Why I use the pulmonary artery catheter

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ABSTRACT

Despite myocardial depression, most early deaths from sepsis are caused by profound vasodilatation, while some are caused by low cardiac output. Most late deaths are caused by multiple organ dysfunction. While fluid resuscitation and vasopressors, combined with definitive source control and antibiotics, may be effective, delayed improvement in organ dysfunction, positive fluid balance, shock and renal failure are associated with poor outcome. Indiscriminate vasopressor therapy may increase mortality rate.

Although observational studies reported increased mortality in association with the pulmonary artery catheter (PAC), these results have been refuted, as summarised in a recent meta-analysis. It is counterintuitive to expect an investigation alone to improve outcome; this requires an effective therapeutic intervention. Perhaps this accounts for the PAC-associated increase in mortality noted in low-risk intensive care unit patients, combined with the reduction in mortality in high-risk patients.

While alternative techniques of advanced haemodynamic monitoring are available, all have pros and cons. The PAC offers accurate cardiac output monitoring, measurement of central venous pressure (CVP) and pulmonary artery occlusion pressure (PAOP), a measure of right ventricular afterload (the pulmonary artery pressure) and mixed venous oxygen saturation, which is a more accurate measure of the adequacy of cardiac output than central venous oxygen saturation. The CVP and PAOP are important measures and can assist with fluid resuscitation. CVP is determined by venous return and right ventricular function, while PAOP is the major determinant of hydrostatic pulmonary oedema. Over half of cases of acute respiratory distress syndrome (ARDS) are due to sepsis, and right ventricular dysfunction in ARDS, measured as CVP > PAOP, is independently associated with death.

The PAC should be considered when particular patients present important therapeutic issues. However, this cannot replace a careful, clinically integrated approach.

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Nearly 20 years ago, Parker and colleagues reported that most early deaths from sepsis could be attributed to excessive vasodilatation.[1] Some early deaths were due to low cardiac output, while most late deaths were due to multiple organ dysfunction. Recent Australian and New Zealand,[2] and European[3,4] epidemiological studies have reported unacceptably high mortality rates of 25%–35% in sepsis, and confirmed the importance of haemodynamic factors. As the risk factors for death include positive fluid balance,[4] chronic heart failure, renal failure and shock (the latter with odds ratios of 3.1 and 2.4, respectively[3]), clinicians continue to focus on circulatory resuscitation in the management of critically ill patients with sepsis.

Need for advanced haemodynamic monitoring

In these patients, circulatory resuscitation complements diagnosis, definitive source management, optimal antibiotic therapy and possible use of novel therapies, such as activated protein C. However, as sepsis results in complex systemic, regional and microregional circulatory disturbances, there are many uncertainties in management, particularly in patients with comorbidities and pre-existing organ dysfunction.

Despite myocardial depression in sepsis, inappropriate systemic vasodilatation usually results in high cardiac output. However, this is not universal as many factors, such as inadequate fluid resuscitation or excessive systemic or pulmonary vasoconstriction, can result in inadequate cardiac output. For example, in a small prospective randomised study of patients with hyperdynamic septic shock receiving either norepinephrine or terlipressin titrated to achieve a target mean arterial pressure of 65–75 mmHg, terlipressin reduced cardiac output, systemic O_2 delivery and consumption.[5] More importantly, in a large multicentre study,[6] septic shock mortality was increased by the non-specific nitric oxide synthase inhibitor 546C88. Non-specific inhibition of nitric oxide synthase results in widespread increases in vascular tone, which were associated with decreased cardiac output, pulmonary hypertension and heart failure, and excess cardiovascular deaths.[6] Kaplan–Meier survival plots diverged between the placebo and 546C88 groups by Day 3, suggesting that important circulatory effects occurred early. This conclusion is supported by analysis of the placebo arms of two recent severe sepsis trials ($n = 1036$), where improvements in cardiovascular, renal and respiratory function between baseline and Day 1 were significantly associated with survival.[7]

Regional and microregional vascular changes likely contribute to multiple organ dysfunction in septic shock. However, laboratory data need to be interpreted in the light of associated systemic effects and appropriateness of the

model; and bedside monitoring remains developmental. Gastric tonometry appeared promising, but is rarely used for patient management. While low-dose dopamine does not appear to alter renal function in sepsis,[8] the notion that specific agents can be used to manipulate regional vascular tone should not be discarded, given the promising findings recently reported with fenoldopam, also a dopamine-receptor agonist.[9] Nevertheless, the relative importance of renal perfusion pressure, cardiac output and possible regional effects is unknown. Within a group of previously normal subjects, there are a range of autoregulatory blood pressure thresholds, and previously hypertensive subjects will have right-shifted pressure–flow relations. Both clinical experience and numerous studies report an apparent improvement in renal function following augmentation of renal perfusion pressure to an adequate target level.

