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Pneumothorax diagnosis with lung sliding quantification by speckle tracking: a prospective multicentric observational study

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Keywords: Lung; Ultrasonography; Point-of-care system; Pneumothorax; Speckle tracking analysis

Short running head: Lung speckle tracking for pneumothorax

Abstract

Introduction: Lung ultrasound is commonly used for the diagnosis of pneumothorax. However, recognition of pleural sliding is subjective and can be difficult for novice. The primary objective was to compare a novices physician's performance in diagnosing pneumothorax from ultrasound (US) scans either with visual evaluation or with maximum longitudinal pleural strain (MLPS). The secondary objective was to compare the diagnostic relevance of US with visual evaluation or MLPS to diagnose pneumothorax with an intermediately experienced and an expert physician.

Methods: We conducted a prospective, observational study in two emergency department and two intensive care unit, between February 2019 and June 2020. We included 99 adult patients with suspected pneumothorax, who received a chest computed tomography (CT). Three physicians with different experience of interpreting US scans (a novice physician, an intermediately experienced physician, and an expert) analyzed the US scans of 99 patients with suspected pneumothorax (50 (51%) with confirmed pneumothorax), which were confirmed by CT scan.

Results: With a threshold of 5%, the MLPS sensitivity was 94% (95% CI [83%; 98%]), and the specificity was 100% (95% CI [93%; 100%]). The novice physician had an area under the curve (AUC) with visual analysis of 0.75 (95% CI [0.67; 0.83]) vs 0.86 (95% CI [0.79; 0.94]) with MLPS ($p = 0.04$). The intermediate physician's AUC for diagnosing pneumothorax with visual analysis was 0.93 (95% CI [0.88; 0.99]) vs 1.00 (95% CI [1.00; 1.00]) with MLPS ($p < 0.01$) and for the expert physician it was 0.98 (95% CI [0.95;1.00]) vs 0.97 (95% CI [0.93; 1.00]), respectively ($p = 0.69$).

Conclusion: In our study, speckle tracking analysis improved the accuracy of US for the novice and the intermediate but not the expert sonographer in the diagnosis of pneumothorax.

Keywords: Lung; Ultrasonography; Point-of-care system; Pneumothorax; Speckle tracking analysis

1. Introduction

According to the international recommendations for lung ultrasound (US), the US diagnosis of pneumothorax is distinguished by the absence of pleural sliding, B-lines and lung pulse, or by the presence of a lung point (1). The US analysis is qualitative and can be difficult to interpret, particularly by non-experienced physicians (2, 3). Finding the presence of pleural sliding seems to be more difficult than acquiring images for novices (3).

Strain is a US technique that consists of the analysis of spatio-temporal tissue deformations by tracking acoustic markers (speckle tracking) (4). In cardiology, to analyze ventricular function, strain is more reproducible than visual analysis (5). The most commonly used US strain technique is the evaluation of global longitudinal strain. A recently published case report and retrospective study suggested that the maximum longitudinal pleural strain (MLPS) makes it possible to detect and quantify pleural sliding by applying global longitudinal strain to the pleural line (6, 7).

As visual analysis of pleural sliding is difficult for novice physicians, the MLPS could facilitate the diagnosis of pneumothorax. Our hypothesis was that MLPS would improve the performance of a novice sonographer in diagnosing pneumothorax from lung US scans. Our primary objective was to compare the test performance characteristic of visual evaluation or speckle tracking (MLPS) for a novice sonographer to diagnose pneumothorax. The secondary objective was to compare the diagnostic relevance of US with visual evaluation or MLPS to diagnose pneumothorax with an intermediately experienced and an expert physician.

2. Materials and Method

2.1. Study Design

This was a multicentric, prospective observational pilot study conducted in two emergency departments and two intensive care units in three university hospitals. The subjects were enrolled between February 2019 and June 2020. In accordance with French law (8) the study protocol was approved by the *Comité de protection des personnes* (CPP Sud-Mediteranée II, ref. 2018-A02969-463), and oral informed consent was obtained from all study subjects.

