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Systematic Review

Is there a difference in PAC versus no-PAC in surgical cardiac and ICU patients?

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Executive Summary

Background

The pulmonary artery catheter (PAC) was introduced in the 1970's by H.J. Swan and W. Ganz to manage haemodynamic perturbances in real-time. Since then, their use has increased however, there have been questions regarding their efficacy for multiple clinical scenarios. As a result, a search for less invasive hemodynamic monitoring methods has begun subsequently decreasing the routine use of the PAC.

Objective

The purpose of this systematic review was to determine the safety and effectiveness of routine use of a pulmonary artery catheter (PAC) or a Swan Ganz catheter post cardiac surgery on mortality rates, complications, days in intensive care unit, day in hospital, and cost in patients undergoing cardiac surgery, or patients who end up in an intensive care unit.

Search Strategy

Medline, All EBM, Embase and Cumulative Index to Nursing and Allied Health Literature (CINAHL) databases were searched using predetermined search terms. Google, British Medical Journal (BMJ) Best Practice, and the National Institute for Clinical Excellence (NICE) were also searched. All searches were from 2012-current. Studies were included if they involved adult cardiac surgery patients, or ICU patients requiring haemodynamic monitoring. All other surgical patients were excluded.

Search Results

Following screening and application of the inclusion/exclusion criteria, 7 articles were included in this review. Of the 7 articles, five were experimental studies[1,2,3,4,5], one was a systematic review[6], and one was an expert recommendation[7].

Results

It should be noted that the high quality review with meta-analysis[6] included in this report only contained one study detailing the outcomes of cardiac surgery patients. As a result, the findings of this paper[6] relate predominantly to general intensive care patients, and this must be kept in mind when interpreting the summary of results.

Overall summary of results regarding main outcomes of interest

Author	Year	Mortality	Complications	Days in ICU	Days in hospital	Cost
Cochrane review						
Rajaram et al.[6]	2013	ND		ND for general surgery patients with PAC	ND	ND
Single studies since Cochrane review						
Brovman et al.[1]	2016	ND				
Chiang et al.[2]	2015	ND in low-risk patients with PAC				
		Higher in high-risk patients with PAC			Higher in patients with PAC	Higher in patients with PAC*
Desai et al.[3]	2015	ND	ND	ND		
Kirton et al.[4]	2015	ND		ND	ND	
Xu et al.[5]	2015	ND	ND			Higher in patients with PAC

Abbreviations: ND = no difference; * not statistically tested; blank boxes indicate unreported results.

Conclusions

Meta-analyses from a Cochrane review[6] show there is no difference in the use of PAC compared to no-PAC in mortality rates, complications, length of stay in ICU, or length of stay in hospital however, these findings are predominantly from general intensive care patient studies.

There is mixed evidence for the cost of PAC versus no-PAC in patients. Expert panel recommendations from Choosing Wisely America are that PAC should not be used routinelyfor cardiac surgery in patients with a low risk of hemodynamic complications[7].

Background

The pulmonary artery catheter (PAC) was introduced in the 1970's by H.J. Swan and W. Ganz to manage haemodynamic perturbances in real-time[1]. PACs provide information on 3 key variables, intracardiac and intrathoracic vascular pressures, and hence preload, cardiac output, and mixed venous oxygen saturation[4]. As a result, the insertion of PACs have been used to guide therapy and reduce morbidity and mortality rates in critically ill patients[8], and are often standard practice for coronary artery bypass graft (CABG) or cardiac valvular surgery[9]. However, PACs have been criticised in the past due to the lack of evidence for their use in multiple clinical scenarios[10], particularly given the invasiveness. As a result, it has been said that the lack of evidence supporting improved outcomes, as well as the decreased familiarity and training in PAC, have triggered the search for less invasive hemodynamic monitoring methods. As a result, many imaging modalities and minimally invasive monitors have surfaced[11].

Following the reservations of the efficacy of PACs a systematic review was conducted in 2013[6] exploring the effectiveness of PACs on mortality, length of stay (LOS) in intensive care unit (ICU) and hospital, and cost of care in adult intensive care patients. As a result, this review will summarise this study and explore published evidence since this review with the view to update the current information on the use of PAC in cardiac surgery and ICU patients.

Aims and Objectives

The purpose of this systematic review was to understand what evidence is available for the safety and effectiveness of routine use of a pulmonary artery catheter (PAC), or a Swan Ganz catheter, during or post cardiac surgery? In order to respond to this question, our objectives were:

1. To systematically search the published and grey literature base for evidence of safety and effectiveness for PAC use versus no-PAC use in cardiac surgery and ICU patients.

2. To synthesise and summarise the recent evidence identified in order to guide clinical practice based on mortality rates, complications, days in intensive care unit, days in hospital, and cost.

Search strategy

Medline, All EBM, Embase and Cumulative Index to Nursing and Allied Health Literature (CINAHL) databases were searched using predetermined search terms (Appendix 1, Table 3). In addition, Google and websites known to the authors to contain clinical guidelines and systematic reviews (British Medical Journal (BMJ) Best Practice, National Institute for Clinical Excellence (NICE)) were also searched in April and May 2017 (Appendix 1, Table 4). Search terms and specific dates are provided in Appendix 1, Tables 4 and 5.

Document Selection

Titles and abstracts identified in each database were exported to EndNote X7 (Thompson, Reuters, Carlsbad, California, USA). Papers identified were screened using inclusion and exclusion criteria established *a priori* (Table 1). Results from items earlier than 2012 were excluded. Titles and abstracts were initially screened, then full text articles were obtained for studies that needed to be further explored. Searches conducted of the Medline, All EBM, EMBASE and CINAHL databases were performed and results screened by one author (MG). Searches of Google, BMJ Best Practice and NICE were conducted and results were also screened by one reviewer (CJ). A consultation process occurred for the appropriateness of any uncertain resources.

Table 1. Inclusion/Exclusion criteria

Population	**Include:** Cardiac surgery patients requiring haemodynamic monitoring (Adults). **Exclude:** All other patient groups undergoing surgery.
Diagnostic/ monitoring tool	**Include:** Insertion of a pulmonary artery catheter or Swan Ganz catheter during cardiac surgery in the operating theater, or post-cardiac surgery in the ICU. **Exclude:** Preoperative haemodynamic monitoring.
Comparison	No diagnostic/monitoring tool or other less invasive methods of monitoring.
Outcomes	Mortality, complications, days spent in ICU, days spent in hospital, cost of care.
Types of evidence	**Include:** Reviews, randomised control trials, cohort studies, cross-sectional studies, clinical guidelines, panel recommendations.

