Sensitivity of lung ultrasound for the detection of pneumothorax one day after pulmonary resection – a prospective observational study

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Received: 25 August 2020 / Accepted: 1 September 2020 / Published online: 3 November 2020
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Summary

Background Chest X-ray (CXR) after thoracic surgery contributes to patient discomfort and costs and is of limited therapeutic value. Lung ultrasound (LU) for pneumothorax may be an alternative to CXR, but diagnostic accuracy data are heterogeneous and biased by insufficient sonographic technique and patient selection. Reported sensitivities range from 0.21 to 1.0. We evaluated the sensitivity of LU on the first day after thoracic surgery under routine conditions.

Methods We performed a prospective observational study (trial-ID DRKS00014557). Consecutive patients undergoing lung resection received standardized LU in addition to routine CXR on the first postoperative day. Ultrasound examiner and radiologist were blinded to corresponding X-ray and ultrasound findings. CXR was used as reference to determine diagnostic test performance of ultrasound. The conformity of sonography- and routine-based therapeutic decisions was evaluated.

Results A total of 68 patients were examined. The mean duration of ultrasound was 145 ± 64 s. CXR identified 23 patients with pneumothorax with a mean apex-to-cupola size of 1.5 ± 1.0 cm. Ultrasound de-

tected 18 patients with pneumothorax. The computed sensitivity of LU was 0.48 (95% confidence interval [0.36; 0.60]). Specificity was between 0.81 and 1.0, the negative predictive value 0.76 [0.66; 0.86]. The sensitivity of CXR was 0.56 [0.44; 0.68]. Air leakage via chest tube correlated weakly with CXR (spearman's $\rho=0.26$) and moderately with LU ($\rho=0.43$). The conformity between sonographically based recommendations and the actual therapy based on routine diagnostics was 96%.

Conclusions Sensitivity of ultrasound for pneumothorax detection nearly reached CXR and resulted in equally safe patient management. Our data can serve as a pilot study for upcoming larger-scaled controlled trials.

Keywords Diagnostic accuracy · Sensitivity · Lung ultrasound · Chest X-ray · Pneumothorax

Main novel aspects

Lung ultrasound under real-life conditions is nearly as sensitive for pneumothorax one day after thoracic surgery as chest X-ray and results in equally safe patient management.

Introduction

Thoracic surgery is usually followed by numerous chest X-rays (CXR). They are associated with high logistic efforts and patient discomfort, are binding multiple personnel resources (transport, technical assistants, radiologists), are costly, and have very limited diagnostic and therapeutic value [1]. Nonetheless, they represent the clinical standard, and there are no recommendations on the appropriate use of chest X-rays in the postoperative course [2]. In the last two decades, lung ultrasound (LU) has been increas-

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Table 1 All known studies on lung ultrasound (LUS) sensitivity compared to chest X-ray (CXR) after noncardiac thoracic surgery and their main characteristics

Study, first author, year	Number of patients	Time of LUS examination	Sonographic definition of pneumothorax	Patient's position	Sensitivity of LUS for pneumothorax	Prevalence of pneumothorax (%)
Goudie 2012 [6]	120	Several times after surgery, on average 2.4 days	Absence of lung sliding and comet tails	Sitting or at least 45° semi-supine	0.21	11
Patella 2018 [7]	50	After chest tube removal	Absence of lung sliding and comet tails	Sitting	1.00	30
Smargiassi 2019 [8]	24	Within 48 h after surgery	Detection of lung point, absence of lung sliding, absence of interstitial syndrome	Sitting and lying	1.00	83

Fig. 1 Forest plot of the previously published sensitivity and specificity of lung ultrasound after noncardiac thoracic surgery. *TP* true positive, *FP* false positive, *FN* false negative,

TN true negative, *CI* confidence interval. Note that in the study of Goudie et al. [6] each hemithorax is counted separately, so that each patient is counted twice

ingly used to identify pneumothoraces and other pulmonary pathologies, exhibiting test parameters, which are superior to CXR and compete with computed tomography (CT) (sensitivity/specificity LU 68–91%/97–100%, CXR 28–76%/100%, [3–5]). However, these findings arise from traumatology, spontaneous pneumothorax, and ventilated intensive care patients who differ from thoracic surgery patients. Postoperative conditions, such as reduced lung volume, diaphragm displacement, mediastinal shift, and adhesions can alter the distribution of extrapulmonary air within the chest and impair the sonographic accessibility. Hence, data on the accuracy of lung ultrasound in postoperative patients is limited. Reported cohorts are heterogeneous regarding type of surgery, patient selection, prevalence of a postoperative pneumothorax, positioning of the ultrasound probe, and time of the ultrasound examination (Table 1). Thus, reported sensitivities of lung ultrasound vary widely from 21 to 100% (Fig. 1; [6–8]). There is a need for further trials on postsurgical patients under well-defined conditions. We conducted a prospective trial on patients with pulmonary surgery, as these patients have the highest risk for a postoperative pneumothorax, using rigorous real-life conditions.

