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Original Research Article

Comparative study of transthoracic ultrasound and chest X-ray in the postoperative period of thoracic surgery

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ABSTRACT

Background: Chest radiography is currently the reference technique in postoperative follow-up of thoracic surgery. However, routine use (almost daily) has been repeatedly questioned. Moreover, transthoracic ultrasound, besides being a useful technique in pleuropulmonary pathology offers additional advantages over the radiograph. The aim of this study is to analyse the diagnostic agreement between radiographic and ultrasound techniques in the postoperative follow-up of thoracic surgery.
Methods: Observational, prospective study, in the postoperative period of thoracic surgery, to study the concordance between the ultrasound and radiographic findings. Sixty patients were evaluated during the postoperative period with the two diagnostic tests, first the transthoracic ultrasound of the 2 hemithorax and then the chest radiograph. Each patient had an ultrasound and an X-ray. The sonographer and radiologist have independently assessed the occurrences of pneumothorax, pleural effusion, pulmonary consolidation, and interstitial pattern.
Results: The Cohen kappa index for pneumothorax was 0.706 ($p < 0.001$), for pleural effusion 0.588 ($p < 0.001$), for interstitial pattern 0.474 ($p < 0.001$) and for pulmonary consolidation 0.282 (p 0.002).
Conclusions: The diagnostic concordance between radiographic and ultrasound techniques in the postoperative period of thoracic surgery is substantial for pneumothorax and pleural effusion, moderate for interstitial pattern, and fair for pulmonary consolidation.

Keywords: Chest radiography, Kappa index, Lung ultrasound, Postoperative complications, Thoracic surgery

INTRODUCTION

It is common for thoracic surgery to lead to different types of pneumothorax and postoperative pleural effusions in patients. Therefore, thoracic drainage is necessary for the evacuation of air and fluid from the pleural space. At the same time, some degree of involvement of the pulmonary parenchyma can be observed in the form of consolidation or involvement of the interstitium. Many of these findings are not apparent, but they always threaten postoperative recovery. Traditionally an almost daily chest X-ray is performed from the surgical intervention to hospital discharge to check whether drainage removal is appropriate or to detect associated pleuropulmonary complications.[1] However, chest X-rays are costly, exposing patients and health care workers to ionizing radiation, requiring patient movement with chest drains, and time consuming.[2-4]

On the other hand, transthoracic ultrasound is an emerging technique that has been shown to be more sensitive and accurate than chest X-ray in different pleuropulmonary pathologies.[5-8] Its main advantages lie in the absence of ionizing radiations, easier device portability, low cost and a rapid learning curve.[9] Being a real-time study, it is possible to immediately integrate the findings with the clinical data and assist in invasive procedures.

Although transthoracic ultrasound is a globally accepted test as far as the authors know the diagnostic concordance between transthoracic ultrasound and chest X-ray has not been studied in postoperative follow-up of thoracic surgery.[9-11] The objective of this study is to analyse the diagnostic concordance (pneumothorax, pleural effusion, pulmonary consolidation and interstitial pattern) between radiographic and ultrasound techniques in the postoperative follow-up of thoracic surgery.

METHODS

This is an observational, prospective study with sequential inclusion of 60 patients in the postoperative period of thoracic surgery from July 2015 to November of the same year.

The study was carried out at 'Hospital Universitario de La Princesa' (Madrid, Spain) and has been approved by the local ethics committee (Registration number: PI-800). Written informed consent was obtained from each patient prior to the surgical intervention.

Post-operative patients of thoracic surgery of both sexes, have been included, regardless of symptoms, diagnosis, type of procedure or surgical approach (Table 1). Patients <18 years old or with subcutaneous emphysema have been excluded.

Prior to opening the study and enrolling the patients, the investigator who was performing the ultrasound examination (thoracic surgeon) underwent an intensive 3-week training phase supervised by a specialist in transthoracic ultrasound (anesthesiologist). During this phase, they performed transthoracic ultrasounds on patients in the postoperative period of thoracic surgery and then compared their findings to the patient's same day chest X-ray. When the findings were inconsistent, the evaluators performed a second ultrasound examination of the previously examined patient to adequately identify the findings that were misinterpreted the first time. Patients participating in this learning phase were not included in the study.

Sixty patients were evaluated during the postoperative period of thoracic surgery with the two diagnostic tests, first the transthoracic ultrasound and then the chest X-ray. The first 20 patients have been evaluated in the postoperative care unit in the immediate postoperative period (initial postoperative stage). The second 20 patients have been evaluated in the hospital ward, when they still had pleural drainage (intermediate postoperative stage). The last 20 patients have been evaluated in the hospital ward, after removal of pleural drainage, in the days before discharge (final postoperative stage).