	Exclude: Qualitative studies, surveys, case studies.
Limits	**Date**: 2012 – current. **Language:** Publications in English.

Data extraction

For each study identified from the searches, details regarding study design, patient cohort, reported outcomes, and a summary of the results were extracted into a table by one author (CJ).

Results

Database searching identified 519 results. The Google search identified 57,600 results which were cropped by Google to 175 results. Each of these results were explored, and subsequently, three were included in this review from the Google search. Searches of BMJ Best Practice and NICE did not reveal any additional studies.

When a screening decision could not be made based on title and abstract alone, full text was retrieved. There were 33 full text articles or resources retrieved and 7 were included in the review (Figure 1).

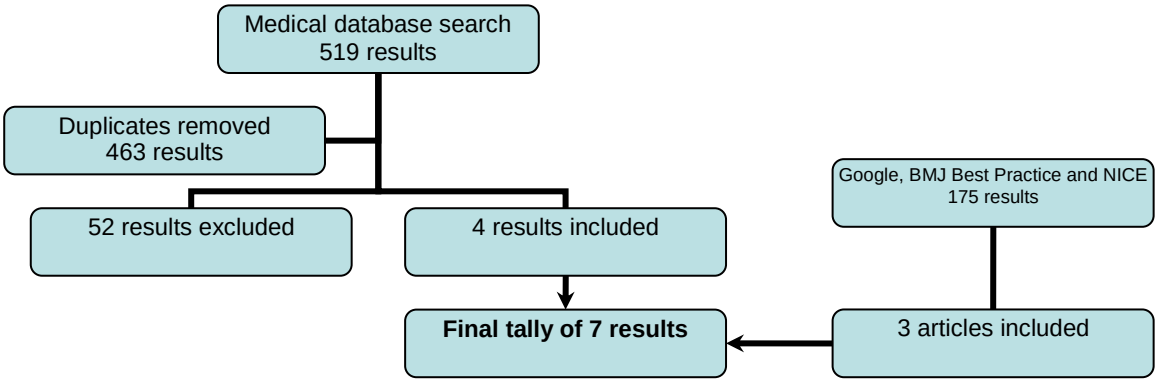

Figure 1. Search results and screening process used in the review

Of the seven items, five were experimental studies[1,2,3,4,5], one was a systematic review[6], and one was an expert recommendation[7]. Of the experimental studies, two were cross-sectional[1,2], one was a randomised control trial[3], one was a cohort study[4], and one was a case-control study[5].

Two studies involved all types of cardiac surgery patients (e.g. coronary artery bypass grafting and heart valve surgery)[1,2]. Two studies involved coronary artery bypass graft patients only[3,5], and one study involved neurointensive care-trauma patients, cardiac surgery patients, and general surgery/transplant patients all in the intensive care unit (ICU)[4]. The systematic review included all randomised control trials that involved patients treated in an ICU and managed with a PAC versus no-PAC[6].

All experimental studies reported mortality rates as an outcome[1,2,3,4,5], as did the systematic review[6]. Two studies reported complications[3,5], three studies reported days in ICU[3,4,6], three studies reported days in hospital[2,4,6], and two studies reported cost[5,6].

Table 2 provides some descriptive information of each study included in this review.

Table 2. Summary of the characteristics and results of included studies.

Author	Year	Study Design	Patient cohort	Participants	Results
Peer reviewed literature					
Brovman et al.[1]	2016	Cross-sectional.	Cardiac surgery.	A total of 116,333 patients undergoing pulmonary artery catheter placement during cardiac surgery in the National Anaesthesia Clinical Outcomes Registry from the Anaesthesia Quality Institute.	Age older than 50 years, American Society of Anaesthesiologists classification of 3 or higher, case duration of longer than 6 hours, and presence of a resident physician or certified nurse anaesthetist were associated with increased likelihood of pulmonary artery catheter (PAC) placement. Age <18 years, or presence of a board-certified anaesthesiologist, were associated with a decreased likelihood of catheter placement. The use of PACs has increased from 2010 to 2014. The presence of a PAC did not alter the risk of cardiac arrest intraoperatively. A nonsignificant decrease in mortality was associated with catheter placement. Transfusion was 75% less likely in the PAC cohort than in the control group.
Chiang et al.[2]	2015	Cross-sectional.	Cardiac surgery.	A weighted sample of 2,063,337 patients undergoing cardiac surgery identified from the Nationwide Inpatient Sample (NIS) from January 1, 2000 to December 31, 2010.	Compared to patients who did not receive a pulmonary artery catheter, those who did on the whole were on average slightly older (66.6 ± 11.9 years v 65.5 ± 12.8 years, $p < 0.001$), more likely to have pulmonary hypertension (7.5% v 5.1%, $p <0.001$), chronic obstructive pulmonary disease(24.6% v 20.7%, $p < 0.001$), obesity (15.0% v 13.1%, $p < 0.001$), and chronic renal failure (10.9% v 9.2%, $p < 0.001$). In multivariate analysis, the risk of operative mortality in patients who underwent pulmonary artery catheterization was significantly higher than in those who did not (4.6% v 3.1%, $p < 0.001$), adjusted OR 1.34(95% CI 1.26-1.43, $p < 0.001$). In propensity matched subgroup analysis operative mortality risk was higher in octogenarian patients (OR 1.24, $p = 0.24$), and patients with congestive heart failure (OR 1.39, $p = 0.023$) who underwent pulmonary artery catheterization. No significant difference in operative mortality was observed in low-risk patients according to whether or not they underwent pulmonary artery catheterization. The incidence of prolonged mechanical ventilation and length of stay 430 days was higher in patients who underwent pulmonary artery catheterization in all subgroups.
Desai et al.[3]	2015	RCT. Pulmonary Artery Catheter v Central Venous Pressure.	Coronary Artery Bypass Surgery.	In this prospective randomized trial, sixty patients were divided equally into two groups, to receive either central venous or pulmonary artery catheter after induction of anaesthesia with high dose of opioid and Inj pancuronium. Patients between 35-65 years with ejection fraction 40-60% undergoing elective off pump coronary artery bypass surgery	Significant number of patients in CVP group were started on inotropes than PAC group (66.6% vs 40%, P=0.038). Among these, 75% in Group A needed it for less than 24 hours compared to 65% in Group B. Both groups needed similar trials of fluid challenge [40% vs 53.33%; P=0.30] and showed similar duration of intensive care unit stay (more than 48 hrs) [66.67% vs 53.3%; p=0.29, chi square test]. No significant difference in complications but there were more in CVP group [6.6 vs 16.6%; P=0.22]. One patient in each group had mortality.

