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Speckle tracking quantification of lung sliding for the diagnosis of pneumothorax: a multicentric observational study

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Abstract

Purpose: Lung ultrasound is used for the diagnosis of pneumothorax, based on lung sliding abolition which is a qualitative and operator-dependent assessment. Speckle tracking allows the quantification of structure deformation over time by analysing acoustic markers. We aimed to test the ability of speckle tracking technology to quantify lung sliding in a selected cohort of patients and to observe how the technology may help the process of pneumothorax diagnosis.

Methods: We performed retrospectively a pleural speckle tracking analysis on ultrasound loops from patients with pneumothorax. We compared the values measured by two observers from pneumothorax side with contralateral normal lung side. The receiver operating characteristic (ROC) curve was constructed to evaluate the performance of maximal pleural strain to detect the lung sliding abolition. Diagnosis performance and time to diagnosis between B-Mode and speckle tracking technology were compared from a third blinded observer.

Results: We analysed 104 ultrasound loops from 52 patients. The area under the ROC curve of the maximal pleural strain value to identify lung sliding abolition was 1.00 [95%CI 1.00; 1.00]. Specificity was 100% [95%CI 93%; 100%] and sensitivity was 100% [95%CI 93%; 100%] with the best cut-off of 4%. Over 104 ultrasound loops, the blinded observer made two errors with B-Mode and none with speckle tracking. The median diagnosis time was 3 [2–5] seconds for B-Mode versus 2 [1–2] seconds for speckle tracking ($p=0.001$).

Conclusion: Speckle tracking technology allows lung sliding quantification and detection of lung sliding abolition in case of pneumothorax on selected ultrasound loops.

Keywords: Point-of-care lung ultrasound, Pneumothorax, Speckle tracking, Lung sliding

Introduction

Pneumothorax may become a serious condition with a potential evolution to cardiac arrest. Sometimes, its

immediate diagnosis and treatment is crucial to prevent a death [1]. Up to 70% of traumatic pneumothorax is missed using a chest X-ray (CXR) [2]. Point-of-care lung ultrasound (LUS) is immediately available at the bedside for emergency physicians, intensivists, anaesthesiologists and pneumologists [3–6]. It is widely used for the early diagnosis of pneumothorax secondary to trauma and invasive procedures and for primary pneumothorax in emergency and critical care [3–5, 7, 8]. Several studies have shown that LUS is more accurate than CXR for the diagnosis of pneumothorax, with higher sensitivity and similar high specificity [9]. Consequently, some authors

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have abandoned the use of CXR in cases of stable trauma patients or normal lung ultrasound [10–12].

However, although LUS superiority to CXR in an emergency setting has been well shown, its sensitivity for the diagnosis of pneumothorax is still considered variable, as it depends on the operator's skill and the technique used [13]. However, specificity and positive values are also variable depending on operator's performance and some cases of false positives have been described with conditions mimicking lung sliding abolishment [12, 14–16].

The main LUS sign in the diagnostic process for pneumothorax is respiratory lung sliding [10, 17, 18]. Evidence of lung sliding rules out pneumothorax below the probe, whereas its absence makes the diagnosis probable, depending on patient condition [18, 19]. However, the detection of lung sliding is purely qualitative, and with some inter-observer reliability it can be challenging, particularly when LUS is performed in difficult conditions [20]. Therefore, alternative qualitative methods have been tested, such as M-mode or lung sliding enhancement with colour or power Doppler [6, 21].

Speckle tracking technology allows the detection and tracking of anatomic structure deformation over time by analysing acoustic markers [22, 23]. This technology is used in cardiology for the quantification of myocardial strain. It also can be used for diaphragm thickening quantification [24–26]. We recently published a case report showing that its application on the pleura allowed quantification of lung sliding in a case of normal lung sliding and pneumothorax [27].

