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Effect of Pulmonary Artery Catheterization on Outcome in Patients Undergoing Coronary Artery Surgery

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Previous studies have suggested that low-risk cardiac surgical patients may be safely managed without pulmonary artery catheterization (PAC). However, no prospective studies have determined whether PAC improves outcome in higher risk patients compared with that following central venous pressure (CVP) monitoring alone. The authors prospectively examined the incidence of and factors related to perioperative morbidity and mortality in 1094 consecutive patients undergoing coronary artery surgery managed with elective PAC (n = 537) or with CVP (n = 557). Perioperative risk factors and demographics that predict morbidity and mortality after cardiac surgery were used to quantify risk classification. Outcome was judged by length of ICU stay, occurrence of postoperative myocardial infarction, in-hospital death, major hemodynamic aberrations, and significant noncardiac systemic complications. No significant differences in any outcome variables were noted in any group of patients with similar quantitative risk classification managed with or without PAC, including those in the highest risk class. In addition, there were no significant differences in outcome among the 39 patients who would have been managed with CVP monitoring only, but who subsequently developed a clinical need for PAC based on the occurrence of serious hemodynamic events compared to patients who had PAC performed electively. This study suggests that PAC does not play a major role in influencing outcome after cardiac surgery, that even high-risk cardiac surgical patients may be safely managed without routine PAC, and that delaying PAC until a clinical need develops does not significantly alter outcome, but may have an important impact on cost savings. (Key words: Anesthesia: cardiovascular. Monitoring: pulmonary artery pressure. Surgery: cardiac.)

SEVERAL STUDIES have suggested that insertion of a pulmonary artery catheter allows for earlier recognition and appropriate correction of significant hemodynamic abnormalities. As many as one-half of these abnormalities may not be adequately assessed based on clinical experience, preoperative catheterization data, physical examination, chest radiography, or other invasive and noninvasive monitors.[1–3]** Data also exist to demonstrate that therapy may be changed in response to pulmonary artery catheterization (PAC) data in one-half or more of cases.[4] Furthermore, a high incidence of prebypass ischemia occurs in patients undergoing cardiac surgery[5–7] and a definite association exists between the occurrence of intraoperative ischemia and perioperative myocardial infarction in patients undergoing coronary artery surgery.[5] Since earlier, more sensitive detection of ischemia may be possible using the pulmonary artery occluded pressure (PAOP) tracing compared with standard ECG monitoring, it has been suggested that the use of the PAOP tracing may help reduce the incidence of perioperative infarction.††

Multiple studies have attempted to show a beneficial effect of PAC on outcome. Rao *et al.* reported a significant reduction in perioperative reinfarction in patients with coronary artery disease undergoing noncardiac surgery monitored with PAC compared with historical controls not using PAC.[8] The reduction in reinfarction rate was attributed in part to the aggressive use of hemodynamic monitoring and improvement of cardiovascular status. Another study of 48 patients with left main coronary artery disease undergoing coronary revascularization concluded that mortality was significantly less in patients monitored with PAC compared with that in historical controls, and that this was due to treatment of hemodynamic aberrations based on information derived from PAC.[9]

It seems intuitively logical that prompt recognition and therapy of hemodynamic abnormalities by PAC *should* improve outcome. Nonetheless, there are currently no data from any prospective randomized study that answers the question of whether the use of PAC reduces patient morbidity and mortality. Such a study would require an extremely large population of patients concurrently randomized to either a control or a PAC group, and performed over a relatively short period of time to eliminate effects of changing anesthetic and surgical technique. Once overt hemodynamic instability occurs, the ethical issues of continuing management without a monitor which many people believe *should* improve outcome in order to test the hypothesis that the non-use of PAC affects outcome adversely, as well as the probable necessity of a mul-