				were included while those with left ventricular dysfunction were excluded.	
Kirton et al.[4]	2015	Cohort. Studies the impact of reduction of PAC over time. 2005-2009.	Intensive Care Unit patients (neutointensive care-trauma, cardiac surgery, general surgery/transplant).	Five-year retrospective review of 1894 hemodynamically monitored patients admitted to 3 surgical ICUs in a university-affiliate, tertiary care urban hospital.	There was a significant change in the type of hemodynamic monitors inserted in 2 of the 3 surgical ICUs (in the general surgery and neurointensive care but not in the cardiac ICU) from PACs to less-invasive devices (Flo- Trac or EDM) during the 5-year study period (P < .001). There was no change in mortality rate over the time period (P =.492). There was an overall increase in the proportion of monitored patients who received intravenous vasoactive agents (P < .001) with a progressive shift from b-agonists to vasopressors (P < .002). Multivariate analyses indicated that age, case mix, and use of vasoactiveb agents were all independent predictors of inhospital mortality (P = .001) but that type of monitoring was not (P =.638). Effect of Monitoring Type on Mortality The type of monitoring experienced was significantly related to mortality. A higher proportion of patients who experienced a conversion (46%) or other mixed approach to monitoring died (44%) than those experiencing only the use of invasive approach Swan Ganz (31%) or only less-invasive probes (33%; P <.001). regression. The multivariate logistic regression showed no effect of type of monitoring (ie; PAC vs less-invasive monitoring) on mortality as an independent predictor (P = .638).
Rajaram et al.[6]	2013	Cochrane review.	Adult patients in intensive care.	5686 patients overall.	13 studies included (5686 patients). Blinding of participants and personnel and blinding of outcome assessment were at high risk in about 50% of the included studies and at low risk in 25% to 30% of the studies. Regardless of the high risk of performance bias these studies were included based on the low weight the studies had in the meta-analysis. 75% of the studies were low risk for selection, attrition and reporting bias. All 13 studies reported some type of hospital mortality (28-day, 30-day, 60-day or ICU mortality). Studies of high-risk surgery patients (eight studies) and general intensive care patients (five studies) were considered separately as subgroups for meta-analysis. The pooled risk ratio (RR) for mortality for the studies of general intensive care patients was 1.02 (95% confidence interval (CI) 0.96 to 1.09) and for the studies of high-risk surgery patients the RR was 0.98 (95% CI 0.74 to 1.29). Of the eight studies of high-risk surgery patients, five evaluated the effectiveness of pre-operative optimization but there was no difference in mortality when these studies were examined separately. PAC did not affect general ICU LOS (reported by four studies) or hospital LOS (reported by nine studies). Four studies, conducted in the United States (US), reported costs based on hospital charges billed, which on average were higher in the PAC groups. Two of these studies qualified for analysis and did not show a statistically significant hospital cost difference (mean difference USD 900, 95% CI -2620 to 4420, P = 0.62).
Xu et al.[5]	2015	Case-control.	Coronary Artery Bypass Surgery.	1361 Chinese patients who consecutively underwent isolated, primary CABG at the Cardiovascular Institute of Fuwai Hospital from June 1, 2012 to December 31, 2012 were included in this study. Of all the patients, 453 received PAC during operation (PAC group) and 908 received no PAC therapy (control group).	The patients who were managed with PAC more often received intraoperative vasoactive drugs dopamine (70.9% vs. 45.5%; P<0.001) and epinephrine (7.7% vs. 2.6%; P<0.001). In addition, costs for initial hospitalization were higher for PAC patients ($14,535 vs. $13,873, respectively, p = 0.004). PAC use was neither associated with the perioperative mortality or major complications, nor was it associated with long-term mortality and major adverse cardiac and cerebrovascular events. In addition, comparison between two wellmatched groups showed no significant differences either in baseline characteristics or in short-term and long-term outcomes.
Grey literature					

Choosing Wisely[7]	2013	Recommendation.	Cardiac surgery.	N/A	**Don't use pulmonary artery catheters (PACs) routinely for cardiac surgery in patients with a low risk of hemodynamic complications (especially with the concomitant use of alternative diagnostic tools (e.g., TEE).** The increased risk of hemodynamic complications as indicated above is defined as a patient with clinical evidence of significant cardiovascular disease; pulmonary dysfunction, hypoxia, renal insufficiency or other conditions associated with hemodynamic instability (e.g., advanced age, endocrine disorders, sepsis, trauma, burns). The use of a PAC during cardiac surgery has been associated with increased mortality and a higher risk of severe end-organ complications. There is clear consensus in the literature that the use of a PAC cannot be recommended as a matter of routine, but for a definite role in a very select group of patients undergoing cardiac surgery. According to a survey by practicing anaesthesiologists, the use of PAC could be recommended for specific indications in cardiac surgery including coronary artery bypass grafting (CABG) with poor left ventricular (LV) function, LV aneurysmectomy, recent myocardial infarction, pulmonary hypertension, diastolic dysfunction, acute ventricular septal rupture and insertion of left ventricular assist device. The appropriate indications remain debatable. However, although the PAC has no role in routine perioperative care, the existence of a specific subpopulation for which the use of this device may be beneficial cannot be excluded.

Summary of findings

Following the extraction of data and summarising the information, evidence contained herein relates to the specific outcomes of interest in the aims of this review.

It should be noted that the high quality review with meta-analysis[6] included in this report only contained one study detailing the outcomes of cardiac surgery patients. As a result, the findings of this paper[6] relate predominantly to general intensive care patients, and this must be kept in mind when interpreting the summary of results.

Mortality

The high quality Cochrane review showed that overall, there is no difference in mortality when using a PAC compared to another device in medical and surgical patients (Figure 2), general ICU patients (Figure 3), or high-risk surgical patients (Figure 4)[6]. There is also no difference in mortality reported at either 28-30 days, or 60 days[6].

Since the Cochrane review[6], there have been five single studies published reporting mortality[1,2,3,4,5].

For cardiac surgery patients, there is no difference in mortality between PAC and no-PAC in low-risk patients (1.3% vs 1.2%). However, there is a difference in mortality in high-risk patients, with more deaths occurring with patients who have a PAC compared to those that do not have a PAC (12.2% v 9.6%)[2].

For coronary artery bypass patients, there is also no difference between PAC versus a central venous catheter in mortality rate[3].

For coronary artery bypass graft patients there is no difference in mortality rates with increased use of PAC[1].

