Derivation and Prospective Validation of a Simple Index for Prediction of Cardiac Risk of Major Noncardiac Surgery

Thomas H. Lee, MD, SM; Edward R. Marcantonio, MD, SM; Carol M. Mangione, MD, SM; Eric J. Thomas, MD, SM; Carisi A. Polanczyk, MD; E. Francis Cook, ScD; David J. Sugarbaker, MD; Magruder C. Donaldson, MD; Robert Poss, MD; Kalon K.L. Ho, MD, SM; Lynn E. Ludwig, MS, RN; Alex Pedan, PhD; Lee Goldman, MD, MPH

Background—Cardiac complications are important causes of morbidity after noncardiac surgery. The purpose of this prospective cohort study was to develop and validate an index for risk of cardiac complications.

Methods and Results—We studied 4315 patients aged ≥50 years undergoing elective major noncardiac procedures in a tertiary-care teaching hospital. The main outcome measures were major cardiac complications. Major cardiac complications occurred in 56 (2%) of 2893 patients assigned to the derivation cohort. Six independent predictors of complications were identified and included in a Revised Cardiac Risk Index: high-risk type of surgery, history of ischemic heart disease, history of congestive heart failure, history of cerebrovascular disease, preoperative treatment with insulin, and preoperative serum creatinine >2.0 mg/dL. Rates of major cardiac complication with 0, 1, 2, or ≥3 of these factors were 0.5%, 1.3%, 4%, and 9%, respectively, in the derivation cohort and 0.4%, 0.9%, 7%, and 11%, respectively, among 1422 patients in the validation cohort. Receiver operating characteristic curve analysis in the validation cohort indicated that the diagnostic performance of the Revised Cardiac Risk Index was superior to other published risk-prediction indexes.

Conclusions—In stable patients undergoing nonurgent major noncardiac surgery, this index can identify patients at higher risk for complications. This index may be useful for identification of candidates for further risk stratification with noninvasive technologies or other management strategies, as well as low-risk patients in whom additional evaluation is unlikely to be helpful. **(*Circulation*. 1999;100:1043-1049.)**

Key Words: risk factors ■ surgery ■ prognosis

Cardiovascular complications are important causes of morbidity with major noncardiac procedures.[1,2] Risk stratification of these patients often relies on noninvasive tests for myocardial ischemia, but analyses suggest that test results are most useful in patients whose clinical data suggest moderate risks for complications and that they have limited impact in high- or low-risk groups.[3–5]

Among the tools for clinical risk stratification are the Cardiac Risk Index[6] and other decision aids.[7] Recent guidelines have recommended a modification of the Cardiac Risk Index,[8,9] but the studies used to develop this and other prior decision aids have relied on small numbers of patients, and they predated recent advances in surgery and anesthesia. Furthermore, the usefulness of available indexes has been limited by the complexity of their formats. We therefore undertook a prospective investigation to derive and validate a simple index for the prediction of the risk of cardiac complications in major elective noncardiac surgery.

Methods

Patient Population

Patients aged ≥50 years who underwent nonemergent noncardiac procedures with an expected length of stay ≥2 days at Brigham and Women's Hospital from July 18, 1989, to February 28, 1994, were eligible for the study. Patients undergoing qualifying procedures were eligible for the study if they underwent postoperative serial cardiac marker sampling as part of their care or gave their consent to the full study protocol, which was approved by the Hospital Institutional Review Board. The full study protocol included preoperative interviews and serial assessments of health status for 1 year after surgery. Patients were approached for informed consent for the full study protocol in the hospital's Preadmission Test Center or on the day before surgery if the patient was hospitalized. Comparison of study logs and operating room schedules indicated that ≈80% of eligible patients were approached by study personnel.

Because some patient subsets underwent preoperative assessment through different systems, the proportion of patients who did not provide informed consent preoperatively for the serial interview portion of the study (621 [14.5%] of the study population) was higher among patients who underwent thoracic (31%), abdominal

Received January 19, 1999; revision received June 1, 1999; accepted June 19, 1999.

From the Department of Medicine, Brigham and Women's Hospital and Harvard Medical School, and the Department of Medicine, University of California, San Francisco School of Medicine, San Francisco, Calif (L.G.).

Reprint requests to Thomas H. Lee, MD, MSc, Partners Community HealthCare, Inc, Prudential Tower Suite 1150, 800 Boylston St, Boston, MA 02199.

