

Impact of the Pulmonary Artery Catheter in Critically Ill Patients

Meta-analysis of Randomized Clinical Trials

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THE PULMONARY ARTERY CATHETER (PAC) is used to diagnose various diseases and physiological states, monitor the progress of critically ill patients, and guide the selection and adjustment of medical therapy.¹ The PAC is often considered a cornerstone of critical care and a hallmark of the intensive care unit (ICU).² Approximately 1 million PACs are used annually in the United States.³ However, despite widespread use of these devices, there are conflicting data about their utility. The majority of nonrandomized studies in critically ill patients have suggested that the PAC is associated with increased morbidity and mortality.⁴ Conversely, some nonrandomized studies have shown improved quality of life when the PAC was used to direct a specific therapeutic approach.⁵⁻⁷

Since the mid-1980s, randomized clinical trials (RCTs) have been conducted to evaluate the efficacy of the PAC. However, none of these trials have been persuasive individually, because

See also pp 1625 and 1693.

Context Randomized clinical trials (RCTs) evaluating the pulmonary artery catheter (PAC) have been limited by small sample size. Some nonrandomized studies suggest that PAC use is associated with increased morbidity and mortality.

Objective To estimate the impact of the PAC device in critically ill patients.

Data Sources 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 Web site for RCTs in which patients were randomly assigned to PAC or no PAC were searched. Results from the ESCAPE trial of patients with severe heart failure were also included. Search terms included *pulmonary artery catheter*, *right heart catheter*, *catheter*, and *Swan-Ganz*.

Study Selection Eligible studies included patients who were undergoing surgery, in the intensive care unit (ICU), admitted with advanced heart failure, or diagnosed with acute respiratory distress syndrome and/or sepsis; and studies that reported death and the number of days hospitalized or the number of days in the ICU as outcome measures.

Data Extraction Information on eligibility criteria, baseline characteristics, interventions, outcomes, and methodological quality was extracted by 2 reviewers. Disagreements were resolved by consensus.

Data Synthesis In 13 RCTs, 5051 patients were randomized. Hemodynamic goals and treatment strategies varied among trials. A random-effects model was used to estimate the odds ratios (ORs) for death, number of days hospitalized, and use of inotropes and intravenous vasodilators. The combined OR for mortality was 1.04 (95% confidence interval [CI], 0.90-1.20; $P=.59$). The difference in the mean number of days hospitalized for PAC minus the mean for no PAC was 0.11 (95% CI, -0.51 to 0.74; $P=.73$). Use of the PAC was associated with a higher use of inotropes (OR, 1.58; 95% CI, 1.19-2.12; $P=.002$) and intravenous vasodilators (OR, 2.35; 95% CI, 1.75-3.15; $P<.001$).

Conclusions In critically ill patients, use of the PAC neither increased overall mortality or days in hospital nor conferred benefit. Despite almost 20 years of RCTs, a clear strategy leading to improved survival with the PAC has not been devised. The neutrality of the PAC for clinical outcomes may result from the absence of effective evidence-based treatments to use in combination with PAC information across the spectrum of critically ill patients.

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they are limited by small sample sizes in heterogeneous populations. Ivanov et al performed 2 meta-analyses on PAC use through 1996.^{8,9} One study focused on mortality from 16 RCTs of the PAC⁸ and the other focused on major morbidity from 12 RCTs⁹; however, neither study restricted the randomization specifically to catheter vs no catheter use. There was no difference found in mortality, but there was a statistically significant difference in major morbidity, which was defined separately for each organ system.^{8,9}

Despite the overwhelmingly negative tenor of the literature, clinicians continue to use the PAC in ICUs based on personal experience and the belief that careful monitoring will improve decision making and clinical outcomes. To provide a broad perspective for the recently completed ESCAPE trial,¹⁰ in which patients with advanced heart failure were randomized to the PAC or clinical assessment alone, we performed a meta-analysis of 13 recently published clinical trials testing the safety and efficacy of the PAC.

METHODS

Study Search

We 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 Web site (<http://www.fda.gov>) for reports of articles pertaining to the PAC. The MEDLINE search results included all articles yielded by other search methods. The search terms used were *pulmonary artery catheter*, *right heart catheter*, *catheter*, and *Swan-Ganz*.