Emergency department or intensive care unit adult patients were included if they met the following criteria: (a) had suspected pneumothorax, (b) needed a chest computed tomography (CT) scan, and (c) could have a lung US two hours before or after the chest CT scan. Patients were not included if there was an indication for drainage between the US and the CT scan. Patients were excluded if the lung US was not made with a linear probe or if the cine loop recorded was not usable for speckle tracking: cine loop < 3 s; ECG not connected. This was a convenience sample because a trained physician had to be present and available.

2.2. Interventions:

Lung US was performed within two hours before or after the chest CT scan. The US was performed with a conventional US device (Vivid S60 or Vivid IQ, GE Healthcare, Medical Systems Israel Ltd, Israel 39120) and a Vivid Vascular (9L-RS) superficial 3.5–10.0 MHz probe. The US was performed by emergency physicians or intensivists who were university trained in lung US and used this in routine practice in emergency medicine or critical care. The cine loops were recorded with an electrocardiographic trace of at least three seconds. The recording was done on a lung area where the diagnosis (pneumothorax or no pneumothorax) was confirmed before or after by a CT scan. The principal investigator retrieved the US cine loops, anonymized them, and processed them with commercially available semi-automated two-dimensional deformation software (EchoPac, GE, Milwaukee, USA). Three physicians judged these cine loops: a physician with no experience in the practice of lung US ("novice") undergoing 30 minutes of theoretical training; a board-certified physician ("intermediate") practicing US weekly; and a board-certified US teacher-researcher physician ("expert"). Each cine loop was analyzed twice: once with visual analysis followed by speckle tracking analysis. For the visual analysis, the doctors used the criteria of the guidelines: absence of pleural gliding, b-line, lung pulse and lung point (1). The speckle tracking analysis (positioning of analysis points and tracking verification) was performed by each physician, with a maximum of two failed attempts. As in the prior study, each physician determined the MLPS from the loop (7). A detailed protocol for data analysis and judge training is provided in the supplementary protocol. Each physician was blinded to the CT diagnosis and to the interpretations of the other two physicians.

2.3. Aims and outcomes:

The primary aim of this study was to estimate the diagnostic performance (sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV], and area under the curve (AUC) of the receiver operating characteristic [ROC] curve) of a lung US novice sonographer using visual analysis or MLPS for the diagnosis of pneumothorax to compare it. The optimal threshold setting was based on the expert's diagnostic analysis with MLPS. The MLPS was compared to the chest CT finding, which was considered the gold standard. The secondary aims were to compare for the diagnosis of pneumothorax, the diagnosis performance with visual analysis or MLPS (a) of an intermediate sonographer, (b) of an expert sonographer; and (c) to show concordance between each physician category.

2.4. Statistical analysis:

The AUC of a novice to diagnose a pneumothorax with visual analysis of recorded cine loops was not known. This was a pilot study. The quantitative variables are expressed as means and standard deviations or as medians and 25th and 75th percentiles. For the qualitative variables, counts and associated percentages are presented. The quantitative variables across the groups were compared using the Student (or Kruskal–Wallis) test. The relationship between the qualitative variables was tested using the Chi-squared test (or Fisher's exact test). The ROC curves were constructed, allowing estimation of the AUC with a 95% confidence interval, and calculated using the De Long method. The optimal threshold for detecting the abolition of pleural sliding was determined using the Youden method. The comparison between the ROC curves for each judging physician was performed using the Hanley and McNeil method. Cohen's kappa test was used to compare the agreement between the judges for each category. The significance level was set at 5%. Statistical analysis was performed using R 4.0.2 (R Development Core Team, 2020; R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Participants

During the study period, 122 patients were recruited, mean age 53 +/- 21 years, 25 (25%) were women, 50 (51%) had a pneumothorax on CT. The study flow chart is shown in Figure 1. MLPS was feasible in 92 (92%) of the scans analyzed by the novice sonographer, in 97 (98%) by the intermediate sonographer, and 97 (98%) by the expert sonographer.

