

AACN Practice Alert

Pulmonary Artery/Central Venous Pressure Monitoring in Adults

Scope and Impact of the Problem

Pulmonary artery pressure (PAP), pulmonary artery occlusion pressure (PAOP), and central venous pressure (CVP) may aid in the differential diagnosis in pulmonary hypertension¹⁻⁴ and may be beneficial in complex shock states.⁵ Less invasive hemodynamic methods, in conjunction with the patient's medical history, may also be useful in the differential diagnosis of cardiogenic shock.⁶

The appropriate use of pulmonary artery catheter (PAC)-guided therapy is associated with decreased mortality in patients with refractory heart failure/cardiogenic shock⁷ but is not associated with improved outcomes in patients with less severe heart failure. In trauma patients, PAC-guided therapy may benefit older, more severely injured patients, but use of a PAC is not associated with improved outcomes in other trauma populations.^{8,9} Use of a PAC is not associated with improved outcomes in other populations, including high-risk cardiothoracic surgery¹⁰ and general intensive care unit (ICU) patients, although many studies are more than 20 years old.¹¹

The addition of CVP monitoring to guided therapy is not associated with improved outcomes in patients with severe sepsis and septic shock.¹²⁻¹⁶ The PAOP and CVP are not accurate for identifying which patients will respond to a fluid bolus with an increase in stroke volume, and alternative methods such as functional

AACN Levels of Evidence

- Level A** Meta-analysis of quantitative studies or metasynthesis of qualitative studies with results that consistently support a specific action, intervention, or treatment (including systematic review of randomized controlled trials)
- Level B** Well-designed, controlled studies with results that consistently support a specific action, intervention, or treatment
- Level C** Qualitative studies, descriptive or correlational studies, integrative reviews, systematic reviews, or randomized controlled trials with inconsistent results
- Level D** Peer-reviewed professional and organizational standards with the support of clinical study recommendations
- Level E** Multiple case reports, theory-based evidence from expert opinions, or peer-reviewed professional organizational standards without clinical studies to support recommendations
- Level M** Manufacturer's recommendations only

hemodynamic indicators should be used.¹⁷⁻¹⁹ Although the CVP has been identified as a fixed target for resuscitation, debate remains about whether CVP, if used at all, should more appropriately be considered a stopping point.^{20,21}

Use of PACs has decreased, particularly in nonsurgical ICUs.²² This decreased use indicates a need for alternative training methods, such as simulation, to maintain proficiency in PAP monitoring if continued use of PACs is anticipated.

Expected Practice

1. Monitor for complications during catheter insertion (arrhythmias), identify patients at increased risk for pulmonary artery rupture/infarction,



- and implement preventive actions to decrease risk for catheter-induced pulmonary artery rupture or infarction. [level D]
2. Verify the accuracy of the invasive pressure monitoring system by performing a square waveform test at the beginning of each shift and any time the system has been disturbed (eg, when obtaining blood samples). [level D]
 3. Obtain PAP/PAOP/CVP with the patient supine with the head of bed (HOB) elevated between 0° and 60°; with the patient in 20°, 30°, or 90° lateral position with the HOB at 0°; or with the patient prone. Allow the patient to stabilize for 5 to 15 minutes after a position change. Note that a longer stabilization period may be needed if the patient is prone. [level B]
 4. Level and reference the transducer's air/fluid interface to the phlebostatic axis (fourth intercostal space half the diameter of the chest) with the patient supine or prone, or with the patient on his or her side (provided that the correct angle-specific reference is verified by using a laser or carpenter's level before PAP/PAOP/CVP measurements). [level B]
 5. Obtain PAP/PAOP/CVP measurements from a graphic (analog) tracing at end-expiration. [level B] If an analog method is not available, use the stop-cursor method with concurrent airway tracing. [level B] Any automated transfer of hemodynamic data from the monitor to the electronic health record should be verified.
 6. With airway pressure release ventilation (APRV), patients breathe spontaneously around the upper pressure limit; thus, the airway pressure tracing is used to identify spontaneous end-expiration, which occurs immediately before the release of airway pressure and the initiation of inspiration. [level C]
 7. If a patient is actively exhaling or there is marked respiratory excursion (> 10-15 mm Hg), measure the PAOP/CVP at a point halfway between the peak and the nadir pressures. [level C]
 8. Use a simultaneous electrocardiographic (ECG) tracing to assist with proper PAP/PAOP/CVP waveform identification. [level C]
 9. PACs can be safely withdrawn and removed by competent registered nurses. [level D]
 10. Accurate alternatives to measuring CVP include measuring peripheral venous pressure (PVP); PVP measurements are obtained from a catheter in the dorsum of the hand or forearm, or from a peripherally inserted central catheter (PICC). [level C]
 11. Continuity from the peripheral venous catheter tip to the central circulation should be verified by checking for an increase in the PVP in response to circumferential occlusion of the arm or leg proximal to the catheter or in response to a sustained inspiratory breath or Valsalva maneuver. [level C]

