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EDITORIAL

Monitoring esophageal pressure

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Esophageal pressure (Peso) has been extensively validated as an estimate of pleural pressure (Ppl). The esophagus is a compliant structure whose rostral–caudal course traverses near the cross-sectional center of the thorax. Thus, the pressure inside the mid-thoracic retro-cardiac esophagus can be utilized to assess the extra-pulmonary intrathoracic pressure. Peso monitoring allows us to estimate trans-pulmonary pressure (P_L), defined as the difference between pressure measured in the airway (Paw) and Ppl. P_L represents the "true" distending pressure of the lung and is of major importance when considering the risk of ventilator (or patient self)-induced lung injuries [1]. Peso also allows us to assess lung and chest wall elastance independently, thus determining the proportion of the respiratory system distending pressure that is needed to expand the lung and chest wall [2]. In spontaneously breathing patients, Peso measurement also allows quantification of respiratory muscle effort and monitor patient ventilator synchrony [2].

Practically, Peso is measured using a dedicated naso- or orogastric catheter equipped with an air-filled balloon connected to a pressure transducer. Though some Peso catheters include an extra lumen for enteral feeding, insertion of a dedicated Peso catheter adjacent to a feeding tube does not typically interfere with measurement [3]. An intensive care unit (ICU) ventilator with an embedded auxiliary pressure port can ideally be used to simultaneously display the Peso and Paw time curves. As alternatives, dedicated devices or even standard ICU monitors (with proper unit conversion from mmHg to cmH_2O) may be used [4]. The esophageal balloon must be carefully placed in the retro-cardiac esophagus, above the gastroesophageal junction (typically 35–40 cm between the nostril or lip and the end of the balloon) and filled with air. Important steps should be completed to ensure Peso measurements reliability [2]. To exclude accidental malpositioning within the airway, inspection of the Peso tracing should confirm it does not appear like the Paw waveform. In passive patients, a gradual, low magnitude rise in Peso during passive insufflation is expected, whereas in actively breathing patients, negative deflection indicative of patient inspiratory effort is observed. Cardiac oscillations in Peso support correct balloon placement. To confirm adequate positioning in the chest, an occlusion test must be performed to verify that changes in Peso amplitude (induced either by a gentle chest compression in passive patients or a patient inspiratory effort) are similar to those measured in Paw during a ventilator circuit occlusion. A ΔPeso/ΔPaw ratio of 0.8–1.2 confirms adequate balloon placement. In addition, to obtain reliable absolute Peso values, some groups advocate adjusting the volume of air insufflated in the balloon to achieve the maximum change in Peso between end-inspiration and end-expiration. Since the dynamic and static tidal variations of Peso are very similar, for clinical purposes, the procedure can be performed without occlusion maneuvers at each filling step simply by observing the tidal variation in Peso [4]. Figure 1 illustrates the steps to obtain reliable Peso values.

Peso measurements are often interpreted directly as estimates of Ppl (i.e., Peso = Ppl), but the weight of the mediastinum and the compliances of esophagus and balloon may introduce some imprecision [5]. To overcome this limitation, some authors proposed to estimate P_L assessing the amount of applied Paw spent to inflate the lung and to displace the chest wall using the lung to respiratory system elastance ratio (E_L/E_{RS}) with $P_L = \text{Paw} \times E_L/E_{RS}$ [6]. This elastance ratio-based strategy is nevertheless based on the questionable assumption that Ppl is equal to 0 at functional residual capacity [7]. Important non-clinical studies suggested that directly measured Peso reliably reflects Ppl and thus P_L in the dependent

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Esophageal pressure (Peso) monitoring in ARDS

PREPARE AND CHECK

1. Position the balloon in the retrocardiac esophagus (usually 35-40 cm from the nostrils or lip to the end of the balloon). Check mouth to exclude coiling of catheter in posterior oropharynx.
2. Fill the balloon with air (manufacturer's volume to start) and inspect Peso tracing for cardiac oscillations suggestive of correct position behind the heart.
3. Perform an airway occlusion test and monitor the Peso- and Paw-time waveforms to evaluate for correct positioning as follows:
   a) Press on the thorax (slow, bilateral, symetric compression during 3 to 4 seconds followed by gentle release). Alternatively, if the patient is actively breathing, wait for a patient's inspiratory effort.
   b) Measure maximum simultaneous change in Peso and Paw and compute ΔPeso/ΔPaw. Target 0.8-1.2. If ok, start the measurements. If not, reposition the balloon from 0.5 to 1 cm, then recheck.
4. Carefully titrate the volume of air in the balloon to obtain the maximal variation of Peso amplitude during tidal ventilation.

