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EDITORIAL

Guiding ventilation with transpulmonary pressure

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Introduction

Improving the short-term and long-term outcome of mechanically ventilated patients remains a difficult task for the intensivist. Randomized controlled trials repeatedly failed to bring evidence supporting new approaches. In this regard, a better characterization of the patient in order to individualize therapy is strongly advocated. The measurement of transpulmonary pressure (P_L) is now possible in our ICUs thanks to a good knowledge about the oesophageal pressure (P_{es}) technique and is and will be facilitated by the possibility of using additional pressure ports on recent modern mechanical ventilators.

What transpulmonary pressure exactly measures

In the 1950s, several observations reported good correlations between changes in pleural pressure (P_{pl}), directly measured in the pleural space, and changes in P_{es}. After refinements of the technique and use of convenient catheters equipped with oesophageal balloons, this technique has been introduced in the research field and has allowed major advances in understanding respiratory system pathophysiology. In patients with spontaneous breathing, the relative changes in P_{es} and P_L have been repeatedly used to quantify the work of breathing using the Campbell diagram or by calculating the pressure time product of the respiratory muscles, considered as the best indicator of the energy consumption of the respiratory muscles.

As for the absolute values of P_{es}, in line with a classical study [1], recent experiments in pigs and in human cadavers showed that the absolute value of the P_{es} is highly reliable, provided that a proper technique is used [2]. There is, however, no unique value of P_{pl}, and a gradient of pressure exists between the upper, anterior part of the pleural space when the patient is lying supine, also referred to as the 'non-dependent' pleural regions, vs. the dorsal, posterior part of the pleural space, also referred to as the 'dependent' pleural regions. This gradient explains the distribution of densities in the lung and may reach values around 10 cmH_2O [1]. Because the oesophagus is approximately situated at mid chest, the value read by the oesophageal catheter therefore reflects the value related to the anatomic position of the oesophagus in the thoracic cavity.

How transpulmonary pressure could guide PEEP: absolute value of oesophageal pressure

The lung collapse characteristically aggregates in dependent lung along a gravitational direction and dependent collapsed lung contributes to intrapulmonary shunting and lowers oxygenation. Positive end-expiratory pressure (PEEP) theoretically maintains positive lung distending transpulmonary pressure at end-expiration, i.e. PEEP minus P_{pl}, leading to minimizing dependent collapse. However, P_{pl} is variable and unpredictable without specific monitoring as a result of abnormal chest wall mechanics and/or increased oedema, so that it is uncertain if PEEP can maintain positive P_L without knowing P_{pl} (for instance in obese patients or patients with ARDS [3]). Oesophageal manometry is a non-invasive technique to measure P_{pl} and thus estimate the lung distending transpulmonary pressure [4]. Preliminary validation of P_{es} to optimize PEEP is encouraging [5]. A clinical trial showed that a ventilatory strategy using P_{es}—a surrogate

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of P_{pl}—at end-expiration to maintain a positive value of P_L had physiological benefits, i.e. better oxygenation and better respiratory system compliance in patients with ARDS [5]. Our recent validation study (pigs and human cadavers) of P_{es} using direct P_{pl} sensor revealed that measured P_{es} accurately reflects local P_{pl} in the mid to dependent lung, adjacent to the oesophageal balloon [2]. Since lung collapse usually predominates in dependent lung in ARDS, setting PEEP using expiratory P_{es} to prevent dependent atelectasis makes sense (Fig. 1). Ideally, however, this measurement should be combined with an assessment of lung recruitability.

How transpulmonary pressure could help to avoid overdistension: calculated value based on the elastance ratio

Ventilator-induced lung injury in ARDS is known to occur in the ventilated, non-dependent lung regions, termed the 'baby' lung [6]. Thus, assessing the risk of local overdistension, i.e. local inspiratory lung distending transpulmonary pressure in the ventilated, non-dependent, lung region, is essential to minimize ventilator-induced lung injury. The direct P_L obtained using the absolute value of P_{es} reflects the value at mid chest and so does not assess the risk of the non-dependent lung.

