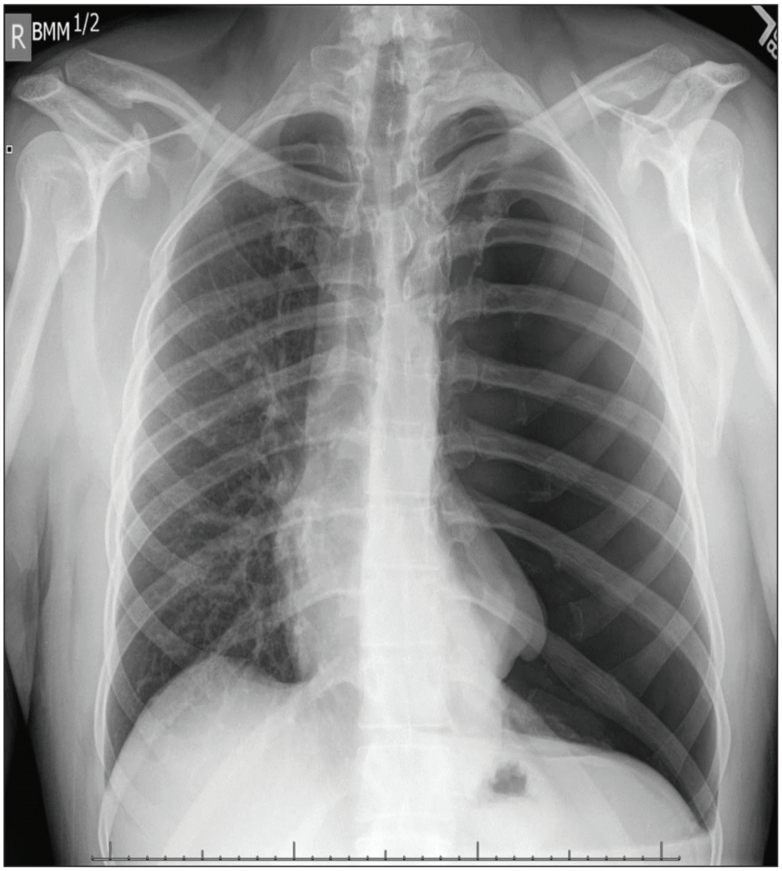

Figure 2. *Chest X-ray showing complete translucency of left hemithorax which is devoid of lung markings consistent with large pneumothorax. There is mild contralateral mediastinal shift towards the right suggesting element of tension.*

between 1,250 and 2,000 ml, with a mean aspiration volume of 1,669.4 ± 253.9 ml.

Table 2 shows the association of the volume of fluid aspirated with the frequency of pneumothorax. In patients having <1,000 ml fluid aspiration, the frequency of pneumothorax was 4.5%% while the frequency of pneumothorax in patients having >1,000 ml fluid aspiration was 12.7%. The association between the volume of fluid aspirated and the frequency of pneumothorax was found to be statistically significant (χ^2 = 5.75, p = <0.05).

Similarly, Table 3 shows the association of the volume of fluid aspirated and the frequency of pneumothorax in

Table 1. *Demographic and clinical characteristics of patients with pneumothorax across two groups.*

Characteristics	Total patients	Group A (≤1,000 ml)	Group B (>1,000 ml)	Subgroup B1 (1,000-1,500 ml)	Subgroup B2 (>1,500 ml)
Pneumothorax cases	23 (8.6%)	6 (4.5%)	17 (12.7%)	5 (29.41%)	12 (70.58%)
Age distribution					
20-30 years		0 (0%)	1 (5.8%)	1 (5.88%)	0 (0%)
31-40 years		1 (16.7%)	1 (5.8%)	1 (100%)	0 (0%)
41-50 years		2 (33.3%)	5 (29.4%)	2 (40%)	3 (60%)
51-60 years		3 (50%)	10 (58.8%)	1 (10%)	9 (90%)
Mean age (Years)		48.3 ± 8.9	50.8 ± 9.3		
Gender distribution					
Male		4 (66.7%)	10 (58.8%)	3 (30%)	7 (70%)
Female		2 (33.3%)	7 (41.2%)	2 (28.57%)	5 (71.42%)