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ticenter cooperative study, make it unlikely that such a definitive study will be undertaken. While many authors have stated the need to conduct such studies,[10–12] others have concluded that such elaborate studies to "prove" effectiveness are impractical and would probably fail to provide the desired answers even if brought to completion.[13] Opinions on the necessity of such a study vary as widely as does PAC utilization in cardiac surgery in the United States. Some large cardiac surgical centers use PAC routinely, while other equally prestigious institutions use PAC infrequently. Keats expressed the current spectrum of opinion on PAC in cardiac surgery when he stated that "Swan-Ganz catheters may be life-saving in Atlanta, but mostly a nuisance in Houston."[14] It is reasonably clear from multiple studies that coronary artery surgery can be performed safely in low-risk patients without PAC monitoring,[15,16] and the enviable results of some centers[5,6,17,18] that infrequently use PAC support this postulate.

We hypothesized that higher risk patients undergoing cardiac surgery would be more likely to benefit from the use of PAC than those of low risk, and it is the former group of patients in whom PAC would be most likely to favorably affect outcome. In view of this, we prospectively examined the incidence of and factors related to morbidity and mortality in high-risk cardiac surgical patients managed with and without PAC.

Materials and Methods

This study was approved by the Institutional Human Investigation Committee. One thousand and ninety-four consecutive adult patients underwent elective coronary revascularization and were prospectively studied after informed consent was obtained. Nine attending anesthesiologists participated in the study. Operating room assignment was based on rotation among all cardiac operating rooms, and assignment of anesthesiologist to a patient included in this study was by chance alone. Anesthetic, surgical, and intensive care management and data acquisition and analysis were previously described.[19] Four anesthesiologists managed patients with CVP catheters unless the surgical team requested that a PA catheter be used electively. Five anesthesiologists inserted PA catheters either before or after induction of anesthesia in patients with indications for PAC (as defined below) or unless requested. Patients who would have otherwise been managed with a CVP catheter but who developed a clinical need for PAC at any time after discontinuation of cardiopulmonary bypass (defined as a clinically detectable, inadequate perfusion state unresponsive to volume infusion, pacing, or a single vasoactive agent) had a PA catheter inserted (PAC-N).

In all cases, transducers were referenced to atmospheric pressure at mid-atrial level and balanced and calibrated at least every 4 h. The proper positioning of all catheters was confirmed by a portable chest radiograph. Patients with PAC had pulmonary artery diastolic pressure displayed continuously and PAOP determined intermittently. Serial cardiac outputs were determined by the thermodilution method and the following hemodynamic profile variables were calculated using standard formulas: cardiac index, stroke index, systemic and pulmonary vascular resistance, and left and right stroke work index. Cardiac output was taken as the average of three consecutive recordings within 10% of each other. Most patients with PA catheters had mixed venous oximetry performed intermittently and a few continuously through fiberoptic oximetric pulmonary artery catheters. These patients had calculation of arterial-venous oxygen content difference, oxygen delivery, intrapulmonary shunt fraction, and oxygen consumption using standard formulas.

All data were collected by personnel who were unaware of the goals of this study, collated by a full-time data manager and stored and analyzed by computer. Postoperative outcome was compared between CVP and PAC-E in groups of patients with similar criteria for elective PAC. Groups were defined by the presence or absence of the following variables: preoperative myocardial infarction less than 6 weeks old, evidence of ventricular dysfunction, or congestive heart failure (see reference 19 for definition). Patients in group I had none of the above criteria, patients in group II had one of the above, and patients in group III had two or more of the above criteria. These groupings were defined to avoid obscuring any small but significant differences that might have existed between CVP and PAC-E in high-risk patients, which might occur by examining outcome irrespective of risk. In addition, this method of grouping patients employs cardiac risk factors that stratify patients of similar cardiac risk into discrete subsets (table 1). The outcome of those CVP patients who developed a clinical need for PAC was also compared with that of PAC-E patients to determine if waiting until hemodynamic instability occurred before utilizing PAC resulted in increased morbidity or mortality.

Two-way analysis of variance was used to compare data for age, number of bypassed vessels, ischemic cross-clamp time, and length of ICU stay within and between groups. The Chi-square test was used to compare all other data within and between groups. The null hypothesis was rejected when P was less than 0.05.