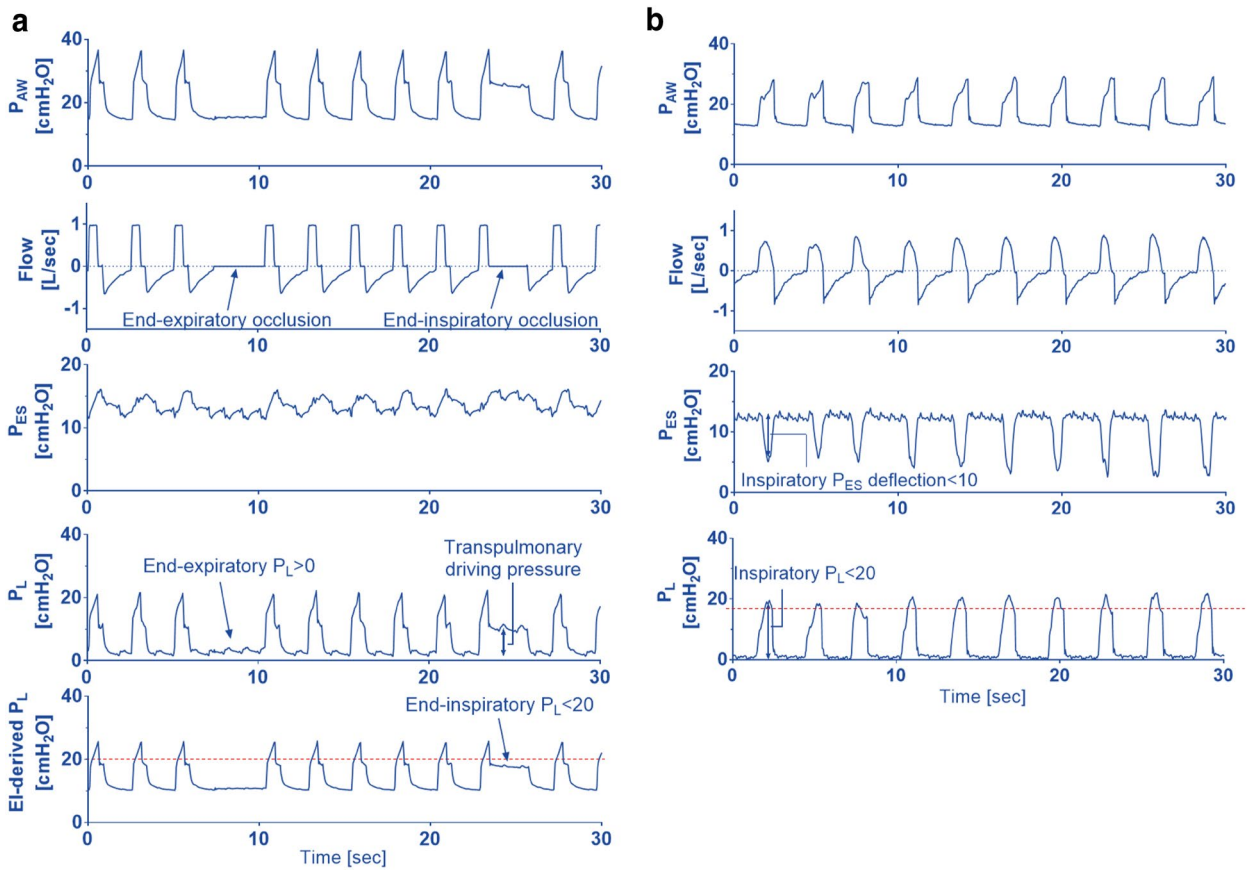

Fig. 1 Oesophageal pressure and transpulmonary pressure waveforms in ARDS patients without spontaneous breathing (**a**) and with spontaneous breathing (**b**). **a** A patient with ARDS was paralysed during volume-controlled ventilation (Carescape R860, General Electrics HealthCare, Chicago, IL, USA) at FiO_2 60%; a tidal volume of 6 mL/kg of predicted body weight; PEEP 15 cmH_2O; respiratory rate 24 breaths/min; inspiratory flow 1 L/s (inspiratory pause 0.2 s). During mechanical ventilation, expiratory hold and inspiratory hold were performed. Oesophageal manometry can find this ventilatory setting 'safe': (1) this PEEP maintained positive P_L (absolute difference between airway and oesophageal pressure) at end-expiration; (2) P_L at end-inspiration (estimated by elastance ratio or EI-derived P_L) was maintained to be less than 20 cmH_2O (red dotted line indicates 20 cmH_2O of EI-derived P_L at end-inspiration). **b** A patient with ARDS preserved spontaneous effort during assisted pressure-controlled ventilation (Hamilton G5; Hamilton Medical AG, Bonaduz, Switzerland) at FiO_2 0.85; inspiratory pressure (airway) 15 cmH_2O, yielding a tidal volume of 6–7 mL/kg; PEEP 14 cmH_2O; respiratory rate 20 breaths/min; inspiratory/expiratory ratio of 1:2, and pressure trigger set at − 2 cmH_2O. Oesophageal manometry revealed that spontaneous effort caused a negative deflection in P_{es} (approx. − 10 cmH_2O) and inspiratory P_L sometimes exceeded 20 cmH_2O. Thus, we decided to paralyse this patient to minimize patient self-inflicted lung injury. Target values of direct P_L at end-expiration during muscle paralysis, elastance derived P_L at end-inspiration during muscle paralysis, negative swing of P_{es} during spontaneous effort and direct P_L at end-inspiration during spontaneous breathing are described

