

PRO: The pulmonary artery catheter has a paramount role in current clinical practice

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ABSTRACT

Ever since its clinical introduction, the utilization of the pulmonary artery catheter (PAC) has been surrounded by multiple controversies, mostly related to imprecise clinical indications and the complications derived from its placement. Currently, one of the most important criticisms of the PAC is the ambiguity in the interpretation of its hemodynamic measurements and therefore, in the translation of this data into specific therapeutic interventions. The popularity of the PAC stems from the fact that it provides hemodynamic data that cannot be obtained from clinical examination. The assumption is that this information would allow better understanding of the individual's hemodynamic profile which would trigger therapeutic interventions that improve patient outcomes. Nevertheless, even with the current diversity of hemodynamic devices available, the PAC remains a valuable tool in a wide variety of clinical settings. The authors present a review exposing the benefits of the PAC, current clinical recommendations for its use, mortality and survival profile, its role in goal-directed therapy, and other applications of the PAC beyond cardiac surgery and the intensive care unit.

Keywords: Cardiac surgery, critical care, hemodynamic monitoring, intensive care unit, pulmonary artery catheterization

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Submitted: 31-Aug-2019 **Accepted:** 26-Sep-2019 **Published:** 22-Jan-2021

INTRODUCTION

The pulmonary artery catheter (PAC) in despite of enduring a significant decline in its use in the recent decades remains the preferred invasive hemodynamic method for multiple surgical interventions—cardiothoracic procedures, lung and liver transplants, and so forth—and in the intensive care unit (ICU) for the management of the critically ill patient.^[1,2] Currently, many alternatives methods are used to measure the parameters displayed by the PAC. However, the exclusive and distinctive data provided by the PAC makes it an attractive monitor in specific settings.^[3]

The notion of right heart catheterization began circa 1929 when Dr. Werner Forssmann was able to advance a catheter from one of his own peripheral veins to his right heart.^[4] This concept was further expanded in the 1970s when Dr. Jeremy Swan incorporated the balloon flotation technique to the pulmonary arterial circulation to allow bedside placement without fluoroscopy and Dr. William Ganz introduced a port for thermodilution and cardiac output measurements.^[5]

The PAC has undergone several modifications that allows the clinician to monitor multiple hemodynamic parameters

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How to cite this article: Szabo C, Betances-Fernandez M, Navas-Blanco JR, Modak RK. PRO: The pulmonary artery catheter has a paramount role in current clinical practice. *Ann Card Anaesth* 2021;24:4-7.

Access this article online	
Quick Response Code:	Website: www.annals.in
	DOI: 10.4103/aca.ACA_125_19

including: continuous cardiac output measurements, right ventricular end-diastolic volume, right heart pressures, obtaining blood samples for mixed venous oxygenation, pulmonary artery and pulmonary artery occlusion pressure (PAOP, also known as “wedge pressure”) as well as therapeutic interventions such as administration of drugs and right atrial and ventricular pacing.^[6]

PRACTICE GUIDELINES FOR THE USE OF PAC

The American Society of Anesthesiologists (ASA) published practice guidelines to determine the appropriate use of PAC based on the following aspects:^[7,8] *Patient factors:* patients at increased risk for hemodynamic disturbances, including: evidence of significant cardiovascular disease, pulmonary dysfunction, hypoxia, renal insufficiency, or other conditions such as endocrine disorders, sepsis, trauma, burns, and advanced age. *Procedure factors:* Surgical interventions associated with an increased risk of complications from hemodynamic changes, including damage to the heart, vascular tree, kidneys, liver, lung, or brain may benefit from pulmonary artery catheterization. The ASA further clarifies that these high-risk procedures are those that have a predictably large chance of significant fluid shifts, hemodynamic disturbances, or other factors with high risk of morbidity and mortality. *Practice factors:* PAC is suitable to be used if the level of training of physicians and nurses is adequate for its interpretation and calibration.