For the MEDLINE search, we used the term *pulmonary artery catheter* as a keyword. We then searched the subject headings *catheterization*, *Swan-Ganz*, and *pulmonary artery catheter*. The search was limited to articles that were written in English, included only human beings, and published between 1985 and 2005. These citations were then manually searched to identify articles that were RCTs, system-

atic reviews, prospective cohort studies, or editorial letters and comments. The references from the citations were also searched to identify additional RCTs.

Eligibility and Data Abstraction

We reviewed references identified by the search method specified above. Additional references were identified by manually searching the bibliographies of these articles. These citations were included in our meta-analysis. We included trials if the randomization scheme included groups that assigned patients to treatment guided by the PAC or treatment without the PAC. We only included trials if they reported death and number of days hospitalized or the number of days in the ICU as outcome measures. Studies were excluded if the randomization scheme did not specify groups as PAC or no PAC, if patients were not randomized to a conventional PAC, if investigators combined randomized and nonrandomized groups when reporting outcomes, or if there were no outcome data on death or hospitalizations.

Eligibility assessment and data abstraction were performed independently in an unblinded standardized manner by 2 reviewers (M.R.S. and V.H.). Abstracted data included eligibility criteria, baseline characteristics, interventions, outcomes, and methodological quality. The outcome of interest was the number of deaths from any cause and the number of days hospitalized. Trial methodological quality was assessed by abstracting reported use of intention-to-treat analysis and reported allocation generation and allocation concealment. Disagreements between reviewers were resolved by consensus.

Data Analysis

Random-effects models were used for the meta-analysis of both mortality and days hospitalized. Mortality was summarized by odds ratio (OR) with 95% confidence intervals (CIs). Days hospitalized were summarized as the difference in mean number of days. The

measures were combined using an empirical Bayes random-effects estimator,¹¹ which also provides an estimate of heterogeneity. The calculations were performed by using FAST*PRO software version 1.80.¹² $P < .05$ was considered statistically significant.

Some of the studies had zero deaths in a particular group, which is problematic for conventional meta-analysis methods. Meta-regression analysis is an alternative method of estimating the pooled OR. Based on the assumption used in standard meta-analysis, we assumed that the OR for mortality remained constant across studies, except for some additional random variation. The model was fitted using a logistic-normal model as implemented in EGRET for Windows.¹³ These results were used as a check on the empirical Bayes estimator.

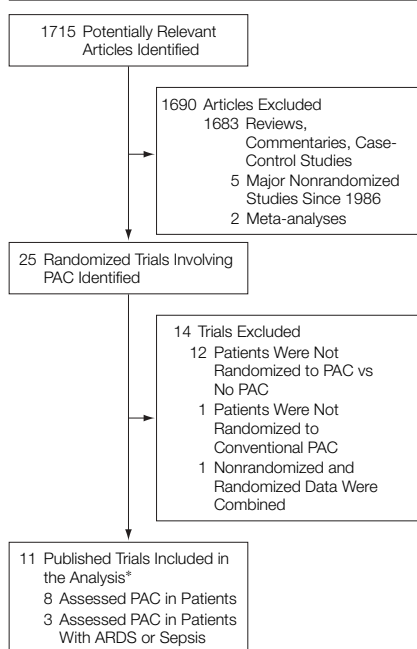
RESULTS

Search Results

We identified 2305 articles with the subject headings *catheterization*, *Swan-Ganz*, or *pulmonary artery catheter* (FIGURE 1). We limited our analysis to articles that were written in English, included only human beings, and were published between 1985 and 2005, which yielded 1715 articles. We manually searched these citations and identified 11 RCTs evaluating the PAC that met the prespecified criteria. In addition, we included 2 recently published trials. The first trial, Evaluation of the Clinical Care and Cost Effectiveness of Pulmonary Artery Flotation Catheters in Intensive Care (PAC-Man), was conducted in England and completed in March 2004.¹⁴ The second trial, the ESCAPE trial,¹⁰ was presented at the American Heart Association meeting on November 9, 2004.

