

# The Use of Pulmonary Artery Catheter in Sepsis Patients: A Literature Review

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## Abstract

This article was to review the literature regarding the use of the pulmonary artery catheter (PAC) in the management of patients with sepsis and septic shock. A PubMed search was conducted in order to identify publications evaluating the use of PAC as a tool for management and therapeutic guidance in patients with sepsis. The bibliographies of all identified publications were reviewed for additional relevant references. Much information is identified in the literature regarding the indications for pulmonary artery catheterization in the assessment and treatment of patients with sepsis. Although the PAC has been widely used for many years, there is no clear benefit with regard to outcome, and there is controversy regarding its use. It is not clear that use of the PAC contributes to reduced morbidity and mortality in patients with sepsis. The role of the PAC is becoming less clear, as newer, non-invasive techniques are developed for hemodynamic assessment of sepsis patients. Large, well-designed clinical trials are needed to better assess the role and potential benefit from use of the PAC in sepsis.

**Keywords:** Sepsis; Monitoring; Pulmonary artery; Catheter; Intensive care; Critical care; Morbidity; Mortality; Circulation

## Introduction

Several studies assessing the adverse effects of sepsis on the heart have shown that myocardial dysfunction is a common, severe complication of sepsis, and the mechanisms responsi-

ble for development of myocardial dysfunction are complex. Hemodynamic monitoring is important in the management of critically ill sepsis patients, because it can help assess hemodynamic variables, identify causes of hemodynamic instability and monitor response to therapy. However, the benefit of hemodynamic monitoring in the management of sepsis and septic shock remains unproven. The pulmonary artery catheter (PAC) is an invasive device used largely in the intensive care unit (ICU) for monitoring, assessment and management of hemodynamic variables in critically ill patients, including patients with sepsis. PAC use varies between different ICUs and is influenced by several factors, including ICU organization, physician preference, patient insurance, race and clinical characteristics [1], but overall the use of the PAC in critical care is declining. The indication for PAC use is matter of debate because, despite earlier promising results, several well-designed studies have failed to show a clear benefit with regard to mortality or other major outcomes [2, 3]. The aim of this review is to summarize the current literature on the use of the PAC in critically ill sepsis patients.

## Literature Search Methods

We conducted a PubMed search using the combinations of the words “Swan-Ganz catheter”, “pulmonary artery catheter” and “sepsis”. All identified manuscripts, including reviews and case series, were considered for inclusion in this review. We also reviewed the bibliographies of all identified manuscripts in an attempt to find additional relevant publications. We limited the scope of our work to studies on humans, published in English in the last 20 years, but we also included studies published in other languages, if they had a meaningful abstract in English. Two authors reviewed all identified manuscripts for relevance to this review, and articles deemed relevant were included. Any disagreement regarding relevance of specific publications was resolved by consensus, after discussion between the authors. All clinical studies identified and used in this review are summarized in Table 1 [4-20].

## Literature Search Results

In 2014, a publication by Gopal et al compared cardiac output measurements derived from thermodilution using a PAC

Manuscript accepted for publication September 05, 2016

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doi: <http://dx.doi.org/10.14740/jocmr2719w>

**Table 1.** Clinical Studies Evaluating the Role of the Pulmonary Artery Catheter in Patients With Sepsis or Septic Shock

