

Methods to monitor respiratory effort during mechanical ventilation

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Clinicians typically prioritize lung-protective targets during the initial hours of controlled mechanical ventilation in patients with acute respiratory failure. However, during the subsequent assisted phase, protective strategies tend to be less stringent, although there is growing evidence that maintaining both lung- and diaphragm-protective (LDP) targets is associated with better patient outcomes.^(1,2)

A significant challenge in implementing LDP strategies is accurately estimating respiratory muscle effort, which, along with ventilator-delivered pressures, determines lung distension. Several physiological variables determine the magnitude of respiratory effort, including respiratory drive, neuromechanical coupling, and muscle trophism. This viewpoint focuses on methods for estimating the pressure generated by inspiratory muscles (P_{mus}) during invasive mechanical ventilation, as these are directly linked to lung stress and respiratory muscle workload.

ESOPHAGEAL PRESSURE

Esophageal manometry remains the gold standard for measuring P_{mus} ⁽³⁾ as esophageal pressure (P_{es}) closely reflects pleural pressure (P_{pl}) due to the esophagus's proximity to the pleural space.⁽⁴⁾ Esophageal pressure is typically measured using a balloon catheter, inserted through the nostrils or oral cavity, and connected to a pressure transducer (such as a ventilator's port or a dedicated acquisition system). Proper positioning and balloon filling are essential, as inadequate calibration can lead to inaccurate measurements of both absolute pleural pressure and its tidal swings.^(5,6) Esophageal and airway pressure variations during an expiratory occlusion should be approximately equal (the ratio between the change in airway and esophageal pressure should be between 0.8 and 1.2) to confirm the correct filling volume and position.⁽³⁾

Once the esophageal balloon is properly calibrated, P_{mus} can be calculated as the difference between the chest wall elastic recoil pressure (P_{cw}) and P_{es} . The P_{cw} represents the pressure needed to expand the chest wall alone. Since P_{mus} acts on the entire respiratory system, it contributes to the expansion of both the chest wall and the lungs.

Although esophageal manometry is the gold standard for assessing inspiratory muscle pressure, it requires specialized expertise for proper calibration and involves additional cost. Given these challenges, noninvasive techniques have been developed as feasible alternatives for estimating inspiratory effort at the bedside.

AIRWAY OCCLUSION PRESSURE

Airway occlusion pressure ($P_{0.1}$) quantifies the drop in airway pressure 100 milliseconds after the onset of inspiratory effort during an occluded breath. It provides an accurate assessment of respiratory drive, as it is unaffected by respiratory mechanics or the patient's conscious response.⁽⁷⁾ Airway occlusion pressure can be used to assess inspiratory effort, detecting low or excessive effort with reasonable accuracy. Validated cutoffs of $P_{0.1}$ for detecting low or excessive effort per minute are $< 1.0 \text{ cmH}_2\text{O}$ and $> 3.5 - 4.0 \text{ cmH}_2\text{O}$, respectively.⁽⁸⁾ However, in patients with high inspiratory effort, $P_{0.1}$ may underestimate the actual effort per breath. A study in children demonstrated that the presence of high airway resistance, tidal volume, and opioid use is associated with $P_{0.1}$ underestimation of effort.⁽⁹⁾

Airway occlusion pressure can be measured through an expiratory occlusion maneuver (Figure 1). Modern ventilators can also display $P_{0.1}$ as a maneuver using a proper occlusion with direct $P_{0.1}$ measurement or by extrapolation based on the drop in airway pressure during the trigger phase.⁽⁸⁾