Qualitative Findings

In total, 5051 patients were randomized into the 13 trials included in our meta-analysis.^{10,14-25} Eight studies focused on patients undergoing major general, abdominal, vascular, or orthopedic surgery.^{15-18,20-22,24} These trials included 2667 (52.8%) of 5051 patients

Figure 1. MEDLINE Articles Evaluated for Inclusion in the Meta-analysis

PAC indicates pulmonary artery catheter; ARDS, acute respiratory distress syndrome.

*Results from the ESCAPE trial¹⁰ and the recently published PAC-Man trial¹⁴ were also included.

in the meta-analysis. Three studies evaluated patients admitted to the ICU who were diagnosed with sepsis or acute respiratory distress syndrome.^{19,23,25} These trials included 910 patients (18.0%) of the meta-analysis study population. Only 1 study, ESCAPE,¹⁰ focused primarily on patients with advanced heart failure.

Baseline Characteristics

Treatment Protocols. Specific hemodynamic targets were outlined in 7 studies^{10,16,18,20-22,24} (TABLE 1). Six studies^{10,18,20-22,24} targeted a specific pulmonary capillary wedge pressure as 1 of the therapeutic goals, 6 studies^{16,18,20-22,24} used the cardiac index, 3 studies^{16,22,24} aimed at oxygen delivery, and 4 studies^{18,20-22} focused on systemic vascular resistance.

Five studies^{15,17,19,23,25} did not require investigators to achieve specific hemodynamic targets. The protocols of these studies called for clinicians to use their own judgment in assessing thera-

peutic goals and designing treatment strategies.

In contrast, 2 studies^{10,16} clearly outlined hemodynamic targets but did not specify which therapies should be selected to achieve these goals. The protocol of the ESCAPE trial¹⁰ encouraged the use of vasodilators and diuretics and discouraged inotropes but did not mandate use of these drugs.

The 5 most specific protocols focused on the surgical population.^{18,20-22,24} These trials outlined treatment strategies to achieve specific hemodynamic goals. A summary of fluids and therapies used in the 13 trials is shown in TABLE 2.

Quantitative Findings. Overall, there was a significantly higher rate of use of vasodilator agents in patients randomly assigned to PAC (OR, 2.35; 95% CI, 1.75-3.15; $P < .001$). In addition, use of inotropes was also significantly higher in patients randomly assigned to PAC (OR, 1.58; 95% CI, 1.19-2.12; $P = .002$).

The meta-analysis of death in the 13 RCTs demonstrated that the PAC did not significantly increase mortality. More importantly, the use of the PAC also did not improve survival (OR, 1.04; 95% CI, 0.90-1.20; $P = .59$) (FIGURE 2).

In addition, the meta-analysis of the number of days hospitalized showed that the PAC did not have a significant impact on this end point (mean for PAC – mean for no PAC, 0.11 days; 95% CI, –0.51 to 0.74; $P = .73$) (FIGURE 3).

COMMENT

Our meta-analysis of 13 RCTs evaluating the safety and efficacy of the PAC demonstrates that use of the catheter neither improves outcomes in critically ill patients nor increases mortality or days in hospital. This provides a broader confirmation of the recent results of the ESCAPE trial,¹⁰ which showed that the routine use of the PAC in patients with advanced heart failure did not reduce or increase death or days in hospital.

PAC: A Diagnostic Tool

Previous clinical trials have evaluated the PAC as an intervention, although

it is only a diagnostic tool, similar to a chest radiograph or an echocardiogram. To expect a diagnostic device to increase survival may be unrealistic unless there is a therapeutic intervention associated with it that improves outcomes. Our meta-analysis emphasizes the lack of consensus about the goals of therapy in critically ill populations, the paucity of standard guidelines on how to use the PAC, and the dearth of therapies that have met modern criteria for evidence, which provide clinical benefit in acutely ill populations.

Use of the PAC in Different Populations

The PAC may be used differently in the spectrum of critical illnesses. Because the role of the PAC in different disease states varies, the catheter may benefit some patients and harm others. The specific role the device plays in treating patients may be a factor in determining its ultimate impact on clinical outcomes. For example, in the ICU and surgical populations, the focus of the PAC is on diagnosis of volume and perfusion status and the selection and titration of drugs. In contrast, in the heart failure population, the PAC is used not only to diagnose volume and perfusion status and titrate therapy, but also to refine drug combinations and select equivalent oral doses of intravenous medications. Because the use of the PAC may vary by disease state, combining the results of different trials may not give an accurate estimate of the impact of the device in specific patient populations. However, none of the individual trials included in our meta-analysis showed a significantly positive effect of the PAC on outcomes, so heterogeneity of response as an explanation for the neutral results would have to be within each trial. We are unable to address this issue because we do not have the individual patient data.