The first aim of our study was to compare the maximal longitudinal pleural strain values in patients with normal lung sliding with values obtained from abolished lung sliding side in a selected cohort of patients with pneumothorax. The second aim was to describe the reliability of the measurement between two independent observers: one senior physician (GD) and one resident (CC). The third aim was to observe how the values associated with information provided by speckle tracking may help the process of pneumothorax diagnosis. We speculated that lung sliding quantification is feasible using speckle tracking technology and may improve the diagnosis performance of lung sliding abolition compared with a standard B-mode ultra-sonographic examination.

Methods

The study was approved by the national ethics committee of the Société Française d'Anesthésie Réanimation (number CERAR-00010254-2019-038). We performed a retrospective analysis of LUS and computed tomography (CT) scan data collected prospectively in four units (two emergency departments and two intensive care units) of three university hospitals, between July 2018 and March 2019.

Take home message

To date, lung sliding detection is purely qualitative. Speckle tracking is the first technology allowing a quantification of lung sliding; it may open new perspectives in the detection of pneumothorax, alveolar stress or pleural diseases.

According to the French law, patient consent was not necessary due to the benign character of the study [28].

Screening, inclusion and exclusion criteria

Informatics register of diagnosis (using national coding tool) was consulted for the study period. All patients with a diagnosis of pneumothorax were considered eligible and screened.

All patients who had a LUS exam for pneumothorax recorded and stored in the ultrasound device with a CT scan confirming the diagnosis (considered as the gold standard) of unilateral pneumothorax were included. Patients with bilateral pneumothorax, absence of cardiac monitoring on ultrasound loops, ultrasound loops of less than 3 s or with acquisition performed by another observer than the four cited investigators were excluded.

Data collection

Ultrasonographic data were prospectively collected from all patients admitted with suspected pneumothorax during the study period. We then selected retrospectively all the LUS loops performed by specific investigators (GD, XB, LM, TM), who are trained senior residents with high experience in performing chest ultrasonographic evaluation. LUS examination was performed at admission according to the French guidelines, using a protocol already described in a previous study [12, 29]. The standard ultrasound protocol includes systematic cardiac monitoring and recording of ultrasound loops of at least 3 s of each ultrasonographic scan. Either the General Electric (GE) Vivid IQ or the GE Vivid S60 ultrasound systems (GE HealthCare, Chicago, Illinois, USA), with a linear probe of 7.5 MHz, were used for the evaluation of lung sliding. For each patient, two ultrasonographic windows were examined by the observer, corresponding to the anterior-inferior chest (4th/5th intercostal space on the medio-clavicular line) on both sides with patients in the supine position. Linear probe was placed in a longitudinal position to provide the "bat sign" and ensure good quality of ultrasound examination. LUS examination was systematically performed before the CT scan. The CT scan was performed at admission for all trauma patients or to confirm pneumothorax in other cases.

Study variables included age, sex, weight and height, the pneumothorax side, presence of a chest tube,

respiratory frequency and presence of spontaneous breathing or mechanical ventilation at the time of the ultrasound exam. In the patients with mechanical ventilation, the tidal volume was annotated.

Data analysis protocol

A full detailed protocol of data analysis is provided in supplemental protocol 1, supplemental data 1 and supplemental Fig. 1.

Statistical analysis

The receiver operating characteristic (ROC) curve was constructed to evaluate the discriminant performance of maximal longitudinal pleural strain to detect the lung sliding abolition. The best cut-off was defined using Youden's method, and accuracy measures (sensitivity, specificity, predictive values and likelihood ratios) were estimated with 95% confidence intervals (CIs) according to this cut-off [30].

Intra- and inter-observer agreements were evaluated by comparing measurements performed by senior physician (GD) and resident (CC), using the intra-class correlation coefficient. This analysis was performed on both normal lung sliding and abolished lung sliding measurements. Our junior investigator (4-year resident) received a training to apply speckle tracking analysis on five normal lung slidings and five pneumothorax ultrasound loops. The training adhered to the method presented in supplemental data.