Discriminant analysis was performed to determine if any characteristics could allow one to distinguish between those who developed a clinical need for PAC and all patients who began without PAC. The 19 independent variables listed in table 4 were tested individually for their univariate relationship to the dependent variables (CVP or PAC-N grouping). Multivariate discriminant analysis was then used to select the linear combination of variables

TABLE 1. Perioperative Patient Characteristics*

	Group I n = 246			Group II n = 515			Group III n = 333		
	CVP†	PAC-E	PAC-N	CVP†	PAC-E	PAC-N	CVP†	PAC-E	PAC-N
# of cases	148	98	13	256	259	17	153	180	9
NYHA Class§¶									
II (%)	0.7	1.0	0.0	0.8	0.4	0.0	0.0	0.0	0.0
III (%)	54.7	48.0	46.2	31.2	30.2	52.9	19.6	15.6	0.0
IV (%)	44.6	51.0	53.8	68.0	69.4	47.1	80.4	84.4	100
Left main disease (%)	3.4	4.1	0.0	5.9	3.1	11.8	5.9	5.0	11.1
Unstable angina (%)§¶	64.9	71.4	46.2	65.6	66.8	70.6	76.5	78.9	88.9
LV dysfunction (%)§¶	0.0	0.0	0.0	73.4	69.5	70.6	98.0	96.1	100
CHF (%)§¶	0.0	0.0	0.0	2.0	4.2	0.0	52.3	60.6	66.7
Dysrhythmias (%)§¶	17.6	13.3	7.7	32.4	30.5	41.2	44.4	34.4	66.7††
MI < 6 weeks (%)§¶	0.0	0.0	0.0	18.0	21.6	21.7	40.5	39.4	33.3
Internal mammary graft (%)	31.1	32.7	23.1	33.2	28.6	17.6	22.9	28.3	11.1
Ca-entry blocker (%)	72.3	74.5	69.2	77.3	70.3	88.2	69.9	68.9	68.7
β-adren. blocker (%)§¶	44.6	39.8	46.2	32.0	31.3	23.5	29.4	20.6	22.2
Nitrates (%)§	57.4	64.3	61.5	70.3	69.9	76.5	67.3	71.1	66.7
Diabetes mellitus (%)§¶	19.6	13.3	7.7	25.4	23.2	23.5	40.5	28.3**	33.3
Reoperation (%)	8.8	11.2	23.1	13.3	14.3	11.8	14.4	12.2	33.3
Renal dysfunction (%)§	25.0	16.3	30.8	15.2	20.1	11.8	22.2	25.0	22.2
Obesity (%)	4.1	3.1	0.0	7.8	4.2	11.8	5.2	7.2	0.0
Gender (% male)¶	69.6	64.3	92.3††	75.8	78.0	64.7	78.4	72.2	55.6
Age (yr)‡	63.5 (9.8)	60.8 (10.1)	64.6†† (10.4)	61.4 (10.2)	61.6 (10.7)	61.0 (9.9)	63.9 (10.2)	64.9 (10.4)	71.4 (11.6)
# of vessels grafted‡	2.73 (.87)	2.92 (.85)	2.46 (.82)	2.84 (.91)	2.80 (.86)	2.76 (.85)	2.74 (.81)	2.79 (.90)	2.33 (.87)
Cross clamp time (min)‡	67.0 (20.2)	66.4 (21.6)	73.2†† (18.6)	69.8 (20.6)	68.8 (21.2)	72.4†† (22.4)	68.4 (17.9)	71.4 (22.1)	66.3 (19.4)
MHI Risk Class§¶									
% normal risk	10.1	7.1	30.8††	0.0	0.0	0.0	0.0	0.0	0.0
% increased risk	22.3	43.9**	23.1	13.7	13.5	11.8	0.0	0.0	0.0
% high risk	67.6	49.0**	46.2	86.3	86.5	88.2	100	100	100