Therapies Associated With the PAC

Another potential reason that the results of our meta-analysis were neutral may be that use of the PAC increased the accuracy of diagnosis, potentially leading to increased survival, but that

Table 1. Overview of Major Randomized Clinical Trials Evaluating the Safety and Efficacy of the PAC

Source, y	No. of Patients	PAC vs No PAC	Population	Design	Hemodynamic Targets	Treatment Strategy	End Points	Results PAC vs No PAC
Harvey et al, ¹⁴ 2005	1041	519/522	Adult ICU patients	Group 1: PAC Group 2: no PAC	No	No	Days in ICU Death	Death: PAC: 346 of 506 (68%) No PAC: 33 of 507 (66%)
Schultz et al, ¹⁵ 1985	70	35/35	Hip fracture; orthopedic surgery	PAC vs no PAC	No	No	Death	1 vs 10
Shoemaker et al, ¹⁶ 1988	88	30/30/28	High-risk general surgery patients	Group 1: no PAC Group 2: PAC with normal goals Group 3: PAC with supranormal goals	Yes Group 2: cardiac index 2.8-3.5, O ₂ delivery 400-550, V _O ₂ 120-140 Group 3: cardiac index >4.5, O ₂ delivery >600, V _O ₂ >170	No	Death Days hospitalized	Death: group 1: 7; group 2: 10; group 3: 1; group 3 vs group 1 (P<.01) Days hospitalized: group 1: mean (SD), 22.2 (2.8); group 2: mean (SD), 25.2 (3.4); group 3: mean (SD), 19.3 (2.4)
Isaacson et al, ¹⁷ 1990	102	49/53	Abdominal aortic reconstructive surgery	PAC vs no PAC	No	No	Complications Days in ICU Days hospitalized Death	17 vs 16 2.7 vs 2.1; P = .13 10.2 vs 9.4; P = .60 1 vs 0
Berlauk et al, ¹⁸ 1991	89	45/23/21	Limb salvage arterial surgery	Group 1: PAC 12 h pre-operation vs Group 2: PAC 3 h pre-operation vs Group 3: no PAC	Yes PCWP ≤15 Cardiac index ≥2.8 SVR ≤1100	Yes SVR >1100 Systolic BP >110 (vasodilator) SVR ≤1100 (inotrope) PCWP <15 (fluids) Cardiac index <2.8 (inotrope)	Days hospitalized Death	Days hospitalized: group 1: mean (SD), 19.4 (11.6); group 2: mean (SD), 18.0 (12.0); group 3: mean (SD), 15.4 (7.5) Death: group 1: 1; group 2: 0; group 3: 1
Guyatt, ¹⁹ 1991	33	16/17	ICU patients	PAC vs usual care	No	No	Days hospitalized APACHE score Death	10.3 vs 8.1 14.4 vs 11.1 10 vs 9
Bender et al, ²⁰ 1997	104	51/53	Elective vascular surgery	PAC vs no PAC	Yes PCWP ≤14 Cardiac index ≥2.8 SVR ≤1100	Yes PCWP (crystalloid) Cardiac index (dopamine) SVR (nitroprusside)	Days in ICU Days hospitalized Death	2.7 vs 2.6 12.5 vs 12 1 vs 1
Valentine et al, ²¹ 1998	120	60/60	Aortic surgery	PAC vs no PAC	Yes PCWP <15 Cardiac index ≥2.8 SVR ≤1000	Yes PCWP (Ringer's lactate) Cardiac index (dopamine) SVR (nitroprusside, nitroglycerin)	Days in ICU Days hospitalized Death	8 vs 7 13 vs 13 3 vs 1
Bonazzi et al, ²² 2002	100	50/50	Aortic reconstructive surgery	PAC vs no PAC	Yes PCWP ≤18 Cardiac index ≥3.0 SVR <1450 O ₂ delivery >600	Yes PCWP (Ringer's lactate, normal saline) Cardiac index (dobutamine) SVR (nitroglycerin)	Acute coronary syndrome, heart failure, arrhythmias Days hospitalized Renal failure Death	2 vs 4 12 vs 11 0 vs 0 0 vs 0
Rhodes et al, ²³ 2002	201	96/105	ICU patients	PAC vs no PAC	No	No	Renal failure Days hospitalized Death	22 vs 12 13 vs 14; P = .81 46 vs 50; P >.99
Sandham et al, ²⁴ 2003	1994	997/997	High-risk major surgery patients	PAC vs no PAC	Yes O ₂ delivery >600 Cardiac index ≥3.5 Mean arterial pressure, 70 PCWP ≤18 Heart rate <120/min Hematocrit, 27%	Yes To achieve hemodynamic goals, the following were tried in order: Fluid loading Inotropes Vasodilators Vasopressors Blood transfusion	Days hospitalized In-hospital death Death at 360 d In-hospital morbidity Pulmonary embolism	10 vs 10; P = .41 78 vs 77; P = .93 163 vs 155 504 vs 523 8 vs 0; P = .004
Richard et al, ²⁵ 2003	676	335/341	ICU patients with ARDS, sepsis, or both	PAC vs no PAC	No	No	28-d death Days hospitalized	199 vs 208; RR, 0.97; 95% CI, 0.86-1.1; P = .67 14 vs 14; P = .67
ESCAPE, ¹⁰ 2005	433	215/218	NYHA class IV heart failure patients	PAC vs no PAC	Yes PCWP ≤15 Right arterial pressure ≤8	No	Days dead or hospitalized over 180 d	HR, 1.00; 95% CI, 0.83-1.21