PAC AND OTHER HEMODYNAMIC METHODS

The major benefit that come with utilization of a PAC is the large amount of data that can be collected in real-time from its use, but the information is only valuable if analyzed by a qualified physician, within the appropriate clinical context in the appropriate clinical setting.^[3,7,8] Specific advantages of PAC over other hemodynamic methods include: a) superior measurements of cardiac output when compared to pulse wave contour analysis (on which accuracy relies on frequent recalibration), esophageal Doppler and bioimpedance,^[3,9,10] b) reliable measurements of venous saturation of oxygen (SvO₂) [more accurate calculation of Fick when compared to central venous oxygen saturation (ScVO₂)], and veno-arterial difference in carbon dioxide pressures (PvaCO₂), when compared to central venous catheter measurements.^[3,11]

In addition, the PAC has demonstrated improved dynamic and qualitative measurements of PAOP and right atrial pressure when compared to echocardiography.^[3] The use of PAC provides the advantage of continuous

monitoring of the ventricular function in cases of acute right ventricular failure, when compared to central venous catheters and without the need to sending the patient to the catheterization lab.^[12]

In patients with acute respiratory distress syndrome, the use of a PAC yields data to improve titration of ventilator settings based on their effects on right ventricular function.^[6] Intraoperatively, when appropriately indicated for patients undergoing cardiac surgery, the information provided by a PAC can be used to continuously assess cardiac output, control left ventricular filling pressures, pulmonary artery pressures (PAP), monitor systemic vascular resistance, and measure SvO₂ before and after cardiopulmonary bypass.^[13] In patients with septic shock, PAC was shown to be more accurate than clinical assessment in differentiating the etiology of shock, as well as assessing fluid responsiveness, vasopressor administration, and determining when cardiac preload and oxygen delivery needed to be evaluated continuously.^[14]

MORBIDITY AND SURVIVAL BENEFIT OF PAC

Overall, most studies agree that the use of PAC and the occurrence of positive clinical outcomes have a linear relationship with the appropriateness of the clinical use and the expertise of the clinician interpreting the data. Brovman *et al.* performed a retrospective study which identified more than 40000 patients that underwent cardiac surgery with a PAC in place between 2010 and 2014 and demonstrated a decrease in blood transfusion rate by 75% (odds ratio [OR] 0.23, 95% Confidence Interval [CI] 0.084-0.64; $P = 0.0048$).^[15]

Similarly, Shaw *et al.* in another retrospective cohort analysis of 6844 patients who underwent cardiac surgery revealed that use of PAC corresponded with a decrease in length of stay when compared to patients without the device (9.39 days without PAC *vs.* 8.56 days with PAC; $P < 0.001$) as well as decreased cardiopulmonary morbidity ($P < 0.001$).^[16] Friese *et al.* investigated mortality with PAC in trauma patients in a retrospective analysis of over 53000 patients from the National Trauma Data Bank including two groups: trauma patients managed with a PAC and those without a PAC. They demonstrated a survival benefit when a PAC was used in older patients, with higher injury severity score and higher base deficit (OR 0.63, 95% CI 0.40–0.98; $P < 0.05$).^[17]

A prospective, multi-center cohort analysis performed by Sotomi *et al.* in a population with acute decompensated heart failure demonstrated that use of PAC resulted in

a decrease in all-cause mortality (hazard ratio [HR] 0.3, 95% CI 0.13–0.70; $P = 0.0006$). The effect was markedly pronounced in patients with lower systolic blood pressure (SBP <100 mmHg, $P = 0.021$) and in patients receiving inotropic therapy ($P = 0.002$).^[18] Likewise, another prospective trial by Rossello *et al.* of 129 patients with cardiogenic shock and concomitant PAC use was also associated with lower short-term (HR 0.55, 95% CI 0.35–0.86; $P = 0.008$) and long-term mortality rates (HR 0.63, 95% CI 0.41–0.97; $P = 0.035$), although the benefit was only significant in patients that did not present with acute coronary syndrome.^[19]

Chittock *et al.* in an observational cohort study of 7310 patients, whose main outcome was hospital mortality rate, demonstrated that PAC use was associated to lower mortality in patients with higher APACHE (Acute Physiology and Chronic Health Evaluation) scores.^[20] Hamilton *et al.* performed a large meta-analysis pooling 29 studies and involving 4805 patients to determine whether preemptive hemodynamic intervention was associated to better postoperative outcomes in patients undergoing moderate and high-risk surgical procedures, and in further subgroup analysis, determined that use of PAC was associated with decreased mortality (OR 0.35, 95% CI 0.19–0.65; $P = 0.001$).^[21]

