Elabdein *et al. The Cardiothoracic Surgeon* (2024) 32:6
https://doi.org/10.1186/s43057-024-00124-2

The Cardiothoracic Surgeon

RESEARCH

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Chest ultrasound to detect postoperative pulmonary complications after thoracic surgery: a comparative study

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Abstract

Background Patients who underwent thoracic surgery procedures were usually subjected to daily chest X-rays until discharge, exposing patients to ionizing radiation and requiring patient movement with chest drains, difficult positioning, and time-consuming. Unlike chest ultrasound, which is a good alternative because it is bedside and accurate in the detection of pulmonary complications. We hypothesize that a thoracic surgery resident with a short training program in chest ultrasound can achieve comparable results to a chest X-ray. Our study aims to analyze the agreement between the two techniques.

Results This is an observational prospective study. Eighty-six adult patients who underwent thoracic surgery were included. Every patient had a chest X-ray and chest ultrasound follow-up on day 0, day 3, and day 5 post-operative. Chest ultrasound examinations were performed by the same resident, and the results were revised by an expert sonographer for the detection of pneumothorax, pleural effusion, pulmonary consolidation, and interstitial pattern. Both diagnostic procedures showed substantial agreement for pneumothorax ($K = 0.661$). For pleural effusion, they showed moderate agreement ($K = 0.448$, $P < 0.001$), and no cases developed an interstitial pattern. Overall, both diagnostic procedures showed perfect agreement ($K = 0.838$, $P < 0.001$). The time lag to perform a chest ultrasound was statistically lower than that to perform. chest X-ray, with a median of 7 min versus 80 min, respectively.

Conclusions Performing chest ultrasound by a thoracic surgery resident is a less time-consuming and easy bedside diagnostic tool. Compared chest ultrasound to the postoperative X-ray showed a perfect diagnostic agreement for pulmonary consolidation and moderate agreement for pleural effusion and pneumothorax.

Trial registration NCT04118621

Keywords VATS, Ultrasound, Postoperative, Complications

Meeting presentation: presented as a poster presentation at European society of thoracic surgeons (ESTS) Annual meeting, June 2023, Milan, Italy.

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Background

Nowadays, there is a wide spectrum of operations in thoracic surgery, including decortication, wedge resection, lobectomy, pneumonectomy, and thymectomy, which can be performed via open surgery or minimally invasively using video-assisted thoracoscopy (VATS) [1]. It is well known that thoracic surgery can lead to various pulmonary complications, such as residual pleural effusion and pneumothorax. Surgeons often insert intercostal tubes to drain air and fluid from the pleural space. These complications can also affect the pulmonary tissue, causing consolidation or involving the interstitial tissue, which can impact postoperative recovery [2].

Traditionally, a daily chest X-ray is performed from the first day of surgery until hospital discharge to assess the amount of residual pleural effusion and other pulmonary complications. However, serial chest X-rays are costly and expose patients and healthcare workers to ionizing radiation. They also require patient movement with chest drains, difficult positioning, and can be time-consuming [3].

On the other hand, ultrasound (US) techniques have become a brilliant diagnostic strategy in clinical medicine. US machines can provide valuable insights into the physiology and pathological processes of the body. US-based diagnostics have also been established in the field of respiratory medicine. Chest ultrasound is a good alternative to chest X-ray because it can be performed at the bedside, and is easier, more sensitive, and more accurate in detecting pulmonary complications [4]. The main advantages of chest ultrasound include avoiding the dangers of ionizing radiation, portability of the device, low cost, and a rapid learning curve. It is also easier and less time-consuming to correlate ultrasound findings with clinical data and assist in invasive procedures [5–7].

We hypothesized that chest ultrasound would show high agreement with chest X-ray in detecting pulmonary complications based on reviewing the recent literature regarding their results [8]. Our study aims to assess the "criterion-related validity of using chest ultrasound compared to chest X-ray in detecting postoperative pulmonary complications and measure the time lag between the two techniques.

