THE SAHLGRENSKA ACADEMY

Lung ultrasound for detection of pulmonary edema in the critically ill

Degree Project in Medicine

Max Olin

Programme in Medicine

Gothenburg, Sweden 2017

Supervisor: Jonatan Oras

Department of Anesthesiology and Intensive Care Medicine

Table of Contents

Abstract

Degree Project

Programme in Medicine

Lung ultrasound for detection of pulmonary edema in the critically ill

Author: Max Olin

Supervisor: Jonatan Oras

Background

For detection and monitoring of pulmonary edema and for guidance in fluid management, chest x-ray (CXR) and thermodilution technique (PiCCO®) is commonly used in the critically ill. Lung ultrasound (LUS) is a cheap and easy method for detection of pulmonary pathology with increasing popularity in emergency departments and intensive care units (ICUs). LUS can be used to detect b-lines as a sign of interstitial lung fluid.

Aim

The primary goal of this study was to investigate if a simplified 8-zone LUS-protocol would correlate to extravascular lung water in patients with critical illness. A secondary goal was to compare LUS-accuracy in detection of pulmonary edema to chest x-ray.

Method

A prospective observational pilot study was conducted. Patients with a PiCCO® catheter and/or having a chest x-ray were enrolled and LUS scans performed at the central intensive care unit (CIVA) at Sahlgrenska university hospital. Following an 8-zone protocol, b-line score (BLS) was correlated to extravascular lung water index (EVLWI) obtained through transpulmonary

thermodilution. CXR reports were examined for signs of pulmonary edema and compared to BLS.

Results

28 patients were enrolled, and 48 lung ultrasound scans performed. LUS compared to transpulmonary thermodilution showed a significant correlation between BLS and EVLWI (r=0.43, p=0.032). In patients with several measurements, there was a positive correlation between changes in BLS and changes in extravascular lung water (p=0.012). The best cut-off value for detection of pulmonary edema was a b-line score of 6. Sensitivity for detection of pulmonary edema using transpulmonary thermodilution was 78% and specificity 64% with an AUC of 0.82. The sensitivity and specificity of b-line score for detection of pulmonary edema using chest x-ray was 100% and 35%.

Conclusions

In this study of patients with critical illness examined with lung ultrasound, the main finding was that b-line score correlated to extravascular lung water measured with PiCCO®. Compared to chest x-ray, LUS could exclude pulmonary edema. Lung ultrasound is a simple and feasible method. It has a steep learning curve and can be used in emergency departments and intensive care units for detection and monitoring of pulmonary edema.

Key words and abbreviations

Lung ultrasound, point of care ultrasound, transpulmonary thermodilution, PiCCO, chest x-ray, emergency medicine, intensive care medicine

ARDS Acute respiratory distress syndrome

BLS B-line score

CI Cardiac index

CO Cardiac output

CT Computed tomography

CVC Central venous catheter

CXR Chest x-ray

COPD Chronic obstructive pulmonary disease

ED Emergency department

EMR Estimated mortality rate

EVLWI Extravascular lung water index (by body weight, kg)

GEDVI Global end-diastolic volume index

ICU Intensive care unit

ITBV Intra-thoracic blood volume. ITBV= GEDV+ pulmonary vessel volume

LUS Lung ultrasound

PAC Pulmonary artery catheter

PiCCO Pulse contour cardiac output

ROC Receiver operating characteristics

SAPS 3 Simplified acute physiology score 3

SI Stroke volume index

SVRI System vascular resistance index

SOFA Sequential organ failure assessment

Background

Pulmonary edema

Pulmonary edema is the accumulation of fluid outside the vasculature of the lung, in the alveoli and the interstitial space. The mechanisms behind pulmonary edema are increased hydrostatic gradient, decreased oncotic pressure in the pulmonary vessels and increased capillary permeability due to endothelial injury. According to pathophysiologic cause, pulmonary edema is divided into cardiogenic and non-cardiogenic pulmonary edema (1).

In cardiogenic pulmonary edema the left ventricle fails to deliver enough blood, or blood with enough pressure, to the systemic circulation. The result is an accumulation and increased pressure in the pulmonary circulation, the hydrostatic pressure in the pulmonary vessels increases (2).

In non-cardiogenic pulmonary edema, the accumulation of extravascular fluid is secondary to inflammatory pathologies of the parenchyma of the lung and/or diminished oncotic pressure. In an inflammatory state, acute respiratory distress syndrome (ARDS), the permeability of the capillaries is increased, and fluid leaves the blood. In fluid overload, renal and liver failure, the oncotic pressure decreases (3).

Clinical setting and diagnostics

In the emergency department (ED), a common complaint is shortness of breath or dyspnea, a symptom that can be caused by a wide range of underlying conditions. In dyspnea of sudden onset, pulmonary embolism, chronic obstructive pulmonary disease (COPD) exacerbation, pulmonary edema, pneumonia, asthma, and pneumothorax should all be considered in the differential diagnosis. As a first radiologic investigatory step, a CXR is commonly performed to acquire more information. Detection of pneumothorax, consolidation, pulmonary edema is by convention by CXR, although a less specific and sensitive method compared to LUS (4). CXR,

produces radiation and requires waiting time, allotted expert personnel (both to man the machine and interpret the picture) and for the patient or the personnel to be moved. The ultrasound machine can be used bedside by the investigating physician and provides information without the delay of expert interpretation.

In the ICU, patients frequently develop pulmonary edema secondary to critical illness (heart failure, ARDS) and to receiving large amounts of intravenous fluids. In detection of pulmonary edema, the clinician is referred to the clinical examination, chest x-ray, CT-scan, invasive monitoring and LUS. Transpulmonary thermodilution by PiCCO or pulmonary artery catheter (PAC) is used for monitoring patients with large shifts in fluid and hemodynamically unstable patients (5).

Compared to radiologic methods, ultrasound is a cheap, non-invasive, quick and accessible method that requires no movement of the patient. However, it has some disadvantages. It is, despite standardized learning and user protocols, user dependent. In most departments it is not yet fully integrated in the clinical process and IT-infrastructure. This makes for a rather cumbersome user experience when reviewing patient information and accessing saved imagery. Nevertheless, there is a growing interest for LUS and most EDs and ICUs have access to ultrasound machines for bedside scanning and evaluation.