Fortunately, our study [2] showed that P_L at end-inspiration in the non-dependent lung, i.e. the most at-risk region, can be reasonably estimated by the following calculation:

$$\left[\text{Plateau pressure} \times \left(\text{Lung elastance}/\text{Respiratory system elastance}\right)\right].$$

Elastance ratio of lung to respiratory system is calculated as the quotient between elastance of the lung and elastance of the respiratory system. Our recent validation study (pigs and human cadavers) of P_{es} using a direct P_{pl} sensor revealed that P_L at end-inspiration (estimated by elastance ratio) reflected the local distending pressure in non-dependent 'baby' lung well [2]. This region is the most susceptible to overdistension at end-inspiration, and its local distending pressure may be a more sensitive marker of risk from barotrauma than conventional 'global' parameters that fail to take account of regional differences or chest wall properties. We do not know enough about the safe limits for this pressure, but keeping it below 22–25 cmH_2O (known as the upper limit of physiological range) appears wise to prevent regional overdistension [4] (Fig. 1).

Respiratory system compliance reflects the aerated lung size, and the airway driving pressure (ratio of tidal volume to respiratory system compliance, i.e. $\frac{\text{Tidal volume}}{\left[\text{Tidal volume}/\text{Airway driving pressure}\right]}$) represents the mechanical distortion caused by tidal volume in the aerated lung (i.e. dynamic strain). It is possible that the lung driving pressure (ratio of tidal volume to lung compliance, i.e. $\frac{\text{Tidal volume}}{\left[\text{Tidal volume}/\text{Lung driving pressure}\right]}$) could be a more precise index [7], especially when chest wall mechanics is significantly impaired and could help to titrate tidal volume, but further validation will be needed.

How transpulmonary pressure could guide spontaneous breathing activity

Spontaneous breathing activity can offer protective effects to the lung and diaphragm in patients with ARDS, i.e. better gas exchange and less diaphragm atrophy [8–10]. However, it is important to note that this protective role of spontaneous effort has been shown in less severe ARDS and with mild spontaneous effort. Recent studies indicate that spontaneous effort may injure and/or worsen already injured lung and diaphragm in severe ARDS, especially when spontaneous effort is vigorous [8–12]. First, vigorous effort may present injuriously high P_L (static and/or dynamic) by lowering P_{pl} despite a limitation of plateau pressure, causing patient self-inflicted lung injury [13]. Second, vigorous spontaneous effort is associated with increasing diaphragm thickness (potentially diaphragm injury), which is associated with prolonged ventilation [9, 10]. Third, vigorous effort can cause lung oedema by increasing transmural vascular pressure (calculated as intravascular pressure minus P_{pl}), i.e. the net pressure to distend the intrathoracic vessels. This harmful phenomenon is well described in patients with ARDS who preserved vigorous effort during volume-controlled low tidal ventilation [14]. Thus, it is important to monitor spontaneous effort activity (reflected by negative dynamic deflection of P_{es}) and maintain P_L within a safe range, to protect not only the lung but also the diaphragm in patients with ARDS (Fig. 1).

Conclusion

Ventilator-induced lung injury and patient self-inflicted lung injury have the potential to generate lung and systemic inflammation and cause organ damage or death. An individualized monitoring using P_{es}, i.e. the absolute value at end-expiration, the calculated end-inspiratory value based on the elastance ratio and the negative swings during spontaneous breathing, might allow a more precise titration of ventilatory settings for a safe and efficient ventilation. This should help to manage the complex interactions of spontaneous breathing and mechanical insufflation. The next generation of randomized controlled trials might incorporate such tools and implementation in clinical practice seems justified today.

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Compliance with ethical standards

Conflicts of interest

TY has a patent on a CNAP device. DLG is supported by SIAARTI/Merck Sharp & Dohme and ESICM (2017 Bernhard Dräger Award for Advanced Treatment of Acute Respiratory Failure), has received payments for travel expenses by Maquet, Getinge and Air Liquide and discloses a research grant by General Electrics Healthcare. LB's laboratory has received grants or equipment from Covidien-Medtronic, Fisher Paykel, Air Liquide, Philips, General Electric.

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