Pleural Pressure: It's Not Just for Chest Tubes Anymore

Respiratory physiology is all about pressure and gravity. Clinicians can manipulate these variables by using mechanical ventilation, changing the patient’s position and adjusting chest drain suction. It’s important to know how to enhance beneficial pressure changes and differentials and to minimize their harmful effects.

Pressure Terms

Transpulmonary pressure or transmural pressure is the difference between alveolar and pleural pressure* – essentially the difference between pressures inside and outside the lung. Normally, it’s about 7cmH₂O, but mechanical ventilation increases it by delivering volume under pressure.¹ Transpulmonary pressures significantly differ in regions of the lung depending on which is gravity dependent.²

Adherence between the pleurae results in an absolute negative pressure; this is what keeps the lungs expanding with the chest wall. In this discussion of respiratory mechanics when referring to the pressure outside the alveoli in relation to the atmospheric or mouth pressure, we’ll use the term intrathoracic pressure to minimize confusion with the always-negative pleural pressure.

<table>
<thead>
<tr>
<th>Pressures</th>
<th>Inspiration (mmHg)</th>
<th>Exhalation (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pleural</td>
<td>Progressively decreases (755)</td>
<td>Progressively increases (758)</td>
</tr>
<tr>
<td>Alveolar</td>
<td>Below atmospheric (757)</td>
<td>Above atmospheric (763)</td>
</tr>
<tr>
<td>Mouth</td>
<td>760 (zero reference point)</td>
<td>760 (zero reference point)</td>
</tr>
<tr>
<td>Transpulmonary</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Flow</td>
<td>In</td>
<td>Out</td>
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Table 1. Pressures During Spontaneous Breathing

Volume Effect on Pressure

Pleural pressure differentials depend on lung volume. In a study of pleural pressure changes,³ at low lung volume during end exhalation, pleural pressure change was about -28 cmH₂O. At 1200mL, it’s only -7, and at total lung capacity, it’s down to -2. Patients with air trapping have more air in their lungs all the time, so this explains their difficulty generating intrathoracic pressure changes needed to cough effectively.³ Pleural pressure is the key to the challenges faced by patients as air trapping worsens.

Research on morbidly obese patients showed airway opening pressure is greater than 1.3 cmH₂O, which means intrathoracic pressure is positive at rest. The chest wall contains more volume and the lung is smaller, impairing lung mechanics and increasing work of breathing.⁴

Balancing Recoil Forces

Normally, the lung wants to collapse and the chest wall wants to expand. It’s the coupling of the pleurae that keep the lung and chest wall moving together. These opposing forces, called recoil, make the absolute pleural pressure negative and account for about 75% of all pleural pressure changes.¹ ⁵ ⁶ The resting volume of the lung is the balance between the elastic recoil pulling the lung in and the chest wall out. Resting volume is high in COPD, leaving less room for fresh air; it’s low in fibrosis (increased lung recoil), making it harder to expand the lungs.¹ ⁵ When pneumothorax disrupts pleural adhesion, recoil takes over, worsening lung collapse and expanding the pleural space.¹ This recoil factor is why the size of the pneumothorax does not always correlate with the size of the hole in the pleura.

A study of lung transplant patients⁷ showed that negative pleural pressure significantly increased peak airway pressures and reduced compliance compared with neutral pleural pressures. Negative pleural pressure counteracted the lung’s normal recoil, causing alveolar hyperinflation. The combination of negative pleural pressure with positive pressure ventilation in patients whose new lungs are undersized in relation to the size of the thoracic cavity can contribute to graft failure. To minimize this transpulmonary pressure gradient, these surgeons avoid chest drain suction on at-risk patients.⁷

A number of research studies have examined how COPD affects work of breathing.³ Increased resistance and decreased compliance require respiratory muscles to generate more negative pleural pressure to overcome recoil and inflate the lung.³ This is hard work. Persons exercising heavily or those with lung disease can use more than 30% of their energy to breathe. Normal respiratory energy expenditure is 2% at rest.¹ Weak, malnourished patients with hypoxia can wear out and go into respiratory failure simply from the work it takes to breathe. Typically, 70% of total work of breathing overcomes elastic recoil and 30% overrides the friction of air flowing through the airways.¹