Ultrasound

Ultrasound waves were discovered by Paul Langevin towards the end of World War I. Working for the British and French, sonography was developed to detect objects underwater. For medical purpose, Scottish professor in Gynecology and Obstetrics, Ian Donald used it to examine grossly enlarged female abdomens in the 1950s (6). In Sweden, Cardiologist Inge Edler and Nuclear Physicist Carl Hellmuth Hertz borrowed a machine from Kockums in Malmö and used it to

generate an echo-encephalogram and M-mode to look at the mitral valve (7). It had by then been used in industry for the detection of cracks after welding since the 1940s.

Lung ultrasound

Development of lung ultrasound was relatively late. The volume of the lung consists mainly of air. Air reflects no ultrasound waves, a necessity for contour formation, resulting in a black image. Therefore, perhaps as a logic misstep, ultrasound was assumed to be unable to provide information about the parenchyma of the lung, initially slowing down the development of the technique. However, in pulmonary pathology, the lung displays direct or indirect ultrasound signs (artifacts) that are distinct and therefore helpful to the examining clinician. In the 1990s Daniel Lichtenstein showed that LUS can be used to distinguish COPD from pulmonary edema and to exclude pneumothorax (8, 9).

During the last 15 years an increased body of evidence has widened the applications for LUS. Lung ultrasound can be used for detection of pleural effusion, atelectatic and consolidated lung parenchyma, as well as quantification of pulmonary edema in heart and kidney failure (10-12).

A-lines

A-lines are defined as hyperechoic horizontal lines parallel to the pleural line occurring at regular intervals below the pleural line. These are artifacts, caused by reverberation between the probe and pleura, and represent aerated subpleural space. They do not exclude the presence of a pneumothorax (8).

B-lines

Extravascular lung water or pulmonary edema manifests as b-lines, the comet-tail artifact or ultrasound lung comet, on lung ultrasound (13-15). It is defined as a vertical line that originates from the pleural line and extends to the bottom of the screen when set at a depth of 18 cm (16). The presence of a b-line excludes pneumothorax (8).

Z-line

Also known as false b-lines, these thin, vertical lines originate from the pleural line that do not move with lung sliding (see below) and usually vanquish after 3-5 cm depth. They hold no clinical significance, but should not be mistaken for a b-line and does not exclude the presence of pneumothorax (17).

Lung sliding

Lung sliding is a sign of the parietal and visceral pleura moving in the respiratory cycle and is not present in pneumothorax, high airway pressure mechanical ventilation or in the left lung in right mainstem bronchus intubation (18, 19).

Lung point

The lung point is a 100% sensitive and specific sign of pneumothorax and marks the transition point between the pneumothorax and connected visceral and parietal pleura (20).

Lung pulse

Lung pulse is most clearly visualized in apnea. The subtle, rhythmic, pleural sliding can also be seen in the left lung of the ventilated patient with right main stem intubation, it is created by the pulse of the beating heart (9).

Pleural effusion

With the patient in a semi supine position pleural fluid is often accumulated dorsal and basal. Fluid appears hypoechoic, i.e. black. To differentiate fluid from air in the parenchyma, the spine is visualized dorsal to the liver or spleen. When air is replaced by fluid, the spine continues to be visible above the diaphragm, resulting in a "positive spine sign". Secondary to the effusion, the lung is commonly atelectatic, represented by a "jellyfish sign", seen as a snapping piece of distal atelectatic lung (12).

Protocols

There are several different protocols that have been studied and validated. The two most frequently used are described below.

Jambrik 28-point protocol

With the patient in supine position, longitudinal scanning of both hemithoraces is performed along the parasternal, midclavicular, anterior and mid axillary lines. The right lung is scanned in intercostal space 2-5, a total of 16 visualizations. The left lung is scanned in intercostal space 2-4, a total of 12 visualizations. By Jambrik et al, a cardiac transducer was used. The sum of the b-lines yields a score denoting the extent of extravascular fluid in the lung. Later, Frassi et al, more extensively described a scoring system where the number of b-lines where added up, yielding a total score of "mild" (5-14 comets), "moderate" (15-29 comets), and "severe" (>29 comets) (21).

Volpicelli 8 zone protocol

Volpicelli divides the lung into 4 segments, 2 frontals and 2 laterals. Using the "bat sign", i.e. positioning the probe perpendicular to the ribs, and finding the 2-3 most representative pictures in the most representative intercostal space. The transducer is then turned parallel to the ribs for maximal parenchyma visualization and the pictures are stored. Among those pictures the most accurate is selected for each of the 8 total zones yielding an A- or B-pattern. B-pattern is defined as 3 or more b-lines separated by more than 7 mm. 2 or more B-pattern zones per lung is considered a positive examination for pulmonary edema (22).

Transpulmonary thermodilution

PiCCO

PiCCO is a trademark device manufactured by Pulsion Medical Systems, Munich, Germany that uses transpulmonary thermodilution technique. The detection catheter is placed in a peripheral artery, the most commonly used artery is the femoral. Axillary and radial artery catheters are

available. PiCCO also measures pulse contour derived parameters such as system vascular resistance, contractility and stroke volume.

An indicator is injected into the circulatory system on the central venous side proximal to the heart and respiratory circulation. A detection sensor in the central venous catheter (CVC) and in the arterial catheter registers the temperature of the passing fluid. Conceptually, the space in between is composed of several mixing chambers organized in series. The temperature curve gives the total volume of distribution between the site of injection and the site of detection.

Pulse contour analysis provides continuous monitoring, and the transpulmonary thermodilution derived values require manual calculation. Three times, a bolus of 20 ml refrigerator cold saline is injected into a central vein via CVC access. The readings should differ no more than 10% from each other. A curve depicting temperature change in the femoral artery is acquired. Volume and temperature of the injectate is used in a modified Hamilton-Stewart equation to acquire cardiac output using the area under the curve produced by the temperature change readings in the femoral artery (23).

Since most of the temperature change occurs in the intrathoracic compartment, intrathoracic blood volume and extravascular lung water can be calculated. These values are indexed by weight (24).

Pulmonary artery catheter
The pulmonary artery catheter (PAC) also uses transpulmonary thermodilution and provides continuous measurements but is more invasive and carries more risk to apply. It is most frequently used to monitor cardiac surgery patients (25).

Gold standard for extravascular lung water measurement

In estimating EVLW, gravimetry post mortem is the ultimate gold standard, however, in clinical practice double indicator (cold saline and green dye) is considered gold standard for quantifying EVLW (26, 27).