3.2. Threshold determination

The ROC curve of the expert's diagnosis of pneumothorax with MLPS is shown in Figure 2. The AUC was 0.97 (95% CI [0.93; 1.00]). The optimal cutoff point was 5% (diagnosis of pneumothorax from 0 to 4). The diagnostic performances are shown in Table 1.

3.3. Primary outcome:

For the novice sonographer, the AUC was 0.75 (95% CI [0.67; 0.83]) and 0.86 (95% CI [0.79; 0.94]) with visual analysis and MLPS, respectively ($p = 0.04$) (Figure 3). The diagnostic performances are shown in Table 1.

3.4. Secondary outcomes

For the intermediate sonographer, the AUC was 0.93 (95% CI [0.88; 0.99]) vs 1.00 95% CI [1.00; 1.00]) with visual analysis and MLPS, respectively ($p < 0.01$; Figure 4). The diagnostic performances are shown in Table 1. The expert's ROC curve for the diagnosis of pneumothorax by visual analysis is shown in Figure 2. The AUC for the expert sonographer was 0.98 (95% CI [0.95; 1]) vs 0.97 (95% CI [0.93; 1.00]) with visual assessment and MLPS, respectively ($p = 0.69$). The agreement between the expert sonographer and the novice sonographer using visual analysis was 0.22 (fair agreement); between the expert sonographer and the intermediate sonographer it was 0.75 (substantial agreement). The agreement between the expert sonographer and the novice sonographer using MLPS was 0.48 (moderate agreement); it was 0.82 (almost perfect agreement) between the expert sonographer and the intermediate sonographer.

4. Discussion

In our study MLPS increased the diagnostic performance of a single novice US user for the diagnosis of pneumothorax. The goal of automatic analysis tools is to save time and improve the quality of measurements for physicians with little experience. Moreover, in our study, speckle tracking improved the performance of the intermediate sonographer, and this physician achieved a clinical performance level in visual analysis comparable to that reported in the literature (9, 10). The diagnostic gain seems more important in novices than in experienced physicians. However, the tool does not allow a novice sonographer to achieve a performance level comparable to that of an expert sonographer. Our results do not confirm that speckle lung tracking should become an objective, operator-independent marker of normal pleural sliding (11). We emphasize the importance of the clinician's guidance or control over the automatic analysis or interpretation tools. This may be because the novice user is less able to adequately identify the pleural line when compared with experts, as suggested by the data from our study.

The minimum MLPS value to eliminate a pneumothorax was set at 5%, based on the expert's results. This is consistent with the data published in a previous study, which defined abolition of pleural sliding with a maximum strain value of 4% (7). Dori et al. have suggested that it will be important to determine not only the normal values of speckle tracking but also the effects of other pathologies on pleural sliding (11). It is likely that other pathologies result in low MLPS values. Indeed, pleural sliding may seem to be abolished or decreased in conditions like apnea, atelectasis, pneumonia, or selective ventilation. It may be decreased, for example, during an acute asthma attack (12, 13). This will need to be evaluated in future studies.

5. Limitations

First, speckle tracking analysis was done with specific software that was not directly implemented in the US device. For the tool to be feasible for clinical practice, the availability of speckle tracking lung tools installed on a US device is necessary. Second, the cine loops were acquired and recorded by a physician trained in the practice of US. Although image acquisition does not seem to be the main problem for novices (3), it is possible that the results would be different if each physician had performed the US. These were not consecutive patients. A trained physician had to be present and available. Finally, the external validity of the study can be considered questionable, since only one doctor per category participated in our study: in particular the presence of a single novice sonographer. It is possible that the novice sonographer improved his performance during the study. However, this bias can only attenuate our main result which is already positive.

6. Conclusion

In our study, the performance of a single novice physician in diagnosing pneumothorax with US was improved using speckle tracking, as compared with visual evaluation. Speckle tracking also increased the performance of an intermediately experienced physician but not the performance of an expert sonographer.