Methods

A cross-sectional study was conducted on patients who underwent thoracic surgeries in the Cardiothoracic Surgery Department at Assiut University Hospital from January 1, 2021, to December 31, 2021. The study was approved by the local ethical committee of the Assiut Faculty of Medicine (IRB NUMB.: 17100891), and written informed consent was obtained from all participants.

Before enrolling patients in the study, the operator who performed the ultrasound examinations (a resident cardiothoracic surgeon) underwent a 6-month training period supervised by (a pulmonologist) with 10 years of experience in performing chest ultrasounds. During this training period, the operator performed ultrasound examinations on postoperative thoracic surgery patients and compared the findings to the patients' same-day chest X-rays. The study results were later revised by an expert sonographer. The decision was revised afterward by the main surgeon if it was not that of the resident. The resident was blind about the chest X-ray which was shown only after the chest ultrasound done

Each patient underwent both a chest ultrasound and a chest X-ray on the same day, with follow-up examinations on day 0, day 3, and day 5 postoperatively.

Bedside transthoracic ultrasound was performed on both hemithoraces using a portable ultrasound device "Vivid S5" with a high-frequency probe (13–6 MHz) and a low-frequency probe (5–2 MHz). The examination was performed with the patient in a supine position at a 30 angle, with the hand behind the head. The examination started with the anterosuperior zone and proceeded sequentially to the anteroinferior, laterosuperior, latero-inferior, and dorsal areas. The ipsilateral arm was slightly adducted, and the patient was slightly inclined (Fig. 1).

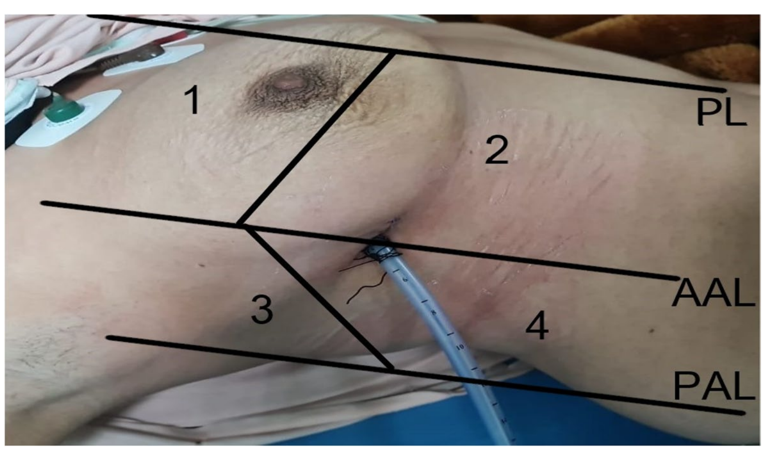

Fig. 1 PL: parasternal line. AAL: anterior axillary line; PAL: posterior axillary line. **1** Anterosuperior area. **2** Anteroinferior area. **3** Lateral superior area. **4** Lateral inferior area

In the context of the chest X-ray is done using chest radiographs (CXRs). CXR was performed according to standard clinical practice (e.g., after coming out of OR, daily follow-up till drain removal) and when demanded by the treating physician for clinical reasons. Anteroposterior bedside CXRs were obtained using a DRX-Revolution mobile X-ray unit (Carestream Health, Inc. © Toronto, Canada). CXR findings were assessed by a radiologist blinded to the US findings. Patients are positioned at an erect posture of the chest and a slightly extended chin, the hands are placed on the hips with the palms facing out, and the shoulders are rolled forward. The central ray is centered on the center of the lung fields.

The objective of the chest ultrasound and X-ray evaluations was to detect four main variables: pneumothorax, pleural effusion, pulmonary consolidation, and interstitial pattern. The presence or absence of these variables was classified as positive or negative, respectively, and as unilateral (right or left hemithorax) or bilateral. Ultrasound and radiographic criteria were established for each variable, following the terminology recommended by the Fleischner Society Nomenclature Committee and the 2012 International Consensus of Experts [9, 10] (Table 1).