If this indicator is a single thermal indicator (cold saline), the volume of distribution will include not only the intravascular but also the extravascular space, without any distinction between interstitial and alveolar water. Injecting simultaneously, through a central venous catheter, a thermal and a strictly intravascular indicator (for instance, indocyanine green dye), detecting the respective dilution curves in the femoral artery, and comparing the volume of distribution of these two indicators gives an estimate of the EVLW content. This method has been validated against the reference gravimetric method, even in humans and yields EVLW measurements with a good reproducibility (26, 28). However, using indocyanine green as an intravascular indicator is relatively expensive and requires specialized densitometry equipment or a fiberoptic catheter to detect the dye curve. It is therefore used exclusively in study settings.

In conclusion, several methods can be applied in investigation and monitoring of extravascular lung water. However, a feasible, precise and reliable method for detection and quantification does not exist.

Aims

The main aim of this study was to investigate if a simplified 8-zone protocol is an acceptable method for detection of extravascular lung-water. Secondary we wanted to test the following hypothesizes:

- B-line score, measured with a simplified 8-zone protocol, correlates with EVLWI measured with PiCCO

- B-line score, measured with a simplified 8-zone protocol, correlates with pulmonary edema detected on CXR

- A simplified 8-zone protocol can be used for exclusion of pulmonary edema

Materials & methods

Patient inclusion

All patients over 18 years admitted to central ICU, Sahlgrenska university hospital, Gothenburg between September 17, 2017 and November 17, 2017 receiving a PiCCO-device for hemodynamic monitoring or having expected high positive or negative fluid shifts ($\pm$>1,5 liters) and/or a diagnostic chest x-ray where evaluated for inclusion in this study. Conscious patients were asked for consent, in mechanically ventilated patients relatives were asked. Patients that were admitted ≥1 day after initial scan, had a follow-up scan.

Ultrasound measurements

A GE Vivid IQ machine with the abdominal probe (2-5 MHz) and a BK Medical Flex Focus 400 exp machine with the same type of probe was used for the examinations. 2 sonographers performed LUS, the student, which performed 44 scans, and the supervisor which performed 4 scans. An 8-zone protocol and all images where obtained in "bat sign" position, i.e. longitudinal scans (Figure 1). The point containing the most b-lines in every zone was selected for representation by the examiner and a 4 second film sequence was saved resulting in a total of eight moving images per exam (in cases where all zones were available for examination).

If one of the basal or apical zones were unavailable for LUS due to dressings, anatomic abnormalities, or drainages, those were given the same score as the neighboring basal/apical zone. If both the basal or apical zones were unavailable, they were given the same score as the other lung´s basal/apical zones. The same was done in patients with other pathologies (severe pleural effusion and consolidated lung), that made b-line scoring non-applicable.
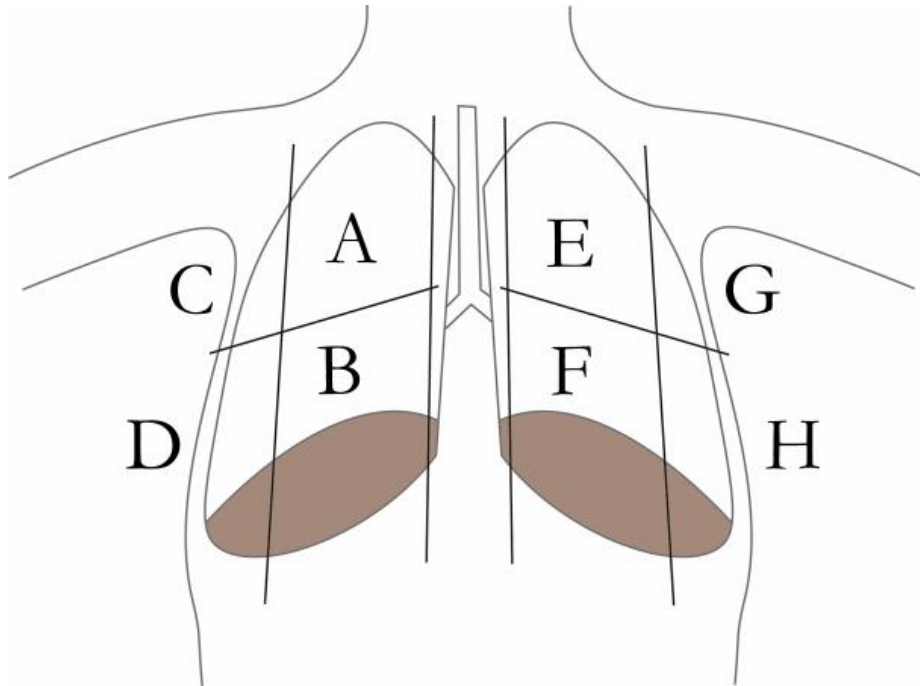
Figure 1 Schematic layout of the 4 frontal and 4 lateral lung views used in the protocol. The apical zones corresponding to intercostal spaces between ribs 1 and 2, and 2 and 3. The basal corresponding to intercostal spaces between ribs 3 and 4, and 4 and 5 and on the right side 5 and 6.

B-line score was performed during or right after the examination. Using a pre-fabricated protocol, the amount of b-lines in the 8 lung zones where given a grade and score. See table 1.

Table 1 *B-line scoring*

Grade	Amount of b-lines	B-line score
None	0	0
Mild	1-2	1
Moderate	3-4	2
Severe	≥5	3

Transpulmonary thermodilution measurements

All measurements were performed using the PiCCO device. Measurements where obtained from the most recent calibration. When possible, new calibrations were performed at the time of the investigation. Fluid balance, weight, pulse oximetry and ventilator settings were also collected.

Clinical data

Patient diagnosis, SAPS, EMR and SOFA was collected from PasIva, patient history from the admission note in Melior and PaO_2 and FiO_2 was collected from LabBest.

Chest x-ray

For patients that had a CXR within 24 hours of the lung ultrasound examination, the radiologists' reports were collected and analyzed for signs of pulmonary edema and congestion. CXRs were graded binary, those with signs of pulmonary edema and those without.

Statistics

Linear regression was used to determine correlation between BLS and EVLWI. For evaluation of BLS and EVLWI, a linear mixed model was used. ROC-curves were used to determine sensitivity and specificity for BLS. Positive and negative predictive value for was calculated for BLS and CXR. Statistical analysis was performed using SPSS (IBM SPSS, Chicago, IL, USA).

