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Accuracy of Transthoracic Ultrasound in the Diagnosis of Different Pleural and Pulmonary Diseases: Zagazig University Experience

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Abstract: Recently, there is an increase application of chest ultrasound to evaluate and monitor pleuropulmonary diseases. Computed tomography (CT) is the gold standard for most different lung pathologies with limitations. This study aims to assess the effectiveness of Chest Ultrasound compared to Computed Tomography in diagnosis of different pleuropulmonary disorders and to define the rules of chest ultrasound in pulmonary medicine. This study was conducted upon randomly selected 110 patients with different pleuropulmonary disorders who were admitted to the respiratory ward and ICU, Zagazig University Hospitals, from April 2018 to April 2020. All patients with abnormal chest X. ray opacities were evaluated for complete history taking, full clinical examination, laboratory investigations, then Chest US was performed on the first day of admission then CT was done as a gold standard for the final diagnosis then results of both Chest US and CT were compared. Compared to CT, Chest US had sensitivity (95.8%) for free pleural effusion diagnosis, specificity (90.3%), and (92.7%) accuracy; for pneumonia, (90.9%), (96.1%), and (94.5%) respectively, while pneumothorax had (81.8%), (98%), and (96.3%) accuracy, respectively; for pulmonary edema, (89.5%), (97.8%), and (96.4%) accuracy, respectively. The US plays a valuable role in the diagnosis of different pleuropulmonary diseases and can be used as the first routine radiological modality in both ward & ICU.

Keywords: chest US, pleural diseases, pulmonary diseases.

经胸超声在诊断不同胸膜和肺部疾病中的准确性：扎加济格大学的经验

摘要：最近,胸部超声在评估和监测胸膜肺疾病方面的应用越来越多。计算机断层扫描(电脑断层扫描)是大多数具有局限性的不同肺部病变的金标准。本研究旨在评估胸部超声与计算机断层扫描相比在诊断不同胸膜肺疾病方面的有效性,并确定胸部超声在肺部医学中的规则。这项研究是对2018年4月至2020年4月在扎加济格大学医院呼吸病房和重症监护室收治的110名不同胸膜肺疾病患者进行的。对所有胸部X线混浊异常患者进行完整病史采集评估,全面的临床检查、实验室检查,然后在入院第一天进行胸部超声检查,然后将电脑断层扫描作为最终诊断的金标准,然后比较胸部超声检查和电脑断层扫描的结果。与电脑断层扫描相比,胸部超声诊断游离胸腔积液的敏感性(95.8%)、特异性(90.3%)和准确率(92.7%);对于肺炎,分别为(90.9%)、(96.1%)和(94.5%),而气胸的准确度分别为(81.8%)、(98%)和(96.3%);对于肺水肿,准确度分别为(89.5%)、(97.8%)和(96.4%)。超声在不同胸膜肺疾病的诊断中发挥着重要作用,可作为病房和重症监护室的首选常规放射检查方式。

关键词：胸部超声、胸膜疾病、肺部疾病。

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Introduction

The international guidelines recommend the use of plain chest X-ray as the first imaging diagnostic techniques in different pleural and pulmonary diseases, despite its low specificity and sensitivity, while CT is the standard diagnostic imaging modality for various pleural and pulmonary disorders, but there are some concerns regarding its use as a routine imaging modality [1]. Compared to CT, being a noninvasive portable technique, Chest US can be used at any time and place for all patients regardless of their age, patients with renal impairment, pregnant female patients, and those with contrast material allergy. However, its use is limited by the time needed to learn US skills and the Interobserver variability. Among different imaging modalities, chest US has gained a leadership position in the integration of both clinical and instrumental bedside evaluation of critically ill patients, so, it can help in the differential diagnosis and management of different critical conditions, including acute respiratory failure, haemodynamic compromise, and cardiac arrest [2, 3].

1. Patient and Method

The randomized comparative prospective cross-sectional study was conducted on 110 patients admitted to our ICU and ward. Our international registration plan approved the study; from April 2018 to April 2020, all patients were evaluated for full history taking, complete clinical examination, Chest X-ray, Chest US, and CT according to our inclusion criteria.

1.1. Inclusion Criteria

Patients with a clinical suspicion of pleural and pulmonary disorders with abnormal chest X-ray opacities were included in our study.

