Intensive Care Med (1984) 10:309–313

Intensive Care Medicine

Bedside estimation of extravascular lung water in critically ill patients: comparison of the chest radiograph and the thermal dye technique

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Accepted: 14 June 1984

Abstract. Extravascular lung water (EVLW) was estimated in 53 critically ill patients by the chest radiograph (CXR) and the thermal dye technique. The comparison between these two methods revealed a direct and positive correlation ($r = 0.83$, $p < 0.001$). However, EVLW-values obtained by the thermal dye technique showed considerable overlap between cases of radiographic low grade pulmonary edema and we were able to identify several reasons for radiographic over- or underestimation of EVLW. In these patients EVLW-measurement by the thermal dye technique provides additional information, thereby probably influencing further treatment.

Key words: Pulmonary edema – Chest X-ray – Extravascular lung water – Thermal-dye technique

Pulmonary edema is a common complication in critically ill patients [7, 8] and can be diagnosed by clinical examination, severe arterial hypoxemia, reduced pulmonary compliance and the appearance on the chest X-ray (CXR).

In pulmonary edema a shift of fluid from the intravascular to the extravascular space causes an increase in extravascular lung water (EVLW) and since the 1960s several methods for measurement of EVLW have been introduced ranging from plethysmographic to computertomographic and double indicator dilution techniques [15]. In 1962 Chinard described a double indicator dilution technique using two isotopes [3]. In such techniques the diffusible indicator can spread throughout the EVLW-space, whereas the non-diffusible indicator remains within the pulmonary circulation. Many of the conclusions gained with this method in the early seventies are still valid, i.e. the independence of EVLW and pulmonary shunting [6, 9, 12, 13], the good correlation that exists between EVLW and CXR-scoring [1, 2, 9, 12, 13] and similarly between EVLW and mean pulmonary artery pressure [2, 9].

The thermal dye technique is a more recent double indicator dilution technique for the bedside estimation of EVLW [10], using indocyanine green as the non-diffusible and heat as the diffusible indicator. With this method, the extravascular thermal volume of the lung is actually determined and this correlates closely with gravimetric determinations of EVLW [10, 11].

In some recent studies excellent correlation between the thermal dye technique and the CXR in estimation of EVLW has been reported [1, 12]. Others have, however, indicated difficulties in the radiologic estimation of EVLW, implying superiority of the thermal dye technique [13].

The aim of this study was (1) to compare the thermal dye technique to the CXR in estimating EVLW in critically ill patients; (2) to identify the discrepancies between CXR and EVLW-values; (3) to compare EVLW-values, hemodynamic and functional pulmonary data, and respiratory treatment in three groups with different CXR findings.

Material and methods

Patient population and modes of treatment

53 consecutive critically ill patients (14 women and 39 men), aged 19 to 87 years, were hospitalized for various non-cardiac ($n = 44$) and cardiac ($n = 9$) reasons, requiring invasive hemodynamic monitoring. The indications for intubation included impaired consciousness or the need of bronchial toilet or the need for mechanical ventilation. The FiO_2 was selected to maintain a PaO_2 above 70 mm Hg. For mechanical ventila-

tion a volume cycled ventilator was used with a tidal volume of 10 to 15 ml/kg. The respiratory rate was adjusted to maintain the $PaCO_2$ between 35 and 45 mm Hg. PEEP was used in some patients (Table 2) and was not expected to influence the data of this study since PEEP has negligible effects on the accumulation of EVLW [12]. The PCWP was assumed to represent the microvascular pressure, though this ignores the possibility of downstream resistance, which may be a negligible consideration in patients with pulmonary edema. Levels of PEEP of 12 cm H_2O are unlikely to interfere with PCWP as a reflection of the left atrial pressure. We did not use a PEEP above 10 cm H_2O, therefore, we did not measure the oesophageal pressure to calculate the transmural PCWP [12].

Eleven patients were studied as soon as possible after admission when essential therapy for the underlying illness guaranteed stable hemodynamics. No diuretic therapy was administered within 8 h before the measurements were made.

