The use of ultrasound in the evaluation of postoperative pneumothorax and lung re-expansion in patients after lung resection

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Gaetana Messina*, Mary Bove*, Antonio Noro*, Giorgia Opromolla*, Giovanni Natale*, Vincenzo Ferrara*, Carminia Maria Della Corte**, Raimondo Di Liello*, Mario Martone*, Rosa Mirra*, Beatrice Leonardi*, Francesco Leone*, Giovanni Vicidomini*, Mario Santini*, Alfonso Fiorelli*

*Thoracic Surgery Unit, Università degli Studi della Campania "Luigi Vanvitelli", Napoli, Italy
**Medical Oncology, Department of Precision Medicine, Università degli Studi della Campania "Luigi Vanvitelli", Napoli, Italy

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INTRODUCTION: *Many clinical studies have shown ultrasonography (US) is useful for the diagnosis of different abnormalities involving pleura; chest ultrasound (CUS) is widely used to detect pneumothorax in patients, but there is no data on its use for the follow-up of lung re-expansion after lung resection.*
MATERIALS AND METHODS: *We performed a unicentric observational study all patients between January 2018 and May 2021 undergoing lobectomy in which lung re-expansion was assessed daily with chest ultrasound (CUS) and chest radiography (CXR) until chest drainage was removed.*
Ultarsound clinical signs indicating a pneumothorax were: the detection of a positive lung point, absence of sliding or a consistent stratosphere sign with an absence of lung pulse, B-lines, I-lines or consolidations.
RESULTS: *Sensitivity, specificity, PPV, NPV of CUS and CXR were, respectively: 86% vs. 98% (p = 0.002); 100% vs. 100% (p = 1.0); 94% vs. 75% (p = 0.231); and 94% vs. 99% (p = 0.7).*
CONCLUSIONS: *Ultrasound is a method available also to the patient's bed, an easy-to-learn technique even for inexperienced operators, therefore it is a valuable tool for checking the post-lobectomy lung expansion, reduce the use of chest radiography.*

KEY WORDS: Chest ultrasound, Chest radiography, Pneumothorax

Introduction

Diagnostic imaging, in particular, chest radiographic examination (CXR), plays a fundamental role in the follow-up of patients undergoing lung resection.
CXR is performed in the first postoperative days at the patient's bedside and, as soon as possible, in an upright position and in the two orthogonal projections, to better evaluate the disposition and the extent of the findings (such as hydro-pneumothorax, atelectasis, etc.). Moreover, the systematic evaluation of sequential radiograms allows to understand the evolution of any pathological alterations and to quantify their severity [1,2].
However, CXR implies radiation exposure for patients and the availability of radiologists and technicians for the execution and reporting. Thus, the availability of a more feasible alternative represents an unmet need in clinical practice.
Diagnosis of pneumothorax (PTX) with ultrasonography (US) was first reported in 1986 by Rantanen. Recently, many clinical studies have shown US is useful for the diagnosis of different abnormalities involving pleura and lung such as pleural effusion, alveolar interstitial syndrome, and PTX. In addition, US is characterized by a high reproducibility, sensitivity and specificity [3]. Chest US (CUS) is currently already widely used to detect PTX

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Correspondence to: Getano Messina (e-mail: adamessina@virgilio.it gaetana.messina@unicampania.it)

in intensive care unit (ICU) patients, but there are no data regarding its use for the follow-up of lung expansion after lung resection. We aimed to evaluate the accuracy of CUS over traditional CXR to confirm lung expansion after lobectomy and to guide the timing of the chest drainage removal [4].

Materials and Methods

Study population and statistical analysis

We performed an observational single-center study in patients undergoing lobectomy for lung cancer [5]. Postoperative lung expansion were daily assessed by both CUS and CXR until the chest drainage was removed, the median time to chest tube removal was 3 days.
Patients with subcutaneous emphysema were excluded considering that pulmonary air is an obstacle to US examination and those undergoing a pneumonectomy, who have always had a pneumothorax, were excluded.
Patients were examined in a supine position or semirecumbent position. The ultrasound probe was positioned at 3 so-called 'blue points' as proposed by Lichtenstein[6] >3 cm [7]. Lung ultrasound, in included patients, was performed by a blinded study investigator in addition to routine chest X-rays.
No modification of the standard patients' care was needed to conduct the study. All patients gave a written informed consent for the procedure, and they were aware that all their data could be used anonymously for scientific purpose. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV) of CUS and CXR were compared with Mc Nemar test. All tests were considered statistically significant with P values ≤0.05.