Author/year	Origin/year	Study design	Findings
Gopal et al, 2014 [4]	Wolverhampton, UK	Prospective observational study, 22 pts with septic shock	Non-invasive cardiac output monitoring had high error rate compared to thermodilution using PAC.
Slagt et al, 2013 [5]	Zaandam, Netherlands	Prospective observational study, 19 pts with septic shock	Strong correlation between cardiac output measurements using thermodilution with PAC (COtd) vs. the FloTrac/VigileoTM (COfv). COfv underestimates COtd in septic shock with low SVR.
Trof et al, 2012 [6]	Amsterdam, Netherlands	RCT, 120 pts	Important outcomes, including ventilator-free days, LOS, organ failure and mortality not significantly different with PAC use.
Bethlehem et al, 2012 [7]	Leeuwarden, Netherlands	Retrospective study, 140 sepsis pts	Comparison before vs. after introducing PAC based protocol in sepsis: PAC use was associated with higher vasopressor use, higher first day but lower overall IV fluid use and reduced ventilator and ICU days.
Spohr et al, 2007 [8]	Heidelberg, Germany	Prospective cohort study, 14 pts with septic shock	Excellent correlation between CCO(PAC) vs. pulse-contour analysis using PiCCO system ( $r^2 = 0.714$ , $P < 0.0001$ ), but limited precision of single CCO(PCCO) measurements vs. CCO(PAC).
Siddiqui, 2005 [9]	Karachi, Pakistan	Retrospective chart review, 10 pts	No complications related to PAC use, but nine of 10 pts died of severe sepsis.
ARDSNet Group, 2006 [10, 11]	Nashville, TN, USA	Fluid and Catheter Treatment Trial (FACTT)	PAC-guided therapy was associated with higher incidence of complications and no improvement in survival. Conservative fluid management improved lung function and resulted in shorter mechanical ventilation and ICU stay.
Shah et al, 2005 [12]	New York, NY USA	Meta-analysis of 13 RCTs from 1985 to 2005	PAC use does not seem to increase mortality or LOS. However, because clinical trials exclude patients for whom a PAC is required, patients excluded from these trials could perhaps benefit from PAC.
Richard et al 2003 [13]	Paris, France	RCT, 36 ICUs, 676 pts	PAC use did not affect morbidity or mortality in ARDS, PAC related infection observed in 10 patients (2.8%).
Yu et al, 2003 [14]	Boston, MA, USA	Case-control within prospective cohort, 1,010 ICU admissions in adults with sepsis	Patients with PAC had slightly (but not significantly) lower mortality and hospital charges, but significantly higher risk of renal failure within 28 days.
Chen et al, 2003 [15]	Taipei, Taiwan, ROC	RCT, 258 pts	Risk of catheter colonization and bacteremia not significantly different when PAC used for 4 vs. 7 days.
Rhodes, 2002 [20]	London, UK	RCT, 201 ICU pts (including 101 pts with sepsis)	Patients in the PAC group received significantly more fluids in the first 24 h, had significantly higher renal failure and thrombocytopenia, but there was no difference in mortality.
Sakka et al, 2000 [16]	Jena, Germany	Prospective study, 12 sepsis or septic shock ICU pts	PAC use not justified solely for CO measurement, because CO can be obtained with similar accuracy from non-invasive methods.
Connors et al, 1996 [17]	Cleveland, OH, USA	Prospective cohort study, 5,735 ICU pts	PAC use associated with increased resource utilization, higher mortality in several subgroups, including patients with sepsis.
Schoenenberger et al, 1995 [18]	Basel, Switzerland	Prospective study, 47 pts	Data obtained after PAC insertion resulted in major change of treatment plan in 21% of patients.
Jardin et al, 1994 [19]	Boulogne, France	Prospective study, 32 pts	Comparing invasive (using PAC) vs. non-invasive (using echocardiography) hemodynamic evaluation in sepsis. PCWP unreliable index of preload, possible overestimation of cardiac output using thermodilution.

CCO(PAC): continuous cardiac output by PAC; ICU: intensive care unit; LOS: length of stay; PAC: pulmonary artery catheter; pts: patients; RCT: randomized controlled trial.

vs. non-invasive cardiac output using the Mostcare monitor in 22 consecutive sepsis patients, and noted that, compared to thermodilution, the non-invasive method had high error rate [4]. Similarly, a study by Slagt published in 2013 compared cardiac output measurements using thermodilution with PAC (COtd) vs. the FloTrac/VigileoTM (COfv) system by uncali-

brated arterial pressure waveform analysis in 19 patients with septic shock. This study showed strong correlation between COfv and COtd values ( $r = 0.53$ ,  $P < 0.001$ ) but also showed that COfv underestimates COtd in septic shock with low systemic vascular resistance (SVR) [5].