Measurements

For the measurement of extravascular lung water (EVLW) a flow directed Swan-Ganz catheter (Edwards Laboratories, California, USA) was placed in the pulmonary artery and a thermistor-tipped single lumen catheter (Edwards Laboratories) was inserted into the left or right femoral arteries. EVLW was measured by injection of 10 ml of iced 5% dextrose solution containing 5 mg of indiocyanine green dye into the proximal port of the Swan-Ganz catheter. Green dye concentration was measured by aspiration of femoral artery blood through a cuvette at 30 ml/min (Waters Instrumentation, California, USA). Withdrawn blood was reinfused at the end of each measurement. Thermal and green dye signals were digitized by a small bedside microprocessor (Model 9310, Lung Water Computer, Edwards Laboratories) and EVLW was computed as the product of the thermodilution flow times the difference in mean transit times of the thermal and green dye curves. At least three sequential EVLW measurements were made; their mean value was recorded as the actual EVLW value and expressed as ml/kg of the initial body weight. The coefficient of variation (CV) of these measurements ranged from 8 to 12%, measurements with a CV greater than 15% were repeated. The results of these measurements were compared to the chest radiographs taken within 1 h of the EVLW-measurement.

A-P chest radiographs were taken in the supine position with a portable unit (Condiamobil, Siemens, Austria). Interpretation of the radiographs was performed by two independent radiologists, without knowledge of the hemodynamic parameters and EVLW-values, according to recently published criteria [8, 12]: Score 0 = no edema; Score +1 = perivascular haziness and hilar indistinction; Score +2 = reticulo-nodular patterns septal lines, vascular obliteration, and bronchial cuffing; Score +3 = bilateral acinar pattern ("patchy infiltrates"), and air space consolidation.

Swan Ganz catheters were used for the measurement of mean pulmonary artery (PP), pulmonary capillary wedge (PCWP), and central venous (CVP) pressures, for collection of mixed venous blood samples, and thermodilution cardiac output (CO) measurements. Blood gas analysis and oxymetry were performed using the IL 1303 and IL Co-oxymeter 282 (Instrumentation Laboratory, USA). Venous admixture (Qs/Qt) and alveo-arterial oxygen difference/fraction of inspired oxygen ($AaDO_2/FiO_2$) were calculated according to established formulae [12]. Colloid-osmotic pressure (COP) was measured in plasma samples by the Oncometer BMT 921 (Thomae, FRG) and the difference COP – PCWP was calculated. Pulmonary vascular restistance (PVR) was calculated with the formula:

$$PVR = \frac{PP - PCWP}{CO} \times 79.9 \text{ dyn} \cdot \text{s} \cdot \text{cm}^{-5}.$$

For statistical evaluation all individual EVLW-values, which were the first values obtained after admission, were correlated to the corresponding radiographic scores. According to the scores three groups were formed and the different parameters were compared amongst these three groups using analysis of variance and Scheffé's test.

Results

Comparison of the thermal dye technique to the CX in estimation of EVLW (Fig. 1)

In 23 patients (43%) there was no radiographic evidence of pulmonary edema (score 0); EVLW-values ranged from 2.3 to 9.3 ml/kg ($\bar{x} = 5.5$, SD = 1.9 ml/kg). Eleven patients (31.4%) developed a +1 score; EVLW-values ranged from 6.2 to 13.7 ml/kg (mean 9.2, SD 2.3 ml/kg). Six patients (11.3%) developed a +2 score; EVLW-values ranged from 6.0 to 14.0 ml/kg (mean 10.8, SD 3.4 ml/kg). Thirteen patients (24.5%) developed a +3 score. EVLW-values ranged from 11.9 to 24.4 ml/kg (mean 15.5, SD 3.2 ml/kg). Linear regression analysis revealed a significant positive correlation between CXR-score and the EVLW-values ($y = 5.56 + 3.19x$; $r = 0.836$; $p < 0.001$).

Table 1. Reasons for over- or underestimation of EVLW by CXR

Reason	No. of patients
Underestimation of EVLW by CXR	
Obstructive airways disease	2
Mechanical ventilation with PEEP	1
Upper airway obstruction	1
Total	4
Overestimation of EVLW by CXR	
Acute bronchitis (bacterial)	1
Hypoinflation	2
Pleural effusions	1

