

Review Article

Pulmonary Artery Catheter (PAC) Under Attack?

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The history of the pulmonary artery catheter (PAC) spans more than 80 years, since the first reported cardiac catheterisation by Forssmann on himself in 1929.¹ Cournard and Ranges, and Cournard and colleagues, respectively, reported for the first time the use of right sided heart catheterisation as a means of accurately measuring cardiac output and right heart pressures.^{2,3} Finally, five years later, Hellens and colleagues introduced the concept and use of the pulmonary “capillary” pressure in humans.⁴ The name of the balloon tipped catheter used to catheterise the pulmonary artery went to Swan and Ganz whose famous relevant paper was published in 1970.^{5,6} The heyday of the Swan-Ganz PAC was during the last quarter of the twentieth century. However, in the 1990s the wind began to change concerning the routine use of the PAC, and in recent years its use has become the subject of controversy.⁷ Indeed, studies have failed to demonstrate a clear benefit from PAC use, while several prospective randomised trials have indicated that using a PAC does not influence outcome. Moreover, as a result of the concerns about the insertion of invasive monitoring systems like PAC, many researchers have focused on the development of reliable alternatives, particularly for the monitoring of cardiac output and related haemodynamic parameters, and the role of the PAC has come under close scrutiny. In this article,

we review the most important studies addressing the use, potential benefit, and safety of the PAC in various clinical settings and patient populations.

Studies and trials addressing the use of the pulmonary artery catheter

Older studies during the 1980s questioned the benefit and safety of PAC monitoring. Among them, Gong and colleagues, in 1987, found that the use of a PAC was associated with higher mortality and a longer hospital stay.⁸ There was no difference in the long-term outcome between the PAC and the non-PAC managed groups. These findings were largely confined to a similar patient population (acute coronary syndromes) with a retrospective look at PAC in the GUSTO II and III trials. In another study, Zion and co-workers analysed a registry containing 5841 hospitalised patients with acute myocardial infarction.⁹ They concluded that although higher in-hospital mortality was found in patients receiving a PAC, this difference was probably related to differences in the severity of chronic heart failure.

Recent studies have not demonstrated any sustained benefit from right heart catheterisation, and some studies have even suggested harm from adverse events related to this invasive procedure. Connors and colleagues in 1996 conducted a retrospective observational study of 5735

critically ill patients (SUPPORT study).¹⁰ Their data suggested that PAC use in the above patients was associated with increased 30-day mortality, increased costs of care, and increased length of stay in the intensive coronary unit. The latter study raised for the first time many questions about the safety of PAC use. However, patients managed with a PAC were more likely to enter the study with multiple organ failure, acute respiratory failure, chronic heart failure, and a higher APACHE III score, factors known to be associated with increased mortality. Moreover, patients receiving a PAC had lower mean arterial pressure and baseline serum albumin concentration, which are also associated with increased mortality. However, it is not clear that PAC use increased mortality, even in the SUPPORT cohort. Other smaller clinical trials similarly found greater mortality in patients receiving a PAC.¹¹⁻¹³

There are also smaller clinical trials that found no benefit from therapy directed by PAC over standard care.^{14,15} Shah et al, in a meta-analysis of 5051 patients studied in 19 randomised controlled trials, found that the use of PAC neither improved survival nor decreased the length of hospital stay.¹⁶ There was also no apparent benefit in high risk surgical patients randomised to PAC or non-PAC management by the Canadian Critical Care Clinical Trials Group.¹⁷ Finally, Yu and co-workers found that, among patients with severe sepsis, PAC placement was not associated with a change in mortality rate or resource utilisation (total length of stay in the intensive care unit, total hospital charges), although there was a small, non-significant trend toward lower resource utilisation in the PAC group.¹⁸

Even when PAC was introduced early in the management of patients with shock, acute respiratory distress syndrome, or both, Richard and co-workers found no significant impact of PAC on mortality or morbidity.¹⁹ The French Pulmonary Artery Catheter Study group found that the PAC itself did not affect outcomes in patients admitted for shock or adult respiratory distress syndrome.²⁰

New interest in the controversy between PAC use or non-use was generated when Randall et al found, in a total of 53,312 patients admitted to the intensive care units of trauma centres participating in the National Trauma Data Bank, that severely injured patients (injury severity score 25-75) who arrive in shock and older patients have an associated survival benefit when managed with a PAC.²¹

However, prospective randomised controlled trials, such as the ESCAPE trial and PAC-Man study, as

well as the recent *post hoc* analysis of the PAC-Man study, did not demonstrate the same benefit in different populations. The ESCAPE investigators found no difference between the two management groups in the primary endpoints, namely days alive out of the hospital.²² A host of secondary endpoints did not differ between the two groups, with a trend in favour of PAC management for functional assessment. The ESCAPE trial revealed that PAC should no longer be considered a standard or routine approach in the management of patients hospitalised for advanced or decompensated chronic heart failure. However, in the ESCAPE trial, patients whom the investigators thought should receive a PAC for optimal management were excluded from the study. The study involved seasoned physician investigators who were highly experienced in managing heart failure, without the dire need for PAC data to guide them. The trial did not record whether the various insertion operators were experienced with PAC use or their level of training.