Ethics

The study was conducted in accordance with the principles of the Declaration of Helsinki. No ethical application was sent to the local ethics committee as this was a student project and a pilot study not intended for publication. The Operations Manager had approved the project and an ethical application for the main project was approved while this pilot study was performed.

Informed consent was obtained from awake patients. Information was given about the nature of the examination, the purpose of the study and that it was optional. For patients under respiratory care relatives were asked when available.

LUS is a pain free, non-invasive and radiation free method that when performed in accordance with protocol produces no discomfort for the patient. When the gel is applied a cold sensation can be experienced. For the examination, the chest needs to be exposed. Specific attention was taken, using protective screens and closed doors to keep the integrity of patients while performing the examination.

The examinations were not meant to influence the care of the patients, however all treating clinicians were informed of the results of the examination, also for other findings than b-lines, such as pleural effusion, pneumothorax, consolidation/atelectasis. Prior to all examinations approval by treating physician and involved personnel was obtained.

During the examination, moving images were saved and later backed up on an external hard drive. All patient data was encoded, and a decoded file was stored in a separate key-coded file.

Results

Patient cohort

A total number of 28 patients, were enrolled. 48 lung ultrasound scans were performed. Repeated

LUS was performed in 10 patients (see patient characteristics in table 2).

Table 2 *Clinical Features*

	Variables	Values
Patient inclusion	Patients	28
	Observations	48
Background data	Sex, m/f	18/10
	Mechanical ventilation	20
	Age, yr*	64 (22 - 80)
	Weight, kg*	89.5 (60.3 - 224)
Admission data	Simplified acute physiology score 3†	61.5 ± 13.3
	Estimated mortality rate, %†	26.8 ± 19.5
	Sequential organ failure assessment†	9.3 ± 3.6
Cause of admission	Sepsis	7
	Cardiac arrest	4
	Postoperative care	3
	Respiratory failure	2
	Acute pancreatitis	2
	Cardiac failure	1
	Postoperative hemorrhage	1
	Trauma	1
	Acute renal failure	1
	Myocardial infarction	1
	Acute respiratory distress syndrome	1
	Ruptured aortic aneurysm	1
	Aortic aneurysm	1
	Liver failure	1
	Cerebral infarction	1
Medical history	Malignancy	8
	Chronic renal failure	5
	Myocardial infarction	4
	Chronic hemodialysis	3
	Heart failure	2
	Chronic obstructive pulmonary disease	2
	Stroke	1

*Data presented as median (min – max).

†Data presented as mean (±SD)

In 18 of 28 patients and 37 of 48 observations transpulmonary thermodilution measurements were available using the PiCCO device (PULSION Medical Systems, Munich, Germany). Mean time from LUS to PiCCO-calibration was 3 hours. For all 28 patients and for 36 of 48 lung ultrasound examinations CXR was available. For all patients with PiCCO-measurements CXR was available at one time point, a total of 28 observations had both CXR- and PiCCO- derived data.

Lung ultrasound data

Using lung ultrasound, a total of 384 zones were examined of which 29 (8%) were not examinable due to dressing etc. Mean BLS was 7,6 (see table 3). Median b-line score was higher in the basal zones vs the frontal zones (2 vs 0, p<0.001, figure 2). Occurrence of b-line score, represented by a ultrasound image, according to zone is showed in figure 3. 32% of the 38 chest x-rays were positive for pulmonary edema compared to 63% of the LUS. Mean EVLWI was 11 mL/kg.

Table 3 *Respiratory and hemodynamic findings*

Variables	Values
B-line score	7.6 ± 4.3
Extravascular lung water index, mL/kg	11 ± 3.3
Global end-diastolic volume index, mL/m^2	883.9 ± 166
Cardiac index, L/min/m^2	3.4 ± 0.8
System vascular resistance index, dyn*s/cm5*m2	1791.5 ± 521.5
Chest X-ray pulmonary edema, y/n	12/26
PaO$_2$, kPa	11.3 ± 2.3
FiO$_2$, %	38 ± 14
PaO$_2$/FiO$_2$	33.4 ± 14.2
Positive end expiratory pressure, cm H$_2$O	9.7 ± 3.1

PaO$_2$, arterial partial pressure of oxygen; *FiO$_2$*, fraction of inspired oxygen.