Supporting Evidence

Monitor for Complications During Catheter Insertion and Use

1. Complications associated with pulmonary artery catheterization are most commonly associated with central venous access; however, approximately 20% of patients experience transient arrhythmias during insertion of a PAC. Right-sided and complete heart block (most likely in patients with preexisting left bundle branch block) occur in 0.3% to 3.8% of patients. Life-threatening complications (pulmonary artery rupture, pulmonary infarction) have been reported in 0.3% to 3% of patients.^{11,23,24}
2. Contraindications for placement of a PAC include presence of a left bundle branch block (risk for complete heart failure), right-sided cardiac mass, tricuspid or pulmonic valve endocarditis, or presence of a mechanical tricuspid or pulmonic valve.²³ Severe tricuspid regurgitation may prevent catheter advancement.²³
3. Caution should be taken in placement and PAOP measurements in patients at increased risk for pulmonary artery rupture (eg, age >60 years, pulmonary hypertension, improper catheter position [catheter insertion >55 cm], cardiopulmonary bypass, and anticoagulation).²³ In addition, incorrect balloon inflation (eg, overwedging or forced inflation) and failure to

deflate the balloon increase the risk for pulmonary artery rupture and thrombosis. In patients at increased risk for pulmonary artery rupture, the end-diastolic pressure in the pulmonary artery should be measured rather than PAOP.

System Assessment to Ensure Accurate Measurement

1. Correct preparation of the pressure monitoring system is required to ensure accurate pressure measurements. The square waveform test, or dynamic response test, determines the ability of the transducer system to correctly reflect invasive pressures.^{25,26} The dynamic response is affected by system problems, such as air bubbles in the tubing, excessive tubing length, loose connections, and catheter patency. Removal of microbubbles during system setup results in an “adequate” or “optimal” system in more than 95% of cases.^{26,27} Any of these problems can affect the accuracy of PAP/PAOP/CVP measurements and must be corrected before pressure measurement. Perform the square waveform test on initial setup, at least once each shift, after opening the catheter system (eg, for zeroing, collecting a blood sample, or changing tubing), and whenever the PAP/PAOP/CVP waveform appears to be damped or distorted.²⁸
2. The addition of a blood conservation device or a needleless access port adversely affects the dynamic response characteristics of invasive pressure monitoring systems.^{26,29,30} The use of a damping device may improve the dynamic response characteristics of the system under these conditions.^{31,32} There are no standards that address the use of blood conservation devices on central catheters, but the effect of devices on the dynamic response characteristics should be considered in any decision.
3. Consider the following changes in PAPs as clinically significant (ie, not reflective of the normal variability in PAP): change in pulmonary artery systolic pressure greater than 4 to 7 mm Hg, change in pulmonary artery end-diastolic pressure (PAEDP) greater than 4 to 7 mm Hg, and change in PAOP greater than 4 mm Hg.³³⁻³⁵ All

hemodynamic values should be interpreted in the context of the patient’s condition. Changes in waveform configuration indicate a need for reassessment of the patient and support the need for documentation of actual waveforms in the patient’s record.

