ORIGINAL ARTICLE

A Cross-Sectional Study on the Accuracy of Volume Assessment of Pleural Effusion by Ultrasonography with Pleural Tap as the Gold Standard in Tertiary Care Setting, Rawalpindi

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ABSTRACT

Objective: To determine the accuracy of three-dimensional ultrasound for volume estimation of pleural effusion, keeping the volume obtained by pleural tap as the gold standard.

Study design: Cross-sectional study.

Place and Duration of Study: The study was conducted at the Department of Radiology, Combined Military Hospital (CMH), Rawalpindi, Pakistan, from 1st January 2023 to 30th June 2023.

Methods: A total of 219 patients who fulfilled the selection criteria were included in the study. After detailed history and clinical examination, all patients underwent volume estimation of pleural effusion by ultrasound using a three-dimensional approach, i.e., anteroposterior, transverse, and craniocaudal. Subsequently, all participants underwent a pleural tap to drain fluid in order to estimate the actual volume. All findings were noted down on a predesigned proforma and accuracy of ultrasonography was assessed.

Results: The mean age of the patients was 42.62±12.96 years, with 112 (51.14%) males. The mean estimated volume of pleural effusion on USG was 668.94 (312 – 963) ml while on thoracentesis was 641.95 (310 - 999) ml. Pneumonia 93 (42.47%) was the leading cause, followed by hemothorax 37(16.89%). 89 (40.64%) had mild, while 11(5.02%) had severe pleural effusion, and the rest had moderate pleural effusion. The sensitivity, specificity, and accuracy of ultrasonography for mild pleural effusion (estimated volume was >10 to <500 ml) was 82.29%, 91.86% and 87.67%, for moderate pleural effusion (estimated volume was >500 to <1500 ml) was 86.95%, 81.73% and 84.47% and for severe pleural effusion (estimated volume was >1500 ml) it was 85.71%, 97.64% and 97.26%, respectively.

Conclusion: Volume estimation by three-dimensional ultrasound had a high sensitivity, specificity, and accuracy for varying severity of pleural effusion, keeping pleural tap as the gold standard.

Keywords: *Fluid Quantification, Pleural Effusion, Ultrasonography.*

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Introduction

An excessive buildup of fluid in the pleural area, known as a pleural effusion, can be caused by increased fluid production, impaired fluid absorption, or both.[1] The hydrostatic and oncotic forces in the visceral and parietal pleural arteries, as well as substantial lymphatic drainage, keep the amount of fluid in the pleural space at 1 to 10 mL on average.[2] If this equilibrium is disturbed, pleural effusion occurs. The amount of pleural fluid that is produced on a daily basis, i.e., 10 mL or 0.01-0.02 mL/kg/hr, is continually absorbed, leaving behind 0.1–0.2 mL of pleural fluid for every kilogram of body weight.[3]

Thoracocentesis (pleural tap) is routinely used to

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treat pleural effusion (PE).[4] Pondering pleural drainage requires careful consideration of fluid volume. Sometimes, the clinical presentation and the actual quantity of effusion differ, making the decision to drain uncertain.[5] Particularly in patients who are on mechanical ventilation or who have thrombopenic patients, the value of puncture should be balanced against the danger of consequences like pneumothorax, bleeding or splenic laceration in the case of a modest volume of pleural effusion.[6] It also has some relative contraindications, including coagulation disorders, the difficulty of the patient to participate and skin disease at the puncture site.[7] In such scenarios, a quick, accurate and straightforward ultrasonographic evaluation for pleural effusion volume measurement is preferred.