Data presented as mean (±SD) unless otherwise indicated. Collected from lung ultrasound, PiCCO-device, CXR statement, respirator and arterial blood gas test.
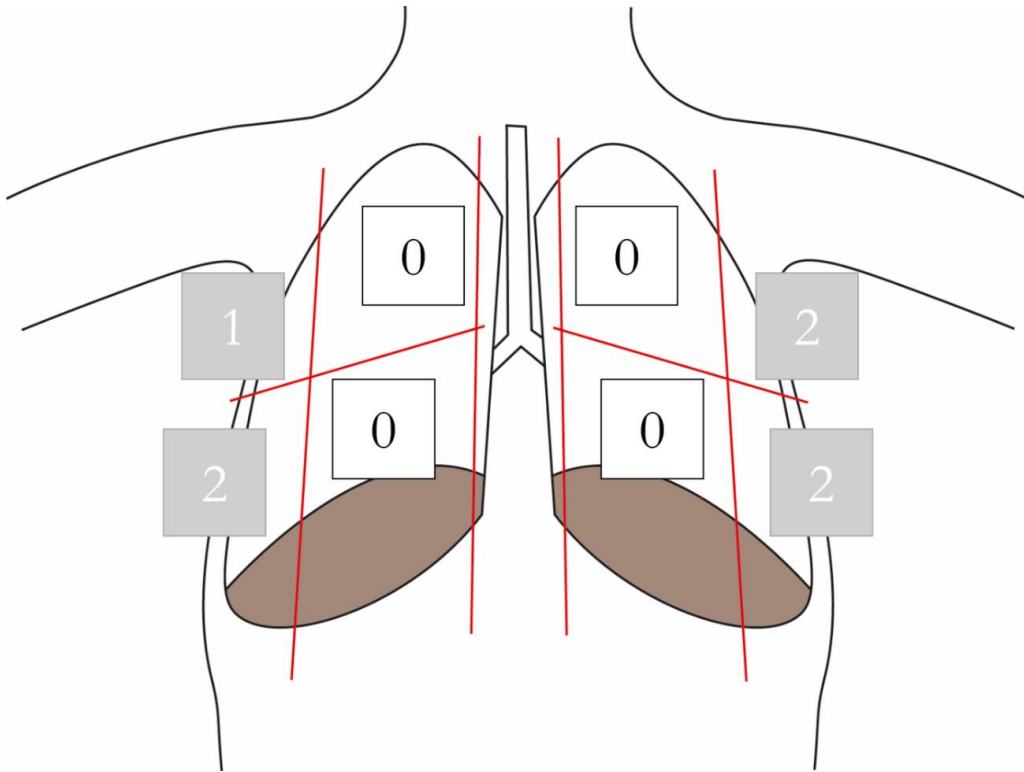
Figure 2 Median b-line score using lung ultrasound according to the lung zones in the applied protocol. Scoring is 0 points, none, 0 b-lines; 1, mild, 1-2 b-lines; 2, moderate, 3-4 b-lines; 3, severe, ≥5 b-lines.
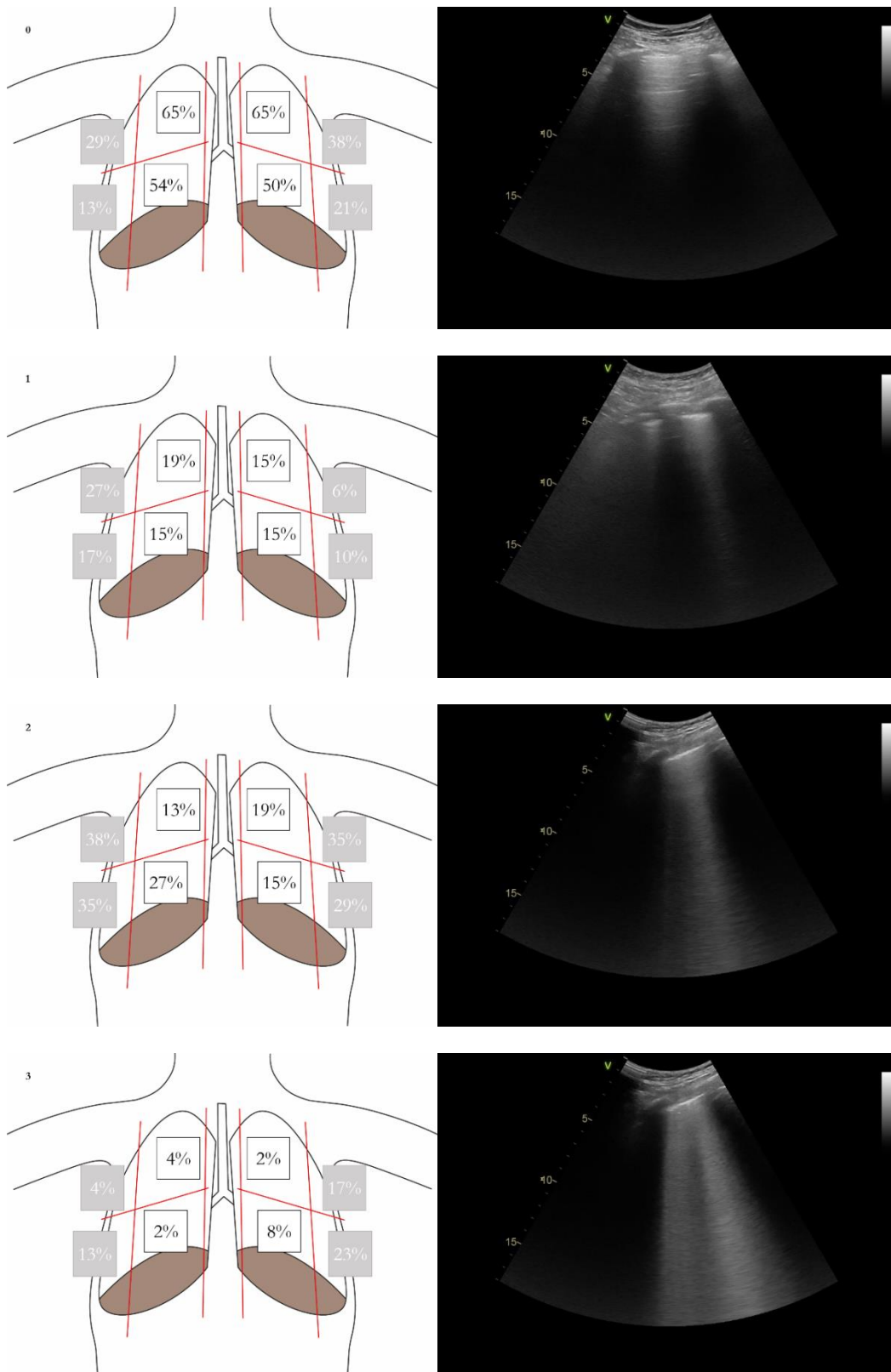
Figure 3 Occurrence of b-lines and grading of b-line score according to lung zone, represented by a corresponding lung ultrasound image. A: 0 b-lines (none, b-line score 0 points), B: 1-2 b-lines (mild, b-line score 1 points), C: 3-4 b-lines (moderate, b-line score 2 points), D: ≥5 b-lines (severe, b-line score 3 points). Describes the prevalence of b-lines among the included patients.

Comparison of lung ultrasound to extravascular lung water and chest x-ray

EVLWI was measured using the PiCCO device and compared to the ultrasound findings, i.e. the BLS. There was a significant correlation between BLS and EVLWI (r=0.43, p=0.032, see figure 4). B-line score of the frontal zones only did not have an association with EVLWI (p=0.319). B-line score of the basal zones only had a significant correlation with EVLWI (p=0.027).

To calculate the sensitivity and specificity of BLS for detection of pulmonary edema, a ROC curve was visualized using EVLWI ≥10 ml/kg as the true condition for pulmonary edema. The AUC was 0.82 and the best cut-off value for BLS was 6 with a sensitivity of 78% and specificity of 64% (see figure 5).

The sensitivity and specificity of BLS for detection of pulmonary edema detected on CXR was 100% and 35%, respectively with an AUC 0.603.

The ROC curve for CXR and EVLWI was not significant, with an AUC of 0.54.