***Circulation* is available at http://www.circulationaha.org**

aortic aneurysm (30%), and other vascular procedures (32%). Patients who provided informed consent before surgery had a lower major cardiac complication rate (see below) than patients who did not (1.7% versus 4.8%; $P<0.001$).

Data Collection

Patients who provided informed consent to the full study protocol underwent preoperative evaluations by study personnel, including detailed medical histories, physical examinations, and laboratory testing. For patients who could not be approached or refused participation in the interview part of the study, clinical data were obtained from the structured evaluation provided by the anesthesiologist in the medical record. This data source was also used to obtain American Society of Anesthesiologists (ASA) class for all patients. Consenting patients agreed to postoperative sampling of creatine kinase (CK) and, if total CK levels were elevated, CK-MB immediately after surgery, at 8 PM on the evening of surgery, and on the next 2 mornings. For other enrolled patients, samples were performed according to the physicians' orders. For the entire study population, the mean (±SD) number of cardiac enzyme samples obtained was 4.0±2.2 (median 4). ECGs were performed in the recovery room and on the first, third, and fifth postoperative days if the patient remained hospitalized.

Total CK was assayed on the ACA discrete clinical analyzer (DuPont). CK-MB was measured until July 30, 1993, with a DuPont ACA ion-exchange chromatography and immunoinhibition assay; after that date, a mass assay for CK-MB was performed on the Stratus instrument (Baxter Diagnostics).

Classification of Outcomes

Follow-up data were collected through daily medical record review by study personnel. The occurrence of all cardiac complications after surgery was classified by a single reviewer (L.G.) who was blinded to preoperative clinical data and who used postoperative clinical information. When the ion-exchange chromatography assay was used to assay CK-MB, acute myocardial infarction was diagnosed if (1) the peak CK-MB was >5% of an elevated total CK or (2) the peak CK-MB was >3% of an elevated total CK in the presence of ECG changes consistent with ischemia or infarction. When the CK-MB mass assay was used, acute myocardial infarction was diagnosed if peak CK-MB levels exceeded the normal range (<5 ng/mL) and the ratio of CK-MB to total CK exceeded 0.0278 or, in the setting of ECG changes, 0.0167. These threshold ratios were estimated to be comparable to the respective thresholds with the activity assay for CK-MB on the basis of regression analyses of samples for which both assays were used.

"Major cardiac complications" included myocardial infarction, pulmonary edema, ventricular fibrillation or primary cardiac arrest, and complete heart block. Diagnosis of pulmonary edema required a formal reading of the chest radiograph by a radiologist consistent with this complication in a plausible clinical setting.

Analysis of Data

Two thirds of the 4315 patients were assigned to the derivation cohort (n=2893), which was used to develop the Revised Cardiac Risk Index. Patients who underwent vascular surgery were divided into those who underwent abdominal aortic aneurysm surgery (n=110) versus all other types of vascular surgery (n=498). Among the other vascular procedures, the most common were femoral-tibial or femoral popliteal artery bypass procedures (46%), carotid endarterectomy (31%), and aorto-bifemoral bypass procedures (9%). No analyses were performed for the other 1422 patients (validation cohort) before prospective validation of the Revised Cardiac Risk Index. The performances of prior decision aids[1,6,7] were compared by use of receiver operating characteristic curve (ROC) analysis.[10]

To develop the revised risk index, clinical correlates of major cardiac complications were identified with a χ^2 test for categorical variables and a t test or Wilcoxon test for continuous variables. Different combinations of clinical variables were tested to identify the definition of ischemic heart disease most strongly correlated with cardiac complications. Variables with a univariate correlation with a P value <0.10 were considered in stepwise logistic regression analyses that identified the factors included in the risk index, with a cutoff P value of 0.05. We compared 2 versions of the new index: 1 in which weights were derived from the logistic regression analysis and 1 in which all variables were assigned an equal value. Because ROC analyses did not show an advantage for the index with variable weights, the index with equal weights for all variables was adopted.

The Revised Cardiac Risk Index was then tested by different approaches, including comparison of major cardiac complication rates within risk classes in the derivation and validation cohorts, analysis of whether the factors were independent predictors of risk in the validation cohort, and comparison of the areas under the ROC for risk-prediction indexes.