A publication by Trof in 2012 reported results of a pro-

spective, randomized clinical trial (RCT) assessing the hemodynamic management of critically ill patients with shock using transpulmonary thermodilution vs. pulmonary artery occlusion pressure. The study included 72 patients with septic shock and 48 patients with non-septic shock (120 patients in total) and showed that important outcomes, including ventilator-free days, length of stay, organ failure and mortality were not significantly different between the two groups. Patients in non-septic shock treated with PAC-based algorithm had fewer mechanical ventilation days and shorter ICU stay compared to the transpulmonary thermodilution algorithm, but there was no significant difference in patients with septic shock [6].

A retrospective study from the Netherlands published by Bethlehem in 2012 evaluated fluid balance and the need for catecholamines before vs. after introduction of a PAC-based protocol in patients with severe sepsis or septic shock admitted to a 22-bed mixed ICU in a tertiary care hospital. In this study, patients treated with a PAC-based protocol received norepinephrine more frequently and at significantly higher maximum doses ( $0.12$  ( $0.03 - 0.19$ )  $\mu\text{g}/\text{kg}/\text{min}$ ,  $n = 59$  vs.  $0.02$  ( $0 - 0.17$ )  $\mu\text{g}/\text{kg}/\text{min}$ ,  $n = 39$ ,  $P = 0.000$ ) and had significantly higher positive fluid balance ( $6.1 \pm 2.6$  vs.  $3.8 \pm 2.4$  L,  $P < 0.001$ ) on the first ICU day, but had significantly lower cumulative fluid balance after 7 days ( $9.4 \pm 7.4$  vs.  $13 \pm 7.6$  L,  $P = 0.001$ ) compared with patients in the historical control group. The study concluded that introduction of a PAC-based protocol was associated with greater need for vasopressors, higher early but lower overall need for IV fluids and significant reduction in ventilator and ICU days [7].

A review paper on myocardial dysfunction in severe sepsis published by Jozwiak in 2011 suggested that echocardiography is the best method for diagnosis of sepsis-induced myocardial dysfunction, but mentioned invasive methods, such as transpulmonary thermodilution monitor and hemodynamic assessment via pulmonary artery catheterization as useful tools to alert clinicians about myocardial dysfunction and to monitor the response to inotropic therapy [21].

A multicenter longitudinal study from Hamilton, Canada, published by Koo et al in 2011 reviewed records of 1,921 patients who received PAC within the first 2 ICU days, in five different ICUs over a 5-year period (2002 - 2006). Multiple logistic regression was used to determine variables associated with PAC use and whether these variables changed over time. This analysis showed that patient factors predicting the use of PAC included severity of illness, as measured by the Acute Physiology and Chronic Health Evaluation II (APACHE II) score (odds ratio (OR): 1.05; confidence interval (CI): 1.04 - 1.06;  $P < 0.0001$ ), elective surgery (OR: 2.82; CI: 2.29 - 3.48;  $P < 0.0001$ ), cardiogenic shock (OR: 5.31; CI: 3.35 - 8.42;  $P < 0.0001$ ), sepsis (OR: 2.83; CI: 1.94 - 4.13;  $P < 0.0001$ ), use of vasoactive medications (OR: 4.04; CI: 3.47 - 4.71;  $P < 0.0001$ ), mechanical ventilation (OR: 2.21; CI: 1.86 - 2.63;  $P < 0.0001$ ), and abdominal aortic aneurysm repair (OR: 10.91; CI: 8.24 - 14.45;  $P < 0.0001$ ). Non-patient factors associated with PAC use were ICU preference and the base specialty of the attending physician ( $P < 0.001$ ). Overall, PAC use decreased from 16.4% to 6.5% of patients over this 5-year period [22].

An article published by Frazier in 2008 reviewed the role, efficacy and complications of PAC use over a decade, and sug-

gested that published data do not support routine PAC use [23].

