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WHAT'S NEW IN INTENSIVE CARE

Ten tips to facilitate understanding and clinical use of esophageal pressure manometry

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Introduction

Esophageal pressure (P_{es}) is a valid surrogate for pleural pressure (P_{pl}) that has been shown to be a useful parameter for more than 50 years of research. One application is to measure transpulmonary pressure (P_L), which is the distending pressure of the lungs; another application is the assessment of patient effort when the respiratory muscles are active. The recent LUNG SAFE international study revealed that P_{es} was employed in less than 1% of patients with acute respiratory distress syndrome (ARDS) [1]. There is, therefore, a large potential for the inclusion of esophageal manometry in clinical practice. Here, we present and describe ten tips to be taken into account to adequately measure and interpret P_{es} in patients with ARDS.

Tips to facilitate understanding and clinical use of esophageal pressure manometry

1. *Understand the introduction technique.* There are several commercially available esophageal balloons [2]. All types of esophageal balloon are introduced trans-nasally (≈ 55 cm) or orally (≈ 40 cm) until the stomach is reached and then inflated with adequate volume. The balloon is then withdrawn until cardiac artifacts appear on the pressure tracings, indicating that the site of pressure measurement (balloon) is placed in the lower third of the esophagus. Since the presence of a nasogastric tube does not seem to significantly affect P_{es} measurement [3], it is possible to use an esophageal catheter in addition to a feeding tube already in place.
2. *Understand balloon inflation and the validation test.* The non-stressed volume is the adequate filling volume, which does not cause underestimation of P_{es} due to low filling volume nor overestimation of P_{es} due to stretch of the balloon. The non-stressed volume varies depending on the specific balloon used and the surrounding pressure. In addition, to minimize the effect of the elastance of esophageal wall, the minimal non-stressed volume should be used to measure P_{es} accurately. This volume can be obtained by measuring the pressure change following a progressive filling of the balloon while knowing the surrounding pressure: this value has been carefully evaluated for each commercially available catheter and tends to be higher when higher pressure is measured [2]. Alternatively, a simple correction can be used, which consists of subtracting the elastic pressure of the esophagus imposed by the filling balloon, when measuring this relationship in vivo [4]. The position of the esophageal balloon is then validated with an occlusion test, using a chest compression (passive patient) or an inspiratory effort maneuver (spontaneously breathing patient) against an end-expiratory occlusion [5]. The rationale is that with no net change in P_L (i.e. zero flow conditions) due to occlusion, changes in airway pressure (P_{aw}) should mirror the changes in local P_{pl} as measured by the esophageal balloon (i.e. $\Delta P_{es}/\Delta P_{aw} = 1.0 \pm 0.2$) [6].
3. *Understand which lung region is reflected by the absolute P_{es} in terms of local P_{pl}.* The static P_{pl} increases from non-dependent to dependent regions along a pressure gradient. Therefore, it is uncertain in which lung regions P_{es} reflects local P_{pl}. A recent validation study of P_{es} using direct a P_{pl} sensor revealed that if properly calibrated (i.e. minimal non-stressed

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volume), P_{es} accurately reflects P_{pl} in the mid to dependent lung regions where the esophagus is located, independently of the mediastinal structures (Fig. 1) [7].