Finally, diagnostic performance of the third independent observer to detect the presence or the absence of lung sliding was observed, was compared between the B-Mode and the speckle tracking technology using the Wilcoxon test for paired samples. Data were analysed by R software version 3.5.3 (R Core Team (2013); R: a language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria, URL <http://www.R-project.org/>). All tests were two sided. A p value < 0.05 was considered significant.

Results

During the study period, 661 patients were admitted for severe trauma or suspected spontaneous pneumothorax. Fifty-two patients were included in the study (Table 1). The flowchart is presented in Fig. 1. Ten patients were receiving mechanically controlled ventilation with sedation. One hundred four ultrasound loops were analysed (52 from pneumothorax side and 52 from normal lung sliding side). The mean value of the maximal longitudinal pleural strain was 1% (± 1) when applied to the abolished lung sliding side versus 46% (± 32) when applied to the lung sliding side ($p < 0.001$). The results are shown in Fig. 2. We found no differences between the 10 patients

receiving invasive mechanical ventilation and the 42 patients not receiving mechanical ventilation in the mean values of the maximal longitudinal pleural strain for abolished lung sliding side 1% (± 1) vs. 1% (± 1); $p = 0.9$ and lung sliding side 44% (± 29) vs 47% (± 33); $p = 0.8$.

The area under the ROC curve of the maximal longitudinal pleural strain value to identify pneumothorax was 1.00 [95% CI 1.00; 1.00]. To detect a pneumothorax loop, the specificity was 100% [95% CI 93%; 100%] and the sensitivity was 100% [95% CI 93%; 100%] when considering the best cut-off of the maximal longitudinal pleural strain of 4% (Fig. 3). The positive predictive value, negative predictive value, positive likelihood ratio and negative likelihood ratio were 100% [95% CI 93%; 100%], 100% [95% CI 93%; 100%], infinite and 0, respectively.