1.2. Exclusion Criteria

The study excluded women who were pregnant, those with problematic ultrasonography windows, those with morbid obesity (BMI > 40), those with dye allergies, those with renal impairment (serum creatinine > 1.5 mg/dl), and traumatized patients, in addition to patients who could not be transferred to do CT. All patients were examined for any pleuropulmonary pathology using modified lung ultrasound protocol, and then lung ultrasound findings were compared to those of CXR and CT.

1.3. Plain Chest X-Ray

This procedure was conducted using (TOSHIBA X-ray beam limiting device, model BLR-1000A). Postero anterior CXR was conducted for patients who could be transferred to the radiology department, while Anteroposterior CXR was performed for ICU patients using portable x rays. A radiologist, unaware of the lung ultrasound and CT findings, evaluated the CXR findings. According to the terminology of the Nomenclature Committee of the Fleischner Society, the anatomic landmarks of the lung apex, mid-auxiliary line, and hilar line, the external limit of the rib cage, mediastinal border, and diaphragm were used to allocate the different regions of lung pathologies [4].

1.4. Chest Ultrasound

This technique was performed using Sonoscape SSI-6000 Medical Systems (Shenzhen, China) with different frequency probes. A curved transducer with frequency 2–5 MHz and linear transducer with frequency 5–12 MHz were used.

2. Technique of Chest Ultrasound

Initially, we started this technique by proper explanation of the procedure to the patients.

Patient position in the sequential order:

Sitting (dorsal and lateral images)

Supine (ventral images)

Right lateral position (dorsal and lateral images)

Left lateral position (dorsal and lateral images)

Raising the arms and crossing them behind the head causes intercostal paces to be extended and facilitates access. The probe was cleaned, and the water-based transducinggel was used to improve the interface. Scanning techniques that were used in transthoracic ultrasound:

Sub-costal: The transducer detects the liver as an acoustic window.

Inter-costal: The transducer was oriented parallel to the ribs.

Landmarks were established, and a search was done for the lesion.

The patient's position was supine or sitting with an elevated arm and clasping the hand behind the neck and using the probe at the inter-costal spaces to detect any chest lesions.

3. CT: Done as Gold-Standard Study

3.1. Scan Protocol

All patients were scanned using a multi-detector scanner 160 detector (Toshiba, Prime Aquilion Japan), the scans were obtained in the supine position and during full inspiration, which we did.

3.2. Patient Position

Patients were positioned on the CT examination table in the supine technique.

Both arms were elevated (place the arms above the head level.

3.3. Image Acquisition

From the apex of the thorax to the lung bases in the

supine position, according to the Nomenclature Committee of the Fleischner Society, Lung regions were allocated using the same anatomical landmarks as with CXR; then, CT scans were interpreted for any mediastinal, pleural, and pulmonary pathologies [4].

3.4. Scan Parameters

Chest CT-scanning was performed from the lower part of the neck to the adrenal gland. Scanning parameters of CT examination were as follows: slice thickness 5 mm, slice interval 0.5 mm, collimation 2.5 mm, scan time 3.9 seconds, feed/rotation 15 mm. A scout was taken with 120 kV and 100 mA, then helical scanning in the craniocaudal direction to minimize the respiratory artifacts.

3.5. Image Reconstruction

The obtained axial images were reconstructed using different post-processing techniques as MPR (multi-planar reconstruction).

3.6. Image Evaluation

It is done by a radiologist unaware of CXR and lung ultrasound findings.

