Hemodynamic Monitoring: Part 1

Hadian M, Pinsky MR. Evidence-based review of the use of the pulmonary artery catheter: impact data and complications. *Crit Care*. 2006;10(suppl):S8.

Gershengorn HB, Wunsch H. Understanding changes in established practice: pulmonary artery catheter use in critically ill patients. *Crit Care Med*. 2013;41:2667-2676.

The first central vascular catheterization was performed in the mid-1940s using fluoroscopic guidance. With the application of balloon tip flotation and bedside insertion techniques, the pulmonary artery catheter (PAC) was moved to the bedside in the intensive care unit (ICU). As recently as 2000, 1.2 million PACs were placed annually with an associated cost of over $2 billion. Despite widespread use of the PAC, outcomes were not rigorously evaluated or risks assessed.

The initial use of the PAC was in patients suffering from acute myocardial infarction. In the 1980s, a consistent increase in PAC use was associated with an increased length of hospital stay and a lack of identifiable long-term benefit. Other investigators associated PAC use with increased in-hospital mortality in patients suffering from congestive heart failure. In the 1990s, concern about the relationship between survival and PAC use continued to grow with the important report from Connors et al in 1996. This retrospective study found increased 30-day mortality associated with PAC use along with increased cost of care and ICU length of stay even with adjustment for risk factors favoring catheterization. Another multicenter trial of PAC use in patients managed with shock, acute respiratory distress syndrome, or both identified no impact of PAC use on mortality or morbidity. The PAC-Man study conducted by the National Health Service in the United Kingdom also showed no difference in hospital mortality between patients managed with and without a PAC. The Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness (ESCAPE Trial) in patients with congestive heart failure found that the use of the PAC did not improve outcomes over clinical judgment.

Shoemaker and other surgical coworkers examined the use of PAC-directed supranormal oxygen delivery in high-risk surgical patients. PAC-guided supranormal oxygen delivery was associated with improved outcomes and decreased resource consumption in the hands of this team. However, subsequent trials by other investigators were unable to replicate these results. Gattinoni et al studied over 700 patients prospectively in 56 centers and were unable to show benefit from PAC-guided management toward supernormal oxygen delivery. Finally, the Acute Respiratory Distress Syndrome Clinical Trials Network Fluid and Catheter Treatment Trial (FACTT) compared PACs with central venous catheters. No improvement in outcome was shown with PAC data as opposed to central venous catheter input.

Pulmonary arterial catheterization requires placement of a foreign body across 2 heart valves. This invasive procedure is associated with complication rates ranging from 5% to 10%. Common complications are hematoma formation, arterial puncture, and arrhythmias requiring treatment. Despite a growing body of evidence favoring limited use of the PAC, reduction in the use of this tool has not been uniform.

Gershengorn and Wunsch used the large Project IMPACT database to determine trends over time in PAC use across ICUs in the United States and variation across intensive care units in placement of PACs in the ICU. These investigators also examined institution- and patient-specific factors associated with more frequent use of PACs. It is important to note that the Project IMPACT data set is a proprietary tool operated by Cerner Corporation, which certifies on-site data collectors to ensure standardization and uniformity in data collection and definitions. In most cases, a randomized sample of ICU admissions was used in this study.

Although PAC use in ICUs in the United States decreased throughout the time interval studied (2001-2008), the overall decline varied based on institution and ICU practice patterns. For example, in high-risk patient subgroups, such as patients on vasoactive medications, some ICUs continued to place PACs in more than 50% of patients. Clinicians in surgical ICUs were more likely to continue to use PACs, and surgical patients were more likely to receive a PAC either before or after admission to the ICU. Possible explanations for the persistent use of PACs in surgical patients include increased comfort with PACs in the operating room environment and greater acceptance of invasive monitoring in patients undergoing major surgery. Although a specific explanation for this change in practice trends is not available, the transport practitioner can expect to see a reduced use of PACs in nonsurgical patients and individuals who do not experience major operative procedures.

Perret C, Tagan D, Feihl F, Marini JJ. The Pulmonary Artery Catheter in Critical Care. *Oxford: Blackwell Sciences*; 1996.

Hollenberg SM. Hemodynamic monitoring. *Chest*. 2013;143:1480-1488.