For coronary artery bypass graft patients, there is no difference in in-hospital or long term mortality rates between PAC and non-PAC[5]. The insertion of a PAC is also not a predictor of mortality in low risk or high risk coronary artery bypass graft patients[5].

For surgical ICU patients (including cardiac surgery patients), the decreased use of PAC and increased use of less-invasive monitoring did not lead to changes in mortality rates (35%) over a 5 year period[4]. When specifically looking at monitor type, more patients who experienced a conversion, or other mixed approach, died compared to those with a Swan Ganz or less invasive probe[4]. This indicates that the use of mixed monitoring or conversions from less invasive monitoring to PAC resulted in increased mortality[4].

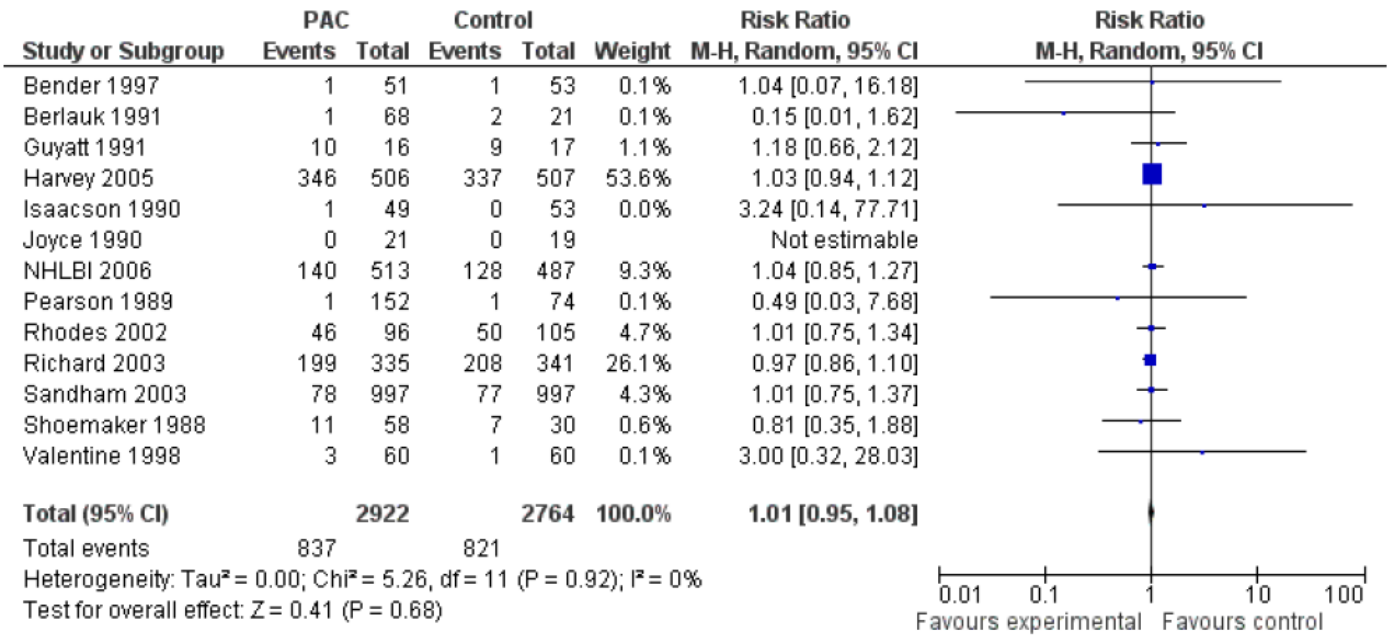

Figure 2. Forrest plot of mortality in combined medical and surgical patients for PAC vs no-PAC (Adapted from [6]).

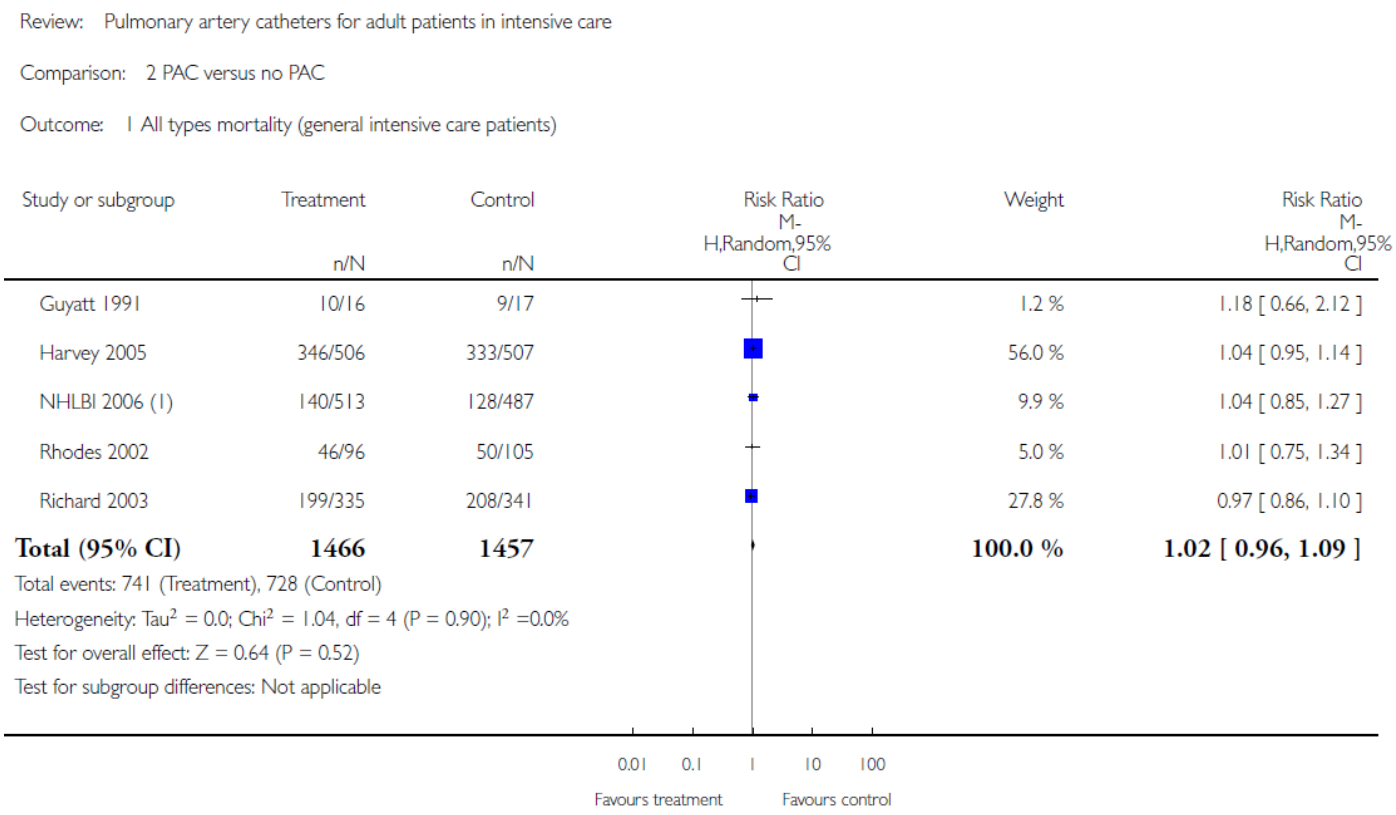

Figure 3. Forrest plot of mortality in general ICU patients for PAC vs no-PAC (Adapted from [7]).