A small prospective cohort study published by Spohr et al from the University of Heidelberg, in Germany in 2007 evaluated continuous cardiac output by PAC vs. pulse-contour analysis using the PiCCO system in 14 surgical ICU patients with septic shock and showed very strong correlation between the two measurement methods ( $r = 0.781$ ,  $P < 0.0001$ ). However, the study also assessed the relationships between the global end-diastolic volume (GEDV) derived by PiCCO vs. traditional PAC-derived filling indicators, including central venous pressure, pulmonary artery occlusion pressure, and right ventricular end-diastolic volume (RVEDV), and did not show any significant correlation. The study concluded that the average bias in continuous cardiac output measurement by both a modified PAC and pulse-contour analysis was small in patients with septic shock, but variability was large [8].

Another retrospective study published by Siddiqui in 2005 reviewed charts of 10 ICU patients with sepsis who had PAC inserted for fluid management and hemodynamic instability at the University Hospital in Karachi, Pakistan in 2004. The authors could not identify any complications related to PAC use, but eight of these 10 patients died, and the cause of death in these patients was "severe sepsis" [9].

The Fluid and Catheter Treatment Trial (FACTT) designed by the ARDSNet Group evaluated treatment of patients with acute lung injury or ARDS, in a two by two factorial design, whereby patients were randomized to receive PAC vs. central venous catheter, and were also randomized to conservative vs. liberal fluid strategy. Mortality during the first 60 days was the primary outcome of this study, and results were published in two manuscripts in the "New England Journal of Medicine" in 2006. A part of the study evaluated PAC vs. central venous catheter and concluded that PAC-guided therapy was associated with higher incidence of complications and no improvement in survival [10]. Similarly, the part of the study that evaluated conservative vs. liberal fluid administration did not show significant difference with regard to mortality, but showed that conservative fluid management improved lung function and resulted in shorter mechanical ventilation and ICU stay [11].

A meta-analysis published in JAMA in 2005 searched MEDLINE (1985 - 2005), the Cochrane Controlled Trials Registry (1988 - 2005), the National Institutes of Health ClinicalTrials.gov database and the US Food and Drug Administration (FDA) website for articles evaluating the use of PAC. Studies included general surgery patients, ICU patients and patients admitted with advanced heart failure or diagnosed with acute respiratory distress syndrome (ARDS) and/or sepsis. Reported outcome measures included hospital stay, ICU stay and mortality. This meta-analysis concluded that, overall, PAC use did not increase mortality or hospital length of stay, but did not confer any benefit [12].

Another review published by Summerhill and Baram in 2005 included several RCTs evaluating the role of PAC insertion in critically ill conditions including sepsis, and concluded that PAC use did not confer any clear benefit and could even be detrimental [24].

Results from an RCT conducted in 36 ICUs in France over a 2-year period (1999 - 2001) were published in 2003 and showed that management involving use of a PAC did not affect

morbidity or mortality in patients with ARDS, shock, or both [13]. In addition, a case-control study (nested within a prospective cohort study) published by Yu et al in 2003, evaluated the use of the PAC in 141 pairs of patients with severe sepsis in eight major academic medical centers in the USA. This study showed that mortality and total hospital charges were slightly, but not significantly lower in patients with PAC. Patients with PAC had significantly increased risk of renal failure within 28 days after onset of sepsis (OR: 3.48, 95% CI: 1.81 - 6.71), but PAC use was not associated with any other organ dysfunction [14]. Similarly, results from an RCT on 201 patients (of which 101 patients had sepsis) published by Rhodes et al in 2002 showed that patients randomized to have a PAC received significantly more fluids in first 24 h and had significantly higher renal failure and thrombocytopenia, but there was no difference in mortality [20].

With regard to PAC-related risk of infection, a prospective, RCT conducted by Chen et al in Taipei, Taiwan, evaluated 258 critically ill patients who had PAC insertion and showed that the risk of catheter colonization, and the risk of bacteremia were not significantly different between patients who had PAC for 4 vs. 7 days [15]. Also, a review article on PAC colonization and infection published by Rello et al in 1997 showed that, compared to other types of catheters, sensitivity in diagnosing pulmonary artery colonization can be improved by evaluating both the tip and the intradermal segments of the catheter. In cases of an indwelling introducer presence, the intradermal segment should be replaced by the introducer tip [25].

