Where is end expiration? Measuring PAWP when the patient is on pressure support ventilation

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Abstract

Background: The hemodynamic information obtained from the pulmonary artery catheter provides physiologic rationale for a selected therapy and allows rapid determination of patients' response to the therapy. A wide range of pressure support levels have been used in pressure support ventilation (PSV), and patients' breathing patterns change from a spontaneous breathing pattern with low levels of PSV to a pressure control pattern with high levels of PSV. Different levels of pressure support have different effects on intrathoracic pressure. Changes in intrathoracic pressure may change the respiratory pattern and affect the timing for measuring the pulmonary artery wedge pressure.

Purpose: The purpose of this study was to identify the pressure support level at which a patient's breathing pattern switches from a pressure control pattern to a spontaneous breathing pattern.

Sample: Fourteen patients admitted to the cardiovascular surgery ICU between January 2001 and December 2001 agreed to participate in the study. Four patients' data were not usable. Ten patients' data were analyzed. In this group, nine patients were male and one female. Patients' ages ranged from 45 to 87 years old with a mean age of 66.7 years. One patient had a left ventricular aneurysm repair, four patients had aortic valve repair and five patients had aortic coronary bypass performed.

Method: This study was an exploratory descriptive study. Simultaneous pressure tracings of the pulmonary artery wedge pressure (PAWP) and proximal airway pressure were recorded during the weaning of pressure support at 2 cm H₂O intervals from 18 cm H₂O to below 10 cm H₂O. End expiration was identified by using the proximal airway pressure when measuring the PAWP. Simultaneous pressure tracings of the PAWP and proximal airway pressure were used to analyze changes in respiratory patterns at different pressure levels during weaning of PSV.

Findings: One patient's breathing pattern switched into the spontaneous pattern at PSV 16 cm H₂O, one at 14 cm H₂O, and the rest of the patients at 12 cm H₂O.

Conclusion: Different levels of pressure support have various impacts on the intrathoracic pressure and alter the respiratory pattern. Using the proximal airway pressure, nurses can identify the location of end-expiration and measure the PAWP accurately.

Background

Since the introduction of the pulmonary artery catheter (PAC) by Dr. Swan and Dr. Ganz in 1970, the PAC has become one of the most commonly used diagnostic devices for hemodynamic monitoring in critical care (Oropello et al., 1999; Shah & Miller, 2007). Using a PAC to guide the management of critically ill patients has been shown to improve survival rates in some studies (Friese, Shafi, & Gentilello, 2006; Shah, & Miller; Vincent et al., 2008). This tool is effective for monitoring patients' hemodynamic status. Many factors may affect the accurate interpretation of these measurements, such as when patients are mechanically ventilated.

Pressure support ventilation (PSV) is a ventilation mode that is designed to support patients' inspiratory effort according to the strength of their respiratory muscles. At higher pressure support levels it provides maximum inspiration support and at the lower pressure support levels it allows patients to breathe spontaneously with minimal airway resistance during inspiration. PSV has gained increasing popularity and is widely used in intensive care units (Aliverti et al., 2006; Amato et al., 1992). Different levels of pressure support have different effects on intrathoracic pressure and change the pulmonary artery wedge pressure (PAWP) measuring methods. Nurses in the critical care unit should be aware of these changes to provide accurate measurements of the PAWP.

