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BRIEF REPORT

M Balik
P Plasil
P Waldauf
J Pazout
M Fric
M Otahal
J Pachl

Ultrasound estimation of volume of pleural fluid in mechanically ventilated patients

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P. Plasil · P. Waldauf · J. Pazout · M. Fric · M. Otahal · J. Pachl
University Hospital Kralovske Vinohrady, Department of Anaesthesiology and Intensive Care,
Šrobárova 50, 10034 Prague 10, Czech Republic

M. Balik (✉)
Westmead Hospital, Department of Intensive Care,
Westmead NSW 2145, Australia
e-mail: balik@fnkv.cz
Tel.: +61-2-98456064
Fax: +61-2-98458308

Abstract *Objective:* The aim was to develop a practical method for estimation of the volume of pleural effusion using ultrasonography in mechanically ventilated patients. *Design:* Prospective observational study. *Setting:* 20-bed general intensive care unit in the university hospital. *Patients and participants:* 81 patients were included after initial suspicion of pleural fluid on chest supine X-ray and pre-puncture ultrasound confirming effusion. Patients with thoracic deformities, post-lung surgery, with diaphragm pathology, haemothorax, empyema and with incomplete aspiration of pleural fluid on post-puncture ultrasound were excluded. *Interventions:* Patients were supine with mild trunk elevation at 15°. Probe was moved upwards in posterior axillary line, and transverse section perpendicular to the body axis was obtained with pleural separation visible at lung base. The maximal distance between parietal and visceral pleura (Sep) in end-expiration was recorded. Thoracentesis was performed at previous probe position and volume of pleural fluid (V) recorded. *Measurements and results:* 92 effusions were evaluated and drained; 11 (12%) were excluded for incomplete aspiration. Success rate of obtaining fluid under ultrasound guidance was 100%; the incidence of pneumothorax or bleeding was zero. Mean Sep was 35 ± 13 mm. Mean V was 658 ± 320 ml. Significant positive correlation between both Sep and V was found: $r = 0.72$; $r^2 = 0.52$; $p < 0.001$. The amount of pleural fluid volume can be estimated with the simplified formula: $V\,(\mathrm{ml}) = 20 \times \mathrm{Sep}\,(\mathrm{mm})$. Mean prediction error of V using Sep was 158.4 ± 160.6 ml. *Conclusions:* Easy quantification of pleural fluid may help to decide about performing thoracentesis in high-risk patients, although thoracentesis under ultrasound guidance appears to be a safe procedure.

Keywords Intensive care · Pleural effusion · Thoracentesis · Ultrasound diagnosis

Introduction

Chest sonography shows better sensitivity and reliability for diagnosis of pleural effusions than bedside chest X-Ray [1, 2, 3]. Ultrasound rules out other etiologies such as atelectasis, consolidation, mass, or an elevated hemidiaphragm, takes less time than radiographic methods and can be repeated serially at the bedside. Thoracentesis performed under ultrasound showed reduced rates of complications [4, 5, 6, 7]. When a radiologic image suggestive of effusion is not confirmed by the chest ultrasound, an unnecessary and potentially harmful thoracentesis can be avoided.

Fluid volume is an important factor when considering pleural drainage. In the case of a small amount of pleural fluid, the benefit of puncture should be weighed against risk of complications like pneumothorax or bleeding, particularly in patients on mechanical ventilation or thrombopenic patients [8]. Positive pressure ventilation changes pleural pressure and distribution of pleural fluid. Patients develop microatelectases in dependent areas, a fall in the functional residual capacity and a cranial displacement of the diaphragm [9, 10]. The maximum separation of pleural layers is observed in expirium, whereas, it is in inspirium in spontaneously ventilating patients. No published study [1, 11, 12] has provided a simple method for quantification of pleural effusions in mechanically ventilated patients.

Materials and methods

The data on 92 thoracenteses performed under ultrasound guidance in patients receiving mechanical ventilation and sedation were prospectively collected during 12 months of 2003 and 2004. Overall, 802 patients were admitted during this period. Patients were included after initial suspicion of pleural fluid on supine chest X-ray (blunting of the lateral costophrenic angle associated with an opacification covering at least the lower lobe) and pre-puncture ultrasonography confirming effusion. An interpleural distance of at least 10 mm was required to include a patient in the study. The inclusion was dependent on the presence of an intensivist experienced in chest ultrasound. The decision to perform thoracentesis was made on clinical grounds alone and was not protocol-driven. To eliminate the effects of possible deformations of pleural space, the authors excluded patients with thoracic deformities, post-lung surgery or with diaphragm pathology. Patients with the presence of empyema, haemothorax or presence of atelectasis without effusion on initial ultrasound examination were also excluded from the study.