Volutrauma and Barotrauma

Volutrauma and barotrauma are caused by high transpulmonary pressures during mechanical ventilation.² This can be high alveolar pressure from the ventilator, low pleural pressure or a combination of the two. Gravity effects cause regional variations in pressure and volume; these are determined by patient positioning: supine, prone, or with the head of the bed elevated.² ⁴ ⁵ ⁶

*Studies that look at pleural pressure measured esophageal pressure to avoid opening the pleural space² ⁴ ⁵ ⁶

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In the Literature

**The Cycle of Comorbidities**

The current issue of *Orthopaedic Nursing* features an article that describes a model to explain potential risks associated with delaying joint replacement surgery. The authors describe intersecting cycles: inactivity, chronic pain, and sleep disturbance and note that it is not enough to identify risks of delay, but to also analyze how these factors interplay with each other. While their focus is on joint replacement, the model has value to examine comorbidities associated with inactivity resulting from a variety of conditions.


**Early ICU Mobility Makes Dollars and Sense**

Researchers at Johns Hopkins and the University of Kentucky report on their financial model for analyzing early mobility and physical rehabilitation of critically ill patients in the current *Critical Care Medicine*. Variables include length-of-stay, per-day costs, program implementation cost, and annual number of ICU admissions. The model was designed and implemented in an Excel spreadsheet, so it can be replicated without extensive data management support.


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**Volutrauma** is damage from too much volume in each ventilator breath. In gravity-dependent areas, alveoli remain closed, and in the uppermost regions, alveoli overfill and even rupture. Overdistention causes an inflammatory response and injury at the cellular level (now called biotrauma), contributing to ARDS. The low tidal volume strategy of 4 to 8 mL/kg IBW has produced significantly higher survival from ARDS worldwide, but no evidence that this is the best strategy for all patients requiring mechanical ventilation.

**Barotrauma** is a high level of positive pressure within the lung that causes air to escape from alveolar spaces resulting in air leak syndromes, pneumothorax, pulmonary interstitial emphysema, and free air in the thoracic cavity. It is most common with mechanical ventilation, but can also occur with diving (during ascent), blast injury, submarine escape training, and air bag deployment. Alveolar overstretching with high pressures will disrupt tissue injured after thoracotomy or trauma much more than normal lung tissue. The stretching and shearing from the difference between pleural and alveolar pressures progress along this margin of injury. One study of pneumothorax determined the swings in pleural pressure during the respiratory cycle had greater effect on oxygenation than peak pressures. Smaller pressure swings were associated with smaller pneumothorax and had less effect on oxygenation.

Under normal conditions, about 1.25% of a pneumothorax is absorbed every 24 hours. It would take 16 days to absorb a 20% pneumothorax. Gas absorption depends on the gradient between the PO₂ in the pneumothorax and the capillaries. If the FIO₂ is near 100%, absorption will occur four to six times faster.

**Pleural Pressure is Key**

The bottom line is that pleural pressure is the key to everything that happens in breathing. When negative, it pulls the lungs open during inspiration and when intrathoracic pressure is positive, it compresses the alveoli to create a strong cough that will clear the lungs of secretions and maintain an open airway. That’s why prolonged air leaks, pleural effusions and other complications relating to the pleural space can be devastating to patient recovery.

**End of Life Education Consortium**

This consortium, initially funded by the Robert Wood Johnson Foundation, is a national education program designed to improve palliative nursing care. There are train-the-trainer and provider courses in the core curriculum, pediatrics, critical care, veterans care, and for APRNs with prescriptive authority. In addition, the site has a number of online and publication resources.

[http://www.aacn.nche.edu/elnec](http://www.aacn.nche.edu/elnec)

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