Pressure changes during different mechanical ventilation modes

The heart is a pressure chamber essentially within another pressure chamber (the lungs). Intrathoracic pressure can be transmitted from the lungs to the pulmonary vessels and change the intraluminal pressure (Marino, 2007). Changes in intrathoracic pressure during the respiratory cycle cause
changes in pulmonary vascular pressure and affect hemodynamic measurements (Bellamy & Mercurio, 1986) such as the PAWP. To minimize the effects of changes in intrathoracic pressure during the respiratory cycle on hemodynamic measurements, it is recommended to measure the PAWP at the end of expiration (Cengiz, Crapo, & Gardner, 1983; Marino, 2007; Swan, 1991). Normally, the elastic recoil forces of the pulmonary parenchyma tend to retract the lung tissue inward and toward residual volume. At the same time, the muscle tone and the normal recoil of the chest wall and diaphragm muscles tend to expand outward. These opposing forces reach equilibrium at the end of the expiration phase (Dantzker, 1998). At this point, the opposite intrathoracic pressures are equal and balanced (Berylhill, Benumof, & Rauscher, 1978; Riedinger, Shelloch, & Swan, 1981), and no movement occurs. At end expiration, the intrathoracic pressure is equal to atmospheric pressure (Brandtstetter et al., 1998; Dantzker; Marino; Wiedemann, Matthay, & Matthay, 1984). As a result, there is no movement of the lung parenchymal tissue, the chest wall, or the airflow in or out of the lungs.

In the intensive care unit, the two most commonly used ventilation modes are spontaneous ventilation and mandatory ventilation. Due to different mechanisms of ventilation, changes in the intrathoracic pressures during the respiratory cycle are totally opposite in these two ventilation modes (Bellamy & Mercurio, 1986). These pressure changes create different waveform patterns on the PAWP tracings (Bridges, 2006).

With spontaneous ventilation, there is a reduction in intrathoracic pressure during inspiration and a subsequent decrease in pulmonary vascular pressure (Swan, 1991). This lower or negative pressure creates a negative deflection in the PAWP tracing (Booker & Arnold, 1993). During expiration, the increased or higher intrathoracic pressure creates a positive deflection in the PAWP tracing. End expiration is the point on the PAWP tracing that is immediately before the negative pressure deflection that occurs with inspiration (Booker & Arnold) (see Figure One).

In positive pressure ventilation such as assist control or pressure control ventilation, the ventilator forces the mixture of gas into the lungs during inspiration and creates a higher intrathoracic pressure, thereby creating a higher pressure waveform in the PAWP tracing during inspiration. While in expiration, the natural recoil of the lung parenchyma, the chest wall, and the diaphragm expel the air out of the lungs passively and create a lower pressure waveform in the PAWP tracing. End expiration can be identified in these tracings as the lower point before the ascent of the waveform (Booker & Arnold, 1993) (see Figure Two).

Depending on the amount of pressure support, pressure support ventilation (PSV) is a partial ventilator support mode (Tobin, 2006). PSV combines the features of spontaneous breathing and mandatory ventilation. At lower levels (5 cm H$_2$O to 8 cm H$_2$O), the pressure support compensates for the additional respiratory load imposed by the resistance of the endotracheal tube, the ventilator tubing, and the demand valve of the ventilator (Jouineaux, Dura, & Levi-Valemsi, 1994; Lessard & Brochard, 1996; Tobin, 2006). In moderate levels (8 cm H$_2$O to 15 cm H$_2$O) of pressure support, the total work of breathing is shared between the patient and the ventilator. This level of pressure support can avoid a load that exceeds the

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**Figure One.** PAWP Tracings of a Patient Breathing Spontaneously

**Figure Two.** PAWP Tracings of a Patient on Assist/Control Mechanical Ventilation

**Figure Three.** PAWP Tracings of a Patient on PSV of 8 cm H$_2$O
patient’s respiratory capacity while improving the patient’s respiratory system compliance and resistant (Lessard & Brochard) by reconditioning the patient’s respiratory muscles (Jouineaux et al., 1994). At high levels (above 15 cm H₂O) of pressure support, which is called PSV max (Jouineaux et al.), a tidal volume of 10 ml/kg to 12 ml/kg can be provided (MacIntyre, 1988).