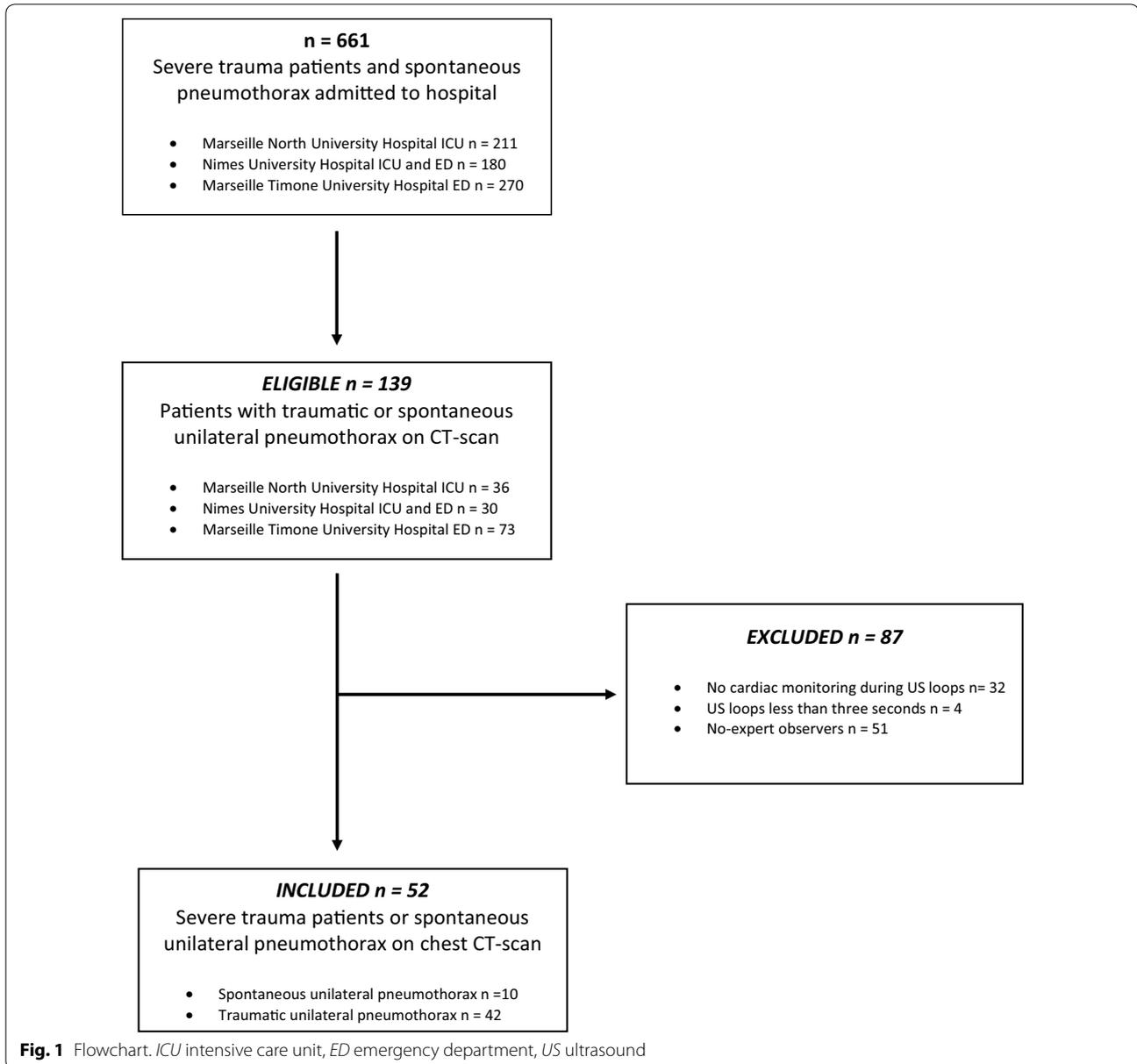
The analysis of the maximal longitudinal pleural strain in loops with normal sliding showed an intra-class correlation coefficient of 0.88 [95% CI 0.82; 0.94] (intra-observer) and 0.18 [95% CI 0.12; 0.26] (inter-observer). The analysis in the pneumothorax loops showed an intra-class correlation coefficient of 0.74 [95% CI 0.61; 0.82] (intra-observer) and 0.52 [95% CI 0.29; 0.70] (inter-observer). Individual intra-observer analysis is provided in Supplemental Table 1 showing no differences between senior physician (GD) and junior physician (CC).

After analysis of 52 loops with normal lung sliding and 52 with pneumothorax in B-Mode and speckle tracking (208 loops), the blinded observer found 102 correct diagnoses over 104 loops in B-Mode (sensitivity and specificity were 95% [95%CI 88%; 99%] and 100% [95%CI 92%; 100%], respectively) and no error with speckle tracking (sensitivity and specificity were 100% [95%CI 92%; 100%] and 100% [95%CI 92%; 100%], respectively).

Discussion

To our knowledge, this is the first study showing that it is possible to quantify lung sliding. A quantitative measurement of longitudinal pleural strain discriminated normal lung sliding and its abolition in patients with pneumothorax with excellent performance. This result is promising for future studies. Furthermore, when used in association with speckle tracking curves and real-time tracking, the longitudinal pleural strain value was faster to be evaluated and had a better diagnostic performance than classic B-Mode.