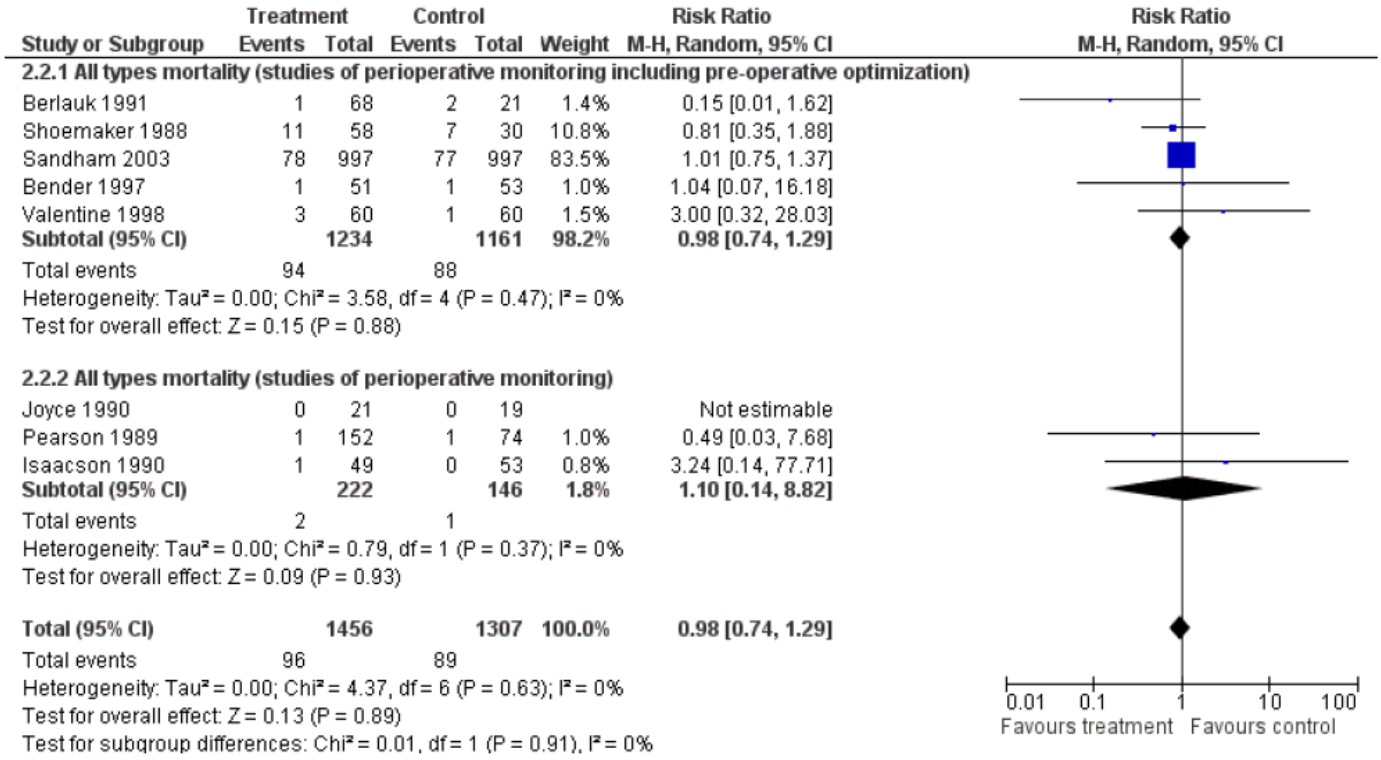

Figure 4. Forrest plot of mortality in combined high-risk surgical patients for PAC vs no-PAC (Adapted from [7]).

ICU Length of Stay

The high quality review showed that overall, there are no differences in length of stay in ICU in PACs when compared to no-PACs for general ICU patients[6] (Figure 5). The evidence is inconclusive regarding LOS in high-risk surgical patients given that a large amount of heterogeneity is reported[7].

Since the Cochrane review[6] there have been two studies that have reported LOS outcomes in PAC patients[3,4].

For coronary artery bypass patients, there is no difference in ICU LOS between PACs and a central venous catheters[3].

For surgical ICU patients (including cardiac surgery patients), a decrease in the use of PACs with a subsequent increase in the use of less-invasive monitoring did not change LOS in ICU over a 5 year period[4].