As PAC efficacy and safety have been under scrutiny because of association with increased morbidity and mortality in observational studies, several researchers attempted to evaluate PAC usefulness and necessity. In 1997, the National Heart, Lung, and Blood Institute (NHLBI) and the US FDA conducted the Pulmonary Artery Catheterization and Clinical Outcomes workshop in Alexandria, Virginia to develop recommendations for improved PAC utility and safety. The workshop concluded that medical staff needs education obtaining and interpreting PAC data and this education effort should be led by professional societies. Areas given high priority for clinical trials included refractory congestive heart failure, ARDS, severe sepsis and septic shock, and low-risk coronary artery bypass graft surgery [26].

A manuscript published by Sakka et al in 2000 presented data (51 cardiac output measurements in 12 patients with sepsis or septic shock) from a prospective clinical trial conducted in Jena, Germany. The study compared four cardiac output (CO) measurement techniques: pulmonary artery thermodilution (CO(PA)), transpulmonary aortic thermodilution (CO(AORTA)), Fick principle-derived (CO(FICK)), and continuous pulmonary artery cardiac output (CCO) measurements, and showed high correlation between the four techniques: CO(PA) and CO(AORTA) had the highest agreement ( $r = 0.98$ ); agreement between CO(PA) or CO(AORTA) and CCO was lower, but still very high ( $r = 0.92$  and  $r = 0.93$ ), and all three techniques had comparable correlation with CO(FICK) ( $r = 0.85$ ,  $r = 0.83$ , and  $r = 0.83$ , respectively). Because CO measurements can be obtained with similar accuracy non-invasively from CO(AORTA), the authors concluded that PAC placement is not justified solely for measurement of CO,

unless CCO measurement is needed [16].

In 1998, Becker reviewed selected outcome studies conducted since 1987 and concluded that there were insufficient data from well-conducted prospective, randomized, studies to show a mortality or morbidity benefit from use of the PAC. The author suggested that until stronger evidence becomes available, use of the PAC should not be considered standard of care in critically ill patients [27].

In 1997, Parker and Peruzzi published a review on the use of the PAC in patients with sepsis and septic shock, based on articles published in English between 1984 and 1996, and concluded that PAC use may be appropriate in patients with septic shock who do not respond to early resuscitative measures. The authors suggested that further research was needed to determine the role of the PAC in patients with sepsis/septic shock [28].

In 1996, a prospective cohort study by Connors et al evaluated the association of right heart catheterization within the first 24 h of ICU stay with survival, length of ICU stay and cost of care, based on data from 5,735 critically ill patients admitted between 1989 and 1994 in five teaching hospitals in Cleveland, Ohio. Data analysis in this study showed association of right heart catheterization with increased resource utilization and higher mortality [17].

In 1995, Schoenenberger et al compared clinical assessment vs. invasive measurements of hemodynamic parameters in 47 critically ill ICU patients and assessed changes in therapy following PAC insertion. In this study, invasive hemodynamic values obtained with insertion of a PAC resulted in a major change in treatment in 21% of patients, thereby suggesting that the PAC is a very useful tool for guiding therapy [18].

In 1994, a prospective study by Jardin et al compared invasive (right heart catheterization using PAC) vs. non-invasive assessment of hemodynamic parameters by measuring CO (thermodilution method), cardiac pressures (right heart catheterization) and left ventricular (LV) volumes (two-dimensional echocardiography) in 32 patients with septic shock. Because of frequent discrepancies between invasive vs. non-invasive data, the study concluded that hemodynamic evaluation based on PAC should be questioned due to possible CO overestimation by the thermodilution method in sepsis [19].

