Right Heart Catheterization and Cardiac Complications in Patients Undergoing Noncardiac Surgery
An Observational Study

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Context Right heart catheterization (RHC) is commonly performed before high-risk noncardiac surgery, but the benefit of this strategy remains unproven.

Objective To evaluate the relationship between use of perioperative RHC and postoperative cardiac complication rates in patients undergoing major noncardiac surgery.

Design Prospective, observational cohort study.

Setting Tertiary care teaching hospital in the United States.

Patients Patients (n=4059 aged ≥50 years) who underwent major elective noncardiac procedures with an expected length of stay of 2 or more days between July 18, 1989, and February 28, 1994. Two hundred twenty one patients had RHC and 3838 did not.

Main Outcome Measure Combined end point of major postoperative cardiac events, including myocardial infarction, unstable angina, cardiogenic pulmonary edema, ventricular fibrillation, documented ventricular tachycardia or primary cardiac arrest, and sustained complete heart block, classified by a reviewer blinded to preoperative data.

Results Major cardiac events occurred in 171 patients (4.2%). Patients who underwent perioperative RHC had a 3-fold increase in incidence of major postoperative cardiac events (34 [15.4%] vs 137 [3.6%]; $P<.001$). In multivariate analyses, the adjusted odds ratios (ORs) for postoperative major cardiac and noncardiac events in patients undergoing RHC were 2.0 (95% confidence interval [CI], 1.3-3.2) and 2.1 (95% CI, 1.2-3.5), respectively. In a case-control analysis of a subset of 215 matched pairs of patients who did and did not undergo RHC, adjusted for propensity of RHC and type of procedure, patients who underwent perioperative RHC also had increased risk of postoperative congestive heart failure (OR, 2.9; 95% CI, 1.4-6.2) and major noncardiac events (OR, 2.2; 95% CI, 1.4-4.9).

Conclusions No evidence was found of reduction in complication rates associated with use of perioperative RHC in this population. Because of the morbidity and the high costs associated with RHC, the impact of this intervention in perioperative care should be evaluated in randomized trials.

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Cardiac complications are the most common cause of death among patients undergoing elective noncardiac surgery.[1,2] In the last 2 decades, multifactorial cardiac risk indexes to assist clinicians in preoperative risk stratification have been developed and prospectively validated.[3-6] In addition, research has shown that intraoperative hemodynamic changes are associated with increased complication rates.[7] These findings logically lead clinicians to consider hemodynamic monitoring via right heart catheterization (RHC) for selected patients undergoing high-risk procedures, with a goal of reducing perioperative complications.[8] The benefit of this strategy is, however, unproven.

The purpose of this study was to evaluate the relationship between use of perioperative RHC and occurrence of major postoperative cardiac events among a large cohort of patients who underwent major nonemergent noncardiac surgeries.

For editorial comment see p 348.

METHODS
Patients

Patients aged 50 years or older who underwent major elective noncardiac surgeries at Brigham and Women's Hospital, Boston, Mass, between July 18, 1989, and February 28, 1994, were eligible for the study. As described in prior reports,[6,9] major noncardiac surgeries were defined as those with an expected length of stay of 2 or more days.

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For the purpose of this study, only procedures electively scheduled and performed in the same or next day following hospital admission were included in the analyses. Because 91% of patients (182/200) who underwent abdominal aortic aneurysm repair also had RHC, patients undergoing this procedure were excluded from the analysis. The Brigham and Women's Hospital Human Research Committee approved the enrollment and clinical data collection protocol.

