Thoracic duct lymph and PEEP studies in anaesthetized dogs

II. Effect of a thoracic duct fistula on the development of a hyponcotic-hydrostatic pulmonary oedema

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Received: 15 March 1986; accepted: 2 October 1986

Abstract. PEEP impedes thoracic duct drainage (LF). This can be counteracted by a thoracic duct fistula. Consequently, lung oedema (LOE) should develop during PEEP more slowly with LF at atmospheric pressure (LF Ap) than with LF against jugular venous pressure (LF JVP). In 12 anaesthetized dogs LOE was produced by Ringer’s solution i.v. (2.5 ml/min per kg) for 6 h during PEEP (10 mmHg) with either LF Ap or LF JVP. Ringer’s + PEEP greatly increased aortic, pulmonary artery and wedge pressures, JVP, and cardiac output. Colloid osmotic pressures in plasma and lymph were drastically reduced, pulmonary effective filtration pressure (EFP) rose by about 20 mmHg. LF JVP increased 7-fold, LF Ap about 19-fold, the respective loss of plasma proteins was 1.83 and 1.06 g/kg during 6 h. Thermal-dye extravascular lung water showed an increment of 68 with LF JVP versus 43 µl/h/g per mmHg with LF Ap. Final lung water content was at any AEFP (12.8–31.9 mmHg) lower with LF Ap than with LF JVP, amounting 12.8 with LF JVP versus 377 µl/g per mmHg with LF Ap. LF Ap decreased the development of LOE during PEEP by bypassing the PEEP-induced high JVP and thus facilitating the removal of interstitial fluid. It is hypothesized that a thoracic duct fistula might aid the treatment of patients with LOE due to ARDS and therefore requiring high levels of PEEP.

Key words: Positive end-expiratory pressure ventilation — Pulmonary oedema — Thoracic duct drainage — Thoracic duct fistula — Lymph flow

Since Ashbaugh et al. [1] demonstrated in 1967 that ventilation with positive end-expiratory pressure (PEEP) in the adult’s respiratory distress syndrome (ARDS) improves pulmonary gas exchange, PEEP is commonly used in the treatment of lung oedema. The effects of PEEP on lung water, however, are still quite controversial [22, 25]. In experimental studies, lung water accumulation has been reported to be reduced [5], aggravated [3, 32], or unaffected by PEEP [2, 10, 14, 24]. Theoretical considerations as well as experimental data show that PEEP affects pulmonary transvascular fluid movement in both directions depending on the accompanying changes in transpulmonary airway and transpulmonary vascular pressures [19]. PEEP, however, might not only influence transvascular fluid movement but also the removal of extravascular fluid by the lymphatics. In a preceding paper [7] it has been demonstrated that PEEP disturbs the intra- to extravascular fluid balance by augmenting the lymph production and impeding the lymph drainage, both effects being brought about by the elevated venous pressure. Creating a thoracic duct fistula during PEEP causes an immediate and sustained enhancement of thoracic duct lymph flow. It can be concluded from these data that a thoracic duct fistula should delay the development (or improve the removal) of lung oedema during PEEP, because about 50% of the lung lymph is drained by the thoracic duct [27]. This hypothesis was tested in anaesthetized dogs by assessing the development of a hyponcotic-hydrostatic lung oedema during PEEP with the thoracic duct draining either against the jugular venous pressure or freely at atmospheric pressure. If a thoracic duct fistula indeed promotes the removal of extravascular lung water, this might be of major importance in patients who have to be ventilated with PEEP because they are suffering from pulmonary oedema due to ARDS.
Materials and methods

Animals, anaesthesia, surgical procedures

The data were obtained from 12 mongrel dogs of both sexes, body weights 24.0–32.0 kg. The animals were pretreated by a phenothiazine derivative (Combelen, Bayer; 0.1 ml/kg i.m.). Anaesthesia was induced by pentobarbital (Nembutal, Abbott; 12 mg/kg i.v.) and maintained by piritramide infusion (Dipidolor, Janssen; 0.4 mg/kg per h). The animals were paralyzed by pancuronium bromide (Pancuronium, Organon; 2–4 mg/h) and artificially ventilated (f = 15 min⁻¹) via an endotracheal tube with O₂:N₂O = 1:1 at an appropriate tidal volume (10–15 ml/kg) to adjust PCO₂ to 35–40 mmHg. Catheters were placed into the aorta, right atrium, vena cava superior, and external jugular veins from a neck incision. A PVC-tube was tied into the thoracic duct at the venous angle. The pleura was not injured. A 7F-Swan-Ganz catheter ( Edwards Laboratories) was floated into the pulmonary artery from the femoral vein.