USE

- Measure direct end-expiratory PL (= Total PEEP – Peso) with an occlusion and titrate PEEP for end-exp PL = 0-2 cmH_2O.
- Measure end-inspiratory PL with the direct technique (= Pplat – Peso) and check that PLdirect < 15 cmH_2O. If not, consider decreasing VT and/or PEEP.
- Measure end-inspiratory PL with the elastance ratio based strategy (PL= Paw x EL/ERS) then check that PL measured this way < 20 cmH_2O. If not, consider decreasing VT and/or PEEP.

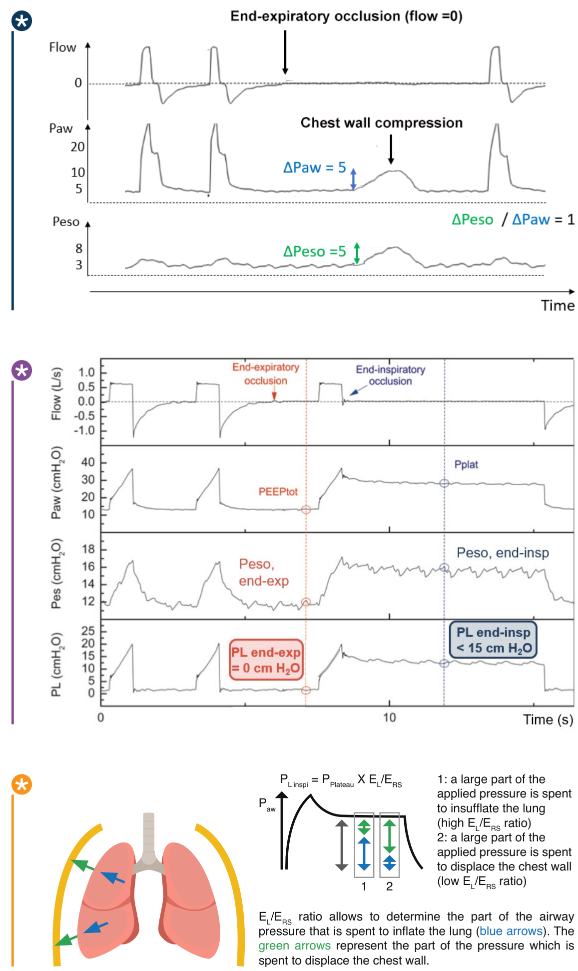

Fig. 1 Esophageal pressure (Peso) monitoring during Acute respiratory distress syndrome (ARDS). *Peso* esophageal pressure, *Paw* airway pressure, *PEEP* positive end-expiratory pressure, *PL* trans-pulmonary pressure, *Pplat* plateau pressure, *VT* tidal volume, *EL* lung elastance, *ERS* respiratory system elastance, *End-inspi* end-inspiration, *End-exp* end-expiration. Target values mentioned in the figure are indicative as optimal values still have to be determined by further studies

lung regions [8], whereas the elastance ratio-based strategy better estimates P_L in the non-dependent regions of the lungs.