4. Results

This study was conducted on 110 patients, 67 males and 43 females, with a mean age of 55.77 ± 14.34 ranging from 21 to 74 years 53.6% were non-smokers, about 79% of cases had co-morbidities, and mainly HTN and diabetes, almost half of the patients 50.9% were admitted to ICU, table 1. For free pleural effusion, US diagnosed 43.6% (n = 48), CXR 39.1% (n=43), while CT 47.3% (n = 52), table 2. US Sensitivity 95.8%, specificity 90.3%, positive predictive value PVP 88.5%, NPV 96.5%, 92.7% accuracy and kappa coefficient 0.854, tables 3–5 with a significant difference between CT and US for the diagnosis of free pleural effusion (table 4), while CXR Sensitivity 100%, specificity 86.6%, PVP 82.7%, NPV 100%, 91.8% accuracy tables 3 and 5 and kappa coefficient 0.834 with significant difference between CT and CXR in the diagnosis of free pleural effusion, table 4. For encysted pleural effusion, US diagnosed 17.3% (n = 19), CXR 20% (n = 22), while CT 17.3% (n = 19) (Table 2). US sensitivity (100%), specificity 100%, PVP 100%, NPV 100%, 100% accuracy tables 3 and 5 and kappa coefficient 1 with a significant difference between CT and US for the diagnosis of encysted pleural effusion, table 4. CXR sensitivity 86.4%, specificity 100%, PVP 100%, NPV 96.7%, 97.3% accuracy tables 3 and 5 and kappa coefficient 0.91 with significant difference between CT and CXR in the diagnosis of encysted pleural effusion table 4. For pneumonia, US diagnosed 30% (n = 33), CXR 29.1% (n = 32), while CT 30% (n = 33), table 2. US, sensitivity 90.9%, specificity 96.1%, PVP 90.9%, NPV 96.1%, 94.5% accuracy, tables 3 and 5 and kappa coefficient 0.870 with significant difference between CT and US in diagnosis of pneumonia, table 4. CXR Sensitivity 84.4%, specificity 92.3%, PVP 81.8%, NPV 93.5%, 90% accuracy tables 3 and 5 and kappa coefficient 0.760 with significant difference between CT and CXR in diagnosis of pneumonia, table 4. For lung mass, US diagnosed 16.4% (n = 18), CXR 16.4% (n = 18), while CT 18.2% (n = 20), table 2. US Sensitivity 94.4%, specificity 96.7%, PVP 85%, NPV 98.9%, 96.4% accuracy, tables 3 and 5 and kappa coefficient 0.873 with significant difference between CT and US in diagnosis of lung mass, table 4. CXR Sensitivity 77.8%, specificity 93.5%, PVP 70%, NPV 95.6%, 90.9% accuracy tables 3 and 5 and kappa coefficient 0.682 with significant difference between CT and CXR in diagnosis of lung mass table 4. For pleural thickening US, diagnosed 20.9% (n=23) CXR 15.4% (n = 17), CT 20.9% (n = 23), table 2. US sensitivity 87%, specificity 96.6%, PVP 87%, NPV 96.6%, 94.5% accuracy, tables 3 and 5 and kappa coefficient 0.835 with significant difference between CT and US in the diagnosis of pleural thickening, table 4. CXR sensitivity 100%, specificity 93.5%, PVP 73.9%, NPV 100%, 94.5% accuracy, tables 3 and 5 and kappa coefficient 0.818 with significant difference between CT and CXR in the diagnosis of pleural thickening, table 4. For the cavitary lesion (lung abscess), US diagnosed 10% (n = 11) CXR 10% (n = 11), and CT 10% (n = 11), table 2. US sensitivity 90.9%, specificity 99%, PVP 90.9%, NPV 99%, 98.2% accuracy, tables 3 and 5 and kappa coefficient 0.899 with significant difference between CT and US in diagnosis of (Cavitary lesion) lung abscess, table 4. CXR Sensitivity 81.8%) specificity 98%, PVP 81.8%, NPV 98%, 96.4% accuracy, tables 3 and 5 and kappa coefficient 0.798 with significant difference between CT and CXR in the diagnosis of cavitary lesion (lung abscess), table 4. For Pneumothorax, US diagnosed in 10% (n = 11) CXR 10.9% (n = 12), while CT 10% (n = 11), table 2. US sensitivity 81.8%, specificity 98%, PVP 81.8%, NPV 98%, 96.3% accuracy, tables 3 and 5 and kappa coefficient 0.798 with significant difference between CT & US in diagnosis of pneumothorax, table 4. CXR sensitivity 75%, specificity 98%, PVP 81.8%, NPV 97%, 95.5% accuracy, tables 3 and 5 and kappa coefficient 0.757 with significant difference between CT & CXR in diagnosis of pneumothorax, table 4 For pulmonary odema US diagnosed 17.3% (n = 19) CXR 19.1% (n = 21), while CT 17.3% (n = 19), table 2 US sensitivity 89.5%, specificity 97.8%, PVP 89.5%, NPV 97.8%, and 96.4% accuracy, tables 3 and 5 and kappa coefficient 0.873 with significant difference between CT & US in diagnosis of pulmonary odema, table 4. CXR sensitivity 76.2%, specificity 96.6%, PVP 84.2%, NPV 94.5%, and 92.7% accuracy, tables 3 and 5 and kappa coefficient 0.756 with significant difference between CT & CXR in diagnosis of pulmonary odema (Table 4).