Ultrasound Parameters

CUS was performed with intercostal (the probe is placed in the intercostal space), transverse and longitudinal scans with various types of probes to recognize any possible findings: low frequency (2–5 megahertz [MHz]) curvilinear probe, high frequency (5–10 MHz) linear probe and sector probe (2-5 MHz). The ultrasound probe was positioned at 3 so-called 'blue points' as suggested by Lichtenstein[6] >3 cm [7].
Considering that thoracic US is very dynamic, an easily transportable device was preferred. US examination was conducted with a systematic approach by one independent operator, along the parasternal, hemiclavicular, axillary, interscapular and paravertebral lines (Fig. 1); supra-clavicular scans were also used for the study of pulmonary apices, with a top-down direction (Fig. 2). Decubitus and position of the patient were modified, as allowed according clinical conditions, in order to maximum widen intercostal spaces [8].

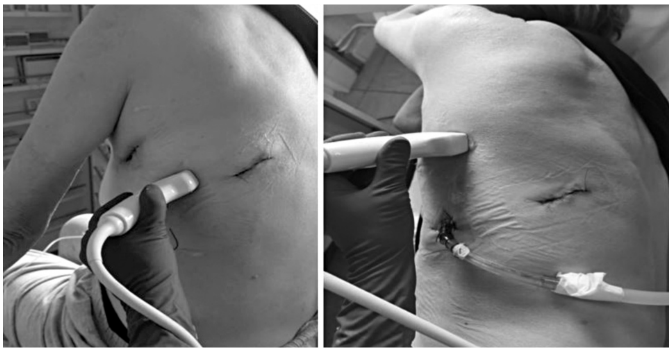


Fig. 1: CUS performed in sitting patient's position (intercostal) and supine (basal pleura diaphragm). All scans were performed exploring the entire chest anteriorly, laterally and posteriorly, along parasternal, mid-clavicular, anterior, posterior and paraspinal axillary lines. CUS: chest ultrasound.

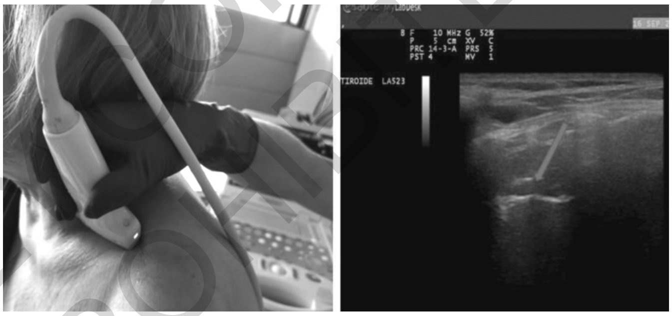


Fig. 2: CUS exploration of the re-expansion of lung apex through supraclavicular approach. CUS: chest ultrasound.

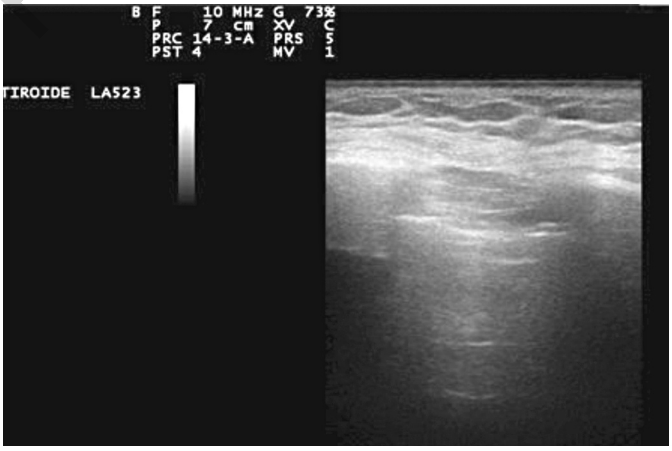


Fig. 3: CUS examination showing absence of lung sliding, absence of B-lines and absence of lung pulse, diagnostic for PTX. CUS: chest ultrasound; PTX; pneumothorax.