Data Collection

As described previously,[6] patients who provided written informed consent to the full study protocol underwent preoperative evaluations by study personnel using a structured data form. These evaluations included detailed medical histories, physical examinations, and laboratory test data collection. For patients who did not undergo this evaluation because they could not be approached or because they refused participation in the interview part of the study, clinical data were obtained by the anesthesiologist from the structured evaluation in the medical record. This data source was also used to obtain American Society of Anesthesiologists (ASA) classification for all patients. The ASA classification system uses the general clinical severity of a patient's systemic illnesses to predict perioperative mortality.[10] Consenting patients agreed to postoperative sampling of creatine kinase (CK) and, if total CK levels were elevated, CK-MB sampling according to a protocol in which samples were collected immediately after surgery, at 8 PM on the day of surgery, and on the next 2 mornings. For other enrolled patients, samples were obtained according to physician order. Electrocardiograms were performed in the recovery room and on the first, third, and fifth postoperative days if patients remained hospitalized. Functional status was measured by the Specific Activity Scale, a 4-level classification system that uses activities of daily living to estimate a patient's functional capacity.[11]

Classification of Outcome

Occurrence of major postoperative events was classified by a single reviewer (L.G.) who was blinded to preoperative clinical data and use of RHC and used postoperative clinical information including cardiac enzyme measurements, electrocardiograms, and clinical events. Diagnosis of myocardial infarction was made on the basis of CK-MB levels and electrocardiographic findings.[6] Diagnosis of postoperative congestive heart failure was obtained from progress notes recorded by clinicians involved in the patients' care. Major cardiac-related events included myocardial infarction, unstable angina, cardiogenic pulmonary edema, ventricular fibrillation, documented ventricular tachycardia or primary cardiac arrest, and sustained complete heart block. Major noncardiac events included pulmonary embolism documented on autopsy, angiography, or high-probability ventilation-perfusion scan, respiratory failure requiring intubation for at least 2 days or reintubation, noncardiogenic pulmonary edema, lobar pneumonia confirmed by chest radiograph and requiring antibiotic therapy, acute renal failure requiring dialysis, cerebrovascular accident with new neurologic deficit, and gastrointestinal bleeding.

Intraoperative variables recorded by the anesthesiologist included initial systolic and diastolic blood pressure, initial heart rate, type of anesthesia, invasive monitoring procedures, surgery time, estimated blood loss, lowest intraoperative systolic blood pressure, maximum heart rate, and episodes of hypertension (systolic blood pressure $>$200 mm Hg or diastolic blood pressure $>$120 mm Hg) and hypotension (systolic blood pressure $<$90 mm Hg or decrease of $>\frac{1}{3}$ from baseline level).

All records were reviewed to evaluate whether RHC was indicated perioperatively to monitor hemodynamic parameters during the perioperative period. In only 1 patient, the chart information suggested that RHC was performed to manage other critical illness or clinical instability preoperatively; this patient was excluded from all analyses for the purposes of this study.

Propensity Score

Preoperative clinical variables that would relate to the decision to use RHC during a major procedure were considered and included in a multivariate logistic regression analysis. The significant independent variables identified in this cohort were sex, myocardial infarction in the 6 months prior to the procedure, history of chronic ischemic heart disease, hypertension, poor general medical status, type of surgical procedure (intrathoracic, vascular, or abdominal), presence of S_3 or jugular venous distension, frequent premature ventricular contractions or cardiac rhythm other than sinus on resting electrocardiogram, preoperative oxygen saturation of less than 94%, use of digoxin, and ASA classification. To represent as completely as possible factors that might influence physicians' decisions to use perioperative RHC, other preoperative variables were also included in the propensity score if they were deemed clinically relevant, even if they were not statistically significant correlates. These variables included age, previous coronary artery bypass graft surgery or percutaneous coronary angioplasty, significant valvular disease, peripheral vascular disease, chronic obstructive pulmonary disease, history of chronic renal failure, diabetes, and preoperative creatinine level of more than 2.0 mg/dL (177 µmol/L). The multivariate regression model of propensity for using perioperative RHC had a *c* statistic of 0.85, which represents the area under the receiver operating characteristic curve.

Case-Matching Procedure

Patients who did not undergo perioperative RHC were matched to patients who had RHC on the basis of propensity score and type of surgical procedure. Patients were randomly selected from those who underwent perioperative RHC, then all 3838 patients who did not have RHC were searched to find those who had the closest propensity score for undergoing RHC (within 0.03 on a scale from 0-1.00).