Measurements

Aortic (AoP), pulmonary artery (PAP), central venous (CVP), jugular venous (JVP), and airway pressures were measured by strain gauge transducers (Statham, P23Db) and continuously recorded on a multichannel recorder (Gould Inc.). Thoracic duct lymph flow (LF) was measured using a previously described arrangement [7], which allowed the thoracic duct to drain either against the pulsatile jugular venous pressure or at atmospheric pressure (AP). The lymph was sampled into graded tubes during 30-min periods and was returned i.v. thereafter. An aliquot of 1 ml was taken for analysis. If the lymph flow exceeded 50 ml/30 min, the lymph was sampled in 50-ml fractions, an appropriate aliquot was taken from each fraction, and the lymph was then returned to avoid major changes in plasma volume. Blood samples (2 ml) were taken and protein concentration (Biuret-method) and colloid osmotic pressure (COP, Onkometer, Fa. Thomae) were measured in plasma (p) and lymph (l). The total amount of removed plasma and lymph for analyses was about 30 ml for the whole experiment.

Cardiac output (CO) and extravascular lung water (EVLW) were determined simultaneously by the thermal-dye method usually in triplicate. A dye bolus (0.025 mg/kg Cardio-Green, Hynson, Westcott & Dunning) was flushed into the right atrium by iced glucose 5%; blood was withdrawn from the aortic arch by a constant flow pump (40 ml/min) through an external cuvette densitometer via a catheter with an internal thermistor at the tip. The blood was returned to the animal immediately after the measurement. CO was computed electronically (HMV-Computer, Regatron AG) from the dye dilution curve. The thermal (th) and dye (d) analog signals were simultaneously recorded on a direct writing system. The appearance time of the dye was corrected for the time delay from the tip of the catheter to the densitometer. On a desk computer (Hewlett Packard 9845B), the dye and thermal dilution curves were digitized and converted into logarithms, the monoexponential decays were extrapolated over 3 decades, the mean transit times (MTT) were calculated, and the EVLW was computed from EVLW = CO(MTTth−MTTd) [12].

At the end of the experiment, the lungs were removed and the residual blood drained by gravity and gentle milking. Final lung water content (FLW) and lung dry weight (LDW) were determined by weighing the lungs before and after drying to constant weight at 80°C.

Effective pulmonary filtration pressure (EFP) was calculated from EFP = (PCWP + 0.4(PAP-PCWP) − COPp + COPl) in analogy to Demling et al. [3] (PCWP = pulmonary capillary wedge pressure). The change in EFP (ΔEFP) was calculated as the difference of mean EFP during control (c) and experimental (e) period ΔEFP = EFPc − EFPe. EVLW gain (ΔEVLW) was calculated as the slope of EVLW vs. time (bₜₜ) (Fig. 2) and related to lung dry weight and change in EFP to take into account the lung size and driving force of capillary filtration, thus yielding ΔEVLW = bₜₜ·LDW⁻¹·ΔEFP⁻¹. Similarly, final lung water was related to lung dry weight and ΔEFP.

Plasma volume (PV) was determined by indocyanine green. A bolus of 0.1 mg/kg was injected intravenously. Plasma concentration was measured from the 5th to 10th min after injection and extrapolated to time = 0 from the monoexponential decay. Transcapillary plasma protein net loss was calculated from plasma volume and plasma protein concentration at the beginning and the end of the experiment.

Experimental protocol

The thoracic duct drained in one group against JVP (n = 6) and in the other group at AP (n = 6). Lymph flow was determined during 30 min periods. At the midpoint of each period a blood sample was taken and the PCWP recorded. EVLW and PV were measured hourly. After a control period of at least 1 h, Ringer’s solution (37°C) was infused intravenously at a rate of 2.5 ml/min per kg. With the start of the volume load the endexpiratory pressure was augmented to 10 mmHg (PEEP). The experiments were terminated after 6 h volume loading.