Due to the wide range of pressure support levels used, patients’ breathing patterns change from a spontaneous breathing pattern in low to moderate levels of pressure support (see Figure Three) to a pressure control pattern in high levels of pressure support (see Figure Four). The PAWP is a difficult parameter to interpret during pressure support ventilation (Ahrens, 1999). The point where the PAWP is measured varies and depends on the patient’s breathing pattern (spontaneous breathing versus pressure control ventilation). No research study had been done to identify at which level of pressure support the patient’s breathing pattern changes from a ventilator control pattern to spontaneous breathing. If pulmonary artery pressure and PAWP are used for clinical treatment decisions, the measurements need to be as accurate as possible (Cengiz et al., 1983). Inappropriate therapies such as fluid management or use of vasoactive drugs can occur due to misinterpretation of pressure and waveform tracings and may be harmful to the patient (Bellamy & Mercurio, 1986; Cengiz et al.; Wiedemann et al., 1984). A consistent method of reading pressure waveform tracings is important to ensure meaningful measurements and subsequent appropriate treatment (Riedinger et al., 1981).

**Purpose**

The purpose of this study was to identify the pressure support level at which the patient’s breathing pattern switches from a pressure control pattern to spontaneous breathing pattern. The results of this study may be able to develop a more accurate method for interpreting the PAWP tracing when the patient is receiving PSV.

**Method**

This study was an exploratory descriptive study. A convenience sample was selected from the cardiovascular surgery intensive care unit. The study protocol was approved by the Conjoint Health Research Ethics Board of the University of Calgary and Calgary Health Region.

**Sample**

Patients who were 18 years or older, who were intubated and ventilated with PSV had a pulmonary artery catheter inserted, and were admitted into the cardiovascular surgery ICU at the Foothills Medical Centre were invited to participate in the study.

The principal investigator met all potential candidates on the cardiac unit on the day of surgery if they were outpatients and the day before surgery if they were inpatients. The purpose of the study, the benefits and possible complications were explained to patients.

**Measurement**

Visual and physical assessment of the patient’s chest wall movement has been used to determine end expiration. Tobin, Perez, Guenther, Lodato and Dantzer (1987) argued that visual and physical assessment of the rib cage and abdominal movement are insufficient to determine flow during inspiration and expiration, especially in tachypnic patients. Also, rib cage and abdominal wall asynchrony is common in critically ill patients with high workloads on the respiratory system (Tobin et al., 1987). Inspection of respiratory impedance from electrocardiogram leads that detect the patient’s chest wall movement has also been found to be ineffective because some tracings are poor quality and some tracings are not correlated with the respiratory cycle (Bellamy & Mercurio, 1986) (see Figure Five). Most researchers suggest monitoring proximal airway pressure with simultaneous display of the PAWP tracing as a more accurate way to determine the end-expiration point (Bellamy & Mercurio; Berryhill et al., 1978; Booker & Arnold, 1993).

A device was developed (see Figure Six) for this study to monitor proximal airway pressure changes during the respiratory cycle to identify end expiration. This device uses the disposable pressure transducer (TruWave Disposable
Data collection

Simultaneous pressure tracings of the PAWP and proximal airway pressure were recorded during the weaning of pressure support at 2 cm H₂O intervals from 18 cm H₂O to below 10 cm H₂O. The location of end expiration for measuring the PAWP could be identified accurately by using the simultaneous proximal airway pressure tracing.

![Diagram Illustrating the Device for Monitoring the Proximal Airway Pressure](image)

**Figure Six. Diagram Illustrating the Device for Monitoring the Proximal Airway Pressure**

![Breathing Pattern of Patients During Pressure Support Ventilation](image)

**Figure Seven. Breathing Pattern of Patients During Pressure Support Ventilation**

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>Mode of Ventilation on Admission</th>
<th>Pressure Support Level Used (cm H₂O)</th>
<th>Breathing Pattern changed at (cm H₂O)</th>
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<th>Age (yr)</th>
<th>Sex</th>
<th>Diagnosis</th>
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<td>16, 14, 12</td>
<td>12</td>
<td>10</td>
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<td>F</td>
<td>Repair LV aneurysm</td>
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<td>M</td>
<td>ACB</td>
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**Key:** A/C = Assist/Control ventilation; SIMV = Synchronized Intermittent Mandatory Ventilation; AVR = Aortic valve repair; ACB = Aortic coronary bypass; LV = Left ventricle
Data analysis
Simultaneous pressure tracings of the PAWP and proximal airway pressure were used to analyze changes in respiratory patterns in different pressure levels during weaning of PSV. A frequency distribution was used to determine at which level of pressure support in cm H₂O, the measuring point (end inspiration) of the PAWP changed from a control breathing pattern to a spontaneous breathing pattern.