As wound dressings were not removed, if necessary probe position was adapted. In case of pathological findings, the ultrasound examination was extended.
The pleural line is the basic structure that should be identified in the image of chest US, it is obtained when the scanning takes place orthogonally to the pleurical plane, furthermore the reflection assumes the connota-

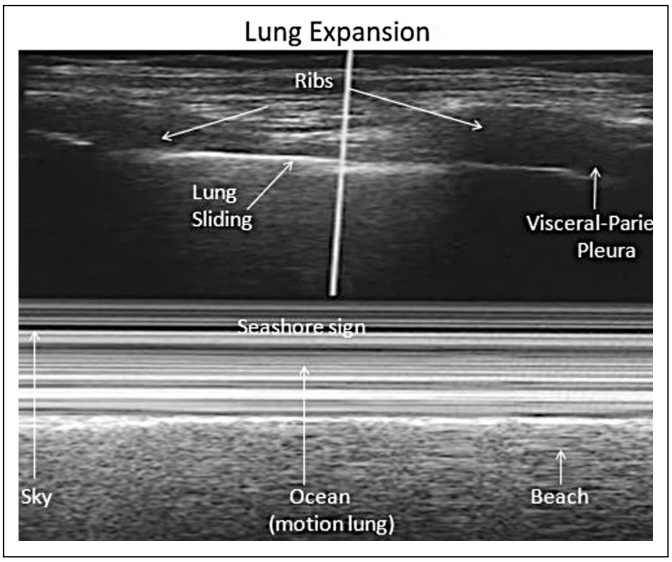


Fig. 4: Seashore sign. Lung sliding identified at pleural line of the normal lung shows a cyclic movement between visceral and parietal pleura.

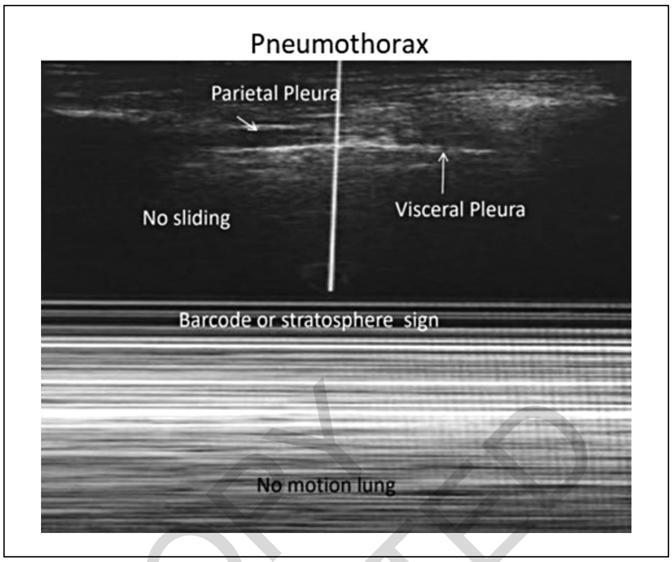


Fig. 5: CUS signs of PTX. Lung sliding is absent, the pelural line is static during respiration. Parallel lines that look like waves in M-mode (Barcode or stratosphere sign). CUS: chest ultrasound; PTX; pneumothorax.

tion of almost perfect specularity; it is a mixed artefactual image of reverberations of the pleural plane and of mirror effects [9] It is reasonable to state that an echo-mirrored lung is a lung in the range of normal or hyper-expanded respiratory inflation, but not deflated in a non physiological manner and with intertitial pathology, the pleural plane showing a massive reflection is well understood in terms of ultrasonography and so are the artifacts that appear. The jump in acoustic impedance between fabrics or gels and air is the basis of a massive acoustic reflection when the ultrasound with its characteristic wavelength affects a much larger target size.

US diagnosis of PTX was based on four main signs: abolition of lung sliding or a consistent stratosphere sign [10], presence of A-lines and absence of B-lines, the lung point, and absence lung pulse (Fig. 3, Fig. 4). The lung sliding identifies when the pleural line of the normal lung shows a cyclic movement between the visceral and parietal pleura with spontaneous respiration [11]. It is considered the basic sign needed to identify when performing CUS.