* See text for definitions; groups based on presence of these risks: MI < 6 wks, CHF, LV dysfunction (I = none, II = one risk, III = more than one risk).
† Includes patients receiving nonelective PAC (PAC-N).
‡ Values are means (± SD).
§ Different among CVP between groups, $P < 0.05$.
¶ Different among PAC-E between groups, $P < 0.05$.
** CVP different from PAC-E within group, $P < 0.05$.
†† PAC-E different from PAC-N within group, $P < 0.05$.

which separated members of the PAC-N group from the CVP group using the minimum Wilk's lambda as a measure of group discrimination. From the factors that were significantly related after discriminant analysis, a model was created that utilized the discriminant analysis coefficients to calculate the probability that any patient would or would not be a member of the PAC-N group.

Results

PATIENT POPULATION

Of the 1094 patients in this study, 537 received PAC electively and the remainder were initially managed with CVP alone. Thirty-nine of the latter patients (7%) developed a clinical need for PAC (PAC-N). The perioperative characteristics of the patients are presented in table 1. Within each group (I–III), CVP and PAC-E patients were comparable with a few exceptions. In group I, there was a greater percentage of patients in the highest risk MHI class in CVP than PAC-E patients and less in the intermediate risk class in CVP than PAC-E patients. In group III, there was significantly more diabetes in CVP than PAC-E patients. There was no significant difference in the distribution of NYHA functional class, left main coronary artery stenosis, use of internal mammary grafts, LV dysfunction, CHF, unstable angina, recent MI, serious preoperative dysrhythmias, cardiac medications, gender, renal dysfunction, number of vessels grafted, aortic cross-clamp time, or age among CVP *versus* PAC-E in any group (I–III). There was a significant increase in the incidence of preoperative cardiac risk factors across groups I, II, and III including higher NYHA functional class, LV dysfunction, CHF, serious dysrhythmias, recent MI, and higher MHI risk classification. In addition, within each group (I–III), the characteristics of PAC-N and PAC-E patients differed slightly. In group I, PAC-N patients were

TABLE 2. Postcardiopulmonary Bypass Morbidity and Mortality

	Group I			Group II			Group III			
	CVP	PAC-E	PAC-N‡	CVP	PAC-E	PAC-N†	CVP	PAC-E	PAC-N‡	Overall
# of cases	148	98	13	256	259	17	153	180	9	1094
Mortality:										
Intraoperative (%)	0.0	0.0	0.0	0.4	1.2	0.0	0.7	3.3	0.0	1.0
Postoperative (%)	0.0	0.0	0.0	2.7	2.3	5.9	2.6	3.3	0.0	2.1
Overall (%)	0.0	0.0	0.0	3.1	3.5	5.9	3.3	6.6	0.0	3.1
Morbidity*										
HR > 110 bpm (%)	12.2	9.2	23.1	11.7	9.7	17.6	16.3	16.6	11.1	12.7
ECG changes (%)	13.5	16.3	7.7	23.8	25.1	29.4	22.2	23.9	44.4	22.1
Postop MI (%)	2.7	4.1	0.0	3.5	3.5	0.0	5.2	5.6	0.0	4.1
Serious dysrhythmias (%)	22.3	20.4	38.5	22.7	23.9	29.4	22.2	18.9	33.3	22.3
Use of vasopressor (%)	10.1	17.3	23.1	12.9	22.8§	23.5	16.3	27.8§	33.3	18.4
Use of vasodilator (%)	27.7	23.5	30.8	16.4	15.8	5.9	17.0	16.1	11.1	18.7
Postop IABP (%)	2.7	5.1	7.7	3.1	3.5	5.9	9.2	11.7	11.1	5.6
Renal dysfunction (%)	2.7	5.1	7.7	3.1	2.7	5.9	5.3	6.1	0.0	4.0
Pulmonary morbidity (%)	3.4	5.1	7.7	6.7	8.9	5.9	9.8	10.6	0.0	7.8
Neurologic event (%)	1.4	3.1	0.0	3.9	2.7	0.0	6.5	7.2	0.0	4.2
ICU days†	2.45 (1.36)	2.86 (2.11)	3.62 (2.94)	3.03 (2.39)	3.12 (2.19)	3.59 (2.86)	2.77 (2.04)	4.27§ (3.16)	3.56 (0.98)	3.16 (2.41)