Statistical Analysis

Univariate correlation between intraoperative parameters and occurrence of perioperative cardiac complications were performed using the χ^2 test and the Fisher exact test for categorical variables and the *t* test or Wilcoxon rank sum test for continuous variables. Variables with a *P* value of less than .10 were entered into the multiple regression analysis. Stepwise logistic regression analysis was used to determine independent ($P<.05$) correlates of cardiac complications after adjustment for preoperative clinical variables.

Differences between matched pairs were evaluated using the Wilcoxon signed rank test for continuous variables. The association between RHC and postoperative complications (after adjustment for propensity score alone and after simultaneous adjustment for propensity and each significant variable) was determined by conditional logistic regression analysis. A 2-sided *P* value of less than .05 was considered statistically significant. Statistical analyses were carried out using SAS software (SAS Institute Inc, Cary, NC).

RESULTS

Patient Characteristics

TABLE 1 shows the clinical characteristics of 4059 patients who underwent major noncardiac surgery (other than aortic aneurysm repair) with (n=221) and without (n=3838) RHC. Overall, patients who underwent noncardiac procedures were relatively young, with a high prevalence of hypertension and a low prevalence of cardiovascular comorbid conditions. Patients who underwent perioperative RHC were significantly older; had a significantly higher prevalence of hypertension, diabetes, congestive heart failure, previous myocardial infarction, and coronary artery bypass graft surgery; and had a worse functional status as measured by the Specific Activity Scale.[11] Right heart catheterization was performed more frequently in patients who underwent high-risk procedures, such as vascular and intrathoracic surgeries, than lower-risk procedures.

Unadjusted Outcomes

In univariate analysis, patients who underwent perioperative RHC were more likely to have postoperative myocardial infarction (2.3% vs 0.8%; $P=.04$) and congestive heart failure (13.6% vs 2.4%; $P<.001$) than patients who did not undergo RHC. In addition, patients who underwent RHC had a 3-fold increase in the prevalence of the combined end point of postoperative major cardiac events (15.4% vs 3.6%; $P<.001$) (TABLE 2). Major noncardiac complications were also more common in patients who underwent perioperative RHC (10.0% vs 2.7%; $P<.001$).

Propensity Score

The multivariate regression model of propensity for using perioperative RHC had a *c* statistic of 0.85, indicating good discrimination between patients who did and did not undergo RHC. The overall cohort had a propensity score of 0.06 (median, 0.02; range, 0.003-0.74) for RHC, reflecting a very low average likelihood of receiving this intervention. Patients who underwent RHC had a mean propensity score of 0.19 (median, 0.12; range, 0.004-0.74).

Multivariate Analysis

After adjustment for the propensity for RHC as well as additional adjustment for type of surgical procedure and all clinical characteristics described in TABLE 3, the odds ratio (OR) of major postoperative cardiac events for patients who underwent RHC was 2.0 (95% confidence interval [CI], 1.3-3.2). After similar adjustments, the OR of postoperative congestive heart failure for patients who underwent RHC was 2.9 (95% CI, 1.7-4.9), while the OR of postoperative acute ischemic syndromes (myocardial infarction or unstable angina) was 1.3 (95% CI, 0.7-2.6). Similar findings were observed for the combined end point of major postoperative noncardiac events (OR, 2.1; 95% CI, 1.2-3.5).

Table 1. Clinical Characteristics of Patients Who Underwent Major Noncardiac Surgery With and Without Perioperative RHC*

Characteristics	All Patients (N = 4059)	RHC: No (n = 3838)	RHC: Yes (n = 221)
Age, mean (SD), y	66 (10)	66 (10)	68 (8)†
Male	2150 (53)	2060 (54)	90 (41)†
History of hypertension	1779 (44)	1638 (43)	141 (64)†
Diabetes	546 (13)	498 (13)	48 (22)†
History of myocardial infarction	557 (14)	481 (13)	76 (34)†
Congestive heart failure‡	677 (17)	591 (15)	86 (39)†
History of CVA	404 (10)	376 (10)	28 (13)
Previous CABG surgery	276 (7)	240 (6)	36 (16)†
Specific Activity Scale class			
I	1262 (34)	1231 (35)	31 (18)
II	848 (23)	807 (23)	41 (23)
III	1336 (36)	1258 (36)	78 (44)
IV	232 (6)	205 (6)	27 (15)†
Procedures			
Vascular	683 (17)	597 (16)	86 (39)†
Orthopedic	1483 (37)	1449 (38)	34 (15)†
Intrathoracic	527 (13)	483 (13)	44 (20)†
Abdominal	498 (12)	469 (12)	29 (13)
Other	866 (21)	838 (22)	28 (13)†