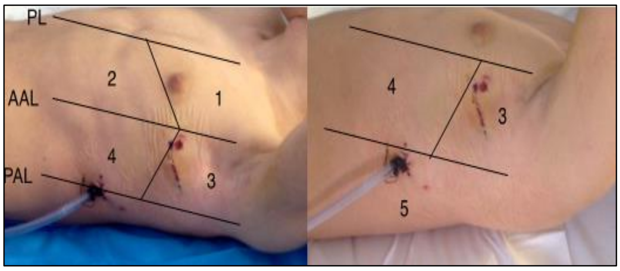
The interpretations of the tests have been carried out by a single thoracic radiologist and by a single sonographer. The ultrasound and radiographic data have been collected in protocols. Both the sonographer and the radiologist were unaware of the outcome of the other test. The ultrasound results have not been shared with the surgical team. The information regarding the basic characteristics of the patients has been obtained from the medical records of the hospital.

All patients underwent bedside transthoracic ultrasound of the 2 hemithorax (bilateral). For this, a Sonosite portable M-Turbo ultrasound equipment has been used, with a high (13-6 MHz) and low frequency probe (5-2 MHz). To perform this technique, it was only been necessary to use the two-dimensional image and M-mode.

Table 1: Basic characteristics of the 60 patients.

	n	%
Age mean (min - max)	53 years (19-86)	
Gender		
Male	31	52%
Female	29	48%
Type of surgical procedure		
Major pulmonary resection	21	35%
Minor pulmonary resection	18	30%
Placement of pleural drainage	11	18.3%
Sympathectomy	5	8.3%
Thymectomy	3	5%
Mediastinoscopy	1	1.7%
Mediastinal mass biopsy	1	1.7%
Type of surgical approach		
Videothoracoscopic surgery	37	61.7%
Thoracotomy	11	18.3%
Closed thoracostomy	11	18.3%
Cervicotomy	1	1.7%
Complications		
None	51	85%
Bleeding	1	1.7%
Atelectasis	3	5%
Chylothorax	1	1.7%
Pneumothorax	3	5%
Prolonged air leak	1	1.7%
Operated side		
Right hemithorax	30	50%
Left hemithorax	24	40%
Both hemithorax (bilateral)	5	8.3%
Upper mediastinum (cervicotomy)	1	1.7%

Five areas were examined in each hemithorax, with the patient lying supine at 30 degrees and with the hand behind the head (Figure 1). The systematic exploration began in the anterosuperior zone, followed sequentially by the anteroinferior, laterosuperior and lateroinferior, ending in the dorsal area with a slight inclination of the patient and a slight adduction of the ipsilateral arm.



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. 5: dorsal area.

Figure 1: Areas of ultrasound examination.

Chest X-rays in the initial stage were performed in supine decubitus with anteroposterior (AP) projection. In the intermediate and final stages, they were performed with 2 projections (posteroanterior and lateral).

The aim of the ultrasound and radiographic evaluations was to detect 4 main variables: pneumothorax, pleural effusion, pulmonary consolidation and interstitial pattern. The presence or absence of some of these variables have been classified as positive or negative respectively and also as unilateral (right or left hemithorax) or bilateral. In turn, the severity of pneumothorax has been quantified as partial or total and the severity of pleural effusion as mild, moderate or severe.[12,13] For this purpose, radiographic and sonographic diagnostic criteria have been established for each variable (Table 2), taking into account the terminology recommended by the Fleischner Society Nomenclature Committee and the 2012 International Consensus of Experts.[14,15] Figure 2 shows ultrasound examples of these 4 variables.