## Discussion

The PAC was introduced in cardiology and critical care in the 1940s [29-31], but the use of the PAC came to critical practice after a landmark publication by Swan et al in 1970 [32]. Although PAC use enhances our understanding of cardiovascular pathophysiology and helps clinicians optimize hemodynamic management, use of the PAC has been criticized due to risks associated with its use and absence of convincing evidence that PAC use improves patient outcome [12, 33-36].

The PAC allows measurement of central venous pressure, right ventricular pressure and pulmonary artery pressure and mixed venous oxygen saturation, and calculation of several hemodynamic variables, including CO, right ventricular ejection fraction and peripheral vascular resistance. Tissue oxy-

generation can be assessed by monitoring mixed venous oxygen saturation (SvO<sub>2</sub>) after insertion of a fiberoptic PAC, and pulmonary artery occlusion pressure can be determined after occlusion of the pulmonary artery using the catheter balloon. When placement of a PAC is not feasible, insertion of a central venous catheter can provide information about tissue oxygen supply and demand by measuring mixed venous oxygen saturation (ScvO<sub>2</sub>) [37].

Traditional indications for PAC insertion are left ventricular dysfunction, myocardial ischemia, valvular heart disease and assessment of patients receiving vasoactive therapy like sepsis patients. However, PAC use has been associated with significant complications, including arrhythmias that usually resolve spontaneously, pneumothorax, thrombosis and hemorrhage, and case reports of pulmonary valve endocarditis have also been published [38, 39]. When PAC is placed *in situ*, infections are another issue which remains of clinical importance, also distal catheter migration and pulmonary artery rupture are rare but significant complications [40-42]. Therefore, because PAC use has been associated with significant complications and increased cost, without a clearly documented outcome benefit, there is an argument that the PAC should not be used in sepsis patients [43], and this is why newer, less invasive techniques, such as echocardiography, Doppler and pulse contour techniques have been developed with some success [44]. PAC insertion guided by bedside echocardiography is safe [45], but older data suggest that heavy colonization of the insertion site, percutaneous insertion in the internal jugular vein rather than subclavian vein, duration of catheterization longer than 3 days, and insertion without full barrier precautions significantly increase the risk of catheter-related infection [46, 47]. PAC insertion can also cause complications years later: a case report published in 2013 described a case where retained PAC fragment was incidentally found lodged in the right heart of a patient 16 years after PAC insertion, thereby highlighting the importance of vigilance during PAC insertion [48].

Regarding the use of PAC in sepsis, the consensus conference of 1997 concluded that use of the PAC may be beneficial in patients with septic shock unresponsive to early resuscitative measures. In such cases, maintenance of normal hemodynamic targets should be the main goal [49]. In 2004, the American College of Critical Care Medicine updated the recommendations for hemodynamic support in adult patients with sepsis, and proposed a level D recommendation for invasive hemodynamic monitoring in patients who do not respond to initial resuscitative efforts. In such cases, the guidelines recommend administration of fluids titrated to defined hemodynamic goals, and adequacy of cardiac filling pressures can be determined by the response of the CO to increasing pulmonary artery occlusion pressure. In this consensus, most experts agreed that the maximum benefit can usually be achieved when pulmonary artery occlusion pressure is in the 12 - 15 mm Hg range [50].

Our literature search shows that there is ongoing debate regarding the benefit from the PAC use. Observational studies suggest that use of the PAC is not associated with improved outcome and may even increase morbidity and mortality. Similarly, randomized controlled trials in sepsis patients and other critically ill patients failed to demonstrate a mortality benefit from use of the PAC [51]. Pulmonary artery catheterization