Since the structure above the pleural line is static during respiration, it produces parallel lines that look like waves in M-mode (e.g., the horizontal line represents time and static structure produces parallel lines). This cyclic movement produces sand-like appearance (also called *seashore sign*) that represents a normal CUS finding (Fig. 5) [12].

Besides the lung sliding, the most common CUS artefacts are A-lines and B-lines. A-lines are horizontal artifactual repetitions of the pleura line. A-line can be found in PTX when lung sliding is absent. B-lines are vertical lines, perpendicular to the pleural line that represents fluid accumulation in the alveoli. Typically, B-lines can be viewed with multi-beam function switched off. The B-line is also known as *comet-tail artefact* which is formed by repetitive reflections of the ultrasound wave arising from the pleural line [13-15].

B-lines are characterized by a long, laser-like appearance that never fades at distal images. B-lines can be typically found in interstitial syndrome and occasionally in dependent regions of normal lung. In PTX, B-lines are abolished (Fig. 3). In conditions with reduced movement between visceral and parietal pleura, lung pulse can be employed to rule out PTX (Fig. 4) [16,17].

The surgeons examines documented 'pneumothorax', 'no pneumothorax' or 'uncertain finding'. In the case of incomplete pneumothorax, the lung point was recorded if possible.

Clinical signs indicating a pneumothorax were the detection of a positive lung point or a consistent stratosphere sign with an absence of lung pulse, B-lines, I-lines or consolidations [18].

The median time between ultrasound and X-ray examinations was 35 min. All X-rays were taken in an upright position. The median duration of sonographic examination was 183 s.

The ultrasound classification of a pneumothorax as small, medium or large by locating the lung point at the anterior, middle or posterior axillary line [19], respectively, correlated weakly with the corresponding pneumothorax size in X-ray.

Lung sliding was the most useful ultrasound sign to rule-out pneumothorax, followed by lung pulse, which was most commonly used in other trials.

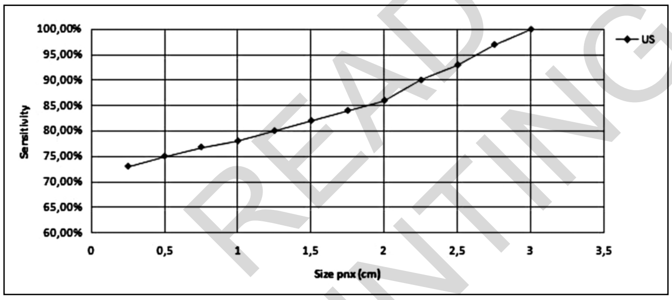
Results

Between January 2018 to May 2021, 157 patients undergoing lung resection [20] (96 males and 61 females) were included in the study, for a total of 525 pairs of examination (CUS and CXR). 47/157 (30%) patients presented pneumothorax due to lack of complete lung expansion during post-operative follow-up. Of these, 41,36/47 (88%) were detected by CXR and CUS; 5,64/47 (12%) by CUS. The sensitivity, specificity, PPV and NPV of CUS and CXR were, respectively: 86% vs. 98% (p=0.002); 100% vs. 100% (p=1.0); 94% vs. 75% (p=0.231) and 94% vs. 99% (p=0.7) (Table I).
Sensitivity of ultrasound increased in accordance with the pneumothorax size. Sensitivity was 78%, 86% and 100% for pneumothoraces with an apex-to-cupula distance of 1, 2 and 3 cm, respectively. (Table II)
However, the therapeutic agreement between ultrasound- and X-ray-based clinical decisions was 97%.

TABLE I - *Comparison between CUS and CXR.*

Sensitivity	Specifivity	PPV	NPV
CUS 86%	CUS 100%	CUS 94%	CUS 94%
CXR 98%	CXR 100%	CXR 75%	CXR 99%

TABLE II - *Sensitivity of ultrasound increased in accordance with the pneumothorax size. Sensitivity was 78%, 86% and 100% for pneumothorax with an apex-to-cupula distance of 1, 2 and 3 cm, respectively.*