*Data are No. (%) of patients unless otherwise noted. RHC indicates right heart catheterization; CVA, cerebrovascular accident; and CABG, coronary artery bypass graft.
†$P<.01$ for RHC vs no RHC.
‡Congestive heart failure defined by history of congestive heart failure or pulmonary edema; paroxysmal nocturnal dyspnea; S_3 and bilateral rales on physical examination; or cardiomegaly and bilateral low redistribution on chest radiograph.

Table 2. Postoperative Complications in Patients Who Underwent Major Noncardiac Surgery With and Without Perioperative RHC*

Postoperative Complications	All Patients (N = 4059)	RHC No (n = 3838)	RHC Yes (n = 221)
Major cardiac events (combined end point)	171 (4.2)	137 (3.6)	34 (15.4)†
Myocardial infarction	34 (0.8)	29 (0.8)	5 (2.3)†
Unstable angina	78 (1.9)	69 (1.8)	9 (4.1)†
Congestive heart failure	124 (3.0)	94 (2.4)	30 (13.6)†
Major noncardiac events	125 (3.1)	103 (2.7)	22 (10.0)†
Bacterial pneumonia	37 (0.9)	32 (0.8)	5 (2.3)†
Noncardiogenic pulmonary edema	8 (0.2)	5 (0.1)	3 (1.4)†
Respiratory failure requiring intubation‡	54 (1.3)	45 (1.2)	9 (4.1)†
Renal failure requiring dialysis‡	12 (0.3)	7 (0.2)	5 (2.3)†
Cerebrovascular accident	21 (0.5)	19 (0.5)	2 (0.9)
Gastrointestinal bleeding	26 (0.6)	22 (0.6)	4 (1.8)†
Pulmonary embolism	10 (0.2)	7 (0.2)	3 (1.4)†

*All data are No. (%) of patients. RHC indicates right heart catheterization.
†$P<.05$ for RHC vs no RHC.
‡See "Methods" section of text for definition.

Table 3. Characteristics of Matched Patient Pairs With and Without Perioperative RHC*

Characteristics	No RHC (n = 215)	RHC (n = 215)	*P* Value
Propensity for RHC, mean	0.174	0.174	.99
Age ≥70 y	95 (44)	100 (47)	.70
Sex, male/female	68 (32)/147 (68)	88 (41)/127 (59)	.06
Peripheral vascular disease	88 (41)	82 (38)	.62
Chronic obstructive pulmonary disease	25 (12)	32 (15)	.39
Myocardial infarction in prior 6 mo	4 (2)	9 (4)	.26
Ischemic heart disease	137 (64)	131 (61)	.62
Valvular disease	17 (8)	16 (7)	>.99
Coronary artery bypass graft	33 (15)	34 (16)	>.99
Coronary angioplasty	5 (2)	12 (6)	.14
Congestive heart failure	81 (38)	83 (39)	.92
Digoxin use	44 (21)	54 (25)	.30
History of hypertension	141 (66)	136 (63)	.69
Diabetes mellitus	47 (22)	49 (23)	.91
Chronic renal failure	26 (12)	18 (8)	.27
Poor general status	54 (25)	57 (27)	.83
Frequent PVCs†	21 (10)	24 (11)	.76
Cardiac rhythm other than sinus†	25 (12)	25 (12)	>.99
S_3 or jugular distension	15 (7)	13 (6)	.84
ASA class[10]			
3	168 (78)	159 (74)	.34
4	18 (8)	25 (12)	.34
Preoperative creatinine >2 mg/dL (177 μmol/L)	30 (14)	26 (12)	.67
Preoperative oxygen saturation <94%	48 (22)	42 (20)	.55
Type of surgery			
Intrathoracic	38 (18)	41 (19)	.80
Vascular	97 (45)	85 (40)	.28
Abdominal	29 (13)	31 (14)	.89

*Data are No. (%) of patients unless otherwise noted. RHC indicates right heart catheterization; PVC, premature ventricular contraction; and ASA, American Society of Anesthesiologists.
†On resting preoperative electrocardiogram.