With these issues in mind, it is not surprising that endpoints for adequacy of circulatory resuscitation remain contentious, particularly when an adequate perfusion pressure requires moderate–high dose vasopressors, or when there is persisting evidence of inadequate microcirculatory flow, such as lack of improvement in lactic acidosis or organ dysfunction. Clearly, other factors, such as direct effects of inflammatory mediators and mitochondrial dysfunction, are also important elements of the systemic disturbance invoked by sepsis. However, therapeutic interventions are currently limited. Consequently, clinicians continue to focus on systemic resuscitation with the aid of advanced haemodynamic monitoring.

The case for the pulmonary artery catheter

Despite well voiced concerns regarding the safety of the pulmonary artery catheter (PAC), many clinicians continue to use it to assist management decisions, albeit with greater care and less commonly than a decade or two ago. This likely reflects the potentially useful physiological information available from the PAC, and the perceived need to augment advanced haemodynamic monitoring in critically ill patients. For example, in the PAC-Man study,[10] where 1014 critically ill patients were randomly allocated to management with or without a PAC, 80% of those in the non-PAC group underwent an alternative form of cardiac output monitoring.

The PAC offers many features that appear to assist decision-making in patients with unstable conditions. Cardiac output values determined by thermodilution with a PAC are accurate if due care is paid to confounders; it is easily measured in both conscious and sedated patients, and continuous measurements can be obtained. Mixed venous oxygen saturation is a more accurate reflection of the adequacy of systemic O_2 delivery than central venous saturation,[11] and can also be displayed continuously.

Although central venous pressure (CVP) and pulmonary artery occlusion pressure (PAOP) may not accurately reflect preload of the right and left ventricles or fluid responsiveness, they are important measures and, appropriately used, can assist in volume resuscitation.[12] PAOP is the main determinant of pulmonary microvascular pressure: it drives fluid filtration and hydrostatic pulmonary oedema. CVP reflects the balance between venous return and right ventricular performance: a high CVP erodes splanchnic and renal perfusion pressures, contributing to inadequate regional flow; a CVP greater than the PAOP is evidence of right ventricular dysfunction, and is independently associated with death in acute respiratory distress syndrome (ARDS).[13] As sepsis accounts for over half of ARDS cases,[14] this is particularly important. Pulmonary artery pressure is the major determinant of right ventricular afterload, and contributes to pulmonary microvascular pressure and hydrostatic pulmonary oedema. Other features, such as the right ventricular ejection fraction and derived variables, and right ventricular pacing, are less commonly used.

Does the pulmonary artery catheter increase mortality?

Observational studies suggesting that mortality was increased in patients receiving the PAC[15-17] forced clinicians to re-evaluate use of the PAC. While these data failed to reveal a mechanism linking PAC insertion with increased mortality, inappropriate treatment decisions and complications during or following PAC insertion (eg, infection and pulmonary artery rupture) need to be considered. Nevertheless, despite the careful methodology and large sample size in these studies, the data have been refuted by more recent studies[10,18-20] and a meta-analysis of 13 randomised controlled trials,[21] which have not found any effect of the PAC — either an increase or decrease — on mortality. These include prospective randomised trials of high-risk surgical patients ($n = 1994$),[18] patients with shock or ARDS ($n = 676$),[19] patients with heart failure ($n = 433$),[20] and general intensive-care unit patients requiring advanced haemodynamic monitoring ($n = 1014$).[10]

As demonstrated in the PAC-Man study,[10] most clinicians choose advanced haemodynamic monitoring — including both invasive and non-invasive measures of cardiac output — in some critically ill patients. The choice of technique depends on local experience and the therapeutic questions being addressed, and rather than being exclusive, a combination of techniques, such as PAC and echocardiography, may be particularly useful.