All statistical calculations were performed using SPSS version 22. The data were described in terms of mean ± standard deviation (±SD) or median and range for non-normally distributed data. Frequencies and relative frequencies were used when appropriate. Cohen's kappa statistics were calculated to evaluate the strength of agreement of the postoperative pulmonary complications including pneumothorax, pleural effusion, and pulmonary consolidation (Fig. 2), using the benchmarks of Landis and Koch for interpretation. The Wilcoxon sign rank test was used to compare paired quantitative variables. A p value of 0.05 was considered statistically significant. The agreements of the study were assessed through using of Measurement of Observer Agreement for Categorical Data which was adopted from Landis and Koch, 1977 [11]. It is classified into 4 categories including never, sometimes, often, and always with index ranges of $0< MR \leq 1$, $1 < MR \leq 2$, $2 < MR \leq 3$, and $4 < MR \leq 5$ respectively other categorizations include $\leq$ 0.2 (poor agreement);

Table 1 Diagnostic ultrasound and radiographic criteria of the 4 main variables [9, 10]

	Ultrasound criteria	Radiographic criteria
Pneumothorax	- Absence of pleural sliding and B lines. - Lung point sign. - Barcode sign.	- Increased normal radiolucency, making the edge of the visceral pleura visible.
Pleural effusion	- Anechoic or hypoechoic pattern separating the visceral and parietal pleura with changes during respiration.	- Increased homogeneous density superimposed over lung fields.
Pulmonary consolidation	- Tissue model (pulmonary hepatization). - Presence of air alveologramas (pinpoint, linear, or hyperchogenic images).	- Heterogeneous opacity or air bronchogram with loss of normal radiolucency.
Interstitial pattern	- Presence of more than 3 B lines in the anterior and lateral regions of the thorax.	- Collection of innumerable small linear opacities that, in sum, produce a network-like appearance. - Kerley B Lines.

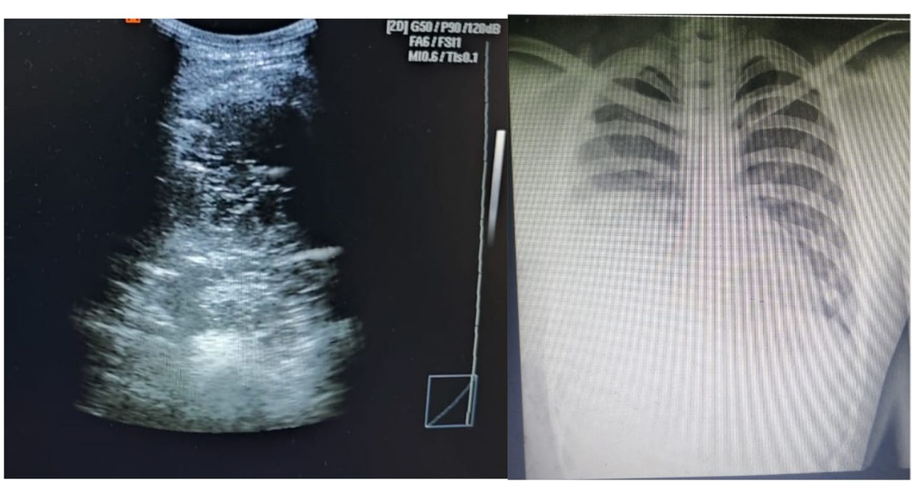

Fig. 2 Chest US and chest X-ray in a patient with pulmonary consolidation

0.21–0.40 (fair agreement); 0.41–0.60 (moderate agreement); 0.61–0.8 (substantial agreement); 0.81 (perfect agreement). The agreements for thoracic surgeries will be taken on (day 0, 3rd, and 5th) days after cardiothoracic surgery.