There was a positive correlation of BLS and EVLWI in patients with several measurements (p=0.012). There was no correlation between changes in BLS and bodyweight (p=0.153).
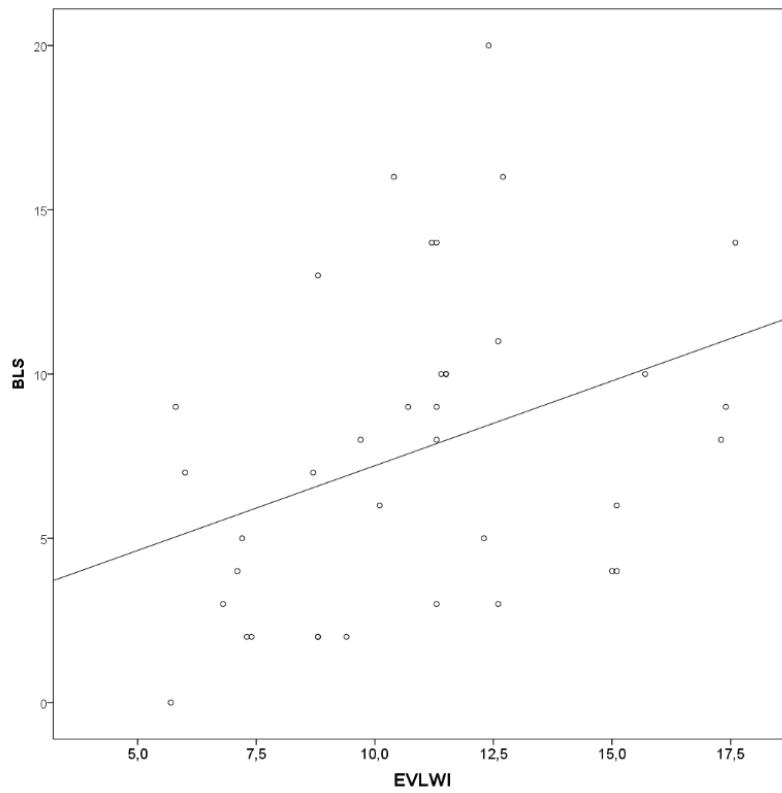
Figure 4 B-line score correlated to extravascular lung water index (r=0.43, p=0.032).
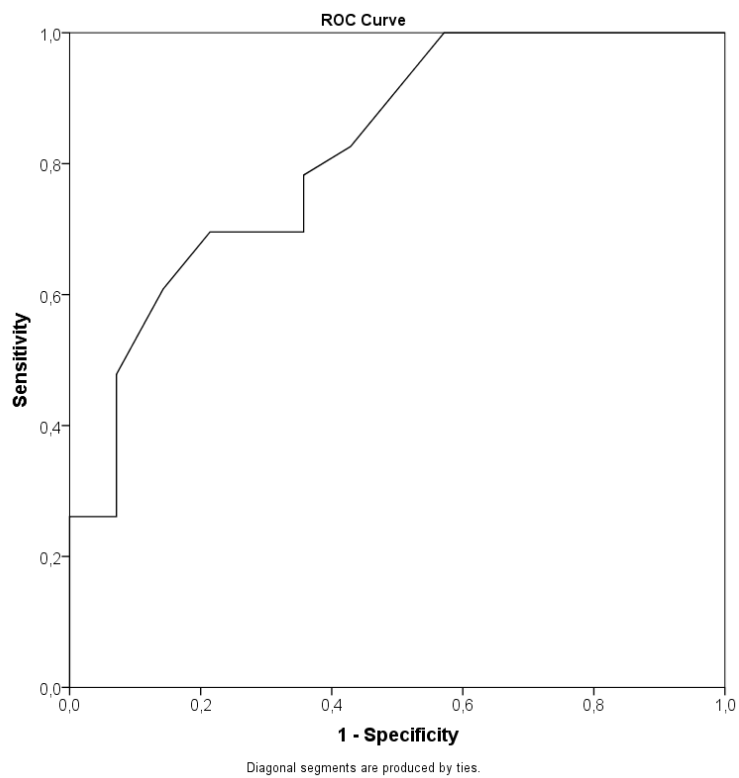

Figure 5 ROC curve for BLS and EVLWI. Using EVLWI ≥10 ml/kg as true condition for pulmonary edema and BLS of 6 as cut-off value provided a sensitivity of 78% and specificity of 64%. AUC was 0.82.

Discussion

In this prospective observational study of ICU patients examined with lung ultrasound, the main finding was that BLS correlated with EVLWI measured with PiCCO. Furthermore, lung ultrasound could exclude pulmonary edema detected with CXR.

B-line score using lung ultrasound correlates to EVLWI using transpulmonary thermodilution technique. The sensitivity and specificity for b-line score in detection of pulmonary edema, defined as EVLWI $\geq$10 mL/kg, was moderate. A b-line score $\geq$6 had an acceptable sensitivity of 78% but only a moderate specificity of 64%. Compared to previous data, this correlation is slightly lower, but in line with, previous studies (29-32).

Comparing chest x-ray results to lung ultrasound, the sensitivity of a b-line score of $\geq$6 in detection of pulmonary edema was 100% and coul be used to rule out pulmonary edema in CXR. However, at this cut off level, the specificity for detection of pulmonary edema was only 35%. In summary, lung ultrasound might be used as a screening tool for pulmonary edema.

Using thermodilution technique as the comparative method is not ideal. In clinical settings EVLWI-values vary across studies and patient groups (33). Many studies validating single transpulmonary thermodilution technique do so in uniform populations and controlled environments (27, 34-37). In one study of 25 postoperative patients, thermodilution-based measurements did not correlate well with PAC measurements (35). In a meta-analysis from 2012, EVLWI-values differed between surgical and septic patients, and in all groups most values were above the proposed normal range of 3-7 ml/kg (33). Perhaps lung ultrasound is the more accurate method in quantification of extravascular lung water. Comparing lung ultrasound to computed tomography there is high concordance between BLS and radiology score for pulmonary edema (38, 39).

There is poor correlation between BLS using lung ultrasound and signs of pulmonary edema using chest x-ray in this material. Neither is there a correlation between EVLWI and CXR. A previous study comparing CXR-score for pulmonary edema to EVLWI measurements show a slight, modestly positive correlation between the two, in line with the findings of this study (40). Previous comparisons show that lung ultrasound is the more sensitive tool compared to CXR in detection of pulmonary edema (21, 22, 39, 41, 42).

Lung ultrasound can be used in EDs and ICUs for detection of pulmonary edema, and perhaps most importantly, exclude it. It can be used to monitor patients with critical illness. In a study of patients undergoing hemodialysis, LUS was done at the start, middle and end of dialysis showing resolution of b-lines as fluid was removed from circulation (40). This has just recently, successfully, been reproduced by this group of researchers, using the same simple 8 zone protocol as in this study (data not published).

