Lesson 264: PreAnesthetic Assessment of the Patient For Whom Placement of a Pulmonary Artery Catheter Is Requested

PREANESTHETIC ASSESSMENT

Dr. Elizabeth A.M. Frost, who is the editor of this continuing medical education series, is clinical professor of anesthesiology at The Mount Sinai School of Medicine in New York City. She is the author of Clinical Anesthesia in Neurosurgery (Butterworth-Heinemann, Boston) and numerous articles. Dr. Frost is past president of the Anesthesia History Association and former editor of the Journal of the New York State Society of Anesthesiologists, Sphere. She is also editor of the book series based on this CME program, Preanesthetic Assessment, Volumes 1 through 3 (Birkhäuser, Boston) and 4 through 6 (McMahon Publishing, New York City).

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Pressure Readings and Waveforms

Pressure readings and waveforms that can typically be seen during catheter advancement are as follows: The CVP, or right atrium (RA), waveform (Figure 1) is followed by a steep rise in systolic pressure in the RV, the PA waveform with an increase in diastolic pressure, the appearance of a dicrotic notch, and the pulmonary capillary wedge pressure (PCWP) tracing (also called PA occlusion pressure), which resembles an atrial pressure curve (Figure 1). When the tip of the PAC is correctly positioned in the PA with the balloon deflated and the lumen not occluded, the typical PA pressure waveform should be graphically displayed.

A widening of the PA pressure tracing with loss of the dicrotic notch and the peak of the pressure tracing occurring later in the cardiac cycle than does the peak of a regular PA waveform can be seen in patients with acute myocardial ischemia, poor left ventricular (LV) compliance, or significant mitral regurgitation. The corresponding PCWP waveform shows prominent V waves (Figure 2). The exact underlying cause of this abnormal waveform is unknown; an ischemia-induced decrease in diastolic ventricular compliance and acute ischemic mitral regurgitation are possible reasons. The sensitivity of PAC monitoring for detecting ischemia is low.

Cannon A waves—large, exaggerated A waves on the CVP tracing—occur when the RA contracts against the closed or stenotic tricuspid valve. They can be seen during rhythm abnormalities, such as a junctional rhythm. Abnormal PAC pressure waveforms, such as V waves, may cause the practitioner to overestimate the true LV filling pressures and must be taken into consideration when hemodynamic calculations are based on these pressure measurements (Figure 2). Failure to recognize V waves may cause the PAC to be advanced further in an attempt to obtain a PCWP tracing, which can increase the risk for PA injury.

Hemodynamic Measurements

The PAC allows measurement of the hemodynamic parameters that determine the function of the heart: preload, afterload, and contractility.

Preload, defined as wall tension at end-diastole, can be estimated with adequate accuracy by using the PCWP. Mechanical ventilation with high positive end-expiratory pressure, mitral valvular disease, and poor LV compliance have all been shown to impair the correlation between the PCWP and LV preload. Large V waves in the pulmonary capillary wedge tracing may be associated with significant mitral regurgitation or acute myocardial ischemia and often lead to an overestimation of LV end-diastolic pressure. PCWP measurements in patients with mitral stenosis or poor LV compliance underestimate LV preload and result in erroneous conclusions about the true loading conditions of the heart.

Afterload, or wall tension during LV contraction, varies during systole but for clinical purposes can best be estimated by using systemic vascular resistance and pulmonary vascular resistance for, respectively, LV and RV afterload (Figure 3).

Contractility can be estimated from the CO in conjunction with the heart rate. If the CO is normal, then contractility should be adequate under the given loading conditions (preload and afterload). However, an underlying cardiac dysfunction may be revealed when loading conditions change. The CO can be measured with the PAC by using the thermodilution method. The CO computation must be programmed for the exact type of PAC and the volume and temperature of the injectate. The change in temperature is plotted against time, and the CO is then calculated with the modified Stewart-Hamilton equation (Figure 4).

The CO is inversely proportional to the area under the curve. The administration of large amounts of fluid during CO measurements yields false-high (warm fluids) or false-low (cold fluids) CO results and thus must be avoided. The PAC allows measurement of the RV CO. It reflects the systemic CO only when no intracardiac shunt, which is caused by atrial or ventricular septal defects, is present. Significant tricuspid regurgitation has been considered a source of error in thermodilution CO measurements. The data, however, are controversial; no effect and an underestimation of true CO have both been reported.