Results

The study included eighty-six patients who underwent thoracic surgery and met the listed inclusion and exclusion criteria. Patients under 18 years old or with subcutaneous emphysema were excluded (Table 2). The diagnosis and operative details are mentioned in (Table 3).

Pulmonary complications were documented in 62 cases (72.1%). Pleural effusion was the most common, documented in 52 cases (60.5%), followed by pneumothorax documented in 49 cases (57.0%), and pulmonary consolidation documented in 30 cases (34.9%). No cases developed an interstitial pattern.

Regarding pneumothorax, both diagnostic procedures showed substantial agreement (K = 0.661, P < 0.001). For pleural effusion, both diagnostic procedures showed moderate agreement (K = 0.448, P < 0.001). For pulmonary consolidation, both diagnostic procedures showed perfect agreement (K = 0.974, P < 0.001). No cases developed an interstitial pattern at day 0, 3rd, and 5th day post-operatively (Table 4). Overall, both diagnostic procedures showed perfect agreement (K = 0.838, P < 0.001). Only two cases at day 0 where we found that there was a difference between pulmonologist and resident opinion with no change or affection to the patient management plan.

The time lag to perform a chest ultrasound examination was statistically lower than the time lag to perform a chest radiograph examination. The median (range) was 7 (3–12) min versus 80 (40–150) min, respectively (P < 0.001), as shown in Table 5.

Table 2 The demographic and clinical data of the studied participants

Baseline characteristics	**(*n* = 86) (%)**	
Age (years)		
• Mean ± SD	40.14 ± 15.49	
• Median (range)	37 (18–74)	
Weight (kg)		
• Mean ± SD	78.57 ± 11.42	
• Median (range)	79 (54–119)	
Gender		
• Male	55	(64.0)
• Female	31	(36.0)
Associated comorbidity		
Diabetic	17	(19.8)
• Oral	13	(81.3)
• Insulin	3	(18.8)
• Controlled	13	(81.3)
• Uncontrolled	3	(18.8)
HTN	17	(19.8)
COPD	11	(12.8)
Asthmatic	2	(2.3)
Smoking status		
• Non-smoker	45	(52.3)
• Smoker	32	(37.2)
• Ex-smoker	9	(10.5)

BMI body mass index, *HTN* hypertension, *COPD* chronic obstructive lung disease. Quantitative data are presented as mean ± SD and median (range), qualitative data are presented as number (percentage)

Table 3 Thoracic diagnosis and operative details

Diagnosis	**(*n* = 86) (%)**	
• Lung mass	20	(23.3)
• Empyema	19	(22.1)
• Bullous lung disease	16	(18.6)
• Mediastinal surgery	14	(16.3)
• Malignant pleural effusion	5	(5.8)
• Lung abscess	4	(4.7)
• others	8	(9.3)
Thoracic operation	(*n* = 86)	
• Lung resection	29	(33.7)
• Decortication	21	(24.4)
• Mass excision	16	(18.6)
• Biopsy	13	(15.1)
• Chest wall surgery	2	(2.3)
• Diaphragmatic plication	2	(2.3)
• Sympathectomy	2	(2.3)
• Diaphragmatic hernia repair	1	(1.2)

Qualitative data are presented as numbers (percentage)

Table 4 Concordance between transthoracic ultrasound and chest X-ray for the four variables

		Chest X-ray		**Kappa**	***P* value**
Chest US		Yes	No		
Total cases	Yes	59	4	0.888	0.000*
	No	0	23		
• Pneumothorax	Yes	34	15	0.661	0.000*
	No	0	37		
• Pleural effusion	Yes	29	21	0.448	0.000*
	No	2	34		
• Pulmonary consolidation	Yes	29	1	0.974	0.000*
	No	0	56		
• Interstitial pattern	Yes	0	0	----	----
	No	0	86		

Table 5 Time lag up to perform chest ultrasound and chest X-ray among studied participants ($n = 86$)

		P value
Time lag to perform chest US (min)		
• Median (range)	7 (3–12)	0.000*
Time lag to perform chest X-ray (min)		
• Median (range)	80 (40–150)	

Discussion

To the best of the authors' knowledge, few research has been done on the concordance, agreement, or reliability between chest US and chest X-ray during the Post-operative period following thoracic surgery.