Limitations to this study is that it is relatively small, not all patients had PiCCO-devices and the ones that did, where not all calibrated at the time of lung ultrasound examination. Another issue is that not all lung zones where available for examination. Point of care lung ultrasound is user-dependent. As such, it is subject to have interobserver variability. This has been previously studied where blinded investigators have graded sonography pictures independently, yielding high interobserver reliability (21). It has however, not been done for this study.

Lung ultrasound is a simple and feasible method. It has a steep learning curve and medical students with no previous experience can easily and quickly learn lung ultrasound scanning and assessment, yielding high concordance with experienced clinicians. Undergraduate students quickly develop confidence in using the method (43, 44). It is quick to perform (<5 minutes), well tolerated by patients and does not disturb the routines of the ward nursing staff.

Conclusions and implications

In conclusion, using a simple 8 zone protocol for lung ultrasound is a useful method for the detection and monitoring of pulmonary edema in the critically ill. Although this study only found a moderate correlation between BLS and EVLWI, lung ultrasound could exclude pulmonary edema compared to CXR. Thus, lung ultrasound could be used as a screening tool for pulmonary edema. Still, further studies are warranted, as an optimal method for the detection and quantification of pulmonary edema remains elusive.

Populärvetenskaplig sammanfattning

Lungödem innebär att vätska från blodet hamnar i och mellan lungans annars luftfyllda blåsor, alveolerna. Det är ett tillstånd som ger svårigheter att andas och inträder vid flera akuta sjukdomar, samt är en vanlig komplikation i samband med allvarlig sjukdom och intensivvård. Det är av nytta för sjukvårdspersonal att snabbt och enkelt kunna diagnosticera och följa mängden lungödem, men i dagsläget saknas en bra metod för att göra det.

Vanligtvis används lungröntgen för att upptäcka och följa lungödem. På intensivvårdsavdelning används avancerad, invasiv monitorering på kritiskt sjuka patienter för att upptäcka och följa bland annat lungvatten när man t ex. tillför stora mängder vätska i blodet med dropp. Med invasiv monitorering menas att man med slangar och mätare som ligger i de stora blodkärlen registrerar blodflöde och blodets temperatur för att kunna beräkna hur mycket lungödem en patient har.

Lungultraljud är en enkel, billig, snabb och bra metod för att titta på olika sjukdomstillstånd i lungan. Vi ville därför undersöka om lungultraljud med ett enkelt, standardiserat protokoll är en pålitlig och precis metod för att upptäcka och följa lungödem hos kritiskt sjuka patienter. I denna studie undersöktes 28 patienter och totalt 48 lungultraljud utfördes.

Vi fann att lungultraljud kan upptäcka lungödem vid jämförelse med invasiv monitorering och att det är bättre än lungröntgen för att upptäcka lungödem. Dock är det i denna jämförelse ett något ospecifikt redskap, varför det kan lämpa sig bäst som screeningmetod, d v s för att försäkra sig om att man inte har lungödem.

Ultraljud och lungultraljud väcker växande intresse inom hälso-och sjukvård i Sverige och internationellt. Det är på grund av praktiska fördelar en tilltalande metod och kan användas för upptäckt av en rad sjukdomstillstånd i lungan. Det är en bra metod för upptäckt av lungödem, men fler studier som tittar på hur man ska använda det mer i detalj behövs.

Acknowledgements

References

1. Ware LB, Matthay MA. Clinical practice. Acute pulmonary edema. The New England journal of medicine. 2005;353(26):2788-96.

2. Gropper MA, Wiener-Kronish JP, Hashimoto S. Acute cardiogenic pulmonary edema. Clinics in chest medicine. 1994;15(3):501-15.

3. Ware LB, Matthay MA. The acute respiratory distress syndrome. The New England journal of medicine. 2000;342(18):1334-49.

4. Xirouchaki N, Magkanas E, Vaporidi K, Kondili E, Plataki M, Patrianakos A, et al. Lung ultrasound in critically ill patients: comparison with bedside chest radiography. Intensive Care Med. 2011;37(9):1488-93.

5. Jozwiak M, Teboul JL, Monnet X. Extravascular lung water in critical care: recent advances and clinical applications. Ann Intensive Care. 2015;5(1):38.

6. Kurjak A. Ultrasound scanning - Prof. Ian Donald (1910-1987). European journal of obstetrics, gynecology, and reproductive biology. 2000;90(2):187-9.

7. Edler I, Lindstrom K. The history of echocardiography. Ultrasound Med Biol. 2004;30(12):1565-644.

8. Lichtenstein D, Meziere G, Biderman P, Gepner A. The comet-tail artifact: an ultrasound sign ruling out pneumothorax. Intensive Care Med. 1999;25(4):383-8.

9. Lichtenstein D, Meziere G. A lung ultrasound sign allowing bedside distinction between pulmonary edema and COPD: the comet-tail artifact. Intensive Care Med. 1998;24(12):1331-4.

10. Siriopol D, Onofriescu M, Voroneanu L, Apetrii M, Nistor I, Hogas S, et al. Dry weight assessment by combined ultrasound and bioimpedance monitoring in

low cardiovascular risk hemodialysis patients: a randomized controlled trial. Int Urol Nephrol. 2017;49(1):143-53.

11. Picano E, Pellikka PA. Ultrasound of extravascular lung water: a new standard for pulmonary congestion. Eur Heart J. 2016;37(27):2097-104.

12. Lichtenstein DA. BLUE-protocol and FALLS-protocol: two applications of lung ultrasound in the critically ill. Chest. 2015;147(6):1659-70.

13. Soldati G, Copetti R, Sher S. Sonographic interstitial syndrome: the sound of lung water. J Ultrasound Med. 2009;28(2):163-74.

14. Soldati G, Giunta V, Sher S, Melosi F, Dini C. "Synthetic" comets: a new look at lung sonography. Ultrasound Med Biol. 2011;37(11):1762-70.

15. Soldati G, Inchingolo R, Smargiassi A, Sher S, Nenna R, Inchingolo CD, et al. Ex vivo lung sonography: morphologic-ultrasound relationship. Ultrasound Med Biol. 2012;38(7):1169-79.