Results

The patients in the derivation and validation cohorts were similar (Table 1), with slightly more patients in the validation cohort undergoing procedures identified as high risk in the Original Cardiac Risk Index (ie, intraperitoneal, intrathoracic, or suprainguinal vascular). Rates of major cardiac complications were 2% and 2.5%, respectively (Table 2).

When 3 prior decision aids were applied in the derivation cohort, all 3 were able to stratify patients into subsets with increasing rates of adverse outcomes (Table 3), but few patients fell into high-risk groups. Only 4% of patients were classified above class I in the Modified Cardiac Risk Index, and only 3% of patients were assigned the highest ASA class.

Correlates of Complications in the Derivation Cohort

The combination of variables that defined preoperative ischemic heart disease with the highest correlation with major cardiac complications included any of the following: history of myocardial infarction, history of a positive exercise test, current complaint of chest pain considered to be secondary to myocardial ischemia, use of nitrate therapy, or ECG with pathological Q waves. In the derivation cohort, major cardiac complications occurred in 1 (2%) of 51 patients with a history of prior angioplasty versus 55 (2%) of 2842 patients without prior angioplasty and in 6 (3%) of 217 patients with prior CABG surgery versus 50 (2%) of 2676 patients without prior bypass surgery (P=NS). Therefore, patients with prior coronary revascularization procedures were categorized as having ischemic heart disease only if they had any of the other criteria for ischemic heart disease listed above. This definition excluded 1 patient with prior coronary angioplasty and 26 patients with prior CABG surgery, none of whom had major perioperative cardiac complications. Preoperative ECG ST-T–wave changes (ST segment elevation or depression or T wave inversion) also were not associated with worse outcomes.

Congestive heart failure was defined by the presence of any of the following: history of congestive heart failure, pulmonary edema, or paroxysmal nocturnal dyspnea; physical examination showing bilateral rales or S3 gallop; or chest radiograph showing pulmonary vascular redistribution. All of these variables were correlated with major cardiac complications. Cerebrovascular disease was defined as a history of transient ischemic attack or stroke.

TABLE 1. Clinical Characteristics of Patients in Derivation and Validation Cohorts

	Derivation Cohort (n=2893)	Validation Cohort (n=1422)	Relative Risks for Major Cardiac Complications and 95% CIs in Derivation Cohort
Male sex*, n (%)	1374 (47)	722 (51)	2.6 (1.5, 4.6)
Age >70 y, n (%)	998 (35)	475 (33)	1.9 (1.1, 3.2)
Mean±SD age, y	66.4±10.1	66.3±9.0	
Type of procedure, n (%)			
Thoracic	346 (12)	184 (13)	1.1 (0.5, 2.3)
Orthopedic	1026 (35)	463 (33)	0.4 (0.2, 0.8)
Abdominal aortic aneurysm	110 (4)	64 (5)	3.6 (1.7, 7.8)
Other vascular	498 (17)	226 (16)	3.9 (2.3, 6.5)
Other abdominal	324 (11)	184 (13)	0.8 (0.3, 1.9)
Other	578 (20)	292 (21)	0.1 (0.04, 0.6)
High-risk procedures (intraperitoneal, intrathoracic, or suprainguinal vascular procedures)*	894 (31)	490 (34)	2.1 (1.2, 3.5)
History of myocardial infarction, n (%)			
Ever	422 (15)	216 (15)	3.5 (2.1, 6.0)
In last 180 days	19 (1)	12 (1)	2.8 (0.4, 18.9)
Current history of ischemic chest pain, n (%)	376 (13)	185 (13)	2.9 (1.7, 5.1)
History of noninvasive test indicating myocardial ischemia, n (%)	200 (7)	100 (7)	2.9 (1.5, 5.7)
Current use of nitroglycerin, n (%)	78 (3)	55 (4)	4.1 (2.1, 8.2)
History of congestive heart failure, n (%)	183 (6)	99 (7)	2.1 (1.0, 4.6)
History of pulmonary edema, n (%)	73 (3)	40 (3)	2.2 (0.7, 6.8)
History or physical examination showing significant valvular heart disease, n (%)	104 (4)	52 (4)	3.2 (1.4, 7.3)
History of cerebrovascular disease, n (%)			
Transient ischemic attack	175 (6)	89 (6)	4.7 (2.6, 8.6)
Prior cerebrovascular accident	155 (5)	78 (5)	2.9 (1.4, 6.1)
Use of insulin for treatment of diabetes mellitus, n (%)	112 (4)	59 (4)	3.5 (1.6, 7.7)
Preoperative evaluation, n (%)			
Rales at both bases or higher	195 (7)	105 (7)	3.0 (1.5, 5.9)
S3 gallop	38 (1)	18 (1)	0
Preoperative laboratory tests, n (%)			
Abnormal rhythm	188 (6.5)	112 (8)	0.8 (0.3, 2.6)
Pathological Q waves on ECG	493 (17)	231 (16)	2.4 (1.3, 4.2)
Cardiomegaly on preoperative chest x-ray	129 (4)	74 (5)	3.1 (1.4, 6.6)
Serum creatinine >2.0 mg/dL	103 (4)	55 (4)	5.2 (2.6, 10.3)
Poor general medical status	381 (13)	179 (13)	1.8 (1.0, 3.4)
Ischemic heart disease†, n (%)	951 (33)	478 (34)	3.2 (1.9, 5.4)
Congestive heart failure†, n (%)	434 (15)	255 (18)	3.4 (2.0, 5.7)