* See text for definitions
† Values are means (± SD)
‡ PAC-N not significantly different from PAC-E, within groups.
§ PAC-E and CVP significantly different, within group, $P < 0.05$.

older and had a greater percentage of both normal MHI classification and male gender than PAC-E. Aortic cross-clamp time was significantly longer in PAC-N than PAC-E in both groups I and II. In group III, PAC-N patients had a significantly higher incidence of preoperative dysrhythmias than PAC-E patients.

Perioperative Complications and Outcome

As shown in table 2, there was no significant difference in overall mortality, need for postoperative IABP, postoperative MI, pulmonary morbidity, renal dysfunction, or neurologic events between CVP and PAC-E or between PAC-E and PAC-N patients in any group (I–III). However, the duration of ICU stay was prolonged in patients receiving PAC compared to CVP in group III. The incidence of ischemic ECG changes, tachycardia, and postoperative hypertension requiring use of vasodilators was not different between CVP and PAC-E or between PAC-E and PAC-N patients in any group. The use of vasoactive infusions to elevate systemic blood pressure or cardiac output was significantly higher among PAC-E compared with that among CVP patients in group II and III, although there was no difference in this event among PAC-E and PAC-N in any group (I–III).

Since PA catheter use was not evenly distributed among anesthesiologists, we examined the incidence of mortality and postoperative MI among the various anesthesiologists (table 3). There were no significant difference in the incidence of postoperative MI or in-hospital mortality among anesthesiologists in this study. Examination of variables associated with poor outcome after coronary artery surgery[19] revealed no significant difference in the distribution of preoperative risk factors (recent MI, left main disease, CHF, or serious dysrhythmias) among anesthesiologists. However, mean aortic cross-clamp times were significantly different between the two anesthesiologists with the highest and lowest mortality rate.

Prediction of PAC-N

The 19 preoperative characteristics used in the univariate and subsequent multivariate discriminant analysis to build a model differentiating those who stayed in the CVP group from those entering PAC-N are listed in table 4. For this population (n = 557), univariate analysis showed that MHI risk classification was the only significantly different characteristic between those who remained with CVP only (n = 518) and those who developed a clinical need for PAC (n = 39). In the multivariate analysis, MHI risk classification, non-use of internal mammary grafts, reoperation, NYHA functional class, and increased age were the most important determinants differentiating those who developed a clinical need for PAC from those who remained with CVP alone. Of note, preoperative factors such as LV dysfunction, CHF, or recent MI (all of which are often the basis for deciding to use PAC) were not significant isolated determinants in the model developed to predict which patients would develop a clinical need for PAC.

Using the discriminant function developed, a classification table was constructed to test its predictive strength in determining clinical need for PAC (table 5). Overall predictive ability of the discriminant function was only

TABLE 3. Role of Anesthesiologist in Postoperative MI and Mortality

	# Pts	% PAC	% Death	% PMI	% CHF	% MI < 6 Weeks	% Left Main Disease	% Serious Preop Dysrhythmias	Cross-clamp Time (min)*
Anesthesiologist									
1	207	68.6	2.4	4.3	14.5	20.3	3.4	25.1	67.9 ± 19
2	83	50.6	2.4	7.2	22.9	15.7	2.4	30.1	65.5 ± 19
3	120	30.8	0.0	2.5	17.5	15.0	5.8	28.3	64.0 ± 17†
4	156	34.0	2.6	2.6	23.7	23.1	6.4	34.0	69.5 ± 24
5	100	59.0	4.0	2.0	22.0	26.0	3.0	27.0	70.6 ± 22
6	133	46.6	6.0	4.5	21.8	19.5	5.3	33.8	73.0 ± 28†
7	66	47.0	3.0	3.0	24.2	30.3	4.5	25.8	74.1 ± 21
8	55	29.1	3.6	7.3	16.4	21.8	5.5	40.0	67.4 ± 18
9	174	54.6	4.0	4.6	12.6	24.1	4.6	32.2	69.1 ± 21
Total	1094	49.1	3.1	4.1	18.7	21.5	4.6	30.3	68.5 ± 21
P value		.0001	.342	.557	.101	.242	.855	.382	.019

* Values are means (±SD).