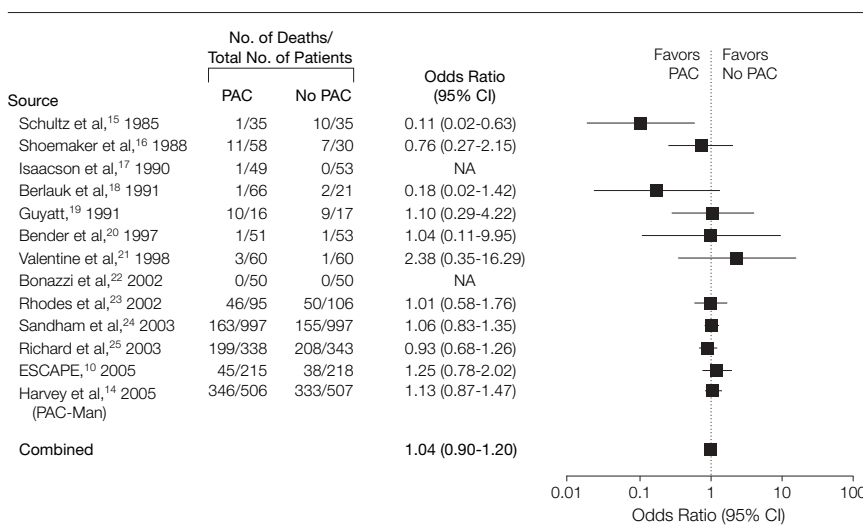
Abbreviations: APACHE, Acute Physiology and Chronic Health Evaluation; ARDS, acute respiratory distress syndrome; BP, blood pressure; CI, confidence interval; HR, hazard ratio; ICU, intensive care unit; NYHA, New York Heart Association; PAC, pulmonary artery catheter; PCWP, pulmonary capillary wedge pressure; RR, relative risk; SVR, systemic vascular resistance.