Table 1 Demographic data of patients' characteristics

Variable	N	%
Age (years)		
Mean ± SD	55.77 ± 14.34	
Range	(21–74)	
Sex		
Male	67	60.9
Female	43	39.1
Smoking habit		
Smoker	51	46.4
Nonsmoker	59	53.6
Comorbidities		
HTN	30	27.3
Diabetes	30	27.3
Cardiac	15	13.6
Renal	2	1.8
Hepatic	10	9.1
No comorbidities	23	20.9
Site of admission		
Ward	54	49.1
ICU	56	50.9

Table 2 Pathology-based diagnostic results

	CT		US		CXR	
N = 110	N	%	N	%	N	%
Free pleural effusion	52	47.3	48	43.6	43	39.1
Encysted pleural effusion	19	17	19	17.3	22	20
Pneumonia	33	30	33	30	29.1	32
Lung mass	20	18.2	18	16.4	18	16.4
Pleural thickening	23	20.9	23	20.9	17	15.4
Lung abscesses (cavitary lesion)	11	10	11	10	11	10
Pneumothorax	11	10	11	10	12	10.9
Pulmonary edema	19	17.3	19	17.3	21	19.1

Table 3 Diagnostic validity compared with CT as a gold standard

	Sensitivity %		Specificity %		PPV %		NPN %		Accuracy %	
	US	CXR	US	CXR	US	CXR	US	CXR	US	CXR
Free pleural effusion	95.8	100	90.3	86.6	88.5	82.7	96.5	100	92.7	91.9
Encysted pleural effusion	100	86.4	100	100	100	100	100	96.7	100	97.3
Pneumonia	90.9	84.4	96.1	92.3	90.9	81.8	96.1	93.5	94.5	90
Lung mass	94.4	77.8	96.7	93.5	85	70	98.9	95.6	96.4	90.9
Pleural thickening	87	100	96.6	93.5	87	73.9	96.6	100	94.5	94.5
Lung abscess	90.9	81.8	99	98	90.9	81.8	99	98	98.2	96.4
Pneumothorax	81.8	75	98	98	81.8	81.8	98	97	96.3	95.5
Pulmonary edema	89.5	76.2	97.8	96.6	89.5	84.2	97.8	94.5	96.4	92.7

Table 4 Kappa agreement and significance compared with CT as a gold standard

	Kappa coefficient %		P-value	
	US	CXR	US	CXR
Free pleural effusion	0.854	0.834	< 0.001 (s)	< 0.001 (s)
Encysted pleural effusion	1	0.910	< 0.001 (s)	< 0.001 (s)
Pneumonia	0.870	0.760	< 0.001 (s)	< 0.001 (s)
Lung mass	0.873	0.682	< 0.001 (s)	< 0.001 (s)
Pleural thickening	0.835	0.818	< 0.001 (s)	< 0.001 (s)
Lung abscess	0.899	0.798	< 0.001 (s)	< 0.001 (s)
Pneumothorax	0.798	0.757	< 0.001 (s)	< 0.001 (s)
Pulmonary edema	0.873	0.756	< 0.001 (s)	< 0.001 (s)

Table 5 Comparison of the AUC-ROC of CXR vs. the US for detecting different pleural and pulmonary diseases

	CXR		US	
	AUC	95%CI	AUC	95%IC
Free pleural effusion	0.913	0.851–0.976	0.925	0.867–0.983
Encysted pleural effusion	0.984	0.962–1.000	1.000	1.000
Pneumonia	0.877	0.793–0.960	0.935	0.873–0.997
Lung mass	0.894	0.758–1	0.899	0.763–1
Pleural thickening	0.870	0.760–0.979	0.918	0.834–1.00
Lung abscess	0.899	0.763–1.00	0.949	0.849–1.000
Pneumothorax	0.894	0.758–1.0	0.899	0.763–1.0
Pulmonary edema	0.894	0.794–0.993	0.936	0.854–1.000