*$P<0.05$ in comparison of derivation and validation cohorts.

†Definition of summary variables: "Ischemic heart disease" indicates patient has history of myocardial infarction, positive exercise test, current complaint of ischemic chest pain or use of nitrate therapy, or ECG with Q waves. Patients with prior CABG surgery or PTCA were included in this definition only if they had current complaints of chest pain that were presumed to be due to ischemia. "Congestive heart failure" indicates history of congestive heart failure, pulmonary edema, or paroxysmal nocturnal dyspnea, physical examination showing bilateral rales or S3 gallop, or chest radiograph showing pulmonary vascular redistribution.

Some factors included in the Original Cardiac Risk Index were present in few patients and were not associated with major cardiac complications. Only 19 patients (1%) had a history of myocardial infarction in the last 180 days (Table 1), and only 5 (0.2%) had critical aortic stenosis. No patient was considered to have unstable angina, class IV congestive heart failure, or active transient ischemia attacks.

Patients who were using β-adrenergic blocking agents at the time of admission had a similar rate of cardiac complications (13/533 patients; 2.4%) as patients who were not

TABLE 2. Major Cardiac Complications in Derivation and Validation Cohorts

	Derivation Set (n=2893)	Validation Set (n=1422)	P
Any major cardiac complication, n (%)	56 (2)	36 (2.5)	NS
Ventricular fibrillation/cardiac arrest	9 (0.3)	7 (0.5)	NS
Complete heart block	2 (0.1)	2 (0.1)	NS
Acute myocardial infarction	28 (1.0)	18 (1.3)	NS
Pulmonary edema	24 (0.8)	18 (1.3)	NS
Cardiac death during admission, n (%)	8 (0.3)	4 (0.3)	NS
Total (cardiac and noncardiac) mortality during admission, n (%)	22 (0.8)	21 (1.5)	<0.05

using these medications (43/2360; 1.8%). In stratified analyses, β-blockers were not associated with major cardiac complication rates in patients with or without ischemic heart disease. There was a trend toward higher complication rates in patients with worse functional capacity as measured by Specific Activity Scale class (1.03%, 1.66%, 2.07%, and 2.98%, respectively; χ^2 test $P<0.05$).

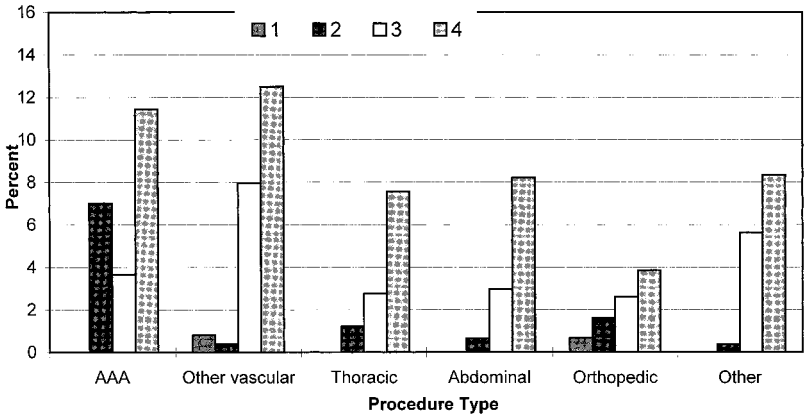
In logistic regression analyses, 6 independent ($P<0.05$) correlates of major cardiac complications were identified in the derivation cohort. These variables (and the rate of major cardiac complications for patients with these characteristics) included high-risk type of surgery (27/894; 3%), ischemic heart disease (34/951; 4%), congestive heart failure (23/434; 5%), history of cerebrovascular disease (17/291; 6%), insulin