Case-Matching Analysis

In this cohort, there were 221 patients (5%) who underwent perioperative RHC. We were unable to adequately match (within 0.03 on a scale from 0-1.00) the propensity score for RHC in 6 patients; hence, the case-matching analysis included 215 pairs of patients with and without RHC. Among these pairs, there were no statistically significant differences between patients with and without RHC with regard to age, cardiovascular risk factors, previous cardiovascular morbidity, use of drugs, functional status, preoperative laboratory profile, and electrocardiographic findings (Table 3). The mean propensity to receive the procedure was nearly identical in the 2 groups (0.17 vs 0.17; $P=.99$).

For matched pairs, the risk of developing major postoperative cardiac events was higher but nonsignificant in patients who underwent RHC (OR, 1.6; 95% CI, 0.9-2.8) (TABLE 4). In analyses for specific types of cardiac complications, postoperative congestive heart failure was significantly associated with perioperative RHC (OR, 2.9; 95% CI, 1.4-6.2). In this matched-pairs analysis, RHC was also associated with increased risk of postoperative noncardiac complications (Table 4).

Several multivariate analyses were performed to adjust for potential treatment selection bias. In the case-matched population, logistic regression models were performed including each variable individually and in combinations to evaluate their impact on the associations between RHC and cardiac complications. The ORs for major cardiac and noncardiac complications did not change substantially (<10%) from the baseline analysis for all 25 variables evaluated.

We further compared intraoperative clinical and hemodynamic parameters between matched pairs (TABLE 5). Although there was no difference in perioperative hypotensive or hypertensive episodes between cases and controls, patients who underwent RHC had higher maximal perioperative heart rate, surgery time, and net positive fluid balance ($P<.001$ for all). Finally, patients managed with RHC had a significantly prolonged mean (SD) length of hospital stay compared with patients who did not have RHC (11.3 [10.2] days [median, 9 days] vs 8.1 [5.6] days [median, 7 days]; $P<.001$).

COMMENT

In this observational study from a large cohort of patients undergoing elective major surgical procedures, perioperative RHC was not associated with improved postoperative outcomes and was associated with prolonged hospitalization. These results were observed despite adjustment for a wide variety of potentially confounding variables using case-matched analysis and multivariate models to adjust for the type of surgical procedures and propensity to use RHC. Indeed, after such adjustments, patients who underwent RHC remained more likely to develop major postoperative cardiac complications compared with patients who did not undergo RHC. Most of this increment in postoperative events was related to higher rates of development of postoperative cardiogenic pulmonary edema and was associated with a greater perioperative net fluid intake.

The rationale for monitoring intraoperative parameters guided by RHC is based in part on the concept that deliberate increases in oxygen delivery may overcome the increased metabolic demand associated with major surgery and, ultimately, improve postoperative outcomes. A pivotal study by Shoemaker et al[12] in the late 1980s suggested that achievement of supranormal values of oxygen transport measures could be associated with decreased mortality in very high-risk patients undergoing noncardiac surgery (with multiple organ dysfunction, massive blood loss, severe trauma, or extensive surgery). However, this subgroup of patients represents a small percentage of the general surgical caseload, even at tertiary care hospitals.[13]

Since this initial report, few randomized trials (with relatively small sample sizes) have addressed the impact of perioperative RHC on clinical outcomes. Most of these studies failed to demonstrate significant differences in cardiac morbidity between groups of patients who did and did not receive RHC.[14-16] These findings resonated in a recent report that questioned the benefit of RHC in critically ill medical patients.[17]