Lung sliding is the cornerstone of LUS examination [19]. It reflects the contact between the parietal and visceral pleura and ventilation of the lung at that probe position [1]. Indeed, lung sliding or any parenchymal sign such as B-lines confirms the transmission of ultrasounds through the visceral layer of the pleura and, therefore, rules out the presence of pneumothorax [10, 17]. However, the abolition of lung sliding is



not enough to confirm pneumothorax and lacks specificity, as it may be due to the absence of ventilation, commonly found in cases of selective ventilation or atelectasis. Differential diagnosis is enhanced not only by the combination with the other LUS signs (pulse, B-lines and lung point), but also by consideration of the clinical context [1, 17, 31, 32]. In some situations, the diagnosis workup for pneumothorax remains challenging [10]. In a meta-analysis of 17 studies, Staub et al. found that absences of lung sliding and B-lines were the most reported ultrasound signs of pneumothorax, with a sensitivity of 81% (95% CI 71; 88) and a specificity of 98% (95% CI 97; 99) [10]. The relatively low sensitivity

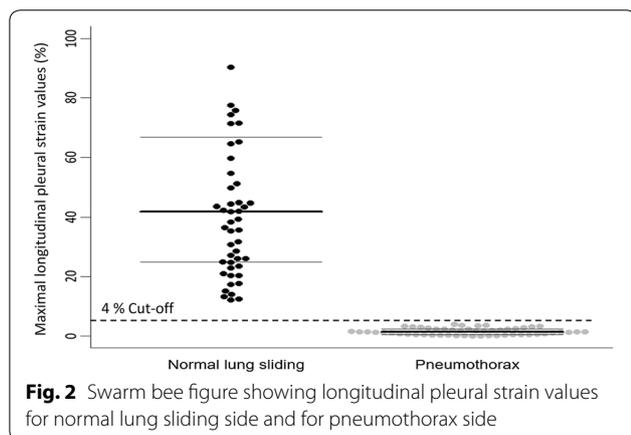
was due to the fact that evaluation of sliding is qualitative and dependent on the operator's skill and expertise [13]. Furthermore, false-negative cases with artefacts mimicking lung sliding in case of pneumothorax have been recently described making this diagnosis challenging despite its relative apparent ease [14–16].

Some studies have tested alternative methods to improve sensitivity by adding colour and power Doppler to the B-mode or using artificial intelligence to examine lung sliding [21, 33]. However, beyond their good performance, these tools still remain qualitative and did not show a superiority in clinical practice as compared to standard B-mode LUS [21].

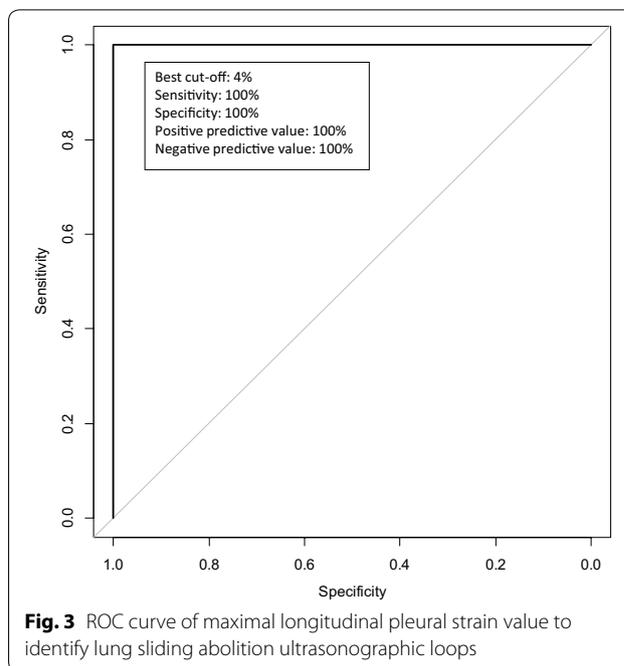
Table 1 Demographic and clinical characteristics of the study population