PAC USE DOES NOT INCREASE MORTALITY

The detractors of the use of PAC have advocated that based on the nature of its invasiveness, associated risks for infection and damage to surrounding structures during insertion, the use of PAC may be associated to increased mortality, although large clinical trials have failed to corroborate these statements. A large meta-analysis performed by Rajaram *et al.* comprising critically ill patients in the ICU as well as patients undergoing high risk surgery, resulting in a pool of 13 trials and involving a total of 5686 patients with and without the PAC, demonstrated that the use of PAC was not associated with higher mortality, as well as no difference in ICU length of stay or cost. Moreover, the authors emphasized that when appropriately applied, the use of PAC to specific groups in the ICU could result in certain benefits such as shock reversal, improved organ function, and less vasopressor use.^[22]

Another study looked at the effect of PAC use in cardiac surgery patients in terms of length of stay and mortality, focusing on the use of PAC after surgery and concluded that there is no significant difference when compared to no PAC when it comes to mortality, complications, length of stay in the intensive care unit and length of stay in the

hospital.^[23] Similarly, a meta-analysis performed by Shah *et al.* revealed that the use of PAC did not increase overall hospital mortality (odds ratio 1.04, 95% CI 0.90–1.20; $P = 0.59$),^[24] and a randomized controlled trial presented by Harvey *et al.* including 1014 patients admitted to the ICU showed no difference hospital mortality in patients managed with and without PAC (adjusted hazard ratio 1.09, 95% CI 0.94–1.27; $P = 0.39$).^[25]

PAC AND GOAL-DIRECTED THERAPY

PAC data has been used to guide therapy in patients in shock with positive results. Bethlehem *et al.* in a retrospective analysis of 140 patients evaluated the influence and impact of PAC-derived data in the management of patients with early sepsis and found that after 7 days the cumulative fluid balance was lower in PAC group (9.4 ± 7.4 liters with PAC *vs.* 13 ± 7.6 liters with PAC; $P = 0.001$) and this was also reflected in a significant reduction in ventilator days (7 with PAC *vs.* 10 without PAC, $P = 0.01$) and ICU days (9 with PAC *vs.* 14 without PAC, $P = 0.001$) compared to controls.^[26]

UTILITY OF PAC BEYOND CARDIAC SURGERY AND THE ICU

Data yielded by the PAC can be used to predict prognosis in different surgical populations. PAC placement to monitor continuous PAP has been shown to predict survival in patients undergoing kidney transplantation if the pulmonary artery systolic pressure is maintained <35 mmHg intraoperatively ($P = 0.04$).^[27] Nowak *et al.* evaluated the prognostic value of data obtained by the use of a PAC, including mean, diastolic and systolic PAP in patients referred for lung transplant and were able to identify the threshold for each specific value that relates to worse outcomes in this population ($P = 0.005$ for mean PAP, $P = 0.035$ for diastolic PAP, and $P < 0.001$ for systolic PAP).^[28] As of today, the PAC continues to be widely utilized standard monitor during orthotopic liver transplantation with a prevalence of 94% (85%–97%) among 119 transplant centers in the United States, with a formal benefit level yet to be validated.^[2]

SUMMARY

In summary, studies have shown that the PAC, when utilized by experienced clinicians, has shown beneficial outcomes and has not shown to have increased mortality. There have been multiple studies where certain populations benefit from PAC-directed therapy. Determining exactly which cohorts of patients benefit from this therapy, however, continue to be elusive. With less experienced clinicians,

misinterpretation of the data provided by PAC can lead to under and/or overtreatment of patients, that can be harmful.^[29] The extensive variety of complex information provided by the PAC can lead to inter-observer variability; therefore, it is necessary to have a specialized clinician interpreting the variables and the clinical situation.^[30] It is ultimately up to the practitioner to determine if placement of a PAC is appropriate for the patient.

Financial support and sponsorship

Support was provided solely from institutional and/or departmental sources.

Conflicts of interest

There are no conflicts of interest.

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