Pleural effusion volume may be quantified or qualitatively approximated using ultrasound technology.[8] A quantitative approach uses several calculations, whereas qualitative estimations categorize effusion as low, moderate, or massive. Ultrasonography has several advantages over radiography, including being non-invasive, affordable, accessible, and repeatable. It is also free of radioactivity.[9] Additionally, chest ultrasonography outperforms radiography in terms of sensitivity and dependability. While radiography in the erect position requires a minimum of 150 mL to identify effusion, ultrasonography has a 100% sensitivity for detecting effusions as tiny as 5 mL.[10]

Numerous studies have been conducted internationally on the effectiveness of ultrasonography in detecting pleural effusions of varying severity. However, there is a paucity of local data. Additionally, although chest radiographs are frequently used to evaluate post-procedural problems such as pneumothorax, they do not offer the quantitative information necessary to assess the effectiveness of therapies meant to lower PE volume. This restriction highlights the clinical value of ultrasound in offering comprehensive volumetric evaluations that are essential for efficiently controlling patient outcomes. Therefore, the current study aimed to determine the accuracy of three-dimensional ultrasound for volume estimation of pleural effusion, keeping the volume obtained by pleural tap as the gold standard. The study would guide about a non-invasive modality which if found to have higher accuracy can be routinely used in our local population for the detection of pleural effusion, for making decisions about whether or not pleural tap should be performed to avoid the development of complications related to the procedure, specifically in patients who are high risk.

Methods

The cross-sectional study was carried out at the Department of Radiology, Combined Military Hospital (CMH), Rawalpindi, Pakistan for a duration of 6 months from 1st January, 2023 to 30th June 2023, after taking approval from the Ethical Review Committee, vide letter no: 199/9/21, dated: 22nd September 2021. The sample size of 219 patients was calculated based on the expected prevalence of pleural effusion of 12.7%, an expected sensitivity of 93% for ultrasonography, an expected specificity of 96%, a 10% absolute precision, a 95% confidence interval, and a 10% dropout rate.[11,12] A non-probability consecutive sampling technique was used.

Inclusion Criteria: A total of 219 patients of both genders and age 18-70 years who had a diagnosis of effusion both clinically and radiologically i.e. more than 10 mm separation of pleural layer by the fluid on ultrasound and change in the layer of fluid with respiration as well as with different positions of the body, were included in the study.

Exclusion Criteria: Patients with effusions which were either encysted or loculated, with empyema, patients who could not maintain their posture or obey instructions related to breathing, patients who had deformities of the thorax, pathology of diaphragms, previous history of surgical intervention of the chest, those with atelectasis without evidence of any effusion on the initial ultrasonographic examination were excluded from the study.

After taking approval from ERC, detailed demographic details, clinical history and physical examination findings were noted down. All patients were monitored for vitals, i.e., heart rate, blood pressure, respiratory rate, and fever, before undergoing the procedure. All patients then underwent ultrasonographic examination by using a three-dimensional approach, i.e., anteroposterior, transverse, and craniocaudal, which was initially

performed with the patient lying on their back (without a pillow or headrest). With perpendicularly placing the transducer to the wall of chest (i.e. scan carried out in a transverse plane without tilting the transducer or making angle of it), insonation of the chest was done at the posterolateral or the dorsolateral area of the wall of chest the gaps between the ribs (as an acoustic window).