Patients (n = 52)	
Male sex	44 (85)
Age (years)	43 [27; 53]
Weight (kgs)	70 [62; 79]
Size (cms)	175 [170; 180]
Reason for admission	
Trauma	42 (81)
Spontaneous pneumothorax suspicion	10 (19)
SAPS II	30 [21; 50]
Pneumothorax features	
Right	25 (48)
Left	27 (52)
Complete	20 (39)
Anterior and/or antero-lateral	30 (58)
Lung contusion in other side	11 (27)
Mechanical ventilation patients	10 (19)
Tidal volume (ml)	450 [450; 490]
Tidal volume (ml/kgs of IBW)	5.9 [5.6; 6.2]
Respiratory rate per minute	24 [20; 26]

Values are n (%) or median [25th; 75th percentile]. Results have been rounded
SAPS II Simplified Acute Physiology Score, IBW ideal body weight



LUS enhanced by speckle tracking allows the application of a quantitative cut-off to diagnose lung sliding abolition. In our study, the maximal longitudinal pleural strain value was constantly lower than 4% in abolished lung sliding. This allows dichotomization of LUS examination for lung sliding. Furthermore, LUS speckle tracking combines real-time visual tracking of the lung sliding and a graphic visualization of the strain values of each segment (supplemental data 2 and 3). This multimodal analysis can provide profiles of lung sliding (presence, absence and lung point), which have previously been



described in a clinical case and shown in Fig. 4 (supplemental data 2 and 3) [27]. We also speculate that lung sliding quantification may become of great interest in the diagnosis of other lung diseases or in evaluation of invasive ventilation strategies during acute respiratory distress syndrome [34].

Our study has several limitations. First, the analysis was performed retrospectively on selected ultrasonographic loops. We used speckle tracking analysis in patients with a confirmed diagnosis of pneumothorax. Thus, we cannot conclude on the proper diagnostic performance of the technic. We did not assess patients with selective intubation, which is also associated with lung sliding abolition. Although the differential diagnosis can be made by detecting lung pulse in standard pleural ultrasound, future studies are needed to determine the ability of the multimodal speckle tracking analysis to differentiate cases of absence of sliding with or without lung pulse [32]. Our cohort was representative of the patients with pneumothorax (young and thin men) but validation studies are required before extrapolating this pleural assessment to a large cohort of patients, such as obese or comorbid patients. Moreover, the good quality of ultrasound loops was insured by high-trained operators. Hence, our findings may differ if the technic is handled by less experienced clinicians.

Second, with the available technology, the speckle tracking analysis cannot be performed in real time when the software does not recognize the shape of a ventricle or when a linear probe is used. This technology cannot