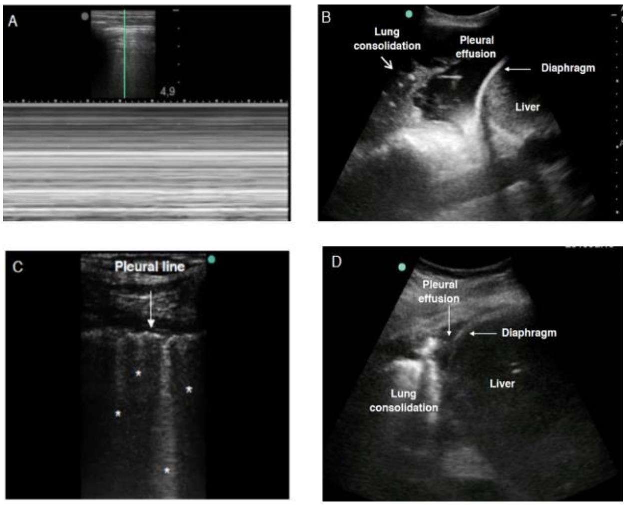


Figure 2: Abnormal ultrasound patterns. A) Pneumothorax. Image in M mode shows the 'stratosphere sign' or 'barcode sign'; B) Pleural effusion and pulmonary consolidation. An anechoic chamber is observable, corresponding to the pleural effusion, adjacent to the consolidated lung, which contains hyperechogenic images that are consistent with an aerial bronchogram; C) Interstitial lung disease. Several B-lines, or 'comet tails' can be seen (*) which originate at the pleural line; D) Pulmonary consolidation with small adjacent pleural effusion.

Table 2: Diagnostic ultrasound and radiographic criteria of the 4 main variables.

	Ultrasound criteria	Radiographic criteria
Pneumothorax	• Absence of pleural sliding and B lines. • Lung point sign.[16] • Barcode sign. • Partial pneumothorax: criteria of pneumothorax present in some areas of the hemithorax. • Total pneumothorax: criteria of pneumothorax present throughout the hemithorax.	• Increased normal radiolucency, making the edge of the visceral pleura visible. • Partial pneumothorax: partial separation between the visceral and parietal pleura. • Total pneumothorax: total separation between the visceral and parietal pleura (throughout the pleural cavity).
Pleural effusion	• Anechoic or hypoechoic pattern separating the visceral and parietal pleura with changes during respiration. • Mild pleural effusion (limited to costodiaphragmatic angle): partially visible diaphragmatic dome. • Moderate pleural effusion: lower lobe collapse. • Severe pleural effusion: collapsed lung.	• Increased homogeneous density superimposed over lung fields. • Mild pleural effusion: blunting of costophrenic angle. • Moderate pleural effusion: when its size is up to half hemithorax. • Severe pleural effusion: when its size is greater than half hemithorax.
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.[17]	• Collection of innumerable small linear opacities that, in sum, produce a network-like appearance. • Kerley B Lines.

A concordance study of the 2 diagnostic tests was performed, expressing the results as a percentage of global agreement (global agreement rate), positive agreement and negative agreement, Cohen kappa index (proportion of agreement exceeding that expected by chance), and its statistical significance (p).

According to the Landis and Koch classification, kappa index values of at least 0.6 were considered substantial. In addition, for the calculation of concordance at the different moments of the study, the simultaneous presence/absence of the four variables which are the objective of this study has been analysed.

Taking into account a pilot study of 10 subjects (20 hemithorax) assuming a proportion of positive findings of at least 0.2 and using an alpha level of 0.05 and beta of 0.2 and a unilateral contrast, the sample size to estimate as significant a concordance ≥0.6, is 60 subjects (120 hemithorax).19

Homogeneity between pairs of kappa indices was tested by the chi-square (chi-squared) test proposed by Fleiss.20 Statistical analysis was performed with the IBM SPSS 21 programs (IBM Corp (Armonk, New York) and Epidat 4.0.

RESULTS

Seventy-six patients (120 hemithorax) were explored in the postoperative period of thoracic surgery, but sixteen patients were not included in the study due to subcutaneous emphysema. Sixty patients were finally enrolled in the study in a period of 5 months. Each patient had a chest X-ray and transthoracic ultrasound. A total of 60 bilateral transthoracic ultrasounds (of the 2 hemithorax) and 60 chest X-rays were performed (20 in AP and 40 with 2 projections: posteroanterior and lateral). Sixteen patients were not included in the study due to subcutaneous. Table 1 summarized some characteristics of patients.

Significant differences between the main characteristics of the three groups (immediate postoperative, intermediate and final postoperative stages) were not found (data not shown). The time of the ultrasound examination was 10±3 minutes, the time interval between ultrasound and the radiograph has been on average 100±60 minutes.

Table 3: Positive and negative findings of transthoracic ultrasound and chest X-ray in 120 hemithorax from 60 patients.

	Positive ultrasound findings	Negative ultrasound findings	Positive X-ray findings	Negative X-ray findings
Pneumothorax	18 (partial 15, total 3)	-	17 (partial 14, total 3)	-
Pleural effusion	18 (mild 16, moderate 2)	-	22 (mild 20, moderate 2)	-
Interstitial pattern	12	-	4	-
Pulmonary consolidation	26	-	18	-
Total findings in 120 hemithorax	74	46	61	59

Table 4: Concordance between transthoracic ultrasound and chest X-ray for the four variables in 120 hemithorax from 60 patients.