Patients were investigated supine with mild trunk elevation at 15°. Ultrasound probe (intercostal probe, 2.5 Mhz, Image Point, Hewlett-Packard, Andover, MA, USA) was moved in cranial direction in posterior axillary line. The transverse section perpendicular to the body axis was obtained with pleural separation visible as an anechoic or hypoechoic layer between two pleural layers. The visceral layer moved during the respiratory cycles with an inspiratory decrease of the interpleural separation. The lung behind the pleural effusion appeared either aerated or consolidated in the case of large pleural effusions. The maximal distance between parietal and visceral pleura (Sep, Fig. 1) was measured off line at the lung base after freezing the image in end-expiration. The diaphragm, liver and spleen had to be clearly visualised before tap to avoid accidental puncture. The lung base is often consolidated and positioned posteriorly in the pleural cavity in ventilated patients. Thus, the maximum separation is frequently found between lung and lateral, rather than posterior, chest wall (Fig. 1). Thoracentesis was performed in a posterior axillary line at the previous probe position; however, it was not directly guided by ultrasound. The ultrasonographic measurements and drainages were performed by six intensivists; however, 48 (52%) of all effusions were taken by the first author. All of the researchers have 5–7 years of experience with echocardiography, and the first author has passed all required exams and is a candidate for European Accreditation of Transthoracic Echocardiography. All thoracenteses were therapeutic, i.e., aimed at draining the pleural space completely. Tap itself was achieved with a 14 G catheter-over-needle (77 effusions; 83.7%) or with intercostal drain of various size (15 effusions; 16.3%). The volume of fluid (V) was recorded and the tap was terminated when no more fluid could be removed. All patients with incomplete aspiration of pleural fluid who had separation of pleural layers of more than 5 mm on post-puncture ultrasound were excluded from the study. Pneumothorax was sought on post-puncture chest X-ray and on chest ultrasound by looking for the presence of anterior pleural sliding, which has negative predictive value of 100% [13].

Statistical analysis was performed using Statistica software, version 6.0. The data distribution was checked using Kolmogorov-Smirnov test showing normal distribution ($p = 0.1$ for pleural volume; $p = 0.06$ for pleural separation). Results are expressed as mean ± SD. Correlation between volume of pleural fluid and Sep was examined by linear regression (Pearson product moment correlation). The mean prediction error was calculated as the mean of the differences between the predicted and observed effusion volumes. Presence of complications was recorded. The impact of PEEP on the relationship between separation of pleural layers and volume of pleural fluid was studied using a test of homogeneity of slopes. The data from left and right pleural effusions [11] were compared using analysis of covariance.

The study included patients with primary indication for thoracentesis and was approved by the hospital ethics com-

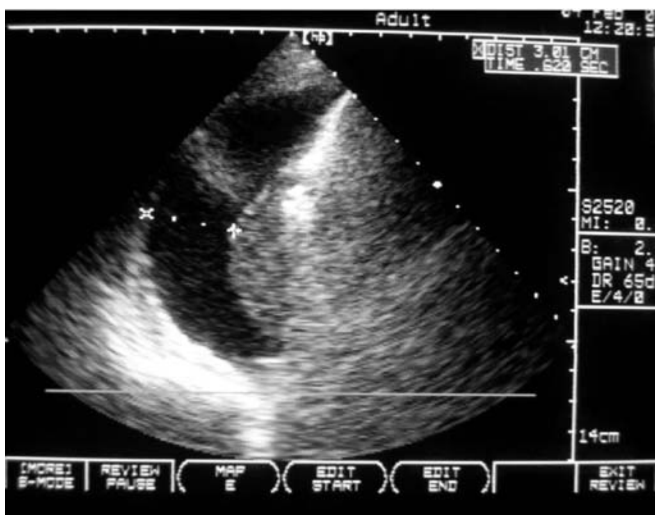

Fig. 1 Sep measurement (Sep maximal separation at lung base)

mittee. Informed consent was not required for the use of data already collected for clinical purposes.

Results

Ninety-two pleural effusions were evaluated, and 11 effusions (12%) were excluded for incomplete aspiration. A total of 81 (47 males and 34 females) mechanically ventilated patients were drained successfully under ultrasound guidance. The age of patients was 60 ± 15 years and the APACHE II score was 19.5 ± 7.1. The dominating causes of pleural fluid accumulation were left ventricular failure ($n = 20$; 24.7%), sepsis with volume overload ($n = 17$; 21%), right ventricular failure ($n = 11$; 13.5%), renal failure ($n = 13$; 16%), pneumonia and sepsis ($n = 6$; 7.4%), heart failure due to valvular dysfunction ($n = 6$; 7.4%), liver failure ($n = 5$; 6.2%) and acute pancreatitis ($n = 3$; 3.7%). The mean height and thoracic circumference were 172 ± 10 cm and 94 ± 10 cm, respectively. Forty-four effusions were right-sided and 37 left-sided.