Positioning of Patients

1. Supine: Results of studies in a variety of populations of patients indicate that PAP/PAOP/CVP measurements are comparable when the patient is supine with the HOB elevated to any angle between 0° and 60°, or when the patient is in a 20°, 30°, or 90° lateral position with the HOB flat, as long as the correct angle-specific reference is used.³⁶ PAP/PAOP/CVP measurements obtained with patients in Trendelenburg or reverse Trendelenburg position are not comparable to measurements obtained with the patient supine.³⁷⁻⁴² The response to sitting with the legs in a dependent position is variable, and measurements made with patients in that position may not be comparable to measurements obtained with the patient supine.⁴³⁻⁴⁶ PAP, CVP, and cardiac index⁴⁷ values obtained with the patient in the seated legs-dependent position should be compared with measurements obtained with the patient supine with backrest elevation.
2. Prone: Patients may be placed prone as a part of therapy for acute respiratory distress syndrome (ARDS) or during surgical procedures. In patients with ARDS, if adequate time is allowed for stabilization (30-60 minutes) after repositioning, positioning patients prone does not cause any clinically significant differences in measurements of PAP, CVP, or cardiac output.⁴⁸⁻⁵⁴ However, variable responses in PAP, PAOP, CVP, and cardiac index may occur depending on whether the patient is a fluid responder or nonresponder.⁵⁵⁻⁵⁷
 - a. In studies done to evaluate the effects of prone positioning of patients on hemodynamic indices, the midaxillary line or the midanteroposterior diameter of the chest has been used as the reference point, although no study has been done to validate this

reference point.⁴⁸⁻⁵⁴ A reference point 5 cm vertical distance below the sternal angle may be more accurate with the patient prone.⁵⁷

3. Rotating beds: No studies have been done in patients in automated proning beds. Studies are needed to describe the effects of the prone/lateral rotation with the bed flat and the prone/reverse Trendelenburg position on hemodynamic indices.
4. Reliable measurements of cardiac output have been obtained only with patients positioned supine with the backrest at 20° or 45° and with patients prone. Clinically significant changes in cardiac output may occur in the 20° lateral position, which may limit concurrent measurements of PAP/PAOP/CVP and cardiac output. Because responses to a given position vary from patient to patient, use a standardized approach to evaluate each patient's PAP/PAOP/CVP compared with measurements obtained with the patient in the flat, supine position.

Waveform Assessment and Interpretation

1. Correct and consistent waveform interpretation is required to ensure accurate pressure measurements. A simultaneous ECG should be used to facilitate correct PAP/PAOP/CVP waveform measurement⁵⁸⁻⁶⁰ and should be read from an analog tracing or the stop cursor method, if an analog tracing is not available.⁶¹⁻⁶³
2. Digital readouts should not be used because they reflect pressures obtained throughout respiration and may be significantly different from end-expiratory pressures.⁶⁴⁻⁶⁶
3. Registered nurses who demonstrate competency can safely withdraw and/or remove PACs. Before incorporating withdrawing and/or removing PACs into nursing practice, verify that it is in your state's scope of practice for registered nurses.⁶⁷

Alternative Sites for Monitoring

1. Peripheral venous pressure (PVP), which is obtained from a catheter in the dorsum of the hand, forearm, or lower extremity, may be an accurate alternative to CVP. In a variety of populations of patients receiving mechanical

ventilation and spontaneously breathing patients (neurosurgical, laparoscopic, colorectal, cardiac, kidney and hepatic transplant, burns),⁶⁸⁻⁷⁵ and a variety of positions (supine, Fowler, Trendelenburg, prone),^{76,77} the PVP was higher than the CVP by approximately 2 or 3 mm Hg. Research in the postoperative and ICU setting is limited. In all positions, continuity from the catheter tip to central circulation must be confirmed by evaluation of an increase in the PVP in response to circumferential occlusion of the arm or leg proximal to the catheter,^{70,78} a sustained inspiratory breath,^{76,78} or a Valsalva maneuver.^{71,77} If continuity is absent (no increase in PVP in response to test), the PVP cannot be used and the catheter should be assessed for patency.^{71,78} The arm and shoulder should be placed in a neutral position, if possible.⁷⁹