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Table

		Se	Sp	PPV	NPV
Novice	Visual analysis	54% 95%CI [39%; 68%]	96% 95%CI [86%; 99%]	93% 95%CI [78%; 96%]	67% 95%CI [53%; 94%]
	MLPS	77% 95%CI [63%; 89%]	83% 95%CI [69%; 92%]	81% 95%CI [67%; 91%]	80% 95%CI [66%; 91%]
Intermediate	Visual analysis	92% 95%CI [80%; 98%]	94% 95%CI [83%; 99%]	VPP = 94% 95%CI [83%; 98%]	VPN = 92% 95%CI [81%; 98%]
	MLPS	100% 95%CI [92%; NaN]	100% 95%CI [93%; NaN]	100% 95%CI [93%; NaN]	100% 95%CI [93%; NaN]
Expert	Visual analysis	98% 95%CI [89%; 100%]	98% 95%CI [89%; 100%]	98% 95%CI [89%; 100%]	98% 95%CI [89%; 1]
	MLPS	94% 95%CI [83%; 98%]	100% 95%CI [93%; NaN]	100% 95%CI [92%; 100%]	94% 95%CI [84%; NaN]

Table 1: Diagnostic analysis of visual analysis and MLPS for pneumothorax by Novice, Intermediate and Expert sonographer.

Se: Sensitivity; Sp: Specificity; PPV: Positive predictive Value; NPV: Negative predictive value; MLPS: Maximum longitudinal pleural strain.