Oxygenation Measurements

Placement of a PAC allows blood to be sampled from the RA, PA, and the tip of the PAC with the balloon inflated (for pulmonary venous blood). Blood drawn from the catheter tip in the PA with the balloon deflated can be used to determine mixed venous oxygen saturation (SvO2). From this measurement, together with data obtained from an arterial blood sample, information regarding oxygen delivery, oxygen consumption, and pulmonary shunts can be derived. Low SvO2 values can be caused by low CO, decreased arterial oxygen saturation, increased oxygen consumption, or decreased hemoglobin concentration. Patients with septic shock, hypothermia, or nitroprusside toxicity typically show increased SvO2 values. Assuming that oxygen consumption and arterial oxygen content are constant, then changes in SvO2 should reflect changes in CO.

Specific PACs

Special-purpose PACs for continuous CO measurement and SvO2 monitoring, in addition to rapid-response thermistor PACs that measure the RV ejection fraction, have been introduced. They are not routinely used in the operating room, but they may be used more frequently for the continuous monitoring of hemodynamic and oxygenation parameters in the intensive care unit (ICU). Occasionally, PAC insertion for hemodynamic monitoring may be necessary for patients admitted to the operating room with hemodynamically significant bradycardia or atrioventricular block that requires pacing. For patients with this indication, specialized PACs for atrial and ventricular pacing are available.

Clinical Trials and Outcome Data

After its introduction, the PAC rapidly gained popularity among anesthesiologists and intensivists. It was assumed that measuring hemodynamic parameters to guide treatment options, with beat-to-beat variability, would prove beneficial for patient outcome. However, in 1996, Connors and
Left ventricular afterload:

\[ \text{SVR} = \frac{(\text{MAP}-\text{CVP})}{\text{CO}} \times 80 \text{ (normal range, 900-1,400 dyne } \times \text{s } \times \text{cm}^2) \]

Right ventricular afterload:

\[ \text{PVR} = \frac{(\text{MPAP}-\text{PCWP})}{\text{CO}} \times 80 \text{ (normal range, 150-250 dyne } \times \text{s } \times \text{cm}^2) \]

Figure 3. Estimating left and right ventricular afterload.

\text{CO, cardiac output; CVP, central venous pressure; MAP, mean arterial pressure; MPAP, mean pulmonary artery pressure; PCWP, pulmonary capillary wedge pressure; PVR, pulmonary vascular resistance; SVR, systemic vascular resistance}

CO = \left[ V(T_b-T_1)K_1K_2 \right] / \left[ T_b(t)dt \right]

Figure 4. The modified Stewart-Hamilton equation for calculating CO.

\text{CO, cardiac output; } K_s, \text{ density factor; } K_0, \text{ computation constant; } T_b, \text{ blood temperature; } T_b(t)dt, \text{ integral of blood temperature change over time; } T_c, \text{ injectate temperature; } V, \text{ volume of injectate}

### Table. Recent Outcome Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Type</th>
<th>Patient Group</th>
<th>Patients Enrolled, No.</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandham et al(^6) (2003)</td>
<td>Prospective, multicenter</td>
<td>High risk, general surgery</td>
<td>1,994</td>
<td>No benefit of PAC-guided therapy compared with standard care</td>
</tr>
<tr>
<td>Polanczyk et al(^6) (2001)</td>
<td>Observational cohort study, single center</td>
<td>Major noncardiac surgery</td>
<td>4,059 total (215 matched)</td>
<td>Increased risk for heart failure and noncardiac events in PAC group</td>
</tr>
<tr>
<td>Harvey et al(^7) (2005)</td>
<td>Prospective, multicenter</td>
<td>General ICU</td>
<td>1,041</td>
<td>PAC use not associated with increased mortality</td>
</tr>
<tr>
<td>Rhodes et al(^8) (2002)</td>
<td>Prospective, multicenter</td>
<td>General ICU</td>
<td>201</td>
<td>PAC use not associated with increased mortality; higher incidence of renal insufficiency and thrombocytopenia in PAC group</td>
</tr>
<tr>
<td>Sakr et al(^8) (2005)</td>
<td>Observational, cohort, multicenter</td>
<td>General ICU</td>
<td>3,147 total (453 matched)</td>
<td>PAC use not associated with increased mortality</td>
</tr>
<tr>
<td>Yu et al(^9) (2003)</td>
<td>Observational, prospective</td>
<td>Severe sepsis</td>
<td>1,010 total (141 matched)</td>
<td>No effect on mortality</td>
</tr>
<tr>
<td>Binanay et al(^10) (2005)</td>
<td>Prospective, multicenter</td>
<td>Decompensated heart failure</td>
<td>433</td>
<td>No effect on mortality</td>
</tr>
<tr>
<td>Richard et al(^11) (2003)</td>
<td>Prospective, multicenter</td>
<td>ARDS</td>
<td>676</td>
<td>No improved outcome</td>
</tr>
<tr>
<td>ARDS Trials Network(^12) (2006)</td>
<td>Prospective, multicenter</td>
<td>ARDS</td>
<td>PAC: 501 CVC: 480</td>
<td>No benefit (but more complications) with PAC-guided therapy</td>
</tr>
</tbody>
</table>

Many studies have failed to show clinical improvement with PAC use.