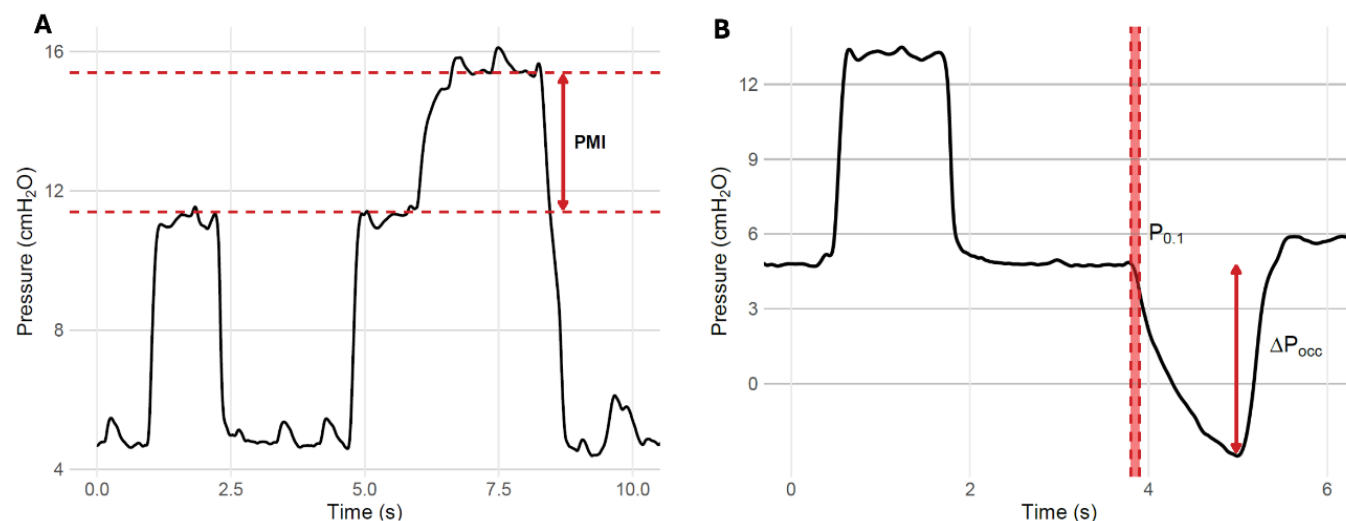


Figure 1 - Airway pressure tracings illustrating the measurements of pressure muscle index, $P_{0.1}$, and ΔP_{occ} .

(A) Pressure muscle index is calculated as the difference between plateau and peak pressures. (B) $P_{0.1}$ is defined as the negative deflection occurring 100 milliseconds after the onset of inspiratory effort, and ΔP_{occ} represents the maximal deflection in airway pressure during an expiratory breath hold, induced by the patient's effort.

PRESSURE MUSCLE INDEX

Pressure muscle index (PMI) is a direct estimate of P_{mus} obtained through an end-inspiratory occlusion maneuver during assisted mechanical ventilation. Unlike in controlled mechanical ventilation, in which plateau pressure is typically lower than peak airway pressure, significant inspiratory effort can result in a plateau pressure exceeding peak airway pressure. While it might seem counterintuitive, the explanation for this phenomenon is simple. The total pressure applied to the respiratory system during inflation is the sum of the pressure delivered by the ventilator and that generated by the respiratory muscles. During an end-inspiratory occlusion, relaxation of the inspiratory muscles allows the respiratory system to recoil at the inflated volume. This recoil is transmitted to the airways, resulting in a rise in airway pressure equivalent to the inspiratory muscle pressure at the onset of the occlusion. The difference between higher plateau pressure and “peak airway pressure”, termed PMI, reflects the contribution of the respiratory muscles to respiratory system inflation.^(10,11)

For reliable measurements, clinicians should ensure a horizontal plateau lasting at least 2 seconds, reached shortly after the occlusion maneuver⁽¹²⁾ (Figure 1). The PMI also allows for estimating the respiratory system static driving pressure, calculated as the plateau pressure obtained during the PMI maneuver minus PEEP.⁽¹³⁾