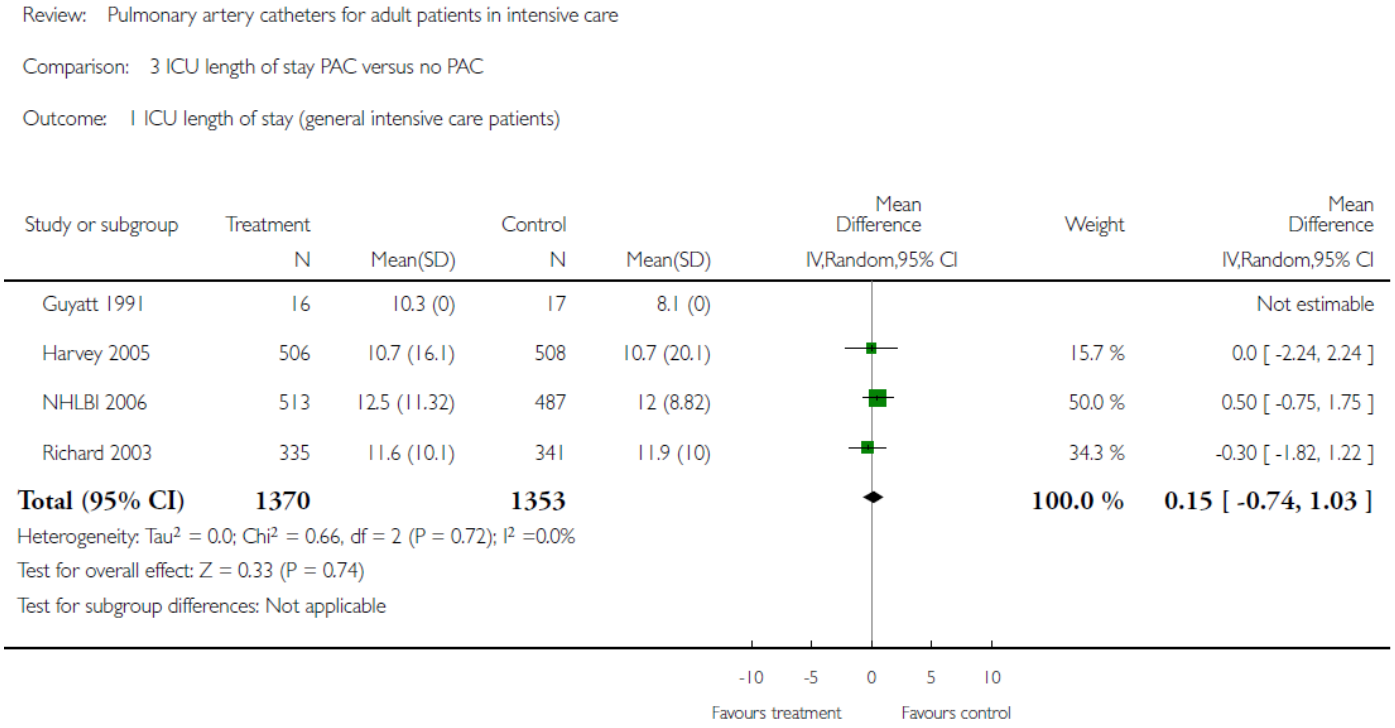

Figure 5. Intensive care unit length of stay in general ICU patients between PAC and no-PAC patients (Adapted from [6]).

Hospital length of stay

The high quality review showed that overall, there is no difference in hospital length of stay between PAC and no-PAC for general ICU patients or high-risk surgical patients[6] (Figures 6 & 7). Since this Cochrane review[6], there have been two single studies that have reported hospital LOS[2,4].

For surgical ICU patients (including cardiac surgery patients), a decrease in the use of PAC and increased use of less-invasive monitoring did not change LOS in ICU over a 5 year period[4].

For cardiac surgery patients, total length of hospital stay >30 days was greater in PAC patients compared to no-PAC patients (4.3% v 3.1%)[2].

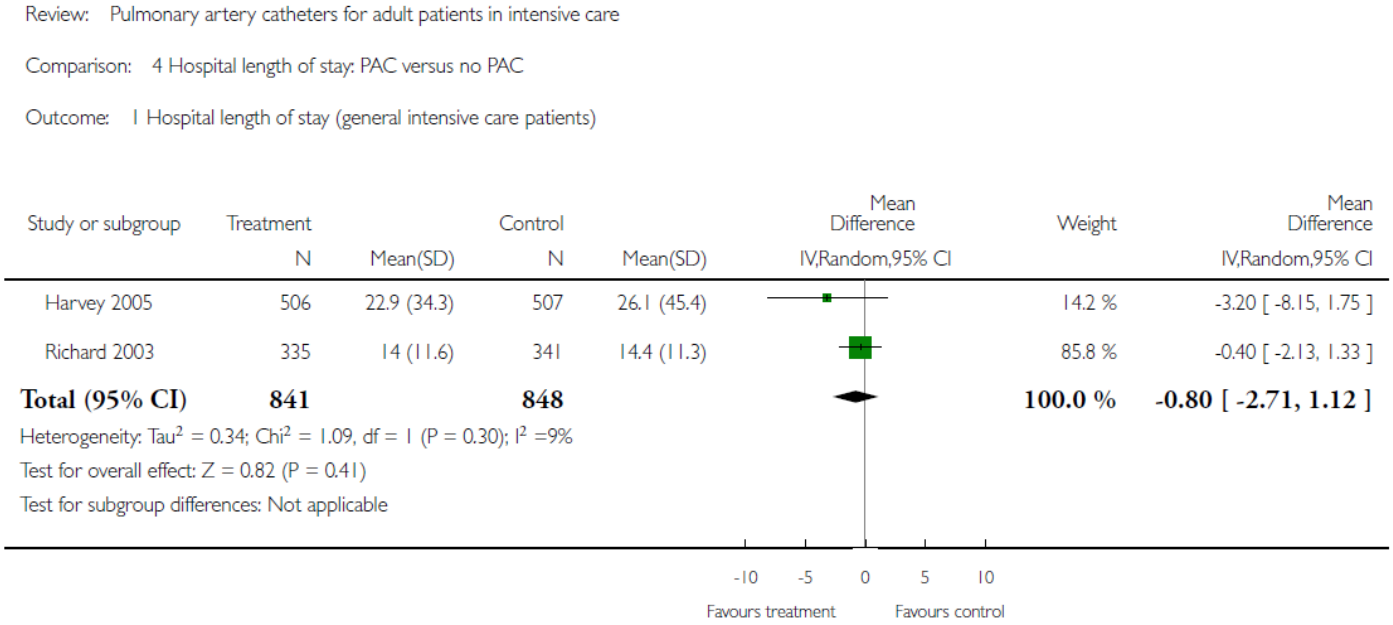

Figure 6. Hospital length of stay in general ICU patients between PAC and no-PAC (Adapted from [6]).