Methods

Study design

We performed a prospective observational study, approved by the ethics committee of University Witten/Herdecke, registered at the German Clinical Trials Registry. The study was funded by the internal grant program of the University Witten/Herdecke (project IFF2018-053). Patients provided consent prior to participation. The primary endpoint was the detection

of a postoperative pneumothorax through lung ultrasound (LU) in comparison to CXR. Patients were examined on the first postoperative day and after chest tube removal, and the diagnostic accuracy had to be analysed separately for mathematical reasons as the reference tests differed: CXR was shot mostly in supine position on the first operative day (impaired sensitivity of CXR), but exclusively upright in the later course after chest tube removal. We report the results of the early postoperative group.

Only surgeries with high potential for postoperative pneumothorax were considered: lung resections except for pneumonectomy, chest-wall resections, and decortication except for sole parietal pleurectomy. The only exclusion criteria were underage patients (<18 years of age), refusal, and patients who were not legally competent. Patients with conditions known to impair sonographic examination of the chest, such as COPD (chronic obstructive pulmonary disease), obesity, postoperative subcutaneous emphysema, fibrosis, were explicitly *included*.

Diagnostic imaging

Patients received CXR as part of the clinical routine the day after surgery. In immobile patients, X-ray was obtained in supine position and anterior-posterior direction. Mobile patients were examined in an upright position and posterior-anterior direction. The X-ray images were analysed by a dedicated radiologist after the discharge of the patient.

A thoracic surgeon with extensive experience in general sonography and special training in thoracic sonography performed lung ultrasound the same day, using a standardized protocol with examination sites on the upper, middle anterior and lateral chest-wall (“BLUE points”, [9]). The patient’s position was semi-

Fig. 2 Important sonographic signs; for detailed explanations, please read [10, 11]. **a** Lung sliding, represented by the seashore sign in M-mode, rules out pneumothorax. Lung sliding is abolished in pneumothorax, but also in severe emphysema, fibrosis, pleural adhesions, for instance; therefore, abolished lung sliding is not diagnostic for pneumothorax. **b** Lung pulse, pulse synchronous vertical lines which end with the pleural line, rules out pneumothorax. **c** Two B-lines, rising from interstitial fluids at the pleural line, sharp, laser-like, rule out pneumothorax. **d** Multiple A-lines, i.e. horizontal repetitions of the pleural line. This sign occurs in healthy subjects as well as in lung emphysema and pneumothorax. Thus, A-lines must be interpreted only in combination with further signs

supine (about 30° elevation). Wound dressings, electrocardiogram electrodes, etc. were not removed, the probe position was adapted if necessary. Sonography probes with 2–5 MHz curved array and 6–13 MHz linear array were used. The sonographer and the radiologist were blinded for the corresponding findings.

For the detection of pneumothorax, we used previously reported technique and definitions [10, 11], which had been evaluated against computed tomography by Daniel Lichtenstein. A pneumothorax was diagnosed only if there was an absence of lung sliding combined with (a) the presence of a lung point or (b) the complete absence of lung-pulse, B-lines, and lung consolidations. Abolishment of lung sliding alone was not sufficient to identify a pneumothorax. The presence of lung sliding, lung pulse, B-lines, or lung consolidation safely excludes a pneumothorax (Fig. 2). We rigorously distinguished these signs from other mimicking artifacts like E-lines which arise from subcutaneous emphysema or artifacts from muscular movements of the chest wall. Inconclusive sonographic findings were excluded from diagnostic accuracy analysis because they would imply further radiologic imaging in real-life.

The sonographic examiner noted a therapeutic recommendation in the case report form (keep chest tube, remove chest tube, place a new chest tube, other). Treating physicians made their therapeutic decisions based on routine data, i.e. clinical examination, routine X-ray, lab findings, being unaware of the sonographic results. After discharge, designated investigators compared the sonographic recommendation and the actual treatment to determine the “therapeutic conformity”.

Air leakage via chest tube was recorded and correlation with imaging findings was computed.