ARDS, acute respiratory distress syndrome; CVC, central venous catheter; ICU, intensive care unit; PAC, pulmonary artery catheter

It is noteworthy that in many subsequent studies specifically designed to show improved patient outcome with PAC use, the conclusions shifted from not being able to show improved outcome to demonstrating no harm to patients from the use of PACs. Recent outcome studies are summarized in the Table.

In the evaluation of patient outcomes, it should be realized that a monitoring device such as the PAC is unlikely to improve outcome by itself unless effective treatment is available and is guided by the measurement of these parameters. In many clinical settings of patients with high rates of mortality (eg, those with sepsis, multiple-organ failure, or acute respiratory distress syndrome), the high rates may persist despite advancements in monitoring because of ineffective therapy. In addition to inadequate treatment options, treatment decisions based on the values obtained for these parameters may be wrong and actually harm the patient.

Physicians’ knowledge about PAC use and interpretation of the results was tested by Iberti et al\(^13\) with alarming results. Up to 47% of physicians were unable to correctly determine the PCWP to within 5 mm Hg. It is also noteworthy that the use of PACs varies widely among different institutions, and even different countries, without apparent differences in patient outcome.

### Indications for PAC Use

National organizations, such as the American Society of Anesthesiologists (ASA), have published practice guidelines for the appropriate use of PACs\(^14\). Specific surgical procedures and medical conditions are not listed as indications for PAC monitoring. Instead, a combination of factors pertaining to the patient, the surgery, and the practice setting should be considered to determine the risk-to-benefit ratio for PAC use in a specific case.

Generally, the routine use of PACs is indicated in high-risk patients (eg, ASA physical status IV) undergoing high-risk procedures (eg, in which large fluid changes or hemodynamic disturbances are expected). The practice setting is important because of evidence that inadequate training or experience may increase the risk for perioperative complications associated with the use of PACs.

### Contraindications

Absolute contraindications to PAC insertion are tricuspid or pulmonary stenosis, tetralogy of Fallot, and an RA or RV mass. Placement of a PAC in such cases can cause serious hemodynamic complications. Newly placed pacemaker wires are a relative contraindication, as is severe coagulopathy. Transient dysrhythmia is common during PAC placement and may cause significant hemodynamic compromise in patients with stenotic valvular lesions, such as severe aortic stenosis. The risk for complications can outweigh the benefits gained by PAC monitoring in these patients.

### Complications

Some of the complications associated with PAC placement are the same as those associated with central venous cannulation: pneumothorax, hemothorax, chylothorax, arterial puncture, thrombosis, infection, hemorrhage, arteriovenous fistula, brachial plexus injury, and air embolization. PAC insertion itself has inherent risks, including transient dysrhythmia during catheter advancement and complete heart block, particularly in patients with a left bundle branch block. Pulmonary artery rupture and endobronchial hemorrhage are associated with a very high mortality rate.
Pulmonary infarction, catheter knotting, valvular damage, thrombocytopenia, endocarditis, thrombus formation, and atrial or ventricular ruptures are further complications that have been reported, although the relative risks are small.

Endobronchial hemorrhage should be treated immediately. The application of lung separation techniques (with the goal of protecting the uninvolved lung) and positive end-expiratory pressure to the involved lung is of primary importance. Percutaneous coil embolization has been introduced as a treatment option for PAC-induced bronchial rupture.18

Future Trends

Recent developments have focused on less invasive methods of hemodynamic monitoring. Transesophageal echocardiography has become an invaluable tool in many clinical scenarios; however, specialized training is required. Less invasive methods of measuring CO, such as the lithium dilution method, pulse contour analysis, and thoracic electrical bioimpedance, are available; however, they have not proved superior when compared with the PAC. The call for large randomized, controlled trials to assess the safety and outcome associated with PAC use has been made ever since Connor and colleagues published their data in 1996. At this point it is unlikely, however, that even the most sophisticated studies will show that PAC use dramatically improves patient outcome. It seems more reasonable to recognize that the PAC is a monitoring/diagnostic device only, and that improved outcome with use can be demonstrated only if effective treatment options are available and such treatment can be guided by use of PAC.