2. Femoral venous pressure-CVP. Femoral (inferior vena caval or iliac venous) venous pressure agrees with the CVP if abdominal pressure is low.⁸⁰⁻⁸² If abdominal pressure (eg, bladder pressure) is increased (≥ 15 mm Hg), the femoral pressure will correlate with abdominal pressure, but will not agree with CVP.⁸³⁻⁸⁵ If using femoral venous/inferior vena caval pressure, confirm that intra-abdominal pressure is less than 15 mm Hg. The difference between CVP and femoral venous pressure is not related to catheter type (introducer, multilumen)⁸⁰ but is affected by HOB elevation (recommended to position the patient supine-flat or $<30^\circ$ HOB elevation during pressure measurements).⁸⁶
3. The CVP can be obtained from a PICC. A continuous flow device (3 mL/h) should be used. The PICC should be referenced at the phlebostatic axis.⁸⁷⁻⁹¹ A shallow slope following a fast flush suggests PICC occlusion.⁸⁸ The CVP obtained from PICCs that support high-pressure infusions such as infusions of radiographic contrast media is also accurate.⁸⁹

Effect of Ventilation on Measurement

1. In patients with pulmonary hypertension, a PAOP greater than 15 mm Hg is an adequate predictor of a left ventricular end-diastolic

pressure (LVEDP) exceeding 15 mm Hg; although absolute values of PAOP and LVEDP may differ 3 to 7 mm Hg on average.⁹² In patients with precapillary pulmonary hypertension (mean PAP \geq 25 mm Hg with normal left ventricular function), the PAOP may be an overestimate of the LVEDP, especially in obese patients or patients with chronic obstructive pulmonary disease.⁹³⁻⁹⁵ When measuring the PAOP, use end-expiratory analog measurement⁶⁶ and ensure complete occlusion without overwedging (eg, PAOP < PAEDP; atrial pressure waveform, free flow within catheter to confirm the tip is not impacted on the vessel wall, highly oxygenated blood [capillary] is obtained from distal port with balloon inflated).^{96,97}

2. Pressure support ventilation (PSV): During PSV, use the proximal airway pressure to identify end-expiration, as the type of ventilation (spontaneous, pressure control) varies depending on the level of pressure support being provided. In one study,⁶⁴ conversion from pressure control ventilation to a spontaneous respiratory pattern occurred at PSV of about 12 cm H₂O.
3. Airway pressure release ventilation (APRV): The effect of APRV on hemodynamic measurements has been evaluated in only 1 study (animal model).⁹⁸ The PAP and left atrial pressure agreed at continuous positive airway pressures from 10 to 35 cm H₂O. Both the PAOP and left atrial pressure increased as the airway pressure increased, which suggests a need to correct cardiac pressures for increased airway pressure (> 10 cm H₂O). No research on this topic has been done in humans; however, patients on APRV breathe spontaneously around the upper pressure limit; thus, the airway pressure tracing may be used to identify spontaneous end-expiration, which occurs immediately before the release of airway pressure and the initiation of inspiration.
4. Active exhalation/large respiratory swings. Debate persists on how to interpret PAP/PAOP in patients with active exhalation or large respiratory excursions (eg, respiratory-induced fluctuation in PAOP >10-15 mm Hg). Under

these conditions, end-expiratory pressures are overestimates of the true PAP/PAOP.⁹⁹ With active exhalation/large respiratory excursions, the PAP/PAOP should be consistently read at the midpoint between the peak and the nadir pressures⁹⁹ or averaged over 3 ventilatory cycles.¹⁰⁰

Implementation/Organizational Support for Practice

Always identify and mark the phlebostatic axis or appropriate angle-specific reference.

Measure PAP/PAOP/CVP with the patient supine (HOB elevated between 0° and 60°), in lateral position (20°, 30°, or 90°), or prone.

Perform a square waveform test at appropriate intervals as determined by your unit protocol.

Read pressures from an analog recording at end-expiration. However, if analog recording is not available, use a stop-cursor method with a concurrent ECG and respiratory waveform to identify end-expiration.

Confirm accuracy of hemodynamic data transferred from the monitor to the electronic health record and provide documentation of waveform recordings to allow evaluation of changes in waveform patterns.

Need More Information or Help?

1. Contact a clinical practice specialist for additional information: go to www.aacn.org then select Practice Resource Network.
2. AACN Hemodynamic Management Pocket Reference Card. Product 400751. <http://www.aacn.org/dm/Products/ProductDetails.aspx?productid=400751&prodtyp=product&subsystem=ORD>.
3. Lough ME. *Hemodynamic Monitoring: Evolving Technologies and Clinical Practice*. St Louis, MO: Elsevier; 2016.

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