Monitoring respiratory mechanics in the prone position

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Esophageal pressure measurement can be used to guide ventilator management in severe ARDS patients, and this strategy has been shown to improve oxygenation, lung compliance and possibly survival when compared with standard practice.

**Takeaway messages**

- The strong pathophysiological rationale for arguing that the beneficial physiological effects of prone positioning translate into clinical benefits in ARDS patients may also support the use of esophageal pressure measurement in the prone position.
- Esophageal pressure at end expiration is potentially useful for guiding the PEEP setting to avoid recruitment in ventral regions after turning patients to the prone position and may allow titration of the ventilator settings according to the patient’s individual physiology.
- Monitoring trends for respiratory system compliance and using data from esophageal pressure in the prone position to monitor lung compliance can provide valuable information for assessing lung recruitment in the prone position.

Although the use of esophageal pressure measurement in the prone position has not been described, it is clear that prone positioning helps maintain safe oxygenation and prevent ventilator-induced lung injury (VILI) in ARDS patients. There is a strong pathophysiological rationale for arguing that the beneficial physiological effects of prone positioning translate into clinical benefits in ARDS patients, which may also support the use of esophageal pressure measurement in the prone position. In this article, we cover the mechanisms by which prone positioning improves oxygenation, and the effects of prone positioning on respiratory mechanics and VILI. We also look at the potential use of esophageal pressure measurement to set and titrate PEEP in the prone position in ARDS patients to promote lung-protective ventilation, and how we can employ the information obtained from transpulmonary pressure measurement in the prone position.

**Effects of prone positioning on oxygenation**

The improvement in oxygenation that comes with prone positioning is due to a reduction in
intrapulmonary shunt, resulting in better ventilation to perfusion matching. In lung injury conditions, turning from the supine to the prone position increases the pleural pressure in the non-dependent region and decreases the pleural pressure in the dependent lung. The effect of this is a notable reduction in the pleural pressure gradient, which results in homogenization of pleural pressure and thus transpulmonary pressure in the ventral to dorsal direction (1, 2, 3, 4). As a result, the ventilation to perfusion matching should be improved in the dependent regions in the prone position, with no change in the non-dependent regions.

However, the validity of esophageal pressure measurement has been questioned for different reasons. One of these is that pleural pressure - and therefore transpulmonary pressure - increases along the vertical axis (higher in dependent, lower in non-dependent regions) in the supine position and this gradient is greater in the presence of ARDS. These factors create uncertainty as to where (in which lung regions) esophageal pressure measurement, if accurate, reflects local distending pressure (5, 6). Therefore, the reduction in the pleural pressure gradient in prone positioning may improve the validity of esophageal pressure measurement.

**Prone positioning and PEEP**

In ARDS patients receiving mechanical ventilation, oxygenation also depends on the ventilator settings, and in particular PEEP. To better explain the effect of the body position and PEEP on ventilation to perfusion matching and intrapulmonary shunt, Richard et al. (2005) measured lung ventilation, perfusion, aeration, and recruitment at PEEP of 0 cmH2O and 10 cmH2O in pigs injured with oleic acid (7). Prone positioning was found to be associated with recruitment in the dorsal regions with concomitant derecruitment in the ventral regions; whereby the extent of this was reduced by PEEP. At zero PEEP, prone positioning was shown to cause redistribution of ventilation towards the dorsal region, while at PEEP of 10 cmH2O, ventilation went towards the ventral region. In 2005, Beitler et al. conducted a post-hoc analysis of data from clinical trials on prone positioning to determine whether that data on prone positioning could be generalized to patients being treated with a high-PEEP strategy (8). This analysis served to highlight the lack of data on the concomitant use of high PEEP and prone positioning. The authors concluded that the ideal combination therapy may involve adjusting PEEP after each repositioning to account for changes in chest wall and lung mechanics in the prone versus the supine position. Yoshida et al. (2018) measured pleural pressure directly in pigs and human cadavers and compared it with esophageal pressure. Esophageal pressure (inspiratory or expiratory) was found to be an accurate reflection of pleural pressure in the lung adjacent to the esophageal balloon (i.e., dependent to mid-lung), if correctly calibrated (9). Therefore, esophageal pressure at end expiration is potentially useful for guiding the PEEP setting in order to avoid derecruitment in ventral regions after turning patients to the prone position. Furthermore, use of esophageal pressure measurement in prone patients may allow
titration of the ventilator settings according to the patient’s individual physiology, and could clarify the mechanisms of improved lung recruitment (10).