TABLE 3. Major Cardiac Complication Rates and 95% CIs in Derivation and Validation Cohorts Stratified by Risk Classification System

	Derivation Cohort (n=2893)		Validation Cohort (n=1422)	
	Events/Pop	Rate (95% CI)	Events/Pop	Rate (95% CI)
Original Cardiac Risk Index				
Class I	31/2200	1.4 (1.0, 2.0)	13/1039	1.3 (0.7, 2.1)
Class II	20/561	3.6 (2.2, 5.5)	15/297	5.1 (2.9, 8.2)
Class III	5/127	3.9 (1.3, 8.9)	8/84	9.5 (4.2, 17.9)
Class IV	0/5	0	0/2	0
ROC area (SE)	0.606 (0.034)		0.701 (0.043)	
Modified Cardiac Risk Index				
Class I	49/2786	1.8 (1.3, 2.3)	29/1371	2.1 (1.4, 3.0)
Class II	6/95	6.3 (2.4, 13.2)	4/44	9.1 (2.5, 12.8)
Class III	1/12	8.3 (0.2, 38.5)	3/7	42.9 (9.9, 82)
ROC area (SE)	0.545 (0.022)		0.582 (0.034)	
ASA class				
Class I	0/140	0	0/65	0
Class II	14/1558	0.9 (0.5, 1.5)	7/729	1.0 (0.4, 2.0)
Class III	35/1078	3.3 (2.3, 4.5)	24/561	4.3 (2.8, 6.3)
Class IV	7/81	8.6 (3.5, 17)	4/43	9.3 (2.6, 22.1)
ROC area (SE)	0.697 (0.031)		0.706 (0.036)	
Revised Cardiac Risk Index				
Class I	5/1071	0.5 (0.2, 1.1)	2/488	0.4 (0.05, 1.5)
Class II	14/1106	1.3 (0.7, 2.1)	5/567	0.9 (0.3, 2.1)
Class III	18/506	3.6 (2.1, 5.6)	17/258	6.6 (3.9, 10.3)
Class IV	19/210	9.1 (5.5, 13.8)	12/109	11.0 (5.8, 18.4)
ROC area (SE)	0.759 (0.032)*		0.806 (0.034)†	

*Within the derivation cohort, $P<0.05$ for comparison of performance of Original vs Modified Cardiac Risk Index, Modified Risk Index vs ASA class, and Original Cardiac Risk Index vs ASA class. Also within the derivation cohort, $P<0.001$ for comparison of Revised Cardiac Risk Index vs both Original and Modified Cardiac Risk Index, and $P=0.055$ for comparison of Revised Cardiac Risk Index vs ASA class. Data on ASA class were missing for 36 patients.

†Within the validation cohort, $P=0.021$ for comparison of Revised Cardiac Risk Index vs Original Cardiac Risk Index, $P<0.0001$ for comparison of Revised Cardiac Risk Index vs Modified Cardiac Risk Index, and $P=0.018$ for comparison of Revised Cardiac Risk Index vs ASA class. Data on ASA class were missing for 24 patients.



Bars represent rate of major cardiac complications in entire patient population (both derivation and validation cohorts combined) for patients in Revised Cardiac Risk Index classes according to type of procedure performed. AAA indicates abdominal aortic aneurysm. Note that by definition, patients undergoing AAA, thoracic, and abdominal procedures were excluded from class I. In all subsets except patients undergoing AAA, there was a statistically significant trend toward greater risk with higher risk class.

therapy for diabetes (7/112; 6%), and preoperative serum creatinine >2.0 mg/dL (9/103; 9%).

Derivation of the Revised Cardiac Risk Index

A logistic regression model that included the 6 independent correlates of major cardiac complications indicated that the adjusted OR for these factors ranged from 1.9 to 3.0. Two indexes were derived from this model. In the variable-weight index, point values were assigned in proportion to the logistic regression model weights for each variable. In the equal-weight model, 1 point was assigned to each variable. ROC analysis showed no significant difference between the diagnostic performances of the models (0.765±0.032 versus 0.759±0.032, respectively; $P=0.28$). Therefore, the Revised Cardiac Risk Index was constructed with each risk factor assigned 1 point.