Table 2. *Comparison of frequency of pneumothorax frequency between group A (≤1,000 ml) and Group B (>1,000 ml).*

Groups	Pneumothorax		X^2	*p*-value
	Present	Absent		
Group A <1,000 ml	06 (2.25%)	127 (47.74%)	5.75	< 0.05
Group B >1,000 ml	17 (6.39%)	116 (43.60%)		

Table 3. *Comparison of pneumothorax frequency between subgroup B1 (1,000-1,500 ml) and subgroup B2 (>1,500 ml).*

Groups	Pneumothorax		X^2	*p*-value
	Present	Absent		
Group B1 (1,000 to 1,500 ml)	05 (3.75%)	67 (50.37%)	4.79	< 0.05
Group B2 > 1,500 ml	12 (9.02%)	49 (36.84%)		

patients belonging to subgroups B1 and B2. In patients having 1,000-1,500 ml fluid aspiration, the frequency of pneumothorax was 29.41%, while the frequency of pneumothorax in patients having >1,000 ml fluid aspiration, the frequency of pneumothorax was 70.58%. The association between the volume of fluid aspirated and the frequency of pneumothorax was found to be statistically significant (χ^2 = 4.79, p = <0.05).

Discussion

Thoracocentesis, commonly called pleural tap, is a very common procedure performed in both wards and critical units of the hospital.[7] It can be performed for diagnostic and therapeutic purposes depending on the indication.[10] When performed under ultrasound guidance, it becomes a safer procedure with approximately 95% of patients tolerating this procedure well without any complications.[11] In cases of therapeutic indication, thoracocentesis largely relieves the patient's symptoms. However, one of the known complications of thoracocentesis is pneumothorax, which is associated with significant morbidity.[7,8] Moreover, there is evidence that there is a relationship between the development of pneumothorax and the amount of aspirated fluid volume during thoracocentesis.[12,13] Therefore, thoracocentesis carries a significant risk: while therapeutic drainage benefits the patient, it may also put them at risk of developing another potentially serious condition. This not only prolongs the patient's hospital stay and increases healthcare costs but also makes them a potential candidate for further surgical intervention. So identification of a cut-off value in the amount of aspirated fluid volume will not only decrease morbidity associated with the procedure but will also help the physician in developing a treatment plan, including multiple settings for aspiration and consideration for other treatment options.

Our study was based on a total of 266 patients who underwent ultrasound-guided thoracocentesis in both outpatient and inpatient departments. The overall frequency of pneumothorax following ultrasound-guided thoracocentesis was found to be 8.64%. This is similar to the findings of Hines et al.[14] who reported a 7.3% frequency of pneumothorax among complications attributed to thoracentesis. Similarly, Shechtman et al.[12] conducted a retrospective study on 550 patients who underwent ultrasound-guided thoracocentesis and found that 66 patients, i.e., 12% developed pneumothorax, which is also consistent with our results. However, in a study conducted in Foggia, Italy, Sperandeo et al.[15] observed that only 3 out of 361 patients (0.83%) developed pneumothorax following thoracentesis, which is much lower than the findings of the current study. This difference may be attributed to the use of transthoracic ultrasound as a real-time guide throughout the procedure in their study, rather than using it solely as a landmark method to identify the best site for puncture. However, the results of the current study are significantly lower than the startling 18.2% frequency of pneumothorax reported by Khan et al.[9] among patients receiving thoracentesis. However, sample bias – the smaller sample size of their study, which comprised only 22 patients, in contrast to the current study's sample size of 266 patients – may be the cause of this disparity.