Several possible explanations for our findings can be postulated. First, physicians may not have properly used the information obtained from RHC monitoring during surgery and the immediate postoperative period. Iberti et al[18] demonstrated in a multicenter survey that physicians' understanding of pulmonary artery catheterization data is extremely variable. Shoemaker et al[12] suggested that the overwhelming majority of RHC performed in general surgery patients is not used to obtain crucial data to adequately evaluate the systemic oxygen profile. Several recent reports, however, also demonstrated that deliberate boosting of cardiac index and oxygen delivery fail to improve outcomes and even may be detrimental in critically ill patients.[19]

Second, as suggested by the report from the Study to Understand Prognoses and Preferences for Outcomes and Risks of Treatment (SUPPORT),[17] RHC may be a marker for an aggressive style of care that contributes to worse outcomes. Similar findings were also reported in studies of the impact of RHC on patients with myocardial infarction.[20,21] Moreover, our findings raise the question of whether some of the increased cardiac morbidity associated with perioperative RHC may be related to an increased risk of pulmonary cardiogenic edema due to greater perioperative fluid loading.

Third, any invasive procedure carries some risk of adverse outcomes.

Table 4. Risk of Postoperative Cardiac Events in Matched Patient Pairs With and Without Perioperative RHC*

	No. (%) of Patients			
	No RHC (n = 215)	RHC (n = 215)	Odds Ratio (95% Confidence Interval)	*P* Value
Major cardiac events (combined end point)	22 (10)	32 (15)	1.6 (0.9-2.8)	.14
Congestive heart failure	11 (5)	28 (13)	2.9 (1.4-6.2)	.006
Acute ischemic syndromes†	10 (5)	12 (6)	1.2 (0.5-2.8)	.67
Major noncardiac events	10 (5)	21 (10)	2.2 (1.4-4.9)	.04

*RHC indicates right heart catheterization.
†Defined as myocardial infarction or unstable angina.

Table 5. Perioperative Clinical Variables of Matched Patient Pairs With and Without Perioperative RHC*

Variables	No RHC (n = 215)	RHC (n = 215)	*P* Value
Heart rate			
Initial, mean (SD), beats/min	75 (15)	74 (13)	.32
Maximal, mean (SD), beats/min	88 (16)	94 (18)	<.001
Heart rate >120/min, No. (%)	6 (3)	17 (8)	.03
Blood pressure			
Initial systolic, mean (SD), mm Hg	138 (21)	136 (24)	.43
Initial diastolic, mm Hg	72 (15)	67 (13)	.001
Hypertensive episode, No. (%)†	7 (3)	15 (7)	.12
Hypotensive episode, No. (%)‡	90 (42)	107 (50)	.12
Time/volume changes, mean (SD)			
Surgery time	3.9 (1.7)	5.0 (1.9)	<.001
Net fluid balance, L§	2.0 (1.2)	3.2 (3.0)	<.001

*RHC indicates right heart catheterization.
†Systolic blood pressure >200 mm Hg or diastolic blood pressure >120 mm Hg.
‡Systolic blood pressure <90 mm Hg or more than ⅓ decrease from baseline level.
§Net fluid balance = intraoperative fluid replacement − estimated blood loss.

Right heart catheterization has been associated with ventricular arrhythmias and heart block,[22-24] catheter-related sepsis,[25] pulmonary embolism,[26] central venous access complications,[27] and death.[28,29] It is possible that the potential benefits of RHC are offset in part by the physiological burden of indwelling instrumentation.[30]

The findings of this study must be interpreted in the context of the limitations of the study design. Generalizability of our findings may be limited to low- and moderate-risk populations who undergo major noncardiac procedures. Because these data represent the practice in only 1 tertiary hospital, these results should be confirmed in other settings. Exclusion of aortic aneurysm repair from our analysis precludes any inference about the usefulness of RHC for this procedure. Because of the observational nature of our data, we cannot entirely exclude the possibility that important confounding variables might have been neglected in the analysis or that adjustment for confounders was incomplete.

However, in this cohort of patients undergoing major elective noncardiac surgery, we were unable to demonstrate evidence of benefit associated with use of perioperative RHC. Because of the morbidity and the high costs associated with RHC, the impact of this intervention in perioperative care should be carefully reevaluated. We believe that the results from this observational study should foster new attempts to address this important question in randomized clinical trials.

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