Agreement (%)						
Observation	**n**	**Global**	**Negative**	**Positive**	**Kappa**	***p***
Pneumothorax[A]	120	92.5	81.7	10.8	0.706	<0.001
Pleural effusion [B]	120	88.4	77.5	10.9	0.588	<0.001
Interstitial pattern	120	93.3	90	3.3	0.474	<0.001
Pulmonary consolidation	120	78.3	70.8	7.5	0.282	0.002

n: observation number. Each variable performs 2 observations per patient (right and left side); A: When the variable was dichotomized (without pneumothorax/with pneumothorax) and kappa was calculated considering two categories: kappa = 0.699 (p <0.001); B: When the variable was dichotomized (without pleural effusion/with pleural effusion) and kappa was calculated considering two categories: kappa = 0.699 (p <0.001)

Table 5: Concordance between transthoracic ultrasound and chest X-ray in 160 observations (4 variables X 2 hemithorax) from 20 patients at each postoperative stage.

Agreement (%)						
Stage	**n**	**Global**	**Negative**	**Positive**	**Kappa**	**p**
Initial	160	81.2	78.1	3.1	0.158	0.030
Intermediate	160	93.1	80.6	12.5	0.743	< 0.001
Final	160	90.1	81.3	8.8	0.578	< 0.001

n: number observation. Each variable performs 2 observations per patient (right and left side). At each stage, there are 4 variables.

Table 3 shows the positive and negative findings of transthoracic ultrasound and chest X-ray. Seventy-four ultrasound examinations were positive in 39 patients (65%) and 61 radiographic examinations were positive in 41 patients (68%). Ultrasonography was normal (negative for the 4 main variables) in 21 patients (35%) and radiography in 19 (32%). Of these 21 patients with normal ultrasound, radiography has been done in 16 cases (80%).

Table 4 shows the agreement between the techniques for the four main variables. For the four variables, the concordance is significantly greater than zero. The kappa indices for pneumothorax and pleural effusion were significantly higher than for pulmonary consolidation (p =0,003 and p = 0,039, respectively). Other significant differences between kappa values were not found.

Table 5 shows the concordance in each of the three postoperative stages considering simultaneously the four types of possible findings. In the three stages, a significant agreement between the techniques has been observed. The kappa indices observed in the intermediate and final stages were significantly higher than those observed in the initial stage (p <0.001 and p = 0.018, respectively), with no significant differences between them (p = 0.168).

We found evidence of significant differences between the four variables and between the three postoperative stages, but not between the two hemithorax (data not shown), so the results are expressed without differentiating between right and left hemithorax.

DISCUSSION

To the authors' best knowledge, the concordance (repeatability, agreement or reliability) between transthoracic ultrasound and chest X-ray in the postoperative period of thoracic surgery has not been studied. Concordance is defined as the degree to which two or more measurements agree on the same sample. One of its indications is when a gold standard diagnostic test is not available (or cannot be done) that allows us to establish the degree to which a measurement coincides with the truth. As is the case of this study where the chest tomography (chest CT) has not been performed. The calculated sample size was 60 patients (120 hemithorax) which allowed us to undertake 60 comparisons between X-rays and ultrasound.

The most used index to express the concordance is the one proposed by Cohen that has been called the kappa index.[18] Its interpretation is performed by correlating its value with a qualitative scale that includes six levels of concordance strength.[18] The fact that the kappa index depends not only on the observed agreements, but also on the prevalence of the observed character and the prevalence observed by each test must be taken into account.[21] Low prevalence penalizes kappa, as is the case in this study where the percentage of postoperative complications is 15%. This justifies that the results of the kappa are lower than the agreement percentage (agreement rate) whose interpretation is usually more intuitive.

Concordance has been substantial for pneumothorax and pleural effusion, moderate for interstitial pattern and fair for pulmonary consolidation. At the same time, the concordance was substantial in the intermediate and final stages of the postoperative period and fair in the initial stage. Between both techniques, agreement occurs primarily at the expense of negative agreement, and positive agreements are mostly produced at the expense of minor findings. The results of this study suggest that the greater the intensity of the findings (pneumothorax, pleural effusion and pulmonary consolidation) the greater the degree of agreement.