All participants were instructed to hold their breath and estimations were made at point when the patient inspired maximally. The greatest interpleural or perpendicular distance was measured between the posterior wall of chest (parietal pleura) and the lung surface posteriorly (visceral pleura). In order to prevent scanning perpendicular to the transverse plane with the associated problems, angulation or tilting of the transducer was rigorously avoided. Patients were then measured (in centimeters) for the erect formulae while sitting up straight (without slouching or reclining). At end expiration, the distance from the base of the lung to the diaphragm and the extent of effusion craniocaudally (lateral height) were measured. The average result was obtained for the statistical analysis after each measurement was carried out three times. The next step was a thoracocentesis with ultrasound guidance in the erect posture. A LOGIQ E9 Ultrasound system (GE Healthcare, Little Chalfont, UK), equipped with a 3–5 MHz convex array transducer, was used for detailed ultrasound scanning and measurements prior to thoracentesis. Ultrasound-guided thoracocentesis was carried out by a consultant radiologist. Pleural tap was carried out in the triangle of safety that was marked by the lateral margin of the pectoralis major, the lateral edge of the latissimus dorsi, the fifth intercostal gap, and the base of the axilla. The fifth intercostal gap was used to introduce a 28-Fr chest tube, which was then linked with an underwater drainage seal. Complete expansion of the lung on radiographs and pleural separation by 5 mm on ultrasound was considered to be a sign that the effusion had been drained completely. The total effusion volume was then calculated using the drained volume. On ultrasound as well as pleural tap, pleural effusion was labeled as mild if the estimated volume was >10 to <500 ml, moderate if the estimated volume was 500 to 1500, and severe if the estimated volume was >1500 ml. The following formula for quantifying PE was adopted:

$$V_{single\ section}\,(ml) = 20 \times Sep\ (mm)$$

Where $V_{single\ section}$ was the calculated PE volume (ml), 20 was the correction factor, and Sep (mm) was the maximum vertical distance between the lateral chest wall and the lung surface.

All findings were noted down and the findings were subjected to statistical analysis.

Data was analyzed using Statistical Package for Social Sciences (SPSS) version 25.00. Quantitative variables such as age, volume of fluid estimated on ultrasound, and pleural tap were presented as mean and standard deviation. Qualitative data such as gender, side of effusion, etiology of effusion, severity of pleural effusion, ultrasound, and on pleural tap were presented as frequency and percentages. A 2x2 table was made for determining the accuracy of ultrasound for mild, moderate, and severe pleural effusion, and findings of pleural tap were kept as the gold standard.

Results

The mean age of the patients was 42.62±12.96 years. There were 112 (51.14%) males, while 107 (48.86%) were females in the study. The mean estimated volume of pleural effusion on USG was 668.94 (312 – 963) ml, and the mean estimated volume of pleural effusion on thoracentesis was 641.95(310 - 999) ml. Figure 1.

Fig.1: Pleural effusion assessment by ultrasound

In terms of age group, 77 (35.16%) patients were between 18 and 35 years, 122 (55.71%) patients were between 36 and 60 years, and 20 (9.13%) patients were between 61 and 70 years. Concerning the side of effusion, 120 (54.79%) patients had effusion on the right side and 99 (45.21%) had effusion on the left side. With respect to etiology of effusion, pulmonary Tuberculosis was diagnosed in 31 (14.16%), pneumonia was diagnosed in 93 (42.47%) patients, malignancy was diagnosed in 24 (10.96%) patients, hemothorax was diagnosed in 37 (16.89%) patients, chronic renal failure was diagnosed in 24 (10.96%) patients, chronic heart failure was diagnosed in 7 (3.20%) patients and corrosive esophagitis was present in 3 (1.37%) patients. On ultrasound, mild PE was present in 89 (40.64%) patients, moderate was present in 119 (54.34%) patients, and severe was present in 11 (5.02%) patients. On pleural tap, mild PE was present in 96 (43.84%) patients, moderate PE was present in 115 (52.51%) patients, and severe PE was present in 8 (3.65%) patients. Table 1.

Table-1: Frequency of Qualitative variables (N=219)

Variables	Frequency (percentage)
Age Group	
18 to 35 years	77 (35.16%)
36 to 60 years	122 (55.71%)
61 to 70 years	20 (9.13%)
Gender	
Male	112 (51.14%)
Female	107 (48.86%)
Side of effusion	
Right side	120 (54.79%)
Left side	99 (45.21%)
Etiology of effusion	
Pulmonary Tuberculosis	31 (14.16%)
Pneumonia	93 (42.47%)
Malignancy	24 (10.96%)
Hemothorax	37 (16.89%)
Chronic renal failure	24 (10.96%)
Chronic heart failure	7 (3.20%)
Corrosive esophagitis	3 (1.37%)
Severity of pleural effusion on ultrasound	
Mild	89 (40.64%)
Moderate	119 (54.34%)
Severe	11 (5.02%)
Severity of pleural effusion on pleural tap	
Mild	96 (43.84%)
Moderate	115 (52.51%)
Severe	8 (3.65%)