Statistics

The study design is a diagnostic accuracy test with an imperfect, but highly specific (100%, [4]) reference test, i.e. CXR. We computed sensitivity (sens), specificity (spec), and negative predictive value (NPV) of ultrasound for pneumothorax according to the following formulae [12]:

If

		CXR	
		Positive	Negative
LU	Positive	a	c
	Negative	b	d

then

$$\text{sens} = \frac{a}{a+b}; \text{spec} \geq \frac{d}{c+d}; \text{NPV} \leq \frac{d}{b+d}$$

All data were entered pseudonymously into a web-based electronic data capture system which is fully compliant with the principles of good clinical practice and all relevant standards of data handling and protection [13]. Statistical analysis was performed using the software “R” (Version 3.5.1; R Foundation, Vienna, Austria) [14]. Data are presented as median with interquartile range if they are nonnormally distributed, as mean ± standard deviation in normally distributed data, and as absolute and relative frequencies. Spearman's rho was calculated to express the correlation of ordinal with continuous data.

Results

A total of 68 consecutive patients were included; their basic characteristics are given in Table 2.

The median time between ultrasound and X-ray was 80 min (interquartile range 42.5, 101.75). Most X-rays (91%) were shot in supine position. The mean duration of sonographic examination was 145 ± 64 s.

Using ultrasound, a pneumothorax was identified in 18 patients and ruled-out in 46 patients. In 4 patients, diagnosis was not possible due to extensive soft tissue emphysema: 2 patients were CXR-negative, 2 patients were CXR-positive for a small pneumothorax (1.4 and 0.6 cm, respectively). The signs by which a pneumothorax was detected or ruled-out are presented in Table 3.

Using X-ray, 23 pneumothoraces were found; the mean size was 1.5 ± 1.0 cm.

The distribution of sonographic and radiologic findings of pneumothorax after removing the chest tube is presented in Table 4. The observed prevalence of a pneumothorax was 0.34.

The diagnostic test parameters are

- $\text{sens}_{\text{LU}} = 0.48$, 95% confidence interval [0.36; 0.60],
- $\text{spec}_{\text{LU}} \geq 0.81$ and ≤ 1.0 ,
- $\text{NPV}_{\text{LU}} = 0.76$ [0.66; 0.86],
- $\text{sens}_{\text{CXR}} = 0.56$ [0.44; 0.68].

A therapeutic conformity was observed in 96% of cases. In three cases, the sonographic recommendation was to remove the chest tube, whereas it was actually retained. Of these 3 patients, two had a small, clinically irrelevant pneumothorax of 1.0 cm and 1.8 cm in CXR, respectively.

Table 2 Patients' baseline characteristics

<i>Sex</i>	
Female	28 (41%)
Male	40 (59%)
<i>Age, years</i>	64.4 ± 8.7
<i>Body mass index, kg/m²</i>	25.8 ± 4.4
<i>Lung function</i>	
Preoperative Tiffeneau test	0.79 ± 0.17
Diffusive capacity of the lung (DLCO/AV), %	66 ± 48
Ipsilateral pretreatment (radiation and/or intrathoracic surgery)	12 (18%)
<i>Operation side</i>	
Left	28 (41%)
Right	40 (59%)
<i>Access</i>	
Open	19 (28%)
VATS	46 (68%)
Conversion	3 (4%)
<i>Resection type</i>	
Lobectomy, bilobectomy	31 (46%)
Segmentectomy, multisegmentectomy	14 (21%)
Atypical resection	15 (22%)
Extended lung resection (with chest wall or diaphragm)	5 (7%)
Chest wall resection	2 (3%)
Bronchial resection	1 (1%)
<i>Operated lobe</i>	
Upper lobe	42
Middle lobe	4
Lower lobe	27
<i>Operation time, minutes</i>	115 ± 50
VATS video-assisted thoracoscopic surgery	

Table 3 Sonographic findings to confirm or rule-out pneumothorax in the study group. Multiple signs could occur simultaneously

<i>Detection of pneumothorax: 18</i>	
Stratosphere sign without rule-out signs	6/18 (33%)
Lung-point	14/18 (78%)
<i>Ruling out pneumothorax: 46</i>	
Lung pulse	42/46 (91%)
Lung sliding	32/46 (70%)
B-lines	11/46 (24%)
Lung consolidations	4/46 (9%)

Table 4 Cross-tabulation of pneumothorax findings

		X-ray (reference test)	
		Positive	Negative
Ultrasound	Positive	10	8
	Negative	11	35

On the first postoperative day, 30% of patients had air leakage via the chest tube. Air leakage was present in 78% of sonographically identified pneumothoraces, but only in 48% of radiologically identified pneumothoraces. There was no air leakage in patients who were negative for pneumothorax in both ultrasound and X-ray. Air leakage correlated weakly with X-ray (spearman's $\rho=0.26$) and moderately with ultrasound (spearman's $\rho=0.43$).

Discussion

To our knowledge, this is the first study on the postoperative use of LU for pneumothorax, which was performed on unselected patients under real-life conditions and used a rigorous sonographic methodology.