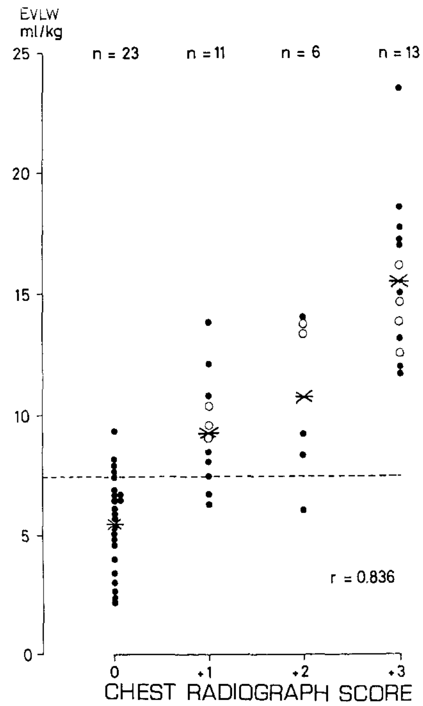

Fig. 1. Correlation of the extravascular lung water (EVLW) in ml/kg body weight and the chest radiograph score ranging from 0 (= no edema) to +3 (= bilateral patchy infiltrates); n = number of patients, r = coefficient of correlation; ● = patients with non-cardiac, ○ = patients with cardiac pulmonary edema; ⋊ = mean values

Discrepancies between CXR and EVLW-values (Table 1)

Accepting an upper normal EVLW-value of 7.4 ml/kg [12], 4 patients with a CXR-score 0 had elevated EVLW-values; 2 of them suffered from chronic obstructive airways disease, 1 patient was ventilated with 3 cm H_2O PEEP and 1 patient had a pulmonary hyperinflation due to upper airway obstruction by laryngeal carcinoma. Three patients with CXR-score +1 and 1 patient with CXR-score +2 had EVLW-values within the normal range. One of them suffered from acute bacterial bronchitis, 2 patients had hypoinflated lungs due to massive ascites and diaphragmatic elevation, and 1 patient had bilateral pleural effusions.

Comparison of EVLW-values, hemodynamic and functional pulmonary data, and respiratory treatment modalities in three groups of different CXR-scores (Table 2)

For this comparison the data of CXR-score +1 and CXR-score +2 patients were pooled. The comparison of CXR-score 0, (+1, +2), and +3 patients revealed a significant difference between all three groups only for the EVLW-values ($p<0.01$). PP, PCWP, $AaDO_2/FiO_2$, Qs/Qt, number of patients ventilated and number of patients on PEEP, and FiO_2 showed a significant difference between CXR-score +3 vs CXR-score 0 and (+1, +2). No difference was found

Table 2. EVLW-values, hemodynamic and functional pulmonary data, and respiratory treatment in three groups of different CXR-scores

	CXR-score 0 $n = 23$	CXR-score (+1, +2) $n = 17$	CXR-score +3 $n = 13$
Age years	49.7 ± 15.6	54.8 ± 14.4	43.2 ± 16.4
EVLW ml/kg	5.5 ± 1.9[b, c]	9.8 ± 2.7[b, c]	15.5 ± 3.2[b]
PP mm Hg	19.9 ± 5.8[b]	23.5 ± 5.3[b]	27.3 ± 7.6[b]
PCWP mm Hg	10.3 ± 4.7[b]	13.7 ± 4.1[b]	16.3 ± 7.7[b]
COP-PCWP mm Hg	8.0 ± 9.2	3.9 ± 4.4	4.8 ± 6.4
CVP mm Hg	6.7 ± 4.5	6.9 ± 3.1	9.1 ± 3.3
PVR dyn · s · cm^{-5}	112.7 ± 45.4	124.1 ± 64.2	125.0 ± 60.0
Qs/Qt %	23.4 ± 12.0[a]	20.0 ± 8.1[a]	33.0 ± 16.3[a]
$AaDO_2/FiO_2$ mm Hg	255.4 ± 152.9[b]	306.8 ± 111.8[b]	440.3 ± 138.5[b]
No. of patients ventilated (%)	2 (26)[b]	5 (29)[b]	9 (69)[b]
No. of patients on PEEP (%)	2 (8)[b]	4 (23)[b]	9 (69)[b]
PEEP cm H_2O	1.6 ± 3.0[b]	4.3 ± 3.8[b]	7.8 ± 3.3[b]
FiO_2	0.29 ± 0.18[b]	0.33 ± 0.20[b]	0.57 ± 0.26[b]

Values are expressed as mean ± standard deviation. [a] $p < 0.05$; [b] $p < 0.01$ for comparison of CXR-score +3 vs score 0 and score (+1, +2); [c] $p < 0.01$ for comparison of CXR-score 0 vs CXR-score (+1, +2) between the three groups for age, COP-PCWP, CVP, and PVR.