The sensitivity, specificity, PPV, NPV and accuracy of USG for mild PE was 82.29%, 91.86%, 88.76%, 86.92% and 87.67%, for moderate PE was 86.95%, 81.73%, 84.03%, 85.00% and 84.47% and for severe PE it was 85.71%, 97.64%, 54.54%, 99.51% and 97.26%, respectively. Table 2.

The variations in the accuracy of small and large pleural effusions might be because of the size of the chest cavity, which typically affects ultrasound results. The fluid amount is often dispersed across a greater region in taller people with larger chest cavities than in those with smaller chest cavities. As a result, it is possible to overestimate or underestimate the volume of fluid in the pleural cavity.

Table 2: Diagnostic accuracy of ultrasound for volume estimation of fluid, keeping pleural tap as gold standard (N=219)

For mild pleural effusion			
Ultrasonography	Pleural Tap		Sensitivity = 82.29%
	Yes	No	Specificity = 91.86%
Yes	79 (36.07%)	10 (4.56%)	PPV = 88.76%
No	17 (7.76%)	113 (51.59%)	NPV = 86.92%
			Accuracy= 87.67%
For moderate pleural effusion			
Ultrasonography	Pleural Tap		Sensitivity = 86.95%
	Yes	No	Specificity = 81.73%
Yes	100 (45.66%)	19 (8.6%)	PPV = 84.03%
No	15 (6.84%)	85 (38.81%)	NPV = 85.00%
			Accuracy= 84.47%
For severe pleural effusion			
Ultrasonography	Pleural Tap		Sensitivity = 85.71%
	Yes	No	Specificity = 97.64%
Yes	6 (2.73%)	5 (2.28%)	PPV = 54.54%
No	1 (0.45%)	207 (94.52%)	NPV = 99.51%
			Accuracy= 97.26%

NPV: Negative predictive value; PPV: Positive predictive value

Discussion

The current study findings revealed that the sensitivity, specificity, and accuracy of USG were high for the detection of mild, moderate, and severe pleural effusion, keeping pleural tap as the gold standard. The majority of the patients were males, aged 36 to 60 years, had right-sided effusion, and the main etiological factors were pneumonia, hemothorax, and pulmonary tuberculosis.

A common finding in clinical practice is pleural effusion, which can result from a variety of traumas.[4] Analyzing the extent of pleural effusions, particularly transudative pleural effusions, may make it possible to determine how fluid buildup and respiratory symptoms (including dyspnea, orthopnea, and hypercarbia) are related.[6] While pleural drainage is not always necessary, repeated measurements are helpful for monitoring and follow-up.[9] It was recently noted that transudative effusions are linked to a high mortality rate at one year, and that in 46% of individuals diagnosed with pleural effusion, the etiology is non-malignant.[13] Since pleural drainage is rarely necessary, it becomes crucial for the doctor to track the amount of fluid and the patient's reaction to treatment over time. Monitoring and optimizing response to medication is especially important for patients with congestive heart failure, who make up the great majority of transudative pleural effusion cases.[11] An excess of lung fluid can have significant therapeutic and prognostic consequences for individuals with nephrotic syndrome or end-stage renal failure receiving peritoneal dialysis. For example, there is a substantial adverse relationship between the quantity of lung comets and the existence of pleural effusion and the left ventricular ejection fraction as well as some diastolic function indicators. Lastly, measuring the amount of effused pleural effusion in cancer patients may aid in improving their palliation by reducing the need for invasive and pointless operations.[12] Even though pleural effusions can be easily seen with a chest ultrasound, computed tomography (CT) is still thought to be a more precise method for determining the amount of pleural fluid in the chest. It has been shown recently that volumetric CT analyses are on par with or even better than pleural tapping.[14] Post-procedural CT shows that the pleural tap operation does not always succeed in entirely draining fluid.[15] Accurate quantification of pleural effusions can then be achieved using volumetric CT scans. However, this process requires money and time, and, most importantly, exposes patients to more radiation.[16,17] For these reasons, numerous attempts have been made to use chest ultrasonography to determine the extent of a pleural effusion. Numerous strategies have been put out, but significant problems still need to be resolved.