**Effects of prone positioning on VILI**

Several studies have demonstrated that the potential for lung recruitment should be taken into account when setting PEEP, and that patients with low recruitability who receive high PEEP may develop overdistension with harmful consequences. CT-scan studies (11) found a reduction in overall overdistension in the prone position. However, the reduction in atelectrauma and tidal hyperinflation measured with prone positioning was only observed in those patients who had shown high potential for recruitment in the supine position and were receiving higher PEEP (15 cmH2O) in the prone position. Therefore, assessing lung recruitability before changing the patient’s position from supine to prone position can help to predict the positive outcome of the prone positioning. Nevertheless, Cornejo et al. (2013) showed that lung recruitment induced by prone positioning was observed regardless of whether the patient was a high or a low recruiter in response to the change in airway pressure in the supine position (12). This finding provides support for changing the patient to the prone position, even if they have been diagnosed as having a low percentage of potentially recruitable lung.

**Effects of prone positioning on respiratory mechanics**

The elastance of the respiratory system is the sum of chest wall elastance and lung elastance. In patients with ARDS, results have consistently shown the chest wall elastance to be higher in the prone position than in the supine position. This may be due to the increase in abdominal pressure (13, 14, 15, 16). Greater stiffness of the anterior chest wall in the prone position would suggest that the lungs are functioning within the rigid boundaries created by the spine and the sternum, leading to a more homogeneous distribution of tidal volume and better gas exchange.

Although results demonstrating the effects of prone positioning on respiratory elastance are not consistent, it is clear that any change in respiratory elastance will generally be due to a change in lung elastance. Assuming that chest wall elastance increases systematically with prone positioning, changes to respiratory elastance in the prone position can be interpreted as follows:

- No change in respiratory elastance indicates a reduction in lung elastance (increase in lung compliance)
- Higher respiratory elastance may be due to an increase in lung elastance (decrease in lung compliance)
- Lower respiratory elastance indicates a considerable reduction in the lung elastance (marked increase in lung compliance) and significant recruitment in the prone position
Therefore, monitoring trends for respiratory system compliance and using data from esophageal pressure in the prone position to monitor lung compliance (VT/(transpulmonary pressure at end inspiration – transpulmonary pressure at end expiration)) can provide valuable information for assessing lung recruitment in the prone position. Hamilton Medical ventilators use the least squares fitting method to continuously calculate respiratory compliance breath by breath, and the layout of the Ventilation Cockpit panels can be configured to display real-time patient data as trends. If prone positioning is associated with lung recruitment, it is indicated by an increase in respiratory compliance; higher respiratory compliance indicates a considerable increase in the lung compliance and significant recruitment in the prone position.

On several Hamilton Medical ventilators, you are able to measure and display esophageal and transpulmonary pressures. Transpulmonary pressure can be used in combination with the Protective Ventilation Tool (P/V Tool) to assess a patient’s potential for recruitment and thus determine whether to change the patient from the supine to the prone position. The P/V Tool performs a respiratory mechanics maneuver that records a quasi-static pressure/volume curve, by means of which you can distinguish between patients with low and high recruitability. This is particularly helpful for ARDS patients, as selecting an appropriate lung recruitment strategy and the correct PEEP setting as an anti-derecruiting force are critical for this patient group.

References