Notably, since the PMI does not account for the inspiratory muscle pressure exerted to overcome airway resistance, it can underestimate the total inspiratory effort, especially in patients with obstructive disorders.⁽¹⁰⁾ Additionally, the accuracy of respiratory system compliance and driving pressure estimates has been considered suboptimal in previous publications.⁽¹⁴⁾ However, in observational studies, higher driving pressure measured with an end-inspiratory occlusion during assisted ventilation was associated with increased mortality, highlighting its potential role as a target for lung protective strategies during assisted ventilation.^(2,15)

OCLUSION PRESSURE

Occlusion pressure during an expiratory hold (ΔP_{occ}) is another method for estimating inspiratory muscle effort. ΔP_{occ} is measured as the maximal negative deflection in the airway pressure elicited by an inspiratory effort during an occluded breath. The end-expiratory occlusion maneuver, available in most ventilators, should be long enough to capture one whole inspiratory effort exerted by the patient while ensuring there are no leaks.

P_{mus} during unoccluded assisted breaths can be estimated as 75% of ΔP_{occ} based on two independent validation cohorts.^(16,17) An estimation of transpulmonary driving pressure using ΔP_{occ} has also been proposed ($\Delta P_{L,dyn}$). This is calculated as the positive pressure delivered by the

ventilator minus 66% of ΔP_{occ} .^(16,18) Although prospective trials indicating targets of $\Delta P_{L,dyn}$ to improve clinical outcomes are lacking, recent physiological trials have targeted $\Delta P_{L,dyn} \leq 20\text{cmH}_2\text{O}$.⁽¹⁹⁾ Both ΔP_{occ} and $\Delta P_{L,dyn}$ have shown excellent performance in detecting high levels of P_{mus} and transpulmonary driving pressure, respectively. However, the accuracy of the absolute values for P_{mus} estimations using ΔP_{occ} may be limited, with relative errors exceeding one-third of the estimated value.⁽¹⁶⁾

PRACTICAL APPROACH

At the bedside, a high respiratory drive ($P_{0.1} > 3.5\text{cmH}_2\text{O}$) can be considered either appropriate or inappropriate, depending on the presence of respiratory alkalosis. Inappropriately high drive may reflect agitation, inadequate sedation or analgesia, or a response to systemic inflammation or lung injury. In such cases, increasing ventilator support is usually ineffective, may worsen alkalosis, and promote lung injury. Conversely, high drive may be appropriate in the context of increased CO_2 production (e.g., fever, overfeeding), ventilatory inefficiency, or underassistance combined with excessive respiratory load. A high drive with low effort ($P_{0.1} > 3.5\text{cmH}_2\text{O}$, $P_{mus} < 5\text{cmH}_2\text{O}$) suggests respiratory muscle weakness, while low drive and effort ($P_{0.1} < 1.0\text{cmH}_2\text{O}$, $P_{mus} < 5\text{cmH}_2\text{O}$) indicate over-assistance or oversedation. A dynamic transpulmonary pressure ($\Delta P_{L,dyn}$) $\leq 20\text{cmH}_2\text{O}$ may be a marker of lung-protective ventilation, though this threshold awaits validation.

CONCLUSION

Monitoring respiratory effort is a crucial aspect of lung- and diaphragm-protective mechanical ventilation, particularly as patients transition from controlled to assisted ventilation. While esophageal manometry remains the gold standard for measuring inspiratory muscle pressure, it has largely been replaced by alternative methods due to its technical complexity and cost. Noninvasive techniques, such as $P_{0.1}$, pressure muscle index, and ΔP_{occ} , provide valuable insights into respiratory effort and lung stress at the bedside.

AUTHORS' CONTRIBUTIONS

G. M. Plens: conceived and wrote the first draft of this manuscript; B. V. Pinheiro and E. L. V. Costa: conceived and critically reviewed this manuscript; I. Telias: critically reviewed this manuscript.

AVAILABILITY OF DATA AND MATERIALS

The contents underlying the research text are included in the manuscript.

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