In the present study ultrasound has detected more cases of pneumothorax than radiography. However, it has failed to detect 5 apical pneumothoraxes seen on radiography, which can be explained by the limitation of ultrasound in detecting those pneumothoraxes found in the apical, mediastinal or posterior regions, as well as its inability to pass through the air.[22] This means that it is impossible to determine the "depth of the pneumothorax" only to establish its limits and location.[23] This is the reason to classify pneumothorax in this study in 2 types depending on the partial or total separation of the lung with the costal wall.

Despite the well-known superiority of lung ultrasound in the detection of pleural effusion when compared with chest X-ray, in this study radiography has detected 4 more cases.[8] This can be explained if we consider that the majority of pleural effusions on radiography have been mild and could also correspond to consolidations such as atelectasis, alveolar occupation or pleural thickening.[24] The limitation of the chest X-ray is that it cannot discriminate some radiopacities, relying many times on the ultrasound for its diagnosis.[24]

The concordance is fair among the techniques for the detection of pulmonary consolidation. Except for 3 lobar consolidations (data not shown) the others have been small (localized). In the postoperative period of thoracic surgery, small intermittent atelectasis, secondary to hypoventilation (pain causes lack of lung expansion) frequently appear.[25] These are characterized by being visible only during exhalation, which facilitates its detection by the ultrasound given its dynamic nature and its high sensitivity in detecting small consolidations that touch the pleura.[15] It has little correlation with conventional radiology since its morphology depends on whether is captured when inhaling or exhaling.

In this study, no cases of postoperative interstitial complication have been reported. Therefore, these findings refer to interstitial pathology (chronic or acute) already present before the surgical intervention.

In the initial postoperative period, the findings of both techniques showed less concordance, which may be due to: the technical limitations of ultrasound and the difficulties in the interpretation of AP radiography.[26,27] There are several factors that can block the passage of ultrasound and are accentuated at this stage: surgical wound and dressings, chest tube, different degrees of subcutaneous emphysema and reduced mobility of the patient (which prevents visualization of the posterior costodiaphragmatic angle).[23] These results suggest the relevance of performing the 2 diagnostic tests (chest X-ray / lung ultrasound) at this postoperative stage.

It can be inferred that ultrasound is beneficial for those patients who require monitoring and evaluation for pneumothorax, pleural effusion and interstitial pattern in the intermediate and final postoperative stage or those who have normal ultrasound. In these subgroups, transthoracic ultrasound could be considered as an alternative to chest X ray, thus avoiding the latter. Routine use of transthoracic ultrasound in an intensive care unit has been shown to be associated with a significant reduction in the request for chest X rays and tomography.[28] Performing a bedside transthoracic ultrasound with a portable handheld machine offers many advantages. It accelerates decision-making by decreasing time required to obtain the X-ray, which will be performed during the day. At a cost-effectiveness level, only the initial acquisition of the ultrasound machine represents an expenditure, subsequently requiring no additional costs except maintenance and repair.

Despite its many advantages, transthoracic ultrasound could not completely replace chest X-ray for several reasons. It has not been shown to be reliable in the initial postoperative period nor in the detection of pulmonary consolidation, it is not useful in patients with subcutaneous emphysema, it is also incapable of obtaining a complete image of the thorax since it cannot visualize the retrosternal space and the posterosuperior zone that is in contact with the scapula. However, attempts to compensate these limitations can be made with an adequate examination of the anterior and lateral chest regions.

This study has limitations. The absence of a gold standard technique such as chest CT is the main limitation of this study. Chest CT cannot be routinely performed on these patients because of their high radiation dose (equivalent to 350 chest X rays) and even for ethical reasons.[29,30] However, consensus (high concordance) is useful in the absence of a gold standard to consider the interchangeability or complementarity of diagnostic techniques. Another limitation is the absence of an interobserver reliability study. Such a study would require additional observers and additional explorations, which is beyond the scope of an observational study. Inter- and intra-observer reliability should be the subject of further study once the agreement between techniques has been established. An alternative design could be a longitudinal study with 3 ultrasound and 3 X-ray studies in three different study moments. However, we chose to undertake the ultrasound and radiographic studies on three group of 20 patient each, in order to have a broader representation of patients with thoracic surgery.

CONCLUSION

The diagnostic concordance between transthoracic ultrasound and chest radiography in the postoperative period of thoracic surgery was fair in the initial stage, but significantly higher in the intermediate and final stages (substantial agreement in both). Moreover, the agreement was higher for the diagnosis of pneumotorax, pleural effusion and interstitial pattern than for the diagnosis of pulmonary consolidation. These results suggest that the use of transthoracic ultrasound in the intermediate and final stages of postoperative thoracic surgery may alleviate the use of chest X rays.

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