Similarly to previous studies, the PAC-Man study found no difference in hospital mortality between patients managed with and those managed without a PAC.²³ Although complications associated with PAC insertion were noted in 9% of the patients treated, none were fatal. Therefore, no clear evidence of benefit or harm from managing critically ill patients with a PAC was found.

Post hoc analyses of the PAC-Man study revealed no favourable effect associated with being managed with a PAC in any of the subgroups studied, other than elective surgical patients.²⁴ However, one criticism of the PAC-Man study is that the study population was probably too severely ill to derive any benefit from management with a PAC. In addition, the lack of a treatment protocol suggested that there is a need to undertake prospective studies based on specific population subsets. In particular, this approach should be considered early in the patient's critical illness in order to optimise the likelihood of reversing or preventing further organ dysfunction.

Treatment protocols using PAC derived data

None of the studies reported used PAC-specific data to drive a treatment protocol that is known to improve outcome. Rivers et al documented markedly improved outcomes when critically ill patients were aggressively treated for circulatory shock with a well defined treatment protocol, using mixed venous oxygen saturation (ScvO₂) values, in the emergency department.²⁵

In some older studies some efforts were made to relate the impact of PAC use to specific treatment goals. Franciosa et al have shown that it is possible to reduce filling pressures to near normal levels (16 mmHg or less) while monitoring or improving stroke volume in patients with heart failure.²⁶ Shoemaker and co-workers found that, in high risk surgical patients managed with a PAC pre- and perioperatively in order to optimise oxygen delivery with specific treatment goals, when a PAC is present, but not used to drive therapy, outcomes are no different than if the PAC is not used.²⁷

The strategy of using haemodynamic targets to tailor treatment has been shown to be effective in improving symptoms and allowing hospital discharge without surgery in patients evaluated for transplantation.²⁸

Finally, the NIH ARDSNet FACTT study, a multi-centre clinical trial of PAC versus central venous pressure management that compared liberal versus conservative fluid management, did not show any benefit from PAC use.²⁹

Complications of PAC placement

Pulmonary artery catheterisation is an invasive procedure. Many recent studies reported a series of complications related to PAC insertion.

The ESCAPE study found that approximately 4% of patients undergoing PAC placement had complications, including aborted cardiac arrest and infection, but there were no PAC-related deaths.²² In the ESCAPE study, PAC-related infections occurred in 2.5% of cases, catheter knotting and pulmonary infarction/haemorrhage in 1% each, and ventricular arrhythmia in 0.5%. The published PAC-Man²³ randomised clinical trial identified an incidence of complications of 10% in patients in whom PAC insertion was attempted. The most common complications were insertion site haematoma (4%), arterial puncture (3%) and arrhythmias (3%). The French study reported that 2.8% of patients enrolled suffered PAC-related infections.²⁰ However, no cases of pulmonary embolism were reported. Finally, Boyd and co-workers reported serious complications in 4.4% of 528 PAC insertions, which did not contribute directly to any of the 31 deaths that occurred.³⁰ In addition, arrhythmias, thrombosis, endocardial vegetations and pulmonary infarction related to PAC insertion have also been reported in other studies.³¹ Sprung and co-workers found that 3% of patients developed a new right bundle branch block (RBBB) after PAC insertion.³² In 60 sequential

PAC insertions, 48% were associated with premature ventricular contractions and 33% were associated with ventricular tachycardia.³³ One patient developed ventricular fibrillation and died. The incidence of complete heart block during pulmonary artery catheterisation of patients with previous left bundle branch block was not higher than the incidence of RBBB in patients without underlying conduction defects. Patil et al also reported an increased risk of RBBB and complete heart block during PAC insertion.³⁴

Furthermore, not only recent studies but also autopsy cases reported a series of complications related to PAC insertion. Connors and co-workers identified thrombosis in 53% and intimal fibrin deposition in 66% in a series of 32 patients brought to autopsy with a PAC in place.³⁵ The incidence of thrombosis was significantly higher when the catheter was in place longer than 36 hours. Pace and co-workers reported that the incidence of aseptic thrombotic endocardial vegetations after PAC use was increased in an autopsy series of 413 patients.³⁶ Finally, Lange and co-workers reported that 11% of the hearts of patients who died with an indwelling PAC in place had evidence of pulmonary infarction.³⁷ Patients with a PAC placement in excess of 2 days had a greater incidence of thrombosis, while valvular haemorrhage occurred in 31%.³⁷ In a series of 141 consecutive autopsy cases, in which a central catheter was present at the time of death, three deaths were attributable to catheter use and two to perforation. Mural thrombi were present in 33% of patients with a PAC and in 29% of patients with central venous catheters.³⁸