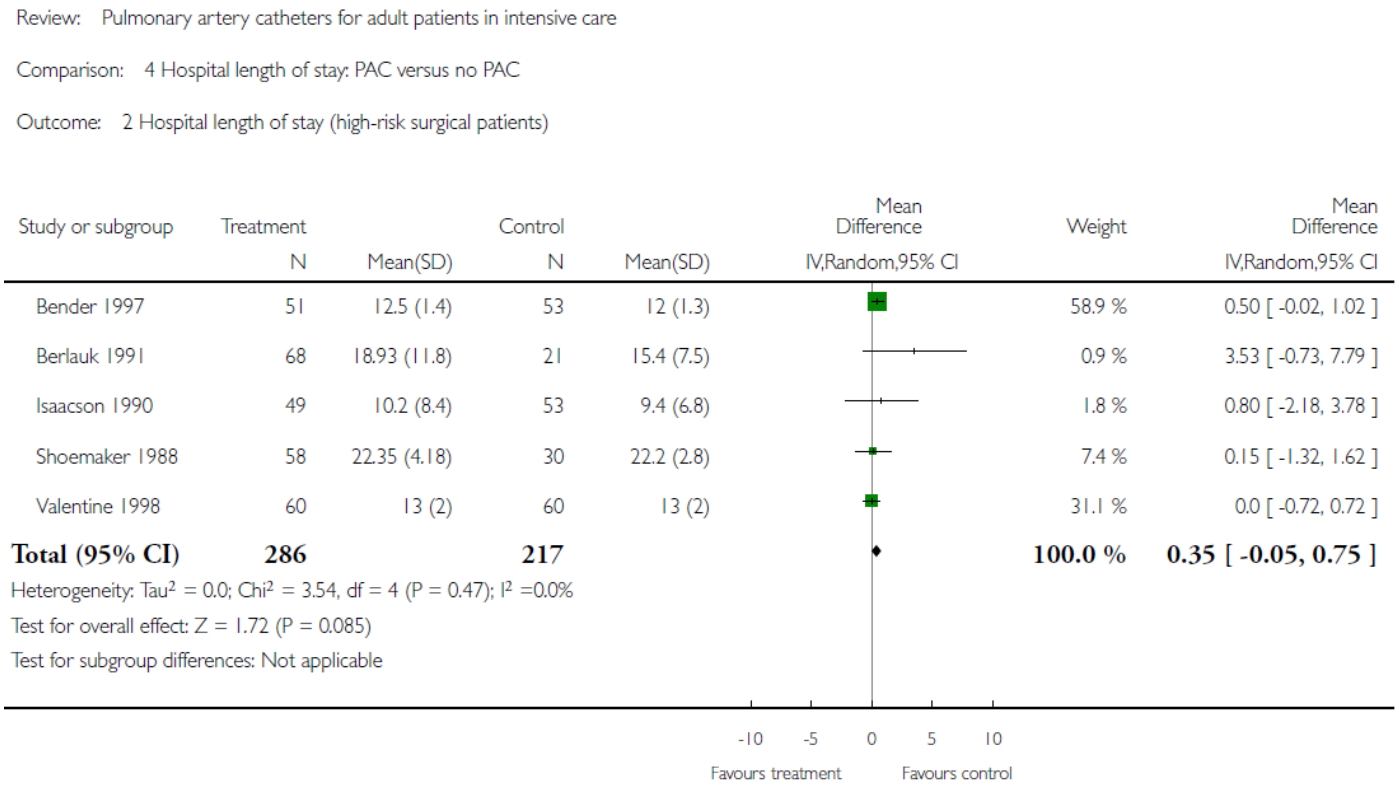

Figure 7. Hospital length of stay in high-risk surgical patients between PAC and no-PAC (Adapted from [6]).

Cost

The high quality review showed that overall, there is no difference in cost of care of PAC versus no-PAC[6] (Figure 8). Since the Cochrane review[6] there have been two single studies reporting cost[2,5].

For coronary artery bypass graft patients, in-hospital costs for the entire hospitalisation were higher in PAC patients compared to no-PAC patients[5]. There are no differences in separate preoperative, intraoperative and post-operative costs between PAC patients and no-PAC patients[5].

For cardiac surgery patients, recent reports have stated that there is a difference in cost between PAC versus no-PAC with PAC costing US $133,000 and no-PAC costing US$125,000[2].

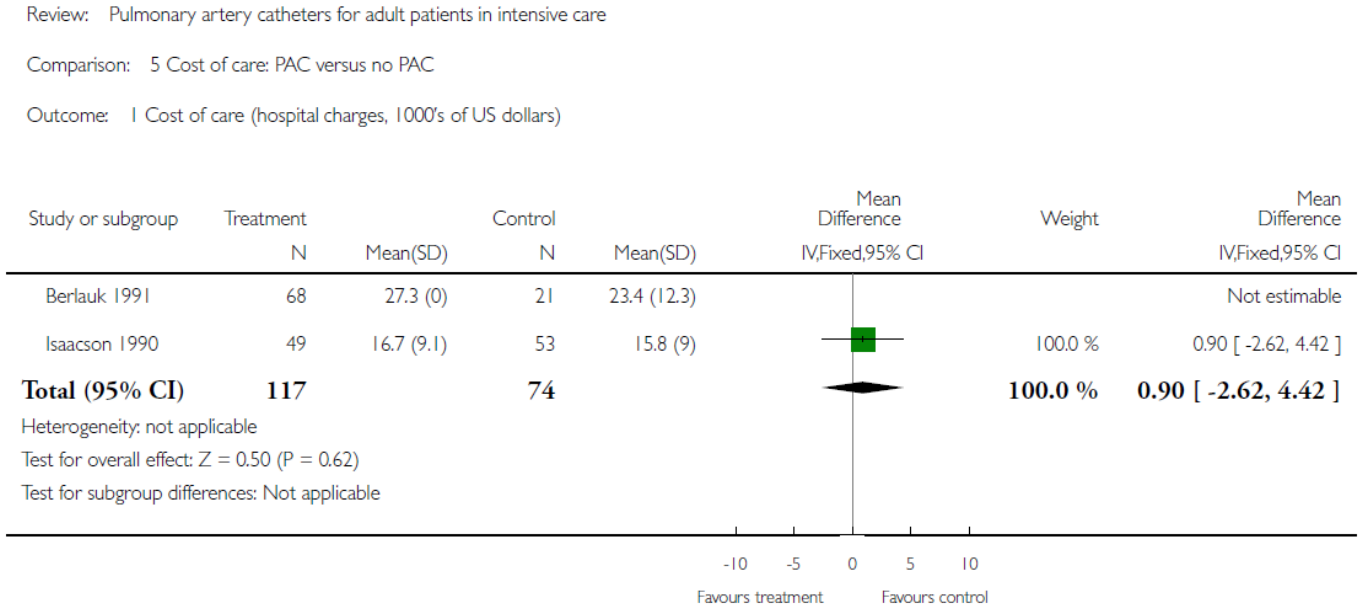

Figure 8. Cost of care of PAC versus no-PAC (Adapted from [6]).

Complications

Two single trials have reported complications[3,5]. For coronary artery bypass patients, there is no difference in complications between PAC versus a central venous catheter[3]. For coronary artery bypass graft patients, PAC is not a predictor of worse outcomes for patients[5].