The degree of agreement between two or more measurements made on the same sample is known as concordance. It is used When a gold standard diagnostic test that enables us to determine how closely a measurement resembles reality is not available (or cannot be performed). As in the case of our study, when a chest CT scan has not been carried out.

Our principal findings were both diagnostic procedures regarding pneumothorax; showed substantial agreement, for pleural effusion; showed moderate agreement while pulmonary consolidation showed perfect agreement and there were no cases of developed interstitial pattern either at day 0, 3rd, and 5th day post-operatively. In our study, chest US detected more cases of pneumothorax than a chest X-ray which added a value for that technique. The time lag was less for chest US in comparison to chest X-ray.

Our study supports the well-known advantage of chest US over chest X-ray in the diagnosis of pleural effusion, especially in the detection of mild pleural effusion, and differentiates it from consolidations like atelectasis, alveolar occupancy, or pleural thickening [12]. According to pulmonary consolidation, the concordance is perfect between the two techniques there is a small intermittent atelectasis resulting from hypoventilation due to pain which prevents lung expansion in the postoperative period of thoracic surgery [13]. These are distinguished by being only visible during exhalation, which makes it easier for the chest US to detect them because of how dynamic they are and how sensitive they are for little consolidations that scrape the pleura [9].

Chest US is an individually subjective examination so it is observer-dependent with a high risk of bias, it depends also on the experience in doing chest US a study by Goudie et al. [14] produced disappointing results, which might have been influenced by a lack of experience. Also, there is a lack of interobserver reliability research. Such research would necessitate more investigators and more investigations. Once the agreement between the two techniques has been confirmed, more research on inter- and intra-observer reliability should be conducted. We are in contrast with this study as after only a 6-month training period our resident was able to do a chest sonography perfectly as the results were revised later by an expert sonographer.

In our study, there was only one operator who was performing the ultrasonography (resident thoracic surgeon) with a training period of 6 months unlike Daniel J. Jakobson et al. [15] where the operator has 10-year experience. we included our patients between the first of January 2021 and the end of December 2021 with a total number of 86 but Daniel J. Jakobson et al. [15] included 80 patients from 2013 to 2017 and Ariza et al. [8] included 76 patients.

In comparison with Ariza et al. [8] and Daniel J. Jakobson et al. [15], our patients were explored in the post-operative period of thoracic surgery, but none of them had surgical emphysema. Most of them were males with a mean age of 40 years. So, from our point of view, our study has a large sample size which might be adding the existing knowledge and is in agreement with Ariza et al. [8].

Although the pain was not measured in our study, one would not anticipate that moving the arm slightly to reach all areas during chest US examination would cause greater discomfort than moving the chest X-ray grid beneath the patient, especially patients in ICU with difficult positioning anteroposterior X-rays, bad quality, and soft films; patients find the initial chest X-ray following thoracic surgery to be extremely unpleasant.

Although our study was done on adult patients only and cannot be generalized to all patients, recent studies from a clinical research program where chest US was routinely performed after pediatric cardiac surgery found several advantages of chest US in evaluating postoperative pulmonary complications and was more accurate than chest X-ray in diagnosing pleural effusion, atelectasis, and lung congestion helping the prognosis of different ICU clinical outcomes [16, 17].

