Current use of the pulmonary artery catheter
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Introduction
The pulmonary artery catheter (PAC) has been incorporated into the management of the critically ill for over 30 years [1]. Initially, the PAC was accepted for clinical use without substantial supporting evidence. Several observational trials and five recent randomized controlled trials did not show positive outcome benefits with the use of the PAC [2–6]. Furthermore, recent editorials have called for the PAC to be eliminated as more noninvasive monitoring becomes readily available [7–9]. On the basis of this evidence and opinion, PAC use appears to be declining. Wiener and Welch [10] reported a 65% reduction in the use of the PAC among medical intensive care unit (ICU) patients and a 63% reduction in the use of the PAC among surgical ICU patients between the years 1993 and 2004. The authors suggested that a lack of demonstrated mortality benefit may have contributed to the decrease in use over the last decade.

We contend that mortality should not be the basis for determining efficacy of monitors. Monitors are diagnostic tools that, if not coupled with appropriate therapeutic interventions, will not contribute to positive outcomes.

Purpose of review
The pulmonary artery catheter is one of the most scrutinized monitors used in intensive care today. Pulmonary artery catheter use is declining due to limited demonstrated beneficial outcomes and the advancement of less invasive monitoring. This study discusses the current use of the pulmonary artery catheter and problems associated with its use including inaccuracy of measurements and data interpretation, inappropriately applied therapeutic interventions, inappropriate delays in applying interventions, and inappropriate patient selection.

Recent findings
This overview presents current controversies surrounding the pulmonary artery catheter. It also discusses commonly used monitors and their lack of demonstrated benefits. In addition, data show that intensivists do not have sufficient knowledge to effectively use the pulmonary artery catheter. When utilized in a timely appropriate manner, pulmonary artery catheter monitoring may benefit a selected patient population.

Summary
In summary, the pulmonary artery catheter monitor continues to be used for intensive care patients. To date, no single monitor is associated with an abundance of clear outcome benefits. There are some clinical data showing that the pulmonary artery catheter may still be useful when applied to the right patient population using appropriately timed therapies.

Keywords
monitoring, outcome benefits, pulmonary artery catheter

Monitors and outcomes
Monitors provide data! These data, in order to be useful, must enhance caregiver knowledge for better decision making. Information obtained from the PAC includes cardiac output, mixed venous oxygen saturation, intrapulmonary pressures, systemic and pulmonary vascular resistance, intracardiac pressures, and ejection fraction. Numerical data alone can not be expected to positively affect outcome [11]. PAC-derived data may help clinicians to formulate an appropriate care plan that, when appropriate and effective therapeutic interventions exist, may impact outcome. Some physicians believe that in the absence of monitoring, clinical acumen alone is not consistently capable of improving patient outcome [12].
The true assessment of any monitor should be predicated on the information it provides and the limitations of its application.

The present literature is devoid of studies that unequivocally demonstrate a mortality benefit for any of the monitoring devices commonly employed in the perioperative period. Ospina-Tascon et al. [13**] recently examined the effect of respiratory, hemodynamic, and neurologic monitoring devices on associated outcome data. Overall, this systematic review of several randomized trials demonstrated the limited positive impact of any monitoring device on outcomes. In this analysis, seven randomized trials evaluated the potential beneficial effects of pulse oximetry on outcomes. None of these trials reported a reduction in mortality. The authors also examined several trials involving outcome data in relation to hemodynamic perfusion devices. These trials revealed a limited amount of evidence regarding a mortality benefit. Specifically, three randomized trials illustrated a mortality benefit with the use of data derived from the PAC. These positive studies employed the PAC early on in the disease process of high-risk surgical patients or utilized preoperative (early) hemodynamic optimization protocols derived from PAC data. Despite the scarce evidence to support mortality benefits of these devices, many of them are still available in clinical practice because the perceived benefits outweigh the risks to patients [13**].

Limitations of pulmonary artery catheter trials
The quality of the research available directly affects one’s ability to draw meaningful conclusions. Serious limitations and flawed methodology plague many of the recent published PAC studies [14**]. Many of the studies are not adequately powered to provide conclusions on rare outcomes such as mortality. Depending on the control group mortality, a study may require an enrollment of several thousand patients in order to achieve statistical significance. Second, it is challenging to incorporate blinding and randomization in PAC studies. Clinical equipoise among physicians is unlikely and concealing the presence of a PAC is difficult. Third, protocols and therapies that are backed by quality evidence are scarcely utilized in published PAC studies.

Implementation of protocols and interventions supported by Class IA data may curb variability in care associated with use of PAC information and reduce the impact of therapeutic trespass [12,14**]. There continues to be uncertainty pertaining to the optimal hemodynamic goals needed for an improved outcome, as well as the methods employed to achieve them. Sandham et al. [15] randomized 1994 high-risk surgical patients to either a PAC group or a control group (no PAC). The authors attempted to achieve supranormal hemodynamic targets in the PAC group. The study demonstrated no mortality difference between groups. The hemodynamic endpoints employed were never independently validated and the treatment group received significantly more interventions. More studies are required to determine the correct parameters required to guide therapeutic measures, and which therapies would be most appropriate.