† Mean cross-clamp time for anesthesiologist # 3 and 6 significantly different (ANOVA; Tukey-a).

67.3% (*i.e.*, number of correct predictions of belonging to either group/total number of cases).

Discussion

No data currently examines whether the use of PAC improves any unfavorable outcome in cardiac surgical patients compared with that in patients simultaneously managed with CVP catheters only. All previous data that support the hypothesis that the use of PAC improves outcome have been confounded by the use of historical controls,[8,9] or small sample size.[9] A major strength of this study compared with that of others is that data were prospectively collected on a large number of patients who received either CVP or PAC monitoring over a relatively short study period to minimize effects of changes in anesthetic and surgical technique that can occur when data are collected over longer time periods or are from multiple centers. Additionally, all data were collected by observers who were not aware of the purpose of the study until it was completed, thus minimizing observer bias. Conversely, our study design was constrained by the ethical issues of withholding PAC in patients who subsequently developed hemodynamic instability. These patients did receive PAC when, in the judgment of the attending anesthesiologist and surgeon, it was imprudent to withhold PAC. Although our data compare the outcome of this subset of patients with another subset who received PAC *before* they developed instability, it does not answer the question of whether the final outcome variables would have been similar if the former patients had never received PAC and had been managed only on the basis of clinical assessment and CVP data. We believe that such a study would be ethically difficult and will probably never be performed.

A major limitation of this study is that assignment to receive PAC or CVP monitoring was not randomized, but was primarily based on assignment to a given anesthesiologist or surgeon. Previous work has suggested that the anesthesiologist *per se* may contribute significantly to outcome and that outcome occurrences may differ significantly among anesthesiologists.[5] Although this was a potential confounding variable, we found no obvious trend between outcome variables and the incidence of PAC among anesthesiologists in this study (table 3). In addition, there were no significant differences in any perioperative risk factors between CVP and PAC-E patients within any groups (I–III) to suggest that patients receiving elective PAC had a greater severity of illness

TABLE 4. Determinants of Clinical Need for PAC

	Univariate		Multivariate		
Variable	F	P	Discriminant F	Analysis *P* value	Discriminant Coefficient
MHI risk class	5.26	.022	8.54	.0223	−.714
Use of internal mammary graft	2.82	.094	2.94	.0063	.432
Reoperation	2.55	.111	4.12	.0035	−.480
NYHA class	2.84	.093	3.35	.0025	−.436
Age	1.77	.183	2.25	.0022	−.379
# of vessels grafted	2.71	.101	<1	NS	
Diabetes mellitus	1.17	.281	<1	NS	
LV dysfunction	<1	.366	<1	NS	
Left main disease	<1	.524	<1	NS	
Serious dysrhythmias	<1	.567	<1	NS	
Use of beta-adrenergic blocking drugs	<1	.598	<1	NS	
Cross-clamp time	<1	.598	<1	NS	
Gender	<1	.647	<1	NS	
Use of calcium entry blocking drugs	<1	.663	<1	NS	
Use of nitrates	<1	.666	<1	NS	
Recent MI	<1	.718	<1	NS	
Unstable angina	<1	.809	<1	NS	
Renal dysfunction	<1	.901	<1	NS	
CHF	<1	.982	<1	NS	

TABLE 5. Actual *Versus* Predicted Clinical Need for PAC Based on Multivariate Discriminant Analysis of Perioperative Variables