Management of the Case Presented

A PAC was easily placed through the right internal jugular vein. The mean PA pressure was elevated, consistent with mild pulmonary hypertension (mean PA pressure, 32 mm Hg). The intraoperative course was uneventful until the aortic cross-clamp was released and full-body perfusion reestablished. A sudden drop in systemic blood pressure was followed by ECG changes, indicative of myocardial ischemia. Fluid and phenylephrine were administered immediately, whereupon normal arterial blood pressure was restored. However, the ECG changes persisted, and widening of the PA pressure tracing with loss of the diastolic notch was noted. Measurement of CO showed a cardiac index of 2.1 L/min per square meter and a PCWP of 22 mm Hg, indicating elevated filling pressures. A gas analysis of mixed venous blood showed an Svo2 of 52% and a hematocrit of 29.28-29.32.2005;128:2722-2731.

2. High-risk surgery is defined as:
   a. A state of physical status III or higher
   b. the indication for PAC placement should be guided
   c. the practitioner should decide to place a PAC based
   d. PCWP correlates poorly with true LV preload in


Post-test

1. American Society of Anesthesiologists (ASA) guidelines state that:
   a. pulmonary artery catheter (PAC) insertion is indicated in all patients undergoing major vascular surgery
   b. the indication for PAC placement should be guided solely by the type of surgery performed
   c. a PAC should be placed in all patients undergoing a prolonged stay in the intensive care unit
   d. the practitioner should decide to place a PAC based on factors related to the patient, surgery, and practice setting

2. High-risk surgery is defined as:
   a. a surgical procedure in which large fluid changes or hemodynamic disturbances are expected, regardless of the type of procedure or disease state
   b. all vascular surgery involving major blood vessels
   c. open abdominal surgery expected to last more than 4 hours
   d. surgery performed in any patient classified as ASA physical status III or higher

3. Which of the following is a true statement regarding the PAC
   a. Its use in the monitoring of myocardial ischemia has high sensitivity and specificity.
   b. V waves are seen early in all patients with acute intraoperative ischemia.
   c. V waves can be seen in patients with significant mitral regurgitation.
   d. It should be inserted in all patients prone to the development of perioperative ischemia, such as those with diabetes mellitus or a history of myocardial infarction.

4. If the correct position of the PAC cannot be confirmed during placement, it should be:
   a. left at an insertion depth of 70 cm because that is correct in most patients
   b. used retroactively and then the correct position confirmed postoperatively via chest radiography
   c. drawn back to approximately 20 cm and only the distal (pulmonary artery) port used for central venous pressure monitoring and infusions until correct placement can be achieved
   d. left in the right ventricle (RV) because monitoring of the RV pressure is equally appropriate

5. The measurement of cardiac output (CO) with a PAC:
   a. always correlates exactly with systemic blood flow
   b. is not influenced by intracardiac shunts
   c. yields a falsely low value if cold fluid is administered
   d. is not affected by the administration of warm fluid

6. Which of the following is a true statement about pulmonary capillary wedge pressure (PCWP)?
   a. PCWP is not affected by mechanical ventilation.
   b. PCWP should always be measured at the end of inspiration.
   c. PCWP gives a true estimate of left ventricular (LV) preload in patients with severe aortic stenosis.
   d. PCWP correlates poorly with true LV preload in patients with decreased LV compliance.

7. There is clear evidence that placement of a PAC:
   a. always improves the patient’s outcome
   b. in most cases is associated with serious complications
   c. can be harmful
   d. does not require an absolutely sterile technique

8. Blood samples for measuring mixed venous oxygen saturation:
   a. can be drawn from the proximal or distal ports of a PAC
   b. yield information about the delivery and consumption of oxygen
   c. typically show low values in septic patients
   d. show high values in patients with a decreased hemoglobin concentration

9. Alternative techniques for measuring CO include:
   a. bioimpedance
   b. pulse contour analysis
   c. lithium dilution
   d. all the above

10. PAC insertion is absolutely contraindicated in:
    a. all patients with aortic stenosis
    b. patients with a right atrial mass or thrombus
    c. patients with pacemaker or defibrillator wires in the right atrium or RV
    d. patients with a suspected patent foramen ovale

References