The current study observed a higher frequency of pneumothorax among male patients. Of the 159 male patients, 14 (8.80%) developed pneumothorax, compared to 9 (8.41%) of the 107 female patients. These results are consistent with the findings of Fawad et al.[7] who also reported a 16.4% (21 out of 128) frequency of pneumothorax among males compared to an 11.5% (13 out of 113) frequency among females. This can be attributed to pneumothorax naturally having a greater male predominance, likely due to anatomical differences, as males generally have larger thoracic cavities, leading to greater pressure changes during fluid aspiration and an increased risk of lung collapse.[16]

Most notably, the current study found a statistically significant association between the volume of fluid aspirated and the frequency of pneumothorax. This is consistent with the findings of Shechtman et al.[12] who observed that the volume of fluid drained was greater in patients who developed pneumothorax compared to those who did not and reported a statistically significant association ($p < 0.05$) between the volume of fluid aspirated and the frequency of pneumothorax. The optimal volume of fluid that can be safely drained during therapeutic thoracentesis remains uncertain due to the lack of studies focusing on large-volume thoracentesis. The risk of iatrogenic pneumothorax tends to increase with the amount of fluid removed, although some patients tolerate larger volumes better than others. According to previous literature, compared with the removal of 0.8–1.2 l, draining 1.8–2.2 l was associated with more than a threefold increase in pneumothorax risk, and this risk nearly sextupled when 2.3 liters or more were aspirated.[7] Additionally, a study by Ault et al.[17] indicated a significant association ($p < 0.01$) between pneumothorax and the aspiration of more than 1,500 ml of fluid. This is consistent with the findings of the current study, where the frequency of pneumothorax increased from 4.5% in Group A (≤1,000 ml) to 12.7% in Group B (>1,000 ml), with a further rise from 6.9% in Subgroup B1 (1,000–1,500 ml) to an overwhelming 19.6% in Subgroup B2 (>1,500 ml).

Identifying such a preventable causative agent in the development of pneumothorax is of prime importance in managing such patients. The relationship of pneumothorax with aspirated fluid volume will help us in making guidelines so that the rate of morbidity and possible mortality can be reduced.

Limitations of the study

This study has several limitations that should be acknowledged. First, while the sample size was deemed adequate, the relatively small number of pneumothorax cases (23 out of 266) limits the generalizability of the findings. Second, being a single-center study, the results may not apply to other settings with different patient demographics or clinical practices. Third, the lack of long-term follow-up may have led to an underestimation of the true frequency of pneumothorax, as delayed complications could have been missed. Lastly, while the study focused on the volume of fluid aspirated, other uncontrolled variables, such as the patient's underlying lung condition, operator experience, and procedural techniques, could have also influenced the risk of pneumothorax. Therefore, future studies should consider multicenter designs with larger sample sizes, incorporate long-term follow-up, and control for additional variables such as operator experience and patient lung conditions to better understand the risk factors for pneumothorax following thoracocentesis.

Conclusion

This study demonstrates that pneumothorax remains a notable complication of ultrasound-guided thoracocentesis, with a statistically significant association between the volume of pleural fluid aspirated and the occurrence of pneumothorax, with higher aspiration volumes (>1,000 ml), particularly >1,500 ml, showing a markedly increased risk. These findings highlight the importance of careful procedural planning and cautious large-volume drainage during thoracocentesis. Establishing safe limits for fluid removal may help minimize procedure-related complications, reduce patient morbidity, and improve clinical outcomes.

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List of Abbreviations

Not applicable.

Conflict of interest

None to declare.

Grant support and financial disclosure

None to disclose.

Ethical approval

Ethical approval was obtained from the Institutional Review Board Committee of Memon Medical Institute Hospital (Ref. No. IRB/MMIH/2024/05, dated: 14-02-2024).

Author's contributions

MK: Conceived the study, designed the methodology, and drafting of manuscript and critical intellectual input.

KAM: Drafting of the manuscript, data analysis and interpretation of results, and critical intellectual input.

HA, KSB, AK: Acquisition of data, reviewed and revised the manuscript critically for important intellectual content, drafting of manuscript, and literature review.

ALL AUTHORS: Approval and responsibility for the final version of the manuscript to be published.

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