Findings
In order to meet the target of 10 samples, 14 patients were recruited because data from four patients were not usable. These patients were admitted to the cardiovascular surgery ICU between January 2001 and December 2001. Reasons for the unuseable data were one patient had a large V wave, one patient was very agitated while measuring his pulmonary wedge pressure and his respiratory rate was up to 30 breaths per minute and he required sedation, one patient’s PA catheter was not able to wedge and, one patient was resting on his left lateral position while the data were collected. Ten patients’ data were analyzed. In this group, nine patients were male and one female. Patients’ ages ranged from 45 to 87 years old with a mean age of 66.7 years. One patient had a left ventricular aneurysm repair (Dor procedure), four patients had aortic valve repair and five patients had aortic coronary bypass performed.

When admitted into the cardiovascular surgery intensive care unit postoperatively, all patients were sedated with Diprivan (Propofol) and on assist controlled (A/C) ventilation (n=9) except one patient (n=1) who was on synchronized intermittent mandatory ventilation (SIMV). When they started to wake up, the ventilation mode was switched to pressure support ventilation with a higher pressure support (16 cm H₂O to 18 cm H₂O depending on the patient’s lung compliance). The level of pressure support was gradually weaned down by 2 cm H₂O increments by the registered respiratory therapist according to the patient’s tolerance and condition. Simultaneous proximal airway pressure tracings were recorded when taking the PAWP during the weaning of the pressure support. One patient’s breathing pattern switched into the spontaneous pattern at PSV 16 cm H₂O, one at 14 cm H₂O, and the rest of the patients’ respiratory pattern switched to the spontaneous pattern at a pressure support level of 12 cm H₂O (see Table One and Figure Seven).

Discussion
Monitoring the proximal airway pressure is an accurate and easy method to assess the respiratory pattern during the inspiratory and expiratory phase when a patient is on pressure support ventilation. Proximal airway pressure measurement accurately identifies the location where nurses should be measuring (higher/upper pressure waveform or lower pressure waveform) on the PAWP waveform to evaluate the patient’s hemodynamic status. Previous researchers found that a pressure support of 5 cm H₂O to 8 cm H₂O is used to compensate for resistance created by the ventilator tubing and reservoir (Jouniaux et al., 1994; Lessard & Brochard, 1996; Tobin, 2006). Aliverti et al. (2006) indicated that when PSV is lower or equal to 10 cm H₂O, patients are actively involved in the whole respiratory cycle (trigger, inspiration, and expiration). In this study, eight out of 10 patients converted from the pressure control mode of breathing pattern into spontaneous breathing pattern at the pressure support of 12 cm H₂O (see Table One).

A PAC is a valuable tool to monitor hemodynamic status. However, due to the complex relationship between the intrathoracic pressure and mechanical ventilation, special training and knowledge on interpretation of the pulmonary catheter readings are essential to provide appropriate care to patients at the appropriate time (Greenberg, Murphy, & Vender, 2009; Vincent et al., 2008).
Limitations
This study had a very small sample size and was conducted on one unit. All patients had cardiovascular disease and received open heart surgery. A study with a larger sample size and patients with different diagnoses is recommended to provide a more generalized application of the results.

Conclusion
Critical care nurses use different tools to assess their patient’s condition, progress, and responses to interventions. Pulmonary arterial wedge pressure provides information on the patient’s cardiovascular status. An accurate measurement of the PAWP is able to guide appropriate and prompt interventions. However, different levels of pressure support have various impacts on the intrathoracic pressure and alter the respiratory pattern. Accurate measurements of PAWP rely on identifying the precise timing of end expiration. If nurses have difficulty in identifying the timing of end expiration, using other measurements such as proximal airway pressure are effective and accurate to locate the timing of end expiration.

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References