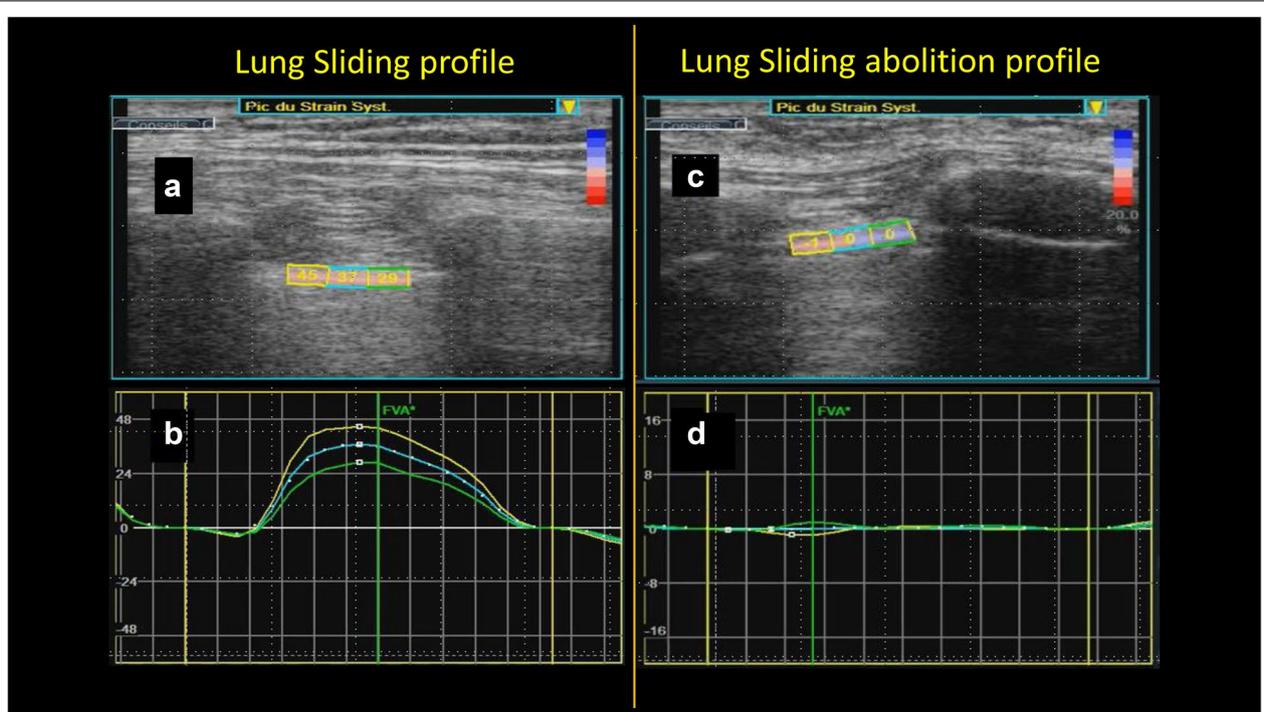


Fig. 4 Typical profiles of normal lung sliding and lung sliding abolition using speckle tracking analysis. **a** Maximal longitudinal pleural strain value of each segment of the region of interest for normal lung sliding. **b** The curves are representing strain over time of each segment for normal lung sliding. White squares correspond to maximal longitudinal strain values. The strain values vary during time due to pleural sliding induced by spontaneous breathing. **c** Maximal longitudinal pleural strain value of each segment of the region of interest in case of lung sliding abolition. The strain values remain low overtime. **d** Curves traducing strain over time of each segment in case of lung sliding abolition. White squares correspond to maximal longitudinal strain values. Curves remain linear despite spontaneous breathing and thoracic movements traducing low strain values

be currently used in daily clinical practice but it opens new field regarding pleural assessment. We speculate this analysis could be implemented quickly in ultrasound devices for the LUS examination after industrial unblocking of integrated speckle tracking software. Indeed, this technology has already been diverted from its original use to the diaphragmatic shortening quantification, with positive results [25].

Third, the inter-observer correlation was low in cases of normal lung sliding although intra-observer correlation was good whoever the observer (senior or junior physicians). It seems that the speckle tracking analysis could be performed by any observer after an appropriate formation. The discrepancy in inter-observer correlation is probably the consequence of a manual selection of the respiratory cycle, which is still observer dependent. This limitation could be resolved using automatic calculation in real time during LUS examination. Indeed, automated measurement technologies are already used in echocardiography with promising results [35, 36]. Moreover, technology allowing automatic detection of the pleural line has already been described [33].

Conclusion

Speckle tracking technology allows lung sliding quantification and a perfect detection of lung sliding abolition in a selected and retrospective cohort study of patients with pneumothorax. Lung sliding quantification may open new perspectives in the detection of pneumothorax, alveolar stress or pleural diseases. Our findings need to be confirmed with prospective studies in unselected patients.

Electronic supplementary material

The online version of this article (<https://doi.org/10.1007/s00134-019-05710-1>) contains supplementary material, which is available to authorized users.

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Compliance with ethical standard

Conflicts of interest

XB and LZ declare a competing interest as an ultrasound teacher for GE (GE MEDICAL SYSTEMS ULTRASOUND) customers. ML declares a competing interest with Amomed, Aguettant, MSD, 3 M, Pfizer, Aspen, Orion.

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