Discriminant Probability (%)	Discriminant Score	# of Pts	% Actual Nonelective PAC
0–25	2.45 to 1.21	68	5.9
25–50	1.17 to −.278	294	3.1
50–70	−.315 to −1.46	148	10.8
70–80	−1.48 to −1.99	31	9.7
80–90	−2.22 to −3.22	14	42.9
90–100	−3.79 to −3.91	2	50.0

than CVP patients (table 1). Multivariate discriminant analysis of this same data base has revealed that elective use of PAC was not a significant determinant of death or PMI when simultaneously considering patient characteristics, surgeon, anesthesiologist, and anesthestic agents (see reference 19; tables 3, 4). Although discriminant analysis did not demonstrate any confounding effect by these latter variables, it is possible that the lack of randomization inserted an unmeasurable bias into this study. Such an occult bias might have obscured the conclusion that elective PAC might have been beneficial compared with CVP monitoring alone, since it spared "sicker" patients from having worse outcomes than the "less sick" patients monitored with CVP catheters alone. Although there is no objective evidence of a skew toward greater severity of illness in patients receiving elective PAC (table 1), our data provide no basis for supporting or denying such a conclusion. Nevertheless, our inability to demonstrate a beneficial effect of elective PAC on outcome is disappointing.

Although this lack of beneficial effect could be masked by the previously mentioned biases, several other factors may be at work to negate the potential benefits of PAC. Previous publications have postulated that the application of advanced technology to provide information on cardiopulmonary integrity is essential to provide satisfactory outcome in critically ill patients by allowing appropriate manipulation of hemodynamic variables.[13,20]†† However, simply showing that a monitoring technique changes therapy[4,21] or provides quantitation of trends in processed variables (such as mixed venous oxygen saturation, cardiac output, etc.) is not sufficient to conclude that the technique effects outcome variables (such as death or myocardial infarction). The greater use of vasoactive infusions and ICU stay in higher risk PAC-E patients may in part be a reflection of how monitoring may change therapy without significantly altering outcome. In addition, PAC-E patients received narcotic-based techniques more often than CVP patients (81.9 *versus* 64.2%) and less PAC-E patients received a neuroleptic technique (diazepam-ketamine) than CVP patients (15.8 *versus* 29.6%, $P < 0.05$). The latter technique has been associated with a lower incidence of postcardiopulmonary bypass vasopressor use compared with that following high dose narcotic in a controlled study of patients undergoing cardiac surgery.‡‡ Thus, the lower use of vasopressors in patients monitored with CVP catheters in group II and III may partly reflect anesthetic drug effects. Although ischemia may be detected by using the PAOP waveform to monitor for appearance of new a-c or v waves, abnormalities of the PAOP waveform can occur with acute increases in afterload due to catecholamine release, with decreases in pulmonary venous compliance, or with mitral regurgitation related to nonischemic mechanisms,[22,23] so that its specificity may be less than optimal. Some authors have reported that a rise in the central venous pressure may be of equal or greater value in detecting ischemia during anesthesia,[24] while others have shown that increases in PAOP during coronary surgery correlated poorly with ECG evidence of myocardial ischemia.[25] Additionally, the PA catheter cannot be used as a continuous monitor of ischemia, since it must be in the wedged position to observe ischemia-related abnormalities in the a-c or v waves. Perhaps the use of continuous monitors (*e.g.*, transesophageal echocardiography to detect regional wall motion abnormalities) that would allow earlier intervention and treatment of all episodes of ischemia might be more likely to effect the incidence of perioperative myocardial infarction than the use of PAC. Furthermore, since as many as one-half of all episodes of ischemia are not preventable by providing optimal hemodynamic indices,[6,7,9,26] it may be that PAC *per se* has less of a role in influencing the incidence of ischemia and infarction than previously thought.[8,27]