Nonetheless, we found a sensitivity of LU for postoperative pneumothorax which is in between the previously reported data in noncardiac thoracic surgery, whereas the sensitivity of CXR was in the known range. The sensitivity of LU was only slightly lower than that of CXR (0.48 vs. 0.56). Similar to previous studies [6, 7], our population contained only operations with a considerable risk for postoperative pneumothorax. However, Goudie et al. excluded unconscious and physically weak patients because patients were examined in sitting position, and counted each hemithorax individually in the statistical analysis, which mathematically explains their low prevalence of pneumothorax (Table 1). They also excluded patients with severe subcutaneous emphysema or wound dressings. Although we did not have these restrictions in our study, we found a better sensitivity.

The trial of Patella et al., which reported excellent test parameters for LU, had very selective inclusion criteria [15] and another time of examination (after chest tube removal). The study of Smargiassi et al., who also demonstrated a high sensitivity of LU and an unusually high prevalence of pneumothorax (83%), did not declare the type of surgery [8]. Thus, the reasons for the variation in the performance of LU remain unclear.

Apart from patient selection criteria, the sonographic technique and terminology may be major factors contributing to varying test results. Several LU studies (e.g. [6, 7, 16]) consider the absence of lung sliding and comet tails as a pneumothorax, which may overestimate the prevalence of pneumothorax. However, the absence of lung sliding is also found in reduced lung compliance, fibrosis, bullous emphysema, and is therefore not specific [15, 17]. "Comet tails" is a collective term that includes some artifacts which rule out a pneumothorax (B-lines, I-lines) and some which do not (e.g. E-lines, Z-lines) [11]. So if a report uses the term "comet tail", the reader cannot be sure if a reliable method was used [18]. The validity increases when additional patterns are sought, like lung-pulse and consolidations.

Our study, like all others, is limited by the lack of a perfect reference test, i.e. CT. Ethically, it is unacceptable to perform a CT to just assess the presence of postoperative pneumothorax. The sensitivity of X-ray is limited, as most patients are examined in supine position on the first day after surgery in daily routine. However, to determine the role of ultrasound as a potential diagnostic alternative, LU must compete with the accuracy of CXR under routine conditions rather than with CT.

Given the lack of CT findings, the pneumothorax size could not be reliably determined. A valid (semi)quantification is not possible with CXR in supine position. Hence, it is unclear whether sonographically false-negative pneumothoraces were of relevant size or not. Nonetheless, the therapeutic conformity between sonographic and conventional assessment was very high, i.e. that the patient would have been treated equally by either LU or CXR. It seems that a negative LU is sufficiently reliable in excluding a pneumothorax, which is represented by the decent negative predictive value in this study. For the clinical question of a relevant pneumothorax, the NPV of LU is more important than its sensitivity. Considering that less than 1% of postoperative CXR have a therapeutic consequence [1], it is the task of future studies to investigate the clinical relevance of LU in a large-scaled population, rather than just sensitivity.

To represent the actual clinical routine, we decided to avoid restrictive patient selection. Inherently, this could have resulted in lower sensitivity, due to the inclusion of patients with impaired sonographic exam conditions, such as obesity or COPD.

Our results are relevant particularly for, but not limited to pulmonary surgery. Cardiac and oesophageal surgery use chest tubes as well, and there are efforts in these areas to reduce radiation according to the ALARA principle (as low as reasonably achievable), too [19, 20]. However, since the postoperative pneumothorax is a distinct entity pathophysiologically different from a spontaneous or traumatic pneumothorax, the experiences from (a) nonsurgical trials or (b) surgical trials with artificial, "academic" conditions should not be applied carelessly to routine surgical patients. Instead, we need large-scale studies which respect the particular anatomy and physiology of the postoperative chest. Our data can serve for planning the sample size of these future studies.

In conclusion, we found a moderate sensitivity of LU for postoperative pneumothorax in an unselected routine patient population, nearly reaching the sensitivity of CXR. Although the sensitivity of LU was slightly lower than CXR, therapeutic decisions based on LU would have resulted in equally safe patient treatment. For further controlled studies, it may be reasonable to introduce a stepwise approach with ultrasound followed by CXR on demand in the case of inconsistent findings or poor exam conditions. This

approach could reduce the use of CXR after thoracic (pulmonary, cardiac, or oesophageal) surgery.

Funding Open Access funding enabled and organized by Projekt DEAL. This research received funding from the internal grant program (project IFF2018-053) of the Faculty of Health at Witten/Herdecke University, Germany.

Conflict of interest T. Galetin, M. Schieren, B. Marks, J. De-fosse and E. Stoelben declare that they have no competing interests.

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