Many studies institute therapeutic interventions that may negatively impact outcome. Patients with PACs often receive more fluids and positive inotropic agents to achieve hemodynamic endpoints, as in the Sandham et al. study [15]. In a recent article by Fellahi et al. [16] a statistically significant independent increase in cardiac morbidity and in-hospital mortality was demonstrated in cardiac surgical patients who received more dobutamine to improve cardiac output. Other studies involving patients undergoing bowel surgery and patients with acute respiratory distress syndrome (ARDS) did not show a beneficial effect of using a liberal fluid protocol for resuscitation [6,17]. Therefore, the use of unproven therapies to improve hemodynamics may be associated with deleterious outcomes in certain patients and clinical situations in PAC studies.

Lack of knowledge regarding appropriate pulmonary artery catheter use
The demonstrated lack of caregiver knowledge when interpreting PAC data could impact decision making resulting in inappropriate and potentially harmful therapeutic interventions [11]. In 1990, Iberti et al. [18] published a landmark study demonstrating a significant deficit in healthcare practitioner knowledge and understanding of the use of the PAC and interpretation of data extrapolated from it. A survey from physician members of the Society of Critical Care Medicine revealed that 33% of responders could not correctly interpret a pulmonary artery occlusion pressure (PAOP) from a clearly marked tracing [19]. Subsequent studies have confirmed the inaccuracy of data interpretation by physicians [20–22]. Squara et al. [23] examined the impact of PAC data on management decisions made by intensivists compared to the opinion of a panel of experts in the analysis of a clinical case. The authors showed that PAC data reduced variability of interventions, improved agreement among intensivists and experts, and reduced the number of harmful treatments. Harmful interventions still persisted 10% of the time, indicating the need for further advanced training among users of the PAC.

Timeliness of care
Timeliness of care may be crucial in determining the effect of PAC monitoring on patient outcomes [11,14**].
Delayed therapies in the critically ill after irreversible injury occurs does not improve outcome.Gattioni et al. [24] randomized 762 critically ill patients to one of three treatment groups [cardiac index (CI) = 2.5–3.5 ml/min per m², CI >4.55 ml/min per m², and Svo₂ >70%]. The authors determined that there was no difference in mortality between any of the groups. However, patients were enrolled in the study up to 72 h after the development of shock. Hayes et al. [25] studied 100 critically ill patients with shock and observed that there was an increase in mortality in the group who achieved supranormal oxygen delivery goals. Similarly, these patients were enrolled up to 24 h after the development of shock. The most recent Fluid and Catheter Treatment Trial (FACTT) evaluated the safety and efficacy of PAC-guided versus central venous pressure (CVP)-guided treatment of patients with acute lung injury (ALI) [6]. Patients did not start receiving the protocol-derived therapies until a mean of 25 h after diagnosis of ALI. This delay in therapeutic management may have contributed to a lack of overall mortality benefit. In critically ill patients, Lefrant et al. [26] demonstrated that a median time of 2 h elapsed from the time when the clinician decided to place the PAC until successful placement. However, the authors do not address the frequent time delay between patient need for further monitoring and the development of irreversible disease [26]. In 2002, Kern and Shoemaker [27] performed a meta-analysis examining the relationship of outcomes and resuscitation therapies based on hemodynamic optimization data derived from the PAC in the critically ill. Those studies enrolling severely ill patients (control mortality group >20%) showed a significant mortality benefit when early hemodynamic optimization occurred prior to the development of organ failure. However, outcomes were not significantly improved with hemodynamic optimization when applied to the less critically ill (control mortality group <15%) or after organ failure developed [27]. This article emphasizes the importance of instituting therapies based on PAC data early on in disease processes.

Rivers et al. [28] further demonstrated in a randomized controlled trial, that early goal-directed therapy in septic shock patients is associated with a 16% absolute reduction in mortality. Although one may question the efficacy of the individual elements that comprised the protocol group, it appears that the early initiation of therapy may have accounted for the beneficial outcomes. Subsequently, 11 peer reviewed trials have indicated that early goal-directed therapy is associated with improved survival rates in patients with severe septic shock [29]. A critical time window may exist where clinicians can use PAC data guided therapies that mitigate morbidity and mortality.

**Selection of the appropriate population for pulmonary artery catheter use**

Therapeutic interventions based on PAC data may only improve outcomes in highly selected patient populations. Healthy patients do not appear to derive benefit from PAC monitoring [11]. In addition, improved outcomes are unlikely to be observed in the terminally ill with irreversible end-organ damage. Friese et al. [30] performed a retrospective analysis of 53312 trauma patients admitted to ICUs across the United States. The authors found that mortality rates were reduced in patients aged 61–90 years, arriving with a base deficit less than –11, or with a higher injury severity score of 25–75. This study suggested that the more critically ill may benefit from therapies initiated from the application of PAC data.