Sep was 35 ± 13 mm; V was 658 ± 320 ml. Significant correlation was found between Sep and V ($r = 0.72$; $r^2 = 0.52$; $p < 0.001$; Fig. 2). The amount of pleural fluid volume can be calculated using Sep and the derived formula: $V = 18.3 \times \text{Sep} + 19.4$. For practical purposes the amount of pleural fluid can be estimated with the simplified formula: $V\,(\text{mL}) = 20 \times \text{Sep}\,(\text{mm})$. Mean prediction error of V using Sep was 149.3 ± 164.4 ml and 158.4 ± 160.6 ml from the simplified formula. Statistically significant correlations were found between V and thoracic circumference ($r = 0.30$; $p = 0.03$) and between V and height ($r = 0.31$; $p = 0.02$). No significance was found for correlations between Sep and thoracic circumference ($p > 0.05$) and between Sep and body height ($p > 0.05$). The overall incidence of pneumothorax or bleeding was zero.

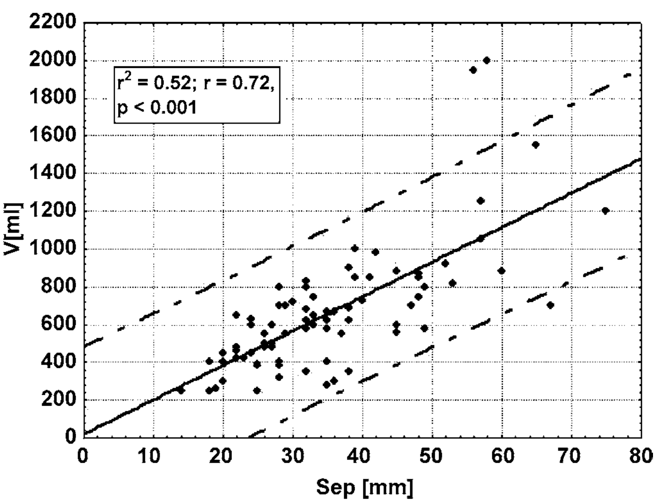

Fig. 2 The relationship between volume of pleural fluid (V) and maximum separation of pleural layers (Sep). Dashed lines represent 95% confidence bands

All patients were ventilated with Drager Evita 4 or Evita 2 devices. At the time of puncture, patients were on volume-control synchronized intermittent mandatory ventilation (SIMV; $n = 34$; 42%), pressure support ventilation (ASB, $n = 25$; 31%) and biphasic positive airway pressure ventilation (BIPAP; $n = 22$; 27%). Patients data were retrospectively divided, according to the level of PEEP, into the groups of less than 8 cm H_2O ($n = 15$; 18.5%), equal to 8 cm H_2O and higher, up to 12 cm H_2O ($n = 38$; 46.9%), equal to 12 cm H_2O and higher ($n = 28$; 34.6%). The impact of PEEP on the proposed relationship was insignificant ($r = 0.85$ for PEEP < 8; $r = 0.70$ for PEEP $8 \leq 12$; $r = 0.90$ for PEEP ≥ 12; $p = 0.34$). Comparison of left and right pleural effusions in terms of correlation with pleural separation did not show significant difference ($r = 0.74$ (L); $r = 0.71$ (R); $p = 0.46$).

Discussion

Ultrasound evaluation of pleural effusion is important in two ways: (1) it helps quantify the pleural fluid using the simplified formula $V\,(\text{ml}) = 20 \times \text{Sep}\,(\text{mm})$ and hence helps in deciding whether or not thoracentesis should be performed in high-risk patients; and (2) it provides visual guidance for thoracentesis. The complication rate in this study was zero. Our pneumothorax rate compares favourably with studies on ventilated patients by Lichtenstein [5] and is less than that reported by Mayo [6] or Fartoukh [4].

The authors excluded small pleural collections by excluding patients with pleural separation smaller than 10 mm on initial ultrasound examination. It was also suggested that the relationship may not be as linear and clinically important for pleural separations below 17 mm [1, 5, 11]. Potential sources of error were the variability of ventilator setting and variable mean airway pressures, regardless of the fact that the impact of PEEP was insignificant. These settings can be related to the degree of lung recruitment, and they modify the shape and size of pleural cavity. The volume can be underestimated, to a certain degree, due to lower lobe collapse in large effusions over 1,000 ml, which may lead to displacement of pleural fluid [1, 12]. Sonographic measurement is also influenced by the size of thoracic cavity. In large thoraces in tall people, the layer measured by ultrasound may cause underestimation of the actual volume of pleural fluid. The results could also be influenced by interobserver variability. The transducer must not be angled or tilted, which may result in a scan that is oblique to the transverse plane. Such measurement may produce overestimation of the effusion width.

Ultrasound performed at the bedside saved time, limited radiation and brought further savings on X-ray material. Adequate drainage of significant pleural effusions maintains low pleural pressure, keeps sufficient transpulmonary pressure and functional residual capacity at the cost of lower peak and plateau airway pressures in patients on mechanical ventilation [14, 15, 16].

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