16. Volpicelli G, Elbarbary M, Blaivas M, Lichtenstein DA, Mathis G, Kirkpatrick AW, et al. International evidence-based recommendations for point-of-care lung ultrasound. Intensive Care Med. 2012;38(4):577-91.

17. Lee FCY. Lung ultrasound—a primary survey of the acutely dyspneic patient. Journal of Intensive Care. 2016;4(1):57.

18. Sim SS, Lien WC, Chou HC, Chong KM, Liu SH, Wang CH, et al. Ultrasonographic lung sliding sign in confirming proper endotracheal intubation during emergency intubation. Resuscitation. 2012;83(3):307-12.

19. Volpicelli G. Sonographic diagnosis of pneumothorax. Intensive Care Med. 2011;37(2):224-32.

20. Lichtenstein D, Mezière G, Biderman P, Gepner A. The "lung point": an ultrasound sign specific to pneumothorax. Intensive Care Medicine. 2014;26(10):1434-40.

21. Jambrik Z, Monti S, Coppola V, Agricola E, Mottola G, Miniati M, et al. Usefulness of ultrasound lung comets as a nonradiologic sign of extravascular lung water. Am J Cardiol. 2004;93(10):1265-70.

22. Volpicelli G, Mussa A, Garofalo G, Cardinale L, Casoli G, Perotto F, et al. Bedside lung ultrasound in the assessment of alveolar-interstitial syndrome. Am J Emerg Med. 2006;24(6):689-96.

23. Stewart GN. Researches on the Circulation Time and on the Influences which affect it. The Journal of physiology. 1897;22(3):159-83.

24. Brown LM, Liu KD, Matthay MA. Measurement of extravascular lung water using the single indicator method in patients: research and potential clinical value. Am J Physiol Lung Cell Mol Physiol. 2009;297(4):L547-58.

25. Uchino S, Bellomo R, Morimatsu H, Sugihara M, French C, Stephens D, et al. Pulmonary artery catheter versus pulse contour analysis: a prospective epidemiological study. Crit Care. 2006;10(6):R174.

26. Mihm FG, Feeley TW, Jamieson SW. Thermal dye double indicator dilution measurement of lung water in man: comparison with gravimetric measurements. Thorax. 1987;42(1):72-6.

27. Tagami T, Kushimoto S, Yamamoto Y, Atsumi T, Tosa R, Matsuda K, et al. Validation of extravascular lung water measurement by single transpulmonary thermodilution: human autopsy study. Crit Care. 2010;14(5):R162.

28. Bock JC, Lewis FR. Clinical relevance of lung water measurement with the thermal-dye dilution technique. The Journal of surgical research. 1990;48(3):254-65.

29. Agricola E, Bove T, Oppizzi M, Marino G, Zangrillo A, Margonato A, et al. "Ultrasound comet-tail images": a marker of pulmonary edema: a comparative study with wedge pressure and extravascular lung water. Chest. 2005;127(5):1690-5.

30. Enghard P, Rademacher S, Nee J, Hasper D, Engert U, Jorres A, et al. Simplified lung ultrasound protocol shows excellent prediction of extravascular lung water in ventilated intensive care patients. Crit Care. 2015;19:36.

31. Anile A, Russo J, Castiglione G, Volpicelli G. A simplified lung ultrasound approach to detect increased extravascular lung water in critically ill patients. Crit Ultrasound J. 2017;9(1):13.

32. Lichtenstein DA, Meziere GA. Relevance of lung ultrasound in the diagnosis of acute respiratory failure: the BLUE protocol. Chest. 2008;134(1):117-25.

33. Eichhorn V, Goepfert MS, Eulenburg C, Malbrain ML, Reuter DA. Comparison of values in critically ill patients for global end-diastolic volume and extravascular lung water measured by transcardiopulmonary thermodilution: a meta-analysis of the literature. Med Intensiva. 2012;36(7):467-74.

34. Sakka SG, Ruhl CC, Pfeiffer UJ, Beale R, McLuckie A, Reinhart K, et al. Assessment of cardiac preload and extravascular lung water by single transpulmonary thermodilution. Intensive Care Med. 2000;26(2):180-7.

35. Bendjelid K, Giraud R, Siegenthaler N, Michard F. Validation of a new transpulmonary thermodilution system to assess global end-diastolic volume and extravascular lung water. Crit Care. 2010;14(6):R209.

36. Hofer CK, Furrer L, Matter-Ensner S, Maloigne M, Klaghofer R, Genoni M, et al. Volumetric preload measurement by thermodilution: a comparison with transoesophageal echocardiography. British journal of anaesthesia. 2005;94(6):748-55.

37. Ostergaard M, Nielsen J, Rasmussen JP, Berthelsen PG. Cardiac output--pulse contour analysis vs. pulmonary artery thermodilution. Acta anaesthesiologica Scandinavica. 2006;50(9):1044-9.

38. Baldi G, Gargani L, Abramo A, D'Errico L, Caramella D, Picano E, et al. Lung water assessment by lung ultrasonography in intensive care: a pilot study. Intensive Care Med. 2013;39(1):74-84.

39. Zanobetti M, Poggioni C, Pini R. Can chest ultrasonography replace standard chest radiography for evaluation of acute dyspnea in the ED? Chest. 2011;139(5):1140-7.

40. Noble VE, Murray AF, Capp R, Sylvia-Reardon MH, Steele DJR, Liteplo A. Ultrasound assessment for extravascular lung water in patients undergoing hemodialysis. Time course for resolution. Chest. 2009;135(6):1433-9.

41. Lichtenstein D, Goldstein I, Mourgeon E, Cluzel P, Grenier P, Rouby JJ. Comparative diagnostic performances of auscultation, chest radiography, and lung ultrasonography in acute respiratory distress syndrome. Anesthesiology. 2004;100(1):9-15.

42. Volpicelli G, Caramello V, Cardinale L, Mussa A, Bar F, Frascisco MF. Detection of sonographic B-lines in patients with normal lung or radiographic alveolar consolidation. Med Sci Monit. 2008;14(3):CR122-8.

43. Flato U, Guimarães H, Petisco G, Bezerra F, Cavalcante A, Berwanguer O. Use of lung ultrasonography in the detection of pneumothorax among medical students and emergency physician. Crit Care. 2011;15(Suppl 2):P46.

44. Lim JS, Lee S, Do HH, Oh KH. Can Limited Education of Lung Ultrasound Be Conducted to Medical Students Properly? A Pilot Study. BioMed research international. 2017;2017:8147075.