Discussion

In this study we have compared two methods for the bedside estimation of EVLW in critically ill patients – the CXR and the thermal dye technique. The CXR is somehow insensitive in the detection of increase of EVLW as radiographic signs of pulmonary edema only occur after a 35% increase of EVLW [14]. As the CXR in these patients has to be performed at the bedside, technical problems might arise causing interpretative difficulties in up to 37% of the CXR films [5]. Treatment with diuretics is also reported to cause problems with radiographic interpretation ("phase lag"), for several hours after administration [12]. Despite all these problems the CXR is the standard method for estimating EVLW, and therefore the newer thermal dye method had to be compared to it. To avoid problems with the CXR interpretation, the films were taken in a standardized manner and repeated if interpretative difficulties arose. To avoid "phase lag" phenomena no diuretics were administered for 8 h before EVLW estimation by the two methods. We found a direct and positive correlation between the CXR-scores and the EVLW-values ($r = 0.83$), which accords with Sibbald's data, which showed a direct and positive correlation between these two methods in both cardiac ($r^2 = 0.44$) and non-cardiac ($r^2 = 0.59$) pulmonary edema [12]. As the number of our cardiac patients was small (Fig. 1), we were not able to confirm Sibbald's results for this group. In another clinical study in trauma patients with respiratory failure a direct and positive correlation between CXR-score and EVLW-values was found ($r = 0.62$ [1]). Therefore, our results accord with recently published data and show a direct and positive correlation between CXR-scores and EVLW-values.

Accepting an upper normal EVLW-value as introduced by Sibbald and assuming that our EVLW-values were not influenced by derecruitment of the pulmonary vasculature [6, 12], we could identify patients with radiographic over- or underestimation of EVLW. We found that pulmonary hyperinflation due to mechanical ventilation with PEEP, chronic obstructive airways disease, and upper airway obstruction caused radiographic underestimation of EVLW. Similar observations have been reported by Zimmerman et al., who explained the dramatic improvement of the CXR that follows PEEP by a further marked increase in lung volume [16].

Bronchial infection, pleural effusion, and hypoinflation of the lungs caused a radiographic overestimation of EVLW. Similar problems produced only 64% accuracy in the initial CXR estimation of elevated EVLW, which lead to the conclusion that the thermal dye technique was superior to the CXR in the estimation of EVLW [13]. Our results do not support the superiority of any of these methods, but suggest that the EVLW estimation by the thermal dye technique in radiographic low grade pulmonary edema (score +1 and +2) may provide additional information thereby probably influencing treatment with diuretics or fluids.

A considerable overlap and no significant difference could be found between the EVLW-values of CXR-score +1 and CXR-score +2. Therefore, and because of the small number of patients in these groups we summarized the data of these groups for comparison with the data of patients with CXR-score 0 and CXR-score +3. Only for the EVLW-values could statistical differences be found between all three groups, again suggesting a close correlation of CXR-score and EVLW thermal dye measurement. PP, PCWP, $AaDO_2/FiO_2$ and Qs/Qt values were significantly higher in CXR-score +3 than in the other scores. Patients with score +3 also required mechanical ventilation more often, significantly higher levels of FiO_2 and PEEP than the two other groups. These results indicate that patients with a score +3 had higher pulmonary artery and wedge pressures, more severe impairment of gas exchange and required special respiratory treatment more often. As we found no difference in the PVR values of the three groups, we rule out any influence of derecruitment of the pulmonary vasculature on our EVLW measurements, which has been reported to cause troubles with the EVLW determination [6].

Our study confirmed a direct and positive correlation between the CXR-score and the EVLW-values by the thermal dye technique. EVLW-values, however, showed considerable overlap in cases of radiographic low grade pulmonary edema, and we were able to identify several reasons for the radiographic over- or underestimation of EVLW. In these patients EVLW-measurement provides additional information, thereby probably influencing further treatment. Patients with severe pulmonary edema had higher EVLW-values, higher pulmonary artery and wedge pressures, more severe impairment of gas exchange, and required more often a special respiratory treatment than patients without or with low grade pulmonary edema.

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