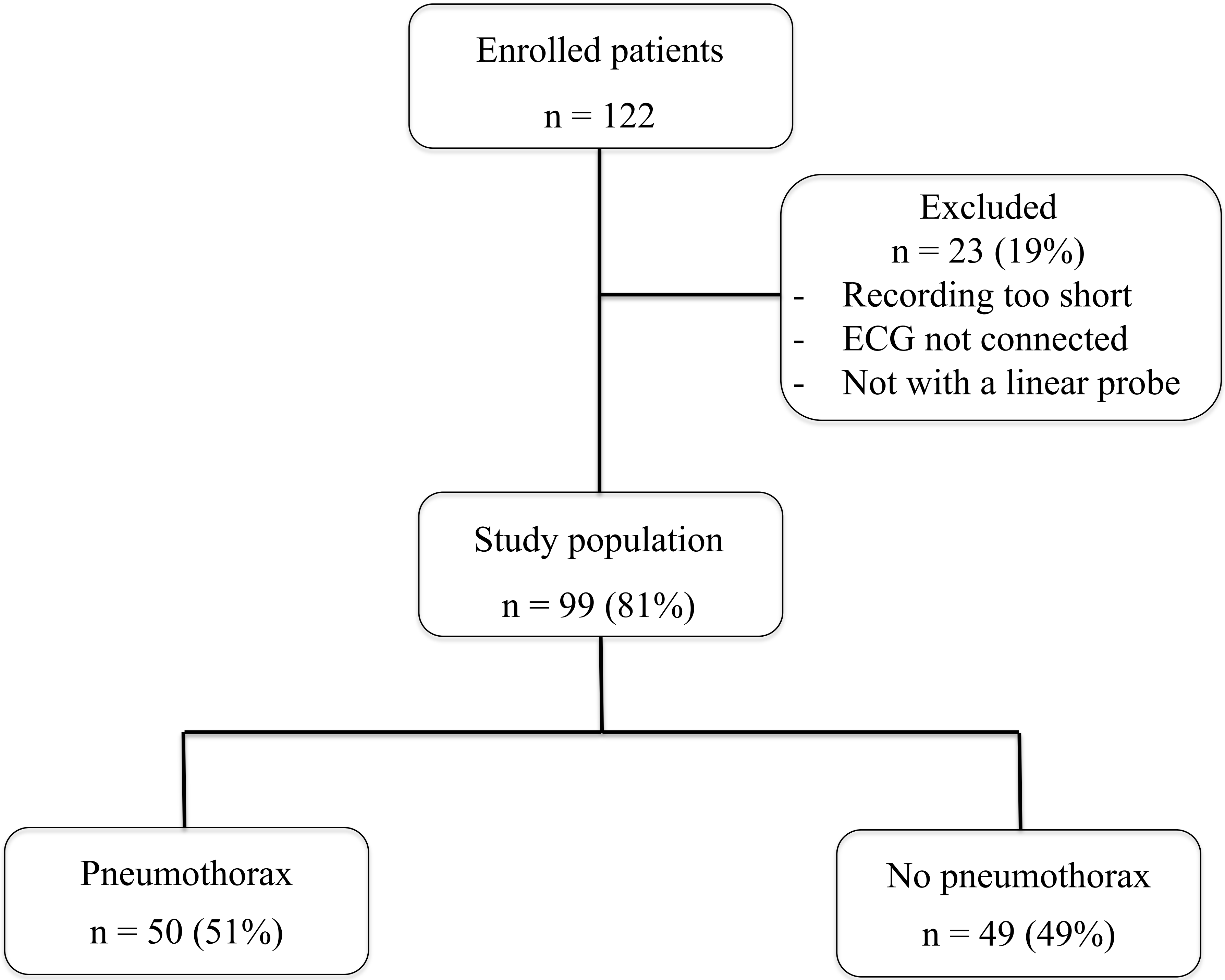
Figure legends

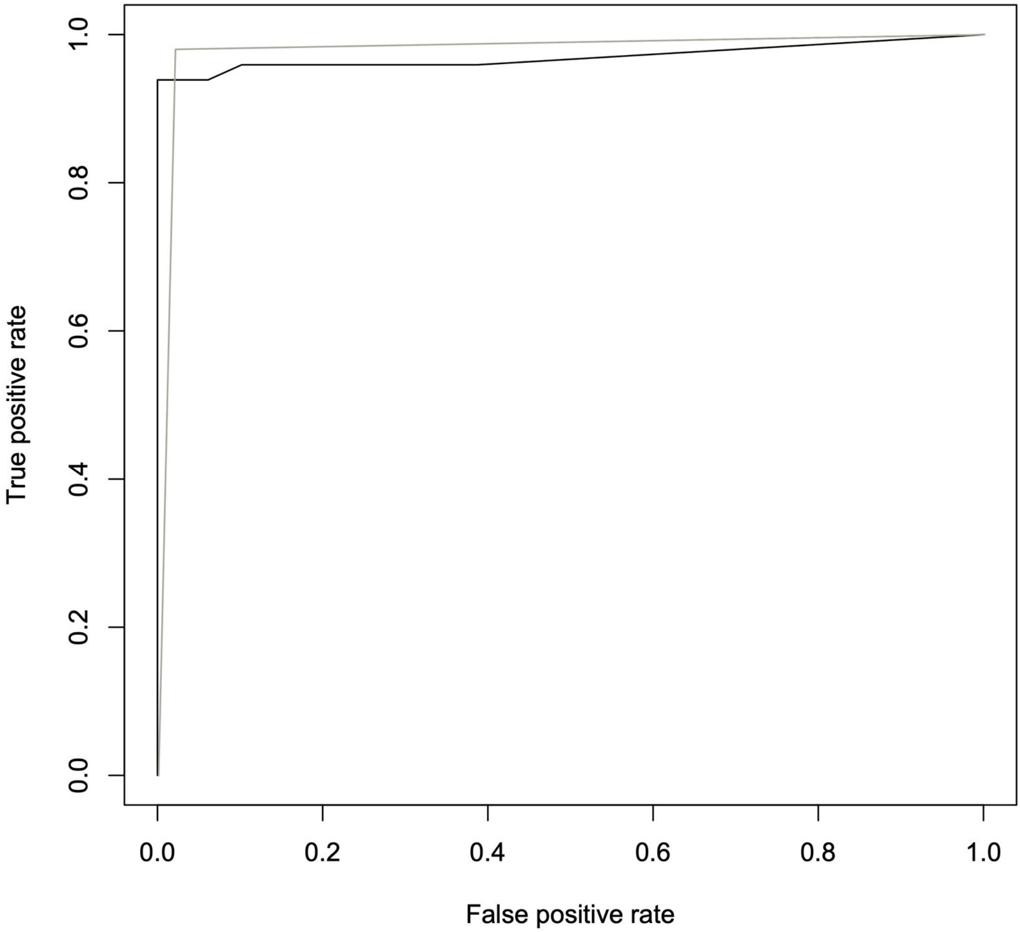
Figure 1: Flow chart

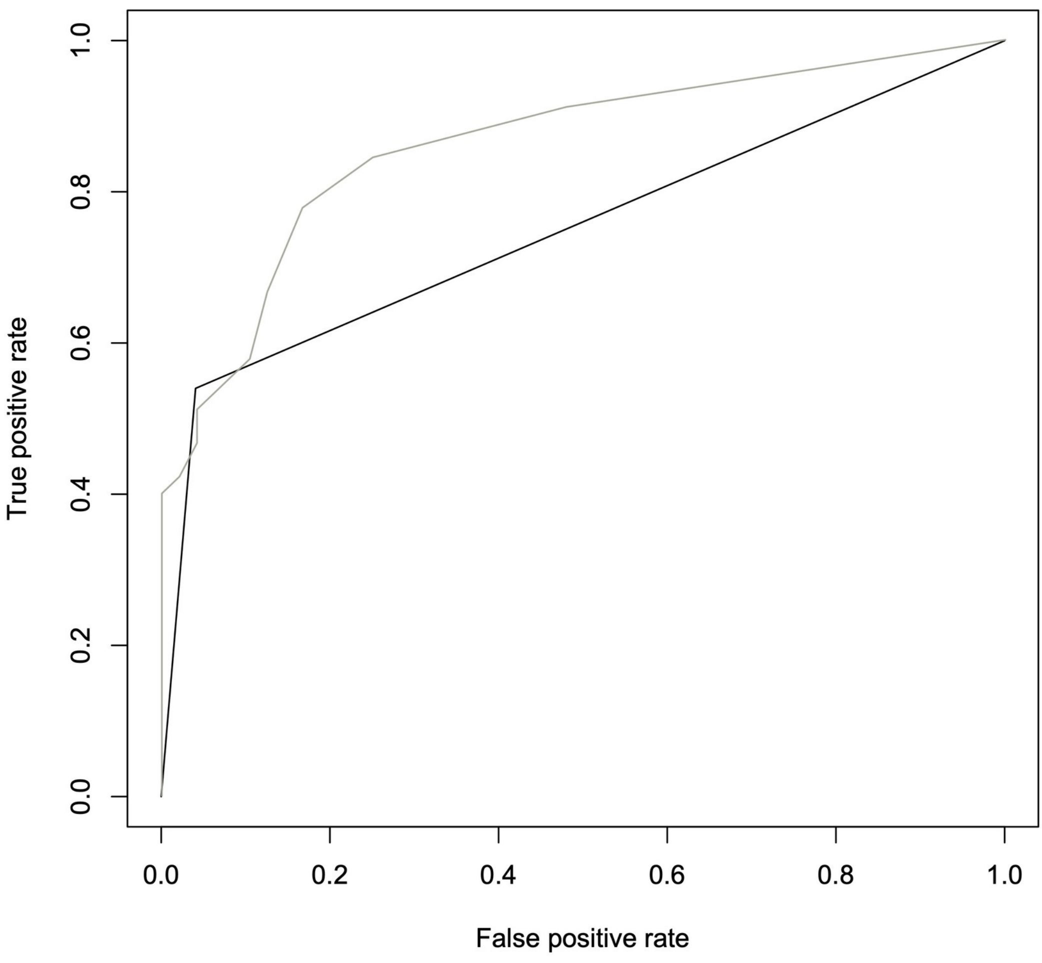
Figure 2: ROC curve of visual evaluation (dark curve) and maximal longitudinal pleural strain value (gray curve) to pneumothorax diagnosis by the expert

Figure 3: ROC curve of visual evaluation (dark curve) and maximal longitudinal pleural strain value (gray curve) to pneumothorax diagnosis by the novice sonographer