**Cardiac surgery**

Pulmonary artery catheter monitoring is still used today in a select cardiac surgical patient population. Jacka et al. [31] performed a survey among 345 American and Canadian anesthesiologists and found that the PAC was used and preferred more than twice as frequently as transesophageal echocardiography during cardiac surgery. Schwann et al. [32] developed a quantitative model for PAC use based on specific patient characteristics. The authors identified the following predictors for PAC placement: presence of an intra-aortic balloon pump, congestive heart failure, redo surgery, New York Heart Association Functional Class IV, decreased ejection fraction, and Society of Thoracic Surgery (STS) risk score [32]. Ranucci [33] reported that PAC-derived data may provide clinicians with early clues related to physiologic changes that may contribute to pathology in cardiac surgical patients with an ejection fraction less than 30%, patients with impaired right ventricular function, patients with left ventricular diastolic dysfunction, patients with acute ventricular septal defects, and patients with left ventricular assist devices. Polonen et al. [34] randomized 403 elective cardiac surgical patients to a protocol group, which included maintaining a Svo₂ more than 70% and a lactic acid less than 2 mmol/l, versus the standard clinical care control group. The PAC-derived data protocol group experienced reduced hospital and ICU length of stay. Post hoc analysis revealed a reduction in mortality. Aside from Polonen et al.’s trial, other PAC trials involving low-risk cardiac surgical patients did not show beneficial outcomes [14**,33].

**Heart failure**

Initial observational prospective studies demonstrated a benefit when using tailored treatment derived from PAC data in patients with acute heart failure [35,36]. As a result of flawed study designs, these trials could not conclusively determine whether improved outcomes were associated with PAC-derived data or other undefined
variables. The National Institutes of Health (NIH) recently funded a randomized controlled trial, Evaluation Study of Congestive Heart Failure and Pulmonary Artery Catheterization Effectiveness (ESCAPE) trial [5]. Four hundred and thirty-three patients with symptomatic heart failure were randomized to PAC-guided therapy and clinical assessment versus clinical assessment alone. There were no differences in the amount of patient days alive and out of hospital during the first 6 months. The ESCAPE trial concluded that the PAC did not provide benefit to patients with advanced heart failure.

Limitations of the ESCAPE trial may hamper the application of its findings to all heart failure patients [35]. Treatments implemented from PAC data may not be supported by quality evidence. Adherence to the PAC protocol may have been less than optimal and misinterpretation of data could have occurred. This trial also required clinical equipoise and excluded more critically ill patients. PAC monitoring may still be indicated in patients with heart failure when initial therapy fails, when volume and perfusion status needs to be clarified, when clinical hypotension or renal failure worsen during therapy, when escalating doses of inotropes or vasopressors are required, when documentation of hemodynamics is required for chronic outpatient infusion drug titration, and when assessment of pulmonary pressures is desired prior to cardiac transplantation [5,35].

Critically ill
Recently, many randomized controlled trials in the critically ill have not shown clear outcome benefits [2–4,6]. The severity of illness may also affect outcomes in this patient population. Chittock et al. [37] performed an observational cohort study examining the relationship between hospital mortality and severity of illness. The authors demonstrated that PAC use was associated with an increase in mortality among the critically ill with lower severity of illness, whereas showing an improvement in mortality among the most severely ill [37]. Most of the recent trials required clinical equipoise in order for patients to be enrolled in the study [38]. This may lead to the exclusion of patients whose physicians feel would benefit from the PAC. As a result, the more severely ill patients could have been excluded from these trials [39]. The PAC may still be warranted in the more critically ill when a knowledgeable physician interprets PAC data and applies beneficial, timely, therapeutic interventions to patients [40].

Conclusion
The present brief review has summarized some of the controversies surrounding the use of the PAC [41,42]. There is limited evidence that clearly shows that major outcomes are improved with any of the frequently used monitoring devices in contemporary practice. A monitor, like a computer, can only be helpful when data that it provides are interpreted correctly. It has been suggested that specific training in PAC utilization and interpretation is needed in order to improve outcomes. Data interpretation does not end the conundrum facing the PAC. As demonstrated, PAC data may only help to achieve benefits for the appropriate patients (i.e. more critically ill), in the appropriate situation (i.e. when reversible disease is present), in a timely manner (i.e. early in disease processes) in environments educated to safely interpret and employ the data. Lastly, physicians should comprehensively investigate therapies that are implemented based on monitor-derived data. The true catalysts for improved outcome may then be discovered [43].

References and recommended reading
Papers of particular interest, published within the annual period of review, have been highlighted as:
* of special interest
** of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 274).


13. Ospina-Tascon GA, Cordioli RL, Vincent JL. What type of monitoring has been shown to improve outcomes in acutely ill patients? Intensive Care Med 2008; 34:800–820. This systematic review is an in-depth report of outcome benefits shown in randomized trials regarding many monitors used in intensive care.

14. Murphy GS, Vender JS. Con: is the pulmonary artery catheter dead? J Cardiothorac Vasc Anesth 2007; 21:147–149. This editorial reports the author’s opinion regarding the controversies surrounding the use of the pulmonary artery catheter in select patient populations.
Current use of the pulmonary artery catheter

Greenberg et al. 253


42 Pinsky MR, Vincent JL. Let us use the pulmonary artery catheter correctly and only when we need it. Crit Care Med 2005; 33:1119–1122.