It is important to be aware of the vascular pressure waveform and the insertion distances for the PAC when managing or moving these patients. The distance from skin

Table 1. Cardiac Pressures Obtained From a Pulmonary Artery Catheter and Distance From Insertion Where Pressure(s) Is Obtained (Spontaneously Breathing Patient)

	Range (mm Hg)	Distance From Insertion (cm)[a]
Right atrium (CVP)	3-6	15-20
Right ventricle		25-30
Systolic	20-30	
Diastolic	2-8	
Pulmonary artery		40-45
Systolic	20-30	
Diastolic	5-15	
Mean	10-20	
Pulmonary artery Occlusion	5-14	50-55

[a]Assumes internal jugular or subclavian vein location.

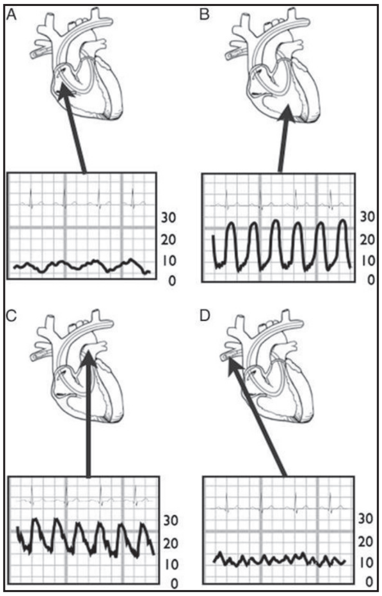
puncture to catheter tip when the catheter enters the thorax is approximately 10 to 15 cm if a subclavian approach is used or 15 cm if an internal jugular insertion technique is used. For the occasional patient with femoral insertion of a PAC, the thorax is entered approximately 30 cm from the femoral puncture site. Transition from the central venous or atrial location to a ventricular waveform generally occurs over a 10-cm distance. A pulmonary artery tracing is obtained an additional 15 cm beyond the tracing obtained for the right atrium. The distance between the right atrium and the pulmonary artery is variable depending on right ventricular configuration. However, awareness of these distances will avoid inadvertent catheter removal or inappropriate excessive insertion (Table 1).

PACs can provide a number of vascular pressure measurements (Table 1). Central venous pressure (CVP, equivalent to right atrial pressure) provides an estimate of right ventricular preload. Unfortunately, CVP waveforms are sometimes difficult to interpret, and physiologic determinants of CVP are many and do not remain constant. CVP is determined by interactions among venous return, which is a function of venous compliance and blood volume, right ventricular function, and pulmonary arterial pressure. In critically ill patients, these values are rarely static and are typically abnormal. Thus, a single measurement of CVP is generally a poor prediction of fluid responsiveness.

Pulmonary artery pressure can be measured at the bedside using a PAC when the catheter is fully inserted. In theory, a continuous column of blood is present between the left atrium, and the tip of the catheter and pressure measured with the distal balloon inflated reflects left atrial pressure and left ventricular preload. A PAC can also be used to track cardiac output by thermodilution. A variety of automated systems to allow frequent cardiac output measurement are available.

There are a number of pitfalls associated with using pulmonary artery occlusion or "wedge" pressure as a surrogate for left ventricular preload. One assumption is that there is

Figure 1. (A) Central venous, (B) right ventricle, (C) pulmonary artery, and (D) pulmonary artery occlusion.



Hollenberg SM. Hemodynamic monitoring. Chest. 2013;143(5): 1480-1488. Reproduced with permission from the American College of Chest Physicians.

no significant mitral valve disease and that a constant relationship between pressure and volume in the left ventricle exists. These assumptions may not be satisfied in many critically ill patients. In addition, there are technical "pitfalls" in measurement including incorrect transducer placement (common), incorrect catheter positioning or calibration, vascular effects of mechanical ventilation, and incorrect waveform interpretation. If data from a PAC are to be used for hemodynamic assessment and titration of therapy, follow serial changes in parameters measured including filling pressures during times of various physiologic stress or during the course of therapeutic interventions.

It is also important to monitor the PAC waveforms while the catheter is in place (Fig. 1). The pulmonary artery occlusion waveform (D) should be visible only when the distal balloon is inflated and a measurement is being made. Prolonged balloon inflation or excessive catheter insertion distance increases the risk of pulmonary artery rupture. In general, the pulmonary artery pressure waveform should be seen with standard catheter insertion (C). Similarly, if the catheter is inadvertently withdrawn, the clinician may note a right ventricular waveform (B). This is also dangerous because right ventricular injury or arrhythmias may occur because of "whip" of the catheter while the catheter tip is in the right ventricle. If the catheter is inadvertently withdrawn, I suggest moving the catheter back so that the tip is within the thorax but proximal to the right ventricle (A). This will be at least 10 to 15 cm from the site of insertion depending on the insertion location.