4. *Understand which lung region is reflected by the dynamic change in P_{es} in terms of local ΔP_{pl}.* A dynamic change in P_{pl} (ΔP_{pl}) results from passive or active inspiration. The normal lung is considered to be a continuous elastic system—exhibiting fluid-like behavior—so that distending pressure applied to a local region of the pleura (i.e. ΔP_{pl}) becomes generalized over the whole lung surface [8]. Thus, change in P_{es} (ΔP_{es}) represents ΔP_{pl} at all points on the lung surface [8]. In contrast, severely injured lungs exhibit solid-like behavior, where the atelectatic lung region impedes the rapid generalization of ΔP_{pl}; in such cases, ΔP_{es} may not reflect overall change in P_{pl}. ΔP_{es} underestimates ΔP_{pl} in dependent lung regions during a spontaneous effort, but can overestimate ΔP_{pl} in dependent lung regions during a controlled breath [9]. The negative pressure generated by the respiratory muscles can be much lower in the dependent regions and not well reflected by ΔP_{es}.
5. *Understand how P_{es} enables lung distending pressure to be estimated.* Esophageal manometry enables calculation of lung distending pressure, i.e. transpulmonary pressure P_L: $P_L = P_{aw} - P_{pl}$. Two different estimates of P_{pl}—and thus P_L—are widely accepted using esophageal manometry, with one based on measured P_{es} [10] and the other based on the elastance ratio of the chest wall to respiratory system [11]. As discussed above, data suggest that P_{es} accurately reflects P_{pl} in the dependent to mid lung regions adjacent to the esophageal balloon; thus, setting positive end-expiratory pressure (PEEP) to maintain P_L based on measured P_{es} positive makes sense if this is the lung region where the lung needs to remain open [10]. The other estimate of P_L based on elastance ratio assumes that P_L is zero at functional residual capacity (where P_{aw} and P_{pl} equal zero) [11], and two different estimates, both derived from esophageal manometry, yield very different estimates of P_L [12]. This issue should be investigated further.
6. *Understand how to apply P_{es} during spontaneous breathing.* Monitoring P_{es} in ARDS patients with spontaneous effort is highly relevant. First, clinicians can assess the patients' effort by the work of breathing and esophageal pressure–time product. To assess the patients' effort is important since either insufficient or excessive levels of spontaneous effort can result in diaphragm injury [13]. Second, P_L calculated on P_{es} is a helpful measure for clinicians to detect the harm of spontaneous effort [14], as suggested by high P_L due to strong spontaneous effort which worsens lung injury [15]. Last, when a spontaneous effort has ended at end-inspiration with reasonable muscle relaxation, P_L during an inspiratory hold can reflect the trans-alveolar pressure (i.e. the component to inflate the alveoli).
7. *Understand how to use P_{es} to estimate vascular distending pressures.* Transmural vascular pressure (i.e. the difference between intravascular and extramural pressure reflected by P_{es}) is the net pressure distending the intrathoracic vessels and is useful to evaluate volume status in patients with ARDS, especially those who have preserved spontaneous effort [5]. Spontaneous effort generates a negative P_{pl}, which in turn increases transmural vascular pressure, distending pulmonary vessels and increasing lung perfusion, despite an apparent drop in intraluminal pressure. Thus, the use of P_{es} can help to detect the risk of pulmonary edema.
8. *Understand how to use P_{es} to estimate the transpulmonary driving pressure.* The driving pressure (ΔP) measured from P_{aw} is the sum of pressures needed to inflate the lung and the chest wall during muscle paralysis; the use of P_{es} can isolate the pressure to inflate the lung (i.e. transpulmonary driving pressure, $\Delta P_L = \Delta P - \Delta P_{es}$) from the classical calculation [16]. ΔP_L may be superior to ΔP for detecting early changes in respiratory mechanics [16]. Further studies are necessary to determine whether ΔP or ΔP_L better predicts mortality in ARDS.
9. *Understand how to use P_{es} to monitor patient–ventilator interactions.* The conventional monitoring of P_{aw} and flow may mask a lot of patient–ventilator interaction. P_{es} can detect asynchrony (e.g. early or delayed cycling, reverse triggering) and enables esti-

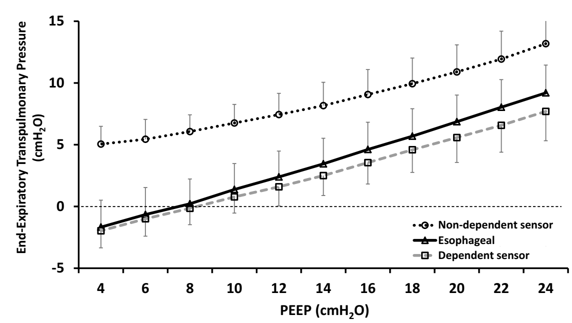

Fig. 1 The spatial relationship of expiratory transpulmonary pressures calculated from esophageal pressure (P_{es}) in lung-injured pigs. (Modified from Yoshida et al. [7]). In surfactant-depleted pigs, expiratory transpulmonary pressure, calculated using P_{es} [i.e. positive end-expiratory pressure (PEEP) minus expiratory P_{es}], reflected the directly measured values in mid (at higher PEEP values) and dependent lung regions (at lower PEEP values)

mation of intrinsic PEEP [5]. The careful monitoring of patient–ventilator interaction helps physicians to adjust ventilatory settings and sedatives.

10. *Understand alternative technique(s) to measure P_{es}.* Although an esophageal balloon is the standard technique to measure P_{es}, a fluid-filled esophageal catheter can be useful, especially to evaluate the dynamic change in P_{es} [17]. The electrical activity of the diaphragm could also be used as an alternative technique to estimate inspiratory activity.

Conclusion

Esophageal pressure manometry data have provided us with a profound understanding of lung physiology. Esophageal manometry has the potential to bring more benefits to improve clinical outcome in patients in ICU.

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Compliance with ethical standards

Conflicts of interest

The authors declare that they have no conflicts of interest.

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