One critique of this study is that a resident with good training in US should allocate a certain amount of time for each patient every day, while 1–2 min of evaluation of the chest X-ray will be sufficient. Although chest radiography may seem disadvantageous in terms of total examination time, it provides convenience to the physician in practice as well as from the follow-up aspect, patients who will need to be followed up for a long time, such as patients who have undergone anatomical lung resection, postoperative lung radiographs are records that many physicians responsible for the patient's treatment can easily access and evaluate, even retrospectively. From this perspective, it would be a more realistic approach for the thoracic US to replace chest radiography in patients who have undergone minor thoracic surgery or in trauma patients, although not in all patient groups. In the same context, Batihan, 2023 [18] illustrated that lung US is a good alternative to traditional chest radiographs in the follow-up of patients with blunt chest trauma regarding pneumothorax, hemothorax, and atelectasis. Reproducibility, real-time imaging, and point-of-care application are the main parameters that make lung US attractive.

We have found a statistically significant difference between time-lag needed to perform chest US and chest X-ray in our patients with a median of 7 min vs. 80 min respectively but we did not find any assessed time lag in other studies like Ariza et al. [15]. Time lag for chest X-ray might be attributed to the fact that we don't have a digital system for X-ray which means that we have to request the technician to come to perform the X-ray then he took the X-ray cassette to the radiology department to print it out and send it back to us.

There are some technical limitations of chest US at the initial postoperative period which can block the passage of ultrasound waves as dressings, surgical wounds, chest tubes, different grades of subcutaneous emphysema, and reduced patient's mobility (which prevents visualization of the posterior costophrenic angle). Furthermore, it is unable to visualize the retrosternal area and the posterosuperior zone that is in relation to the scapula, preventing it from acquiring a complete image of the thorax. So it is very important to do an adequate examination of the anterior and lateral chest regions [18].

One of the issues that negatively affected our study is the complete absence of a gold standard method like CT chest. Due to their excessive radiation exposure which is equal to 350 chest X-rays, as well as ethical considerations, these individuals cannot have routine CT chest exams [19]. Chest US could be considered as an add-on tool to the standard follow-up chest X-ray, thus avoiding a large number of serial chest X-rays or requesting a CT scan in an intensive care unit [20, 21].

We need to further evaluate the feasibility and effectiveness of using chest US in trauma patients and the applicability of using the smartphone-powered US machine in such instances.

Conclusions

Performing chest ultrasound by a thoracic surgery resident is a less time-consuming and easy bedside diagnostic tool. Compared chest ultrasound to the postoperative X-ray showed a perfect diagnostic agreement for pulmonary consolidation and moderate agreement for pleural effusion and pneumothorax.

Limitations of the study

- The lack of reliability assessment between different raters is recommended for future studies as it is a very important psychometric property and actually should be established before the validity assessment. Also, the assessor was not blinded while reviewing the X-ray.
- CT chest was not available to be performed for all the patients included in the study.

Abbreviations

VATS	Video-assisted thoracoscopy
US	Ultrasound
CT	Computed tomography
ICU	Intensive Care Unit
COPD	Chronic Obstructive Pulmonary Disease

Acknowledgements

Not applicable.

Authors' contributions

Ali Zein Elabdein: data collection, statistical analysis, and analysis of data. Hussein Elkhayat: administrative, technical, or material support and interpretation of data. Ramy Abdelrheim Hassan: conception and design. Mahmoud Khairy Elhaish:supervision. All authors read and approved the final manuscript.

Funding

No funding sources.

Availability of data and materials

The data underlying this article will be shared on reasonable request to the corresponding author.

Declarations

Ethics approval and consent to participate

The study was approved by the local ethical committee of Assiut Faculty of Medicine (IRB NUMB.: 17100891), and written informed consent was obtained from all participants. Clinical registration number: NCT04118621

Consent for publication

A written consent was taken from every patient before enrollment in our study.

Competing interests

The authors declare that they have no competing interests.

Received: 23 November 2023 Accepted: 29 March 2024
Published online: 09 April 2024

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