seems to be more accurate than clinical assessment alone in evaluating the cause of shock (hypovolemic, cardiogenic or septic), and is also useful in evaluating the cause of pulmonary edema (cardiogenic vs. non-cardiogenic). The PAC may be useful in cases where hemodynamic intervention with fluids and dopamine is ineffective, and also in cases where there is need for precise evaluation of cardiac preload and optimization of oxygen transport. Mixed venous oxygen content (commonly measured as oxygen saturation) is a highly relevant parameter in the monitoring of critically ill patients, but its measurement requires catheterization of the pulmonary artery. As cardiac dysfunction is a very common and severe complication of septic shock, the catheterization of the pulmonary artery is used to monitor the effects of inotropic therapy, to alert clinicians for cardiovascular changes and optimize therapy. However, a matter of debate for its use is the fact that although treatment corner stones for sepsis include adequate volume resuscitation and improvement of tissue oxygenation, specific hemodynamic endpoints remain controversial and direct measurements of tissue oxygenation are not possible. This would suggest a need for a consensus opinion on how PACs are actually used to obtain the different physiological variables which can influence patient management.

PAC use provides hemodynamic data that can assist decision-making in critically ill patients, and many clinicians use advanced hemodynamic monitoring and obtain invasive or non-invasive measures of CO to guide therapy in critical illness. The PAC-Man study, which was published in 2005, evaluated 1,014 critically ill patients randomly assigned to management with (n = 519) vs. without (n = 522) a PAC, and showed no evidence of benefit or harm from use of the PAC, but also showed that 80% of patients in the non-PAC group underwent an alternative form of CO monitoring [52].

Every procedure in medicine has its own indications, and the role of the PAC remains contentious. Of course there are circumstances where use of the PAC may be considered, such as in sepsis patients with significant pre-existing comorbidities or presence of severe ARDS, in sepsis patients with persistent deterioration and multiple organ failure, or in cases with diagnostic dilemmas, such as probable co-existing underlying pathologies. Pulmonary artery catheterization has been in clinical use since 1970, and has been a valuable tool for the assessment of cardiorespiratory performance in critically ill patients, but there has been criticism that PAC use has encouraged physicians and intensivists to make decisions based on numerical targets rather than clinical signs, and incorrect interpretation of data has also been a concern [53]. The best approach for use of the PAC seems to be careful clinical management that takes into account data derived from advanced hemodynamic monitoring, invasive and/or non-invasive [54]. As there is increasing use of non-invasive methods for the assessment and management of cardiovascular complications in sepsis, there is need for large prospective trials in order to define whether use of the PAC offers benefits in patients with severe sepsis and septic shock.

An interesting Editorial published by Pr Vincent in Critical Care Medicine in 2011 discussed the declining use of the PAC in recent years, and classified the reasons for reduced PAC use as “bad” and “good”. “Bad” reasons include the pub-

lication of randomized controlled trials failing to prove a clear benefit, the availability of less invasive monitoring techniques, the use of ScvO<sub>2</sub> monitoring and the fashion that follows the trend, whereas “good” reasons include the widespread use of echocardiography, efforts to reduce healthcare expenses, and the tendency to avoid overuse of the PAC in patients who will not clearly benefit [55].

Finally, although an Editorial published by Dr. Marik in the *Annals of Intensive Care* in 2013 reported the “Obituary of the Pulmonary Artery Catheter” [56], we believe that the PAC is still a very useful tool for a limited number of critically ill patients, and therefore its optimal use deserves further investigation.

## Conclusions

Pulmonary artery catheterization has a significant role in the management of patients with sepsis and septic shock, not only as a diagnostic tool, but also as a means to monitor the hemodynamic response to therapy. Although clinical management of hemodynamic instability in sepsis is facilitated by pulmonary artery catheterization, our literature review shows that PAC use has not been associated with clear benefit with regard to outcome in sepsis, and use of the PAC in the ICU is declining all over the world. The PAC remains a valuable educational tool for the assessment of sepsis patients, but because its efficacy and safety is under scrutiny, well-designed large prospective clinical studies are needed to better assess its role.

## Conflicts of Interest

This work was supported solely by department funds. All authors state that they do not have any conflicts of interest to report.

## Author Contributions

DV did literature search and wrote the manuscript. VK assisted with literature search and edited manuscript. CP collected data and edited manuscript. IK reviewed the literature and edited manuscript. MK reviewed the literature, revised and finalized the manuscript. All authors have read and approved the final version of the manuscript submitted for publication.

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