5. Discussion

Years ago, chest US was a neglected area with perceived notions about its application in air-filled structures, but, the last two decades have shown significant progress and revolution in the field of its application for care of patients in both ICU &non-ICU settings [3]. In this study, for free pleural effusion diagnosis, CXR specificity and accuracy were lower than that of chest US (86.6% VS 90% and 91.9% vs. 92.7%) with a higher CXR sensitivity (100% vs. 95.8%). Regarding encysted pleural effusion, US validity was higher than CXR. For pneumonia, the validity of chest US was higher than CXR For lung mass, US Sensitivity 94.4%, specificity 96.7%, PVP 85%, NPV 98.9%, and 96.4% accuracy were higher than CXR., US showed sensitivity and accuracy of pneumothorax higher than CXR (81.8% vs. 75% and 96.3% vs. 95%). US showed a higher validity than CXR for lung abscess diagnosis. US sensitivity, specificity, accuracy for the diagnosis of pulmonary edema was higher than that of CXR. There was registered higher specificity for US vs. CXR for pleural thickening diagnosis (96.6 % vs. 93.5%) but with lower US sensitivity (87% vs. 100%). For free pleural effusion, this study results were in harmony with El Mahalawy et al. [4], who showed higher CXR specificity (90%) with lower sensitivity (70%) but, higher validity of the US, in harmony with El Ziat et al. [5] who showed, higher US validity. For pneumonia diagnosis, this study results were in harmony with [4-6] who showed higher US validity and lower CXR

validity. For pneumothorax diagnosis, this study results were in contrast to Azad et al., [7] who showed low CXR sensitivity (50-52%) but specificity 100%. In harmony with El Mahalawy et al. [4] and Azad et al. [7], who showed higher validity for the US with low CXR validity. Also, in agreement with El Ziat et al. [5] who showed high US validity. For pulmonary edema diagnosis, this study results were in contrast with [4] showed lower CXR validity, but showed higher US validity. In this study, the sensitivity of the CXR for pleural effusion was 100%, as it is troublesome to acquire both PA and lateral views in hospitalized patients, also patients included must have CXR opacities. The US is used to confirm effusion in a patient with normal or abnormal CXR being able to detect as little as 5–50 ml of pleural fluid. Most CXR findings for pneumonia were in the upper and middle lung zones and the sensitivity of CXR to detect pneumonia in the lower lung zones was lower than that in the upper and lower lung zones. With the use of US, absence of lung-sliding sign and comet tail sign attested to pneumothorax. The diagnosis of pulmonary edema is made through co-relation between symptoms, clinical examination finding and chest radiographs. Being peripherally located, US could easily detect the pleural thickening and determine its cause.

5.1. Strengths

(1) US plays an important role in the diagnosis of different pleuropulmonary diseases.

(2) Transthoracic US plays a valuable role, yet, it is operator-dependent and training must become a routine examination tool in pulmonary medicine.

(3) Transthoracic US is relatively inexpensive, no radiation exposure and easy to handle so it is recommended to be performed at the bedside in critically ill patients and pregnant women.

(4) The advantages of transthoracic ultrasound as rapid, real time, low cost, bedside availability, safe, no invasive and no radiation exposure have made ultrasound an indispensable diagnostic tool in modern pulmonary medicine, in detecting pleuropulmonary diseases.

5.2. Limitations

As chest US is an operator-dependent diagnostic modality that requires more focused and more supervised training to ensure that the operator can precisely and correctly interpret the different sonographic findings, as inadequate training may increase the risk of complications.

6. Conclusion

Based on the previous data with the compared results of chest US and CXR to CT as a gold standard diagnostic modality, chest US can be used as the first imaging diagnostic modality in both ward and ICU for evaluating different pleuropulmonary diseases, especially for free and encysted pleural effusion, peripherally located pneumonia, peripherally located lung mass, pulmonary edema, and pneumothorax.

6.1. Recommendations

(1) TUS can be considered a routine radiological investigation tool for all chest diseased patients to its various advantages and little limitations.

(2) Being operator-dependent, so, more training is needed for chest physicians to adequate diagnosis of different pleuropulmonary disorders.

6.2. Future Research

(1) Synchrony echocardiography together with chest US will be helpful in the diagnosing of different pleuropulmonary disorders for rapid exclusion of cardiac causes of acute dyspnea in respiratory ICU.

(2) More research is needed for automated interpretations of B- lines in the diagnosis of interstitial lung syndrome.

Institutional Review Board Statement

The ethical committee of the Faculty of Medicine, Zagazig University (ethical approval number: #4309/4_2_2018) approved this research. All patients enrolled had given written informed consent before participating in the study.

Informed Consent Statement

Written informed consent for publication was obtained from all from participating patients.

Data Availability Statement

Available upon request from the corresponding author.

Research Highlights

- Pleural and pulmonary diseases are increasingly being evaluated and monitored using chest ultrasonography. To a certain extent, CT is the gold standard modality for diagnosing most pleural and pulmonary disease, but there are certain concerns.
- Our present study's assumption is that chest ultrasonography can be employed as the first routine imaging modalities in both the ward and ICU to diagnose various pleuropulmonary disorders.

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