Table 2. Therapies in PAC vs No PAC Groups

	No. of Patients		Hemodynamic Targets	Treatment Strategy	Crystalloid, mL*		Colloid, mL*		Packed Red Blood Cells, Units*		No. of Inotropes (%)		No. of Vasodilators (%)			
	PAC	No PAC			PAC	No PAC	PAC	No PAC	PAC	No PAC	PAC	No PAC	PAC	No PAC	PAC	No PAC
Harvey et al, ¹⁴ 2005	519	522	No	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
Schultz et al, ¹⁵ 1985	35	35	No	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
Shoemaker et al, ¹⁶ 1988	30; 30	28	Yes	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
Isaacson et al, ¹⁷ 1990	49	53	No	No	3308 (1547)	2979 (1044)	93 (189)	115 (261)	0.2 (0.7)	0.2 (0.5)	NA	NA	NA	NA		
Berlauk et al, ¹⁸ 1991	43; 23	21	Yes	Yes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
Guyatt, ¹⁹ 1991	16	17	No	No	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
Bender et al, ²⁰ 1997	51	53	Yes	Yes	5137 (315)	3789 (306)	NA	NA	1.3 (0.1)	1.8 (1.5)	NA	NA	NA	NA		
Valentine et al, ²¹ 1998	60	60	No	Yes	5100 (270)†	4060 (190)	NA	NA	NA	NA	NA	NA	NA	NA		
Bonazzi et al, ²² 2002	50	50	Yes	Yes	4500 (3250-6500)†	3250 (2500-4750)	NA	NA	825 (500-1500)	975 (500-2000)	NA	NA	NA	NA		
Rhodes et al, ²³ 2002	96	105	No	No	4953 (3140-7000)†	4295 (2535-6049)	NA	NA	NA	NA	24 (28.2)	21 (23.6)	NA	NA		
Sandham et al, ²⁴ 2003	997	997	Yes	Yes	NA	NA	546 (54.8)†	446 (47.7)	564 (56.6)	469 (47.0)	488 (48.9)	327 (32.8)	847.5 (8.5)	39 (3.9)		
Richard et al, ²⁵ 2003	338	343	No	No	NA	NA	NA	NA	NA	NA	296 (88.6)	307 (90.3)	NA	NA		
ESCAPE, ¹⁰ 2005	215	218	Yes	No	NA	NA	NA	NA	NA	NA	94 (43.7)	86 (39.4)	78 (36.3)	41 (18.8)		

Abbreviations: NA, not available; PAC, pulmonary artery catheter. *Data are presented as mean (SD) or mean (range). †P<.05.

Figure 2. Odds Ratio (PAC vs No PAC) for Mortality of RCTs Evaluating the Safety and Efficacy of the PAC



CI indicates confidence interval; NA, not available; PAC, pulmonary artery catheter; RCT, randomized clinical trial. P for heterogeneity=.36.

hemodynamic data also triggered use of therapies that worsened outcomes. Four studies included in our analysis presented information on how fre-

quently intravenous inotropes and vasodilators were used.^{10,23-25} It may be that inotropes and vasodilators were used more frequently in pa-

tients who received the PAC because objective hemodynamic goals were present. There are few data, and no RCT data, that show either class of drugs improves outcomes in acutely ill patients. In fact, the use of inotropic agents and some vasodilators have been associated with increased morbidity and mortality in the advanced heart failure population.^{26,27} In addition, there is little evidence from RCTs to support the use of fluid loading, blood transfusions, or intravenous vasodilators to achieve hemodynamic goals.²⁸ Although use of the PAC may have allowed physicians to diagnose clinical and hemodynamic status more accurately, it may have also triggered the use of drugs that ultimately worsened outcomes.

Quality of Hemodynamic Data

Quality of hemodynamic data is also a critical factor in determining the impact of the device on clinical outcomes. Eleven studies in our analysis did not include a protocol for interpretation of hemodynamic wave-

forms. Thus, there may have been inaccuracies in the hemodynamic data, which had an impact on morbidity and mortality. In addition, only the ESCAPE trial required study nurses to undergo formal training in hemodynamic waveform interpretation. Without standard protocols for the PAC, there may have been errors in gathering hemodynamic data, which may have ultimately affected clinical outcomes.