Figure 4: ROC curve of visual evaluation (dark curve) and maximal longitudinal pleural strain value (gray curve) to pneumothorax diagnosis by the practicing physician


Enrolled patients
n = 122
Excluded
n = 23 (19%)
- Recording too short
- ECG not connected
- Not with a linear probe
Study population
n = 99 (81%)
Pneumothorax
n = 50 (51%)
No pneumothorax
n = 49 (49%)


True positive rate
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8
1.0
False positive rate



1.0
0.8
0.6
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0.0
True positive rate
0.0
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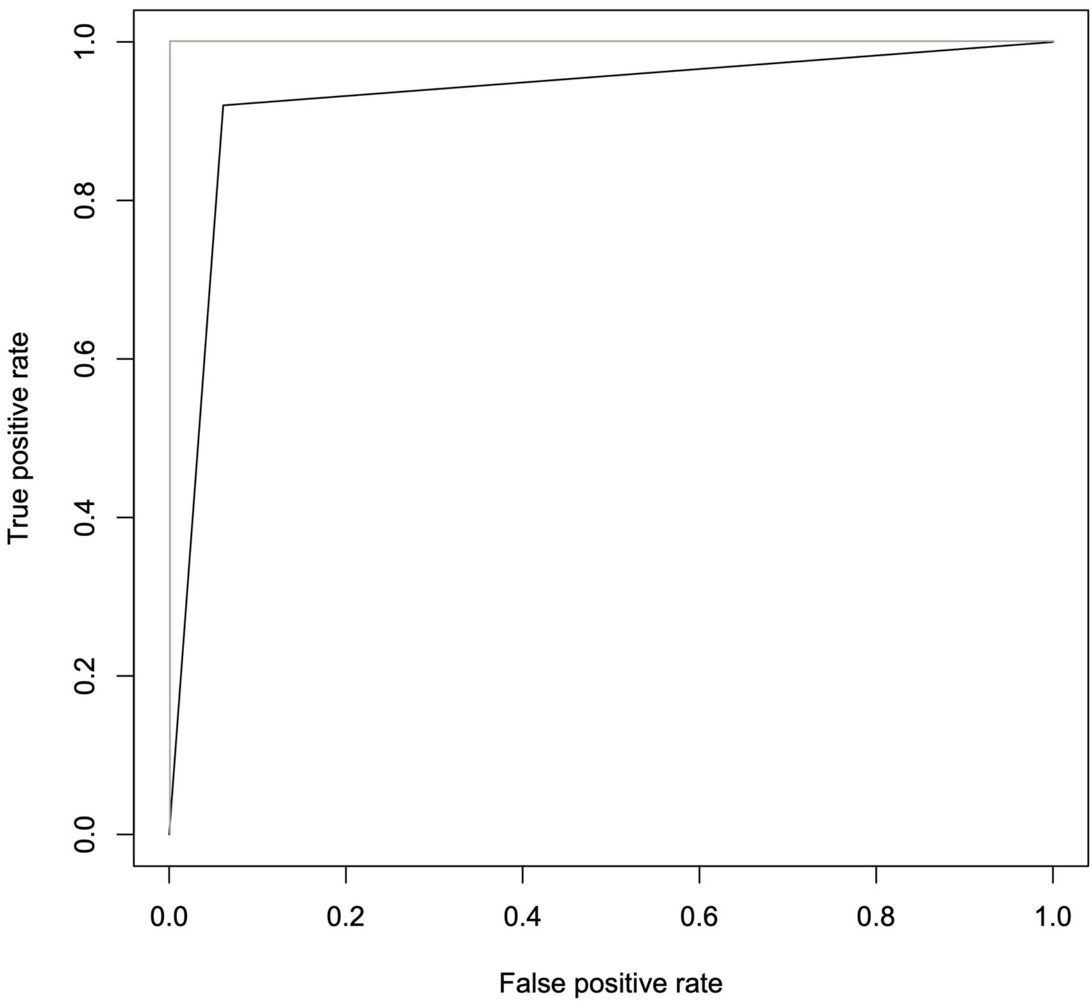
1.0
False positive rate



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False positive rate