Expert Recommendations

The American Society of Anaesthiologists have partnered with Choosing Wisely America to create five practice recommendations[7]. One of these recommendations relates directly to the use of PACs, and states:

"**Don't use pulmonary artery catheters (PACs) routinely for cardiac surgery in patients with a low risk of hemodynamic complications (especially with the concomitant use of alternative diagnostic tools (e.g., TEE).**

The increased risk of hemodynamic complications as indicated above is defined as a patient with clinical evidence of significant cardiovascular disease; pulmonary dysfunction, hypoxia, renal insufficiency or other conditions associated with hemodynamic instability (e.g., advanced age, endocrine disorders, sepsis, trauma, burns).

The use of a PAC during cardiac surgery has been associated with increased mortality and a higher risk of severe end organ complications. There is clear consensus in the literature that the use of a PAC cannot be recommended as a matter of routine, but for a definite role in a very select group of patients undergoing cardiac surgery. According to a survey by practicing anesthesiologists, the use of PAC could be recommended for specific indications in cardiac surgery including coronary artery bypass grafting (CABG) with poor left ventricular (LV) function, LV aneurysmectomy, recent myocardial infarction, pulmonary hypertension, diastolic dysfunction, acute ventricular septal rupture and insertion of left ventricular assist device. The appropriate indications remain debatable. However, although the PAC has no role in routine perioperative care, the existence of a specific subpopulation for which the use of this device may be beneficial cannot be excluded."

Discussion

Older, sicker patients are most likely to be monitored by a PAC[1,2]. One explanation for this is that there is a possibility that a bias exists in the studies in that sicker patients, who were generally older, were being selected for PACs[2].

Patient selection for PAC insertion, and the management of these patients, is not standardised, and varies widely according to physician preference[2,5,6]. As a result, ineffective or harmful therapy may contribute to the increased risk of adverse outcomes, and therefore, may explain some of the mixed evidence regarding outcomes[2,4]. For example, the presence of a resident or certified registered nurse anaesthetist, has been associated with increased likelihood of PAC placement, and the presence of a board-certified anaesthesiologist has been associated with a decreased likelihood of PAC placement[1].

Another explanation for the mixed evidence may be due to poor understanding of the information that the PAC provides. Given that PAC does not have a direct therapeutic application, and is a diagnostic tool and monitoring device that provides information to guide therapeutic intervention, the question becomes about the clinical decisions made based on PAC data regarding therapeutic interventions. The PAC itself cannot modify outcomes; it is the information that they gather and the decisions that are made as a result of their information. Any subsequent clinical outcome is directly related to these decisions[5,6]. For example, increased use of vasoactive drugs have been shown in patients who received PAC monitoring[5]. This increased use of drugs might partly be a reflection of how monitoring and unnecessary information may affect therapy without significantly altering outcomes, such as mortality[5]. It is therefore, paramount that the appropriate staff are trained on the use of PAC to ensure hemodynamic monitoring and subsequent decisions regarding interventions have been adequately informed from PAC data[5].

It should be noted that the absence of PAC monitoring may lead to an increase the use of inotropes given that cardiac output cannot be measured without PAC and a reliance is then placed solely on pulmonary artery pressure and pulmonary capillary wedge pressure guided interventions[3]. Additionally, although there has been no negative impact of a shift away from PAC use reported, there is an increased administration of vasopressors, which suggests a more pre-emptive approach to increase mean arterial pressure after correction of the intravascular volume deficits[4]. As a result, these hemodynamic interventions may introduce an increased risk of complications and adverse events[12].

The evidence-base for PAC use in cardiac and ICU patients is limited. There are only a few prospective randomised trials that address PAC use in critically ill patients, high-risk surgical patients, shock and acute respiratory distress syndrome, congestive heart failure and acute lung injury. Further, these studies have small sample sizes and lacked a strictly defined treatment protocol. It is difficult to design an RCT to assess PAC use because they are monitoring and diagnostic tools intended to guide clinical therapy, and not therapies themselves. Currently, there is no large, prospective, randomised studies to determine the impact of PAC use in cardiac surgery[5].

Recent developments in technology have allowed less invasive methods of haemodynamic monitoring than PAC to be developed. The less invasive methods have been shown to provide adequate information for haemodynamic management decisions without increasing mortality[4] however, this has yet to be adequately compared to PAC[6].

Conclusions

Meta-analyses show the use of PAC does not change mortality rate, the number of complications, length of stay in ICU, or length of stay in hospital in ICU or cardiac surgery patients. There is equivocal evidence for the cost of PAC versus no-PAC in patients. Expert panel recommendations are that PAC should not be used routinely in for cardiac surgery in patients with a low risk of hemodynamic complications[7].

There is mixed evidence for the cost of PAC versus no-PAC in patients. Expert panel recommendations from Choosing Wisely America are that PACs should not be used routinely for cardiac surgery in patients with a low risk of hemodynamic complications[7].

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Appendix 1

Table 3. Database Search Terms

Search terms in Medline*	
1	Exp Catheterization-Swan-Ganz/
2	Exp Heart-Catheterization/
3	pulmonary art?ery catheter*.ti,ab.
4	(pulmonary arter* adj5 (flotation or cathet*)).mp.
5	(right?heart and catheter*).mp.
6	swan?ganz*.ti,ab.
7	OR 1-6
8	exp Critical care/
9	exp Intensive-Care-Units/
10	critical care unit*.mp.
11	((intensiv* or critical or post?an?esthesia) adj5 care unit).mp.
12	high dependency unit*.mp.
13	critical care.ti,ab.
14	Exp thoracic surgery/
15	exp Operating Rooms/
16	OR 8-15
17	7 AND 16
18	limit 17 to (english language and humans and yr="2012 -Current")

*(Similar terms (appropriately translated) were used in other databases.)

Table 4. Information sources and search terms

Information sources (searches conducted 12/05/2017)	**Search Terms**	**Hits (results included)**
Google	swan AND ganz OR "pulmonary artery catheter" OR pac AND "cardiac surgery"	57,600 (4)
BMJ Best Practice	swan AND ganz OR "pulmonary artery catheter" OR pac AND "cardiac surgery"	61 (0)
The National Institute for Health and Care Excellence (NICE)	“pulmonary artery catheter”	35 (0)

Table 5. Database search dates

Information sources	Date of search
All EBM (Ovid) *	27/04/2017
Medline (Ovid) Ovid MEDLINE(R) In-Process & Other Non-Indexed Citations, Ovid MEDLINE(R) and Ovid OLDMEDLINE(R) 1950 to Present	27/04/2017
EMBASE (Ovid)	27/04/2017
CINAHL	03/05/2017

*(includes The Cochrane Database of Systematic Reviews, DARE, CENTRAL and ACP Journal Club)