P_L measurements can be used to set positive end-expiratory pressure (PEEP) and/or tidal volume (VT) in patients with acute respiratory distress syndrome (ARDS) with the goal of individualizing lung protective ventilation (Fig. 1). As direct measurements are considered to represent P_L in the dependent lung regions, some authors proposed to titrate PEEP for P_L at end-expiration (direct measurement) between 0 cmH_2O and 2 cmH_2O, to avoid lung collapse in these regions. In a preliminary randomized controlled study, such a strategy (where PEEP was set to target expiratory P_L between 0 cmH_2O and 10 cmH_2O according to a FiO_2/P_L table) led to higher PEEP levels than a classical PEEP/FiO_2 table and was associated with better oxygenation and respiratory system compliance [9]. A larger randomized controlled trial however failed in demonstrating better outcome with a similar Peso-guided strategy targeting expiratory P_L between 0 cmH_2O and 6 cmH_2O, compared to a more aggressive PEEP/FiO_2 Table [10]. Post hoc analyses suggest that the P_L targets used in these trials may have caused over-distension in some patients. The inspiratory P_L, a measure of the maximal stress applied to the lungs during inspiration, measured with the direct technique was permitted to reach 20 cmH_2O, which is roughly the lung stress experienced at total lung capacity in healthy adults and thus quite high. A post hoc reanalysis of the larger trial suggested that expiratory P_L between − 2 cmH_2O and 2

cmH_2O was associated with decrease in mortality [11]. Titrating PEEP to achieve slightly positive expiratory P_L may be particularly beneficial in obese patients [12, 13] in whom Ppl is often high [13]. Once PEEP is set to reach the target end-expiratory P_L, VT can be individualized to keep end-inspiratory P_L or lung driving pressure (ΔP_L, computed as end-inspiratory minus end-expiratory P_L within a safe range. Limits of respectively 15 cmH_2O and 12 cmH_2O can be proposed even if optimal values still must be determined).

Because the elastance ratio-based P_L reflects P_L in the non-dependent lung regions, where over-distension occurs, this measurement has been suggested to titrate PEEP to the maximal possible value while checking for over-distension (maximal P_L value accepted). This strategy allowed to avoid ECMO in 7/14 patients suffering from influenza A H1N1 associated ARDS targeting an elastance ratio-based inspiratory P_L of 25 cmH_2O [14]. This led to very high PEEP associated with plateau pressure (P_{Plat}) often higher than 30 cmH_2O. The stress applied to the lung was however considered as "safe", as end-inspiratory P_L was controlled. Given the preponderance of data suggesting that over-distension can cause clinically significant lung injury, we nevertheless recommend maintaining inspiratory P_L well below 20 cmH_2O (direct measurements) or 25 cmH_2O (elastance ratio-based measurements) even if this hypothesis has not been formally tested. In fact, the safe range for inspiratory P_L and for ΔP_L warrants clinical studies.

Peso measurements also provide information of major interest during assisted ventilation. It allows us to identify start and end of the inspiratory effort and is thus a sensitive tool to detect patient ventilator asynchronies, particularly ineffective efforts and reverse triggerings, and to optimize ventilator settings to improve synchrony [2]. In addition, Peso monitoring allows precise measurement of inspiratory effort intensity. Peso decrease in amplitude during tidal ventilation is proportional to the intensity of the effort and the maximal pressure generated by the inspiratory muscles during a breath can easily be computed as ΔPeso plus the component needed to expand the chest wall [2]. For physiological studies, the pressure time product and the work of breathing are often used to quantify inspiratory effort more precisely [2]. Bedside effort monitoring using Peso can be used to optimize the amount of support and PEEP during assisted ventilation to keep the effort in an acceptable range that however still has to be determined with further studies [15].

In summary, Peso is a well-validated bedside tool that can help individualize mechanical ventilation to each patient's unique respiratory system characteristics both during controlled and assisted ventilation. In practice, it can be used to set PEEP and to monitor for occult excessive lung stress. In specific situations, this allows us to safely exceed conventional limits on PEEP and plateau pressure. It also provides help assessing patient ventilator synchrony and respiratory effort to optimize assisted ventilation.

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Declarations

Conflicts of interest

LP reports lecture and travel fees from Hamilton Medical, Getinge, Air Liquid medical system, Löwenstein and Fisher and Paykel, all unrelated to this work. LP reports consulting fees from Löwenstein and Getinge, unrelated to this work. JRB reports consulting fees Arrowhead, Biomarck, Global Blood Therapeutics, Hamilton Medical, Mezzion, Sedana Medical, and Stimit within the past year, all unrelated to this work. JRB reports support from the US National Institutes of Health (Grants R01-HL168102, UG3-HL166785) related to this work. FB reports consulting fees from Löwenstein Medical and ALMS, travel fees from ALMS and Draeger and research support from Covidien and Getinge Group, outside this work.

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