Discussion

US has many advantages; it allows a rapid two-dimensional representation of organs otherwise difficult to represent without the use of advanced techniques. It does not use ionizing radiations and can be used practically anywhere with relatively low costs [21].
Ultrasound surgeons are independent of other medical personnel and may combine the findings of clinical examination and ultrasonography to improve diagnostic accuracy. However, ultrasound requires training and profound knowledge of underlying physical and physiological principles.
Utrasound shows images but also analyzes functions for the real time nature of its representations and for the possibility of exploiting the Doppler effect. Recently, diagnostic US has reached a surprising degree of improvement, however, its use for exploration of the lungs is still under evaluation. In addition, we still consider CUS as *artifactual ultrasound*, that is different from *classical* anatomical or functional US.
Indeed, CUS is the analysis of the artifacts that originate from the ventilated lung that cannot be associated to morphological findings. Therefore, when a lung is insulated by transthoracic way, the acoustic energy hits a parieto-pulmonary interface with a very high acoustic impedance gradient. The almost exclusive interaction mechanism is represented by a massive reflection of ultrasound. If the scan takes place orthogonally to the pleural plane, the reflection takes on a connotation of almost perfect specularity. The image that would derive with any type of probe is acquired is a mixed artifactual image of reverberations of the pleural plane and mirror effect. It is reasonable to say that a lung specular to the echo is a lung in the range of normal respiratory inflation or hyper-expanded, but not deflated in a non-physiological way with interstitial pathology. The pleural plane showing massive reflection is well understood in terms of ultrasonography and the artifacts that appear are also clear.
For certain pathologies of the chest (as PTX) many data from the literature confirm a better performance of the CUS compared with CXR only. These data underline the role of CUS especially during PTX monitoring or conservative, operative treatment or for the study of the residual pleural cavity after lung resection surgery. The evaluation of post-surgical chest imaging includes the systematic analysis of the aspect of the surgical space, the diaphragm of the residual lung, the position of the mediastinum, the analysis of the contralateral lung and the location of the thoracic drainage tubes and the re-expansion pulmonary. Elasticity is one of the characteristics of the lung, which if intelligently exploited can be used to occupy the space that the removed lung lobe has left. This allows the discharged patient to have more lung volume available for his own physiological needs. Ultrasound shows high values of sensitivity towards pneumothorax with respect to chest X-ray [22], especially towards pnmeumothorax, when studied in a supine patient; it allows the collection of more information thanks to the exploration of the anterior, lateral and posterior regions searching for lung points. In case of right or left upper lobectomy, ultrasound parameters should be searched, above the clavicle, in the infraclavicular region and posteriorly in the paraspinal region. The scapula covers part of the upper and lower lobes. In case of right or left lower lobectomy the ultrasound parameters should be sought with interscapolovertebral scans and below the apex of the scapula.
A dedicated radiologist, who was blinded to the results

of ultrasound examinations, evaluated the postoperative chest x-ray and a single trained surgeon who was blinded to the results of chest x-ray performed chest ultrasound, they relevant pneumothorax by an apex-to-cupula distance.

Conclusions

CUS is a method immediately available even at the bedside of the patient [23,24] with speed of execution, without the patient needing to maintain his posture for a long time and characterized by the possibility of execution even during the physical examination. In addition, it is easy to learn technique even for inexperienced operators, and interpretation of immediate results based on the clinical questions [25]. CUS is a valuable tool for checking post-lobectomy lung expansion. Its routine use could reduce the need for CXR and thus decrease the health cost and radiation exposure. Further studies are encouraged.

Riassunto

L'ecografia del torace è ampiamente usata per riscontrare lo pneumotorace, ma non vi sono dati sui controlli della successiva riespansione del polmone dopo interventi di resezione.
Abbiamo fatto uno studio osservazionale unicentrico della nostra casistica raccolta dal gennaio 2018 a maggio 2019 dopo lobectomia, con controllo quotidiano mediante l'ecografia toracica e radiografie del torace fino alla rimozione del drenaggio pleurico.
La sensibilità, specificità, PPV, NPV dell'ecografia e della radiografia del torace sono state rispettivamente 86% vs. 98% (p = 0.002); 100% vs. 100% (p = 1.0); 100% vs. 100% (p = 1.0); 94% vs. 75% (p = 0.231); and 94% vs. 99% (p = 0.7).
In coclusione l'ecografia risulta essere un metodo affidabile anche dei pazienti a letto, ed una tecnica di facile apprendimento anche per operatori poco esperti, quindi valido per i controlli dell'espansione polmonare dopo lobectomia, riducendo la necessità dell'uso delle radiografie ripetute del torace.

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