Need to define associated therapeutic interventions

In defending the use of the PAC and similar investigations, it is worth considering the failure of most studies to define an associated therapeutic intervention. For example, the important study of early, goal-directed therapy in sepsis by Rivers et al[22] used a treatment algorithm based on measured parameters, including haemoglobin level and central venous oxygen saturation. When there was evidence of inadequate oxygen delivery in early sepsis, they used a transfusion threshold of 100 g/L. This contrasted with the findings of Hebert and colleagues[23] that there was no disadvantage when transfusion threshold was limited to 70 g/L in stable critically ill patients. Clearly, there were major differences in study design, and multicentre studies confirming the findings of Rivers et al would increase confidence in their result. However, a similar notion must apply to the PAC. Studying the PAC without defined therapeutic decisions is analogous to measuring the haemoglobin level without defining transfusion threshold or the clinical state of the patient. In addition to the obvious impact that haemoglobin has on oxygen content of blood, and the effect of transfusion on preload, it is the major determinant of blood viscosity (responsible for >90% of variation in blood viscosity). Given that resistance to blood flow is the quotient of vascular hindrance (vessel diameter) and viscosity, transfusion may raise blood pressure and limit vasoconstriction independent of any effect on preload.[24] In addition to the importance of haemoglobin to the interpretation of haemodynamic measurements, this illustrates the complexities that need to be considered when clinicians use these data.

Conclusions

In summary, most interventions may increase complications, and clinicians accept the risk only when it is outweighed by the potential therapeutic benefit. Arguably, this underlies the observation that the PAC is associated with increased mortality in the healthiest patients, where therapeutic intervention is likely to be the least influential, and is associated with reduced mortality in the sickest patients, where therapeutic intervention might have most impact.[25] Similarly, the ARDS Network Fluid and Catheter Treatment Trial (FACTT)[26] defines treatment decisions with strict protocols based on "wet versus dry" fluid management and PAC- versus CVP-derived data. Irrespective of the outcome of this study, it seems likely that attention will focus on the detail of the protocol, rather than the monitoring tools required to enact that protocol. If the PAC can help distinguish adequate resuscitation fluids from those resulting in fluid overload and worse outcome, and this can be tested in a well designed study, these data will make an important contribution to the literature. In other words, appropriate application of the data available from a PAC to an appropriate question with therapeutic implications is central to its continued use; the FACTT study addresses some of these issues with one particular study design and protocol.

Many patients with sepsis, with or without shock, respond quickly to definitive source management, appropriate antibiotics, and straightforward resuscitation measures. Central venous access for infusion of pressors and CVP measurement may be all that is required. However, advanced haemodynamic monitoring should be considered on an individual patient basis, taking into account the appropriateness and availability of alternative techniques. For example, dynamic methods of assessing fluid responsiveness, such as respiratory blood pressure variation or change in vena cava diameter, are valid only during relaxed mechanical ventilation, and are also influenced by tidal volume, respiratory mechanics, heart rate and aortic elastance. Patients with an irregular heart rhythm are excluded, and the data have not been validated for situations where left ventricular contractility is impaired; fluid responsiveness may not be an indication for fluid loading. Finally, given the tendency to encourage spontaneous breathing in intubated patients, and the need to titrate resuscitation fluids in non-intubated patients, these techniques have limited utility.

Similarly, techniques requiring anaesthesia or deep sedation, such as the oesophageal Doppler, also have limited use in most critically ill patients. The transpulmonary thermodilution technique, often combined with pulse contour analysis, allows accurate measurement of cardiac output, and also measures extravascular lung water and preload. However, this requires alternative arterial access, with the potential for additional complications, and fails to estimate right ventricular afterload, the forces driving hydrostatic pulmonary oedema, or the adequacy of cardiac output. Finally, although echocardiography yields abundant important data, it is operator-dependent and provides only intermittent measurements.

While it is surprising that the apparently simple issue of whether to use the PAC remains contentious, there are circumstances where it may be considered, taking into account these uncertainties and the issues in individual patients. Given the increasing prevalence of comorbidities and the complexity faced by intensivists, it is impossible to consider all situations. However, recent indications for a PAC include:

- Failure of the patient's condition to respond rapidly, with persistent lactic acidosis or persistent multiple organ dysfunction syndrome;

- Significant pre-existing comorbidities, such as severe chronic heart failure, chronic lung disease or chronic renal impairment (about 34% of patients in the EPISEPSIS study[3]);
- Sepsis with severe ARDS, where pulmonary hypertension and right ventricular dysfunction may complicate mechanical ventilation (about 25% of patients with ARDS[27]), particularly with high mean airway pressures or positive end-expiratory pressure;
- Unexplained deterioration in the patient's condition; and
- Diagnostic dilemmas, such as probable co-existing pathologies (eg, sepsis with either pulmonary embolism or myocardial ischaemia).

My usual choice in these circumstances is a PAC, often combined with echocardiography. Nevertheless, without a careful, clinically integrated approach, it is unlikely that data derived from any advanced haemodynamic monitoring tool will be an adjunct to management.

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