Several mediators of morbidity and mortality after coronary artery surgery are unlikely to be affected by the use or non-use of PAC. These include the occurrence of significant cerebral embolic phenomenon, graft thrombosis, excessive bleeding, or errors in operative technique or judgement. Indeed, 15 of the 34 deaths in this study were attributable to multifactorial causes, such as major postoperative central nervous system events, sepsis, and multiple organ failure. Once patients have developed multisystem organ failure after these events, one might postulate that invasive hemodynamic monitoring could improve outcome of these patients by facilitating improved perfusion status *via* manipulation of central venous pressure, PAOP, cardiac output, systemic arterial blood pressure, and mixed venous oxygen saturation. However, these routinely used variables obtained from invasive monitoring devices have been shown to be poor prognostic indicators in critically ill postoperative patients.[28,29] Perhaps the use of different physiologic goals of therapy, such

‡‡ Tuman KJ, Keane DM, Silins AI, Spiess BD, McCarthy RJ, Ivankovich AD: Effect of high dose fentanyl on fluid and vasopressor requirements after cardiac surgery. J Cardiothorac Anesth 2:419–429, 1988

as oxygen transport-red cell mass (flow) variables,[29] that could be optimized by use of PAC would lead to improvement in outcome in those few patients who develop multiple organ and circulatory failure after cardiac surgery.

A large number of subtle influences can cause misinterpretation of PAC data.[30] PAOP may not always provide a reliable index of left ventricular end-diastolic pressure for a variety of technical and physiologic reasons. More importantly, this extrapolated measure of end-diastolic pressure may not reflect the end-diastolic volume, a more correct measure of preload.[31] There is a poor correlation between PAOP and left ventricular end-diastolic volume after coronary artery surgery,[32] probably because of altered ventricular compliance. In addition, measurement of cardiac output and mixed venous oxygen saturation may be accompanied by subtle errors that may go unnoticed unless attention is given to their avoidance.

Misinterpretation of PAC data could lead to suboptimal treatment decisions and negate any positive effects on outcome that might be associated with PAC. The PA catheter itself is simply a monitor and not a form of therapy, and our negative results may in part reflect suboptimal physician use of PAC rather than an inherent defect in the monitor. We believe that our experience with PAC data interpretation is not unique and cannot alone explain the results of this study. Nevertheless, the human element cannot be eliminated from analysis of outcome events related to the use or non-use of PAC and, as such, even elaborate randomized clinical trials to prove or disprove effectiveness may not provide clear-cut information.

If we consider the 518 patients who never received PAC, the cumulative direct cost savings in terms of equipment and physician's fees for those patients in this study is substantial. Invasive monitoring costs are difficult to assess, however, without due consideration of indirect costs of use and, if not used, the indirect costs of failure to provide optimal cardiopulmonary support. For instance, if invasive monitoring allows us to keep that population of patients alive longer who are extremely ill and will die regardless of therapy, it will indirectly cause enormous increases in costs and provide no benefit. On the other hand, if patients who would have died now live because of the precisely titrated care made possible by invasive monitoring, then the benefit is enormous. Analyzed in this way, the direct costs of use or non-use of PAC are trivial compared with the potential indirect costs. Unfortunately, neither this nor any previous study can predict or quantitate the potential indirect cost *versus* benefit of PAC in any subset of patients.

Pending further prospective randomized studies in this subset of patients, we believe our data suggest that even high-risk cardiac surgical patients can be safely managed without routine PAC. If these patients subsequently develop a need for PAC, this can be done promptly and efficiently, either through a previously inserted introducer sheath or even by the surgeon from the surgical field once the chest is open, if the patient's chest is draped and intraoperative access to the neck is limited.[33] This approach appears to be justified, since our data show that subsequent insertion after hemodynamic aberrations occurred did not adversely effect outcome compared with outcome in similar patients who received elective PAC. Secondly, as demonstrated by our discriminant analysis (table 5), preoperative patient risk factors were not successful in determining which patients would develop a need for PAC-N. We conclude that even high-risk cardiac surgical patients may be safely managed without routine preoperative PAC, that delaying placement of a PA catheter until a clinical need develops does not significantly change outcome, and that this approach may have an important impact on cost savings.

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