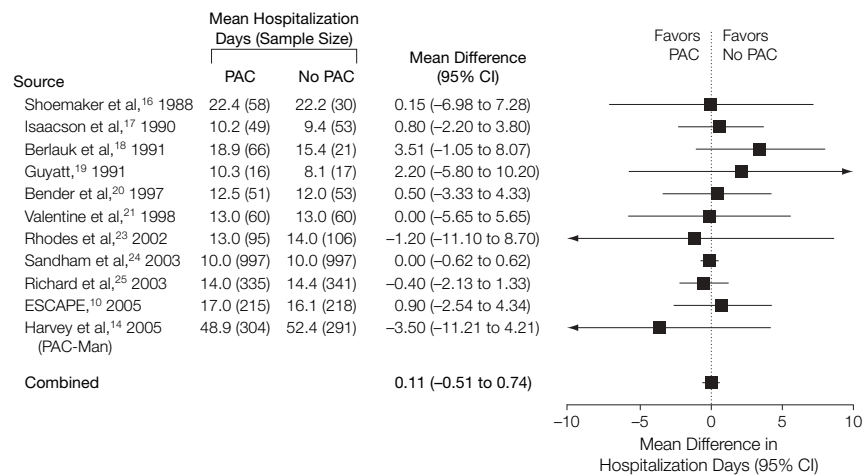
Hemodynamic Targets: The Wrong Surrogates?

Although many of the studies included in our meta-analysis outlined specific hemodynamic goals, there are few definitive data to support the use of any hemodynamic target. The decision to optimize filling pressures in the ESCAPE trial was based mostly on the positive results of single-center, non-randomized studies using these targets.^{29,30} In contrast, there are few data, even from nonrandomized studies, to support maximizing cardiac index and oxygen delivery.³¹ It may be that the observed neutral effect of the PAC was because investigators were targeting drugs, fluid, and blood replacement to the wrong end points.

Ongoing Randomized Studies

We identified 1 additional unpublished trial evaluating the safety and efficacy of the PAC. The Fluids and Catheter Treatment Trial focused on 1000 patients with acute respiratory distress syndrome.^{32,33} Patients were randomized in a 2 × 2 factorial design to a liberal vs conservative fluid treatment strategy and to therapy guided by a PAC or central venous catheter. The primary end point was death at 60 days. The investigators outlined specific hemodynamic goals and treatment strategies for the use of inotropes, vasopressors, fluids, and diuretics. The trial was started in 2001 but was suspended by the Office for Human Protections From Research³² for questions about the ethics of the protocol. After extended review by external consultants, the trial was restarted in 2002 with no major revisions to the protocol.

Figure 3. Mean Difference in the Average Number of Days Hospitalized in PAC Randomized Controlled Trials (Mean for PAC – Mean for No PAC)



CI indicates confidence interval; PAC, pulmonary artery catheter. *P* for heterogeneity = .91.

Future Studies

The overview by Ivanov et al⁹ suggests that nonfatal end points may be improved by disease-specific targeting of therapy and the ESCAPE trial¹⁰ suggested the possibility of quality of life improvement. Future trials should look at alternate clinical end points, particularly symptom status. Furthermore, given the absence of harm for major clinical end points, renewed emphasis should be placed on the development of novel therapies that might be effective when coupled with the diagnostic information obtained from the PAC.

Conclusions

During the past 60 years, the PAC has evolved from a simple diagnostic tool to a device that is used for monitoring and determining goal-directed therapy. Our meta-analysis shows that despite the widespread acceptance of the PAC, use of this device across a variety of clinical circumstances in critically ill patients does not improve survival or decrease the number of days hospitalized. The patients included were those in whom physicians had clinical equipoise about the use of the PAC. That is, clinicians were uncertain about the use of the PAC before they randomized patients.

Although our results suggest that the PAC should not be a standard of care,

all of the trials excluded patients in whom clinicians thought a PAC was required for treatment. Thus, it is possible that patients who are outside the boundaries of these trials, such as those who are evaluated for heart and lung transplantation, derive benefit from the PAC. However, these results suggest that the PAC should not be used for the routine treatment of patients in the ICU, patients with decompensated heart failure, or patients undergoing surgery until or unless effective therapies can be found that improve outcomes when coupled with this diagnostic tool.

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Study concept and design: Shah, Hasselblad, Stevenson, Binanay, O'Connor, Sopko, Calif.

Acquisition of data: Shah, Hasselblad, Stevenson, Binanay, O'Connor, Calif.

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Drafting of the manuscript: Shah, Hasselblad, Stevenson, O'Connor.

Critical revision of the manuscript for important intellectual content: Shah, Hasselblad, Stevenson, Binanay, O'Connor, Sopko, Calif.

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Obtained funding: Shah, Stevenson, O'Connor, Calif.

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