Complications related to PAC insertion, similar to those described above, have also been reported in smaller series.³⁹⁻⁴² Other less frequent complications include acute superior *vena cava* syndrome, false aneurysm of the pulmonary artery, insertion of a Swan-Ganz catheter into the intrathecal space, and knotting of the catheter.⁴³⁻⁴⁶

It should be emphasised that catheter-related complications increase with the duration of catheterisation, occurring more frequently in catheters maintained for longer than 48-72 hours.^{10,37,39,41} Accordingly, the PAC seems to have acceptable morbidity and mortality rates if properly placed and maintained for 72 hours or less.³⁹ Moreover, when haemodynamic evaluation but not monitoring is required, a strategy of PAC insertion and quick removal immediately after the acquisition of pressure tracings, could provide invaluable information for the differential diagnosis of various clinical conditions (such as cardiogenic pulmonary oedema vs. acute respiratory distress syn-

drome, and cardiogenic shock vs. hypovolaemia in the setting of acute myocardial infarction).⁴⁷

It is also stressed that complications can be expected to occur more frequently during urgent placement and with inexperienced operators.

Guidelines and considerations for use of the PAC in heart failure and related conditions

The 2008 European Society of Cardiology guidelines for the diagnosis and treatment of acute and chronic heart failure had already relegated PAC use to a class IIa recommendation (level of evidence C) in haemodynamically unstable patients who are not responding as expected to traditional treatments.⁴⁸ PAC insertion should be considered in distinguishing cardiogenic from non-cardiogenic pulmonary oedema in complex patients with concurrent cardiac and pulmonary disease, especially when echo-Doppler measurements are difficult to obtain, or when levels of brain natriuretic peptide are inconclusive. The PAC remains the principal means of assessing pulmonary vascular resistance and reactivity in patients undergoing evaluation for cardiac transplantation, and occasionally for placement of a left ventricular assist device.

In patients with suspected pulmonary hypertension (PH), right-heart catheterisation is required to confirm the presence of PH, establish the specific diagnosis, and determine the severity of PH (strength of recommendation: A). In addition, in patients with suspected PH, right-heart catheterisation is required to guide therapy (strength of recommendation: B).⁴⁹

Finally, the insertion of a PAC for the diagnosis of acute heart failure is usually unnecessary.

The American Heart Association/American College of Cardiology updated guidelines for chronic heart failure relegated PAC use to a class IIb indication in patients with refractory end-stage heart failure.⁵⁰

Concerning right heart failure, catheterisation of the pulmonary artery is more invasive than echocardiography, but it is useful in evaluating right ventricular function and in confirming the presence of right ventricular failure in ICU patients.⁵¹

In myocardial infarction complicated by cardiogenic shock or progressive hypotension, right heart catheterisation was considered as a class I indication in previous reports.⁵² However, in view of the recent data concerning PAC use, such a recommendation is no longer included in the recently published guidelines on myocardial infarction.⁵³

Clinical perspectives

The PAC, with its ability to provide continuous haemodynamic information, will continue to be a reliable device for the research and development of therapeutic agents for critical and acute cardiac care. However, taking into account the data presented above, in recent years PAC use has become a subject of controversy.⁵⁴⁻⁶⁰ Over the past 15 years, several controlled trials have shown that PAC has limited value in achieving better outcomes in critically ill patients. For heart failure, the ESCAPE trial arrived at a similar result and conclusion. There are difficulties with PAC insertion, use and data interpretation, and complications associated with the device.⁶¹ It should be also taken into account that target patients in ESCAPE (as well as in other randomised controlled trials) were sufficiently ill to make the use of PAC reasonable, but also sufficiently stable to make crossover to PAC for urgent management unlikely. Thus, the population was defined specifically to exclude severely sick patients who might have derived the greatest benefit. Finally, Pinsky and Vincent, in a recent perspective, pointed out that the problem not only pertains to PAC use or non-use, but also to the interpretation of PAC data.⁵⁴ They rather noted that no monitoring device will improve outcomes unless it is coupled with a specific treatment plan that is known to improve outcomes. Vincent and co-workers concluded that the PAC is still a valuable tool for haemodynamic monitoring, when used in selected patients and by physicians adequately trained to correctly interpret and apply the data derived.⁵⁶

Conclusions

There remains a need for prospective randomised trials studying the effectiveness of the PAC, including a defined treatment protocol of proven efficacy. PAC is a valuable monitoring device when used in carefully selected patients who are most likely to benefit, and by physicians adequately trained in haemodynamic monitoring.

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