Among radiologists, sonography is widely recognized

as a sensitive and specific method for the detection of pleural effusion.[18,19] This view is not widely held among the remainder of the medical community, perhaps because the literature does not provide the maximum level of evidence. Keeping this in view, our study aimed to determine the diagnostic accuracy of ultrasonography for the assessment of pleural effusion volume, keeping pleural tap as the gold standard, in order to provide evidence to the treating physicians and radiologists working in the local settings regarding the utility of a non-invasive imaging modality.

Our study results showed that the accuracy of ultrasound for mild pleural effusion was 87.67%, for moderate PE it was 84.47% and for severe PE it was 97.26%. In a study conducted in Lahore, the sensitivity, specificity, and accuracy of transthoracic ultrasound for detecting pleural effusion were 100%.[20] A recent systematic review revealed that the pooled sensitivity of lung ultrasound was 91% for detecting pleural effusion volume.[15] Smit et al. revealed that ultrasonography was 85% sensitive and 77% specific for detecting pleural effusion.[5] In a study by Mohamed et al. it was revealed that ultrasonography had a sensitivity of 100%, a specificity of 100% and an accuracy of 100%.[16] Roch et al. revealed that for moderate pleural effusion, the sensitivity of ultrasound was 83% and the specificity was 90%.[17] In a systematic review, it was revealed that the mean sensitivity and specificity of ultrasonography for detecting pleural effusions was 93% and 96%, respectively.[12] These findings support our study findings that for volume estimation of pleural effusion, ultrasound had a high sensitivity, specificity, and accuracy for varying severity of pleural effusion.

Our study highlighted the importance of ultrasonography, which is a low-cost, portable, radiation-free technique that demonstrated consistently good sensitivity, specificity, and accuracy in identifying pleural fluid in our clinical setting and population.

For the diagnosis of pleural effusion, lung ultrasound is a simple, less invasive bedside method that has higher sensitivity and specificity.[19] It is essential for visualizing the effusion and can also be used to differentiate between pleural effusions of varying severity.[21] Ultrasonography can also be used to measure the amount of pleural effusion that is being drained and to determine when to stop the drainage.[22,23]

The current study had certain limitations. Firstly, it was single-centered and the sample size was small, so there is an issue of generalizability of the results. Secondly, a comparison with a chest X-ray was not done, so it cannot be commented on whether the accuracy of ultrasound is higher than that of chest X-ray. Lastly, pleural effusions were only qualitatively analyzed using Ultrasound, but the quantitative estimation using different formulas was not done.

Conclusion

The current study findings conclude that ultrasound had a high sensitivity, specificity, and accuracy for volume estimation of pleural effusion, keeping pleural tap as the gold standard. The current study findings propose that before performing a pleural tap, an ultrasound should be done to estimate the amount of fluid that needs to be drained so that unnecessary punctures during pleural tap can be avoided. Future studies must be carried out on a large sample size to validate the findings of the current study.

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Author Contributions

AB: Manuscript writing for methodology design and investigation
ND: Revising, editing, and supervising for intellectual content
HA: Data acquisition, curation, and statistical analysis
AA: Conception and design of the work
MI: Writing the original draft, proofreading, and approval for final submission
AZ: Validation of data, interpretation, and write-up of results