Patients with 0, 1, 2, or more factors were assigned to classes I, II, III, or IV, respectively; rates of major cardiac complications ranged from 0.5% to 9% (Table 3). Statistically significant ($P<0.05$) differences were found in rates of major cardiac complications between all classes. ROC analysis indicated that the diagnostic performance of the Revised Cardiac Risk Index was superior to all 3 of the prior decision aids.

Validation of the Prediction Rule

Diagnostic performance of the Revised Cardiac Risk Index was similar in the derivation and validation cohorts, as reflected in ROC analyses (Table 3). Within any specific class of the Revised Cardiac Risk Index, the complication rates were not statistically different between the derivation and validation cohorts. Within the validation cohort, the relative risk for patients in class II compared with patients in class I (2.2 [95% CI 0.4, 11.0]) was not significantly different from the corresponding relative risk in the derivation cohort (2.7 [95% CI 1.0, 7.5]).

In the validation cohort, the outcome rate was significantly higher in class III than class II (6.6% versus 0.9%; $P<0.001$). The relative risk of class III versus class II in the validation cohort (7.5 [95% CI 2.8, 20.0]) was not significantly different from the corresponding relative risk in the derivation cohort (2.8 [95% CI 1.4, 5.6]) ($P=0.11$).

The difference between class IV and class III in outcome rates in the validation cohort did not reach statistical significance (11.0% versus 6.6%; $P=0.15$). The relative risk of class IV versus class III in the validation cohort (1.7 [95% CI 0.8, 3.4]) was not significantly different from the corresponding relative risk in the derivation cohort (2.5 [95% CI 1.4, 4.7]) ($P=0.38$).

Four of the factors in the Revised Cardiac Risk Index were independent correlates of major cardiac complications in the validation cohort: high-risk type of surgery, ischemic heart disease, congestive heart failure, and history of cerebrovascular disease. There were trends or significant univariate associations with major cardiac complications for insulin therapy for diabetes (3/59 patients, 5%; relative risk 2.4; 95%

TABLE 4. Rates of Major Cardiac Complications and Multivariate ORs* Among Patients With Individual Risk Factors in Derivation and Validation Sets

	Derivation Set (n=2893)		Validation Set (n=1422)	
	Crude Data	Adjusted OR (95% CI)	Crude Data	Adjusted OR (95% CI)
Revised Cardiac Risk Index				
1. High-risk type of surgery	27/894 (3%)	2.8 (1.6, 4.9)	18/490 (4%)	2.6 (1.3, 5.3)
2. Ischemic heart disease	34/951 (4%)	2.4 (1.3, 4.2)	26/478 (5%)	3.8 (1.7, 8.2)
3. History of congestive heart failure	23/434 (5%)	1.9 (1.1, 3.5)	19/255 (7%)	4.3 (2.1, 8.8)
4. History of cerebrovascular disease	17/291 (6%)	3.2 (1.8, 6.0)	10/140 (7%)	3.0 (1.3, 6.8)
5. Insulin therapy for diabetes	7/112 (6%)	3.0 (1.3, 7.1)	3/59 (5%)	1.0 (0.3, 3.8)
6. Preoperative serum creatinine >2.0 mg/dL	9/103 (9%)	3.0 (1.4, 6.8)	3/55 (5%)	0.9 (0.2, 3.3)

*Based on logistic regression models including these 6 variables.

CI 1.2, 4.8) and for preoperative serum creatinine >2.0 mg/dL (3/55 patients, 5%; relative risk 2.3; 95% CI 0.7, 7.1). These variables were not independent correlates of cardiac complications in the multivariate analysis within the validation cohort (adjusted OR 1.0 and 0.9, respectively), but the ORs for major cardiac complications for these 2 variables were not significantly different in derivation and validation cohorts.

Within the validation cohort, comparisons of areas under the ROC indicated better diagnostic performance of the Revised Cardiac Risk Index compared with the prior decision aids (all $P<0.01$). The Revised Cardiac Risk Index was also compared with a prior index for patients undergoing vascular surgery.[2] ROC analysis indicated superior diagnostic performance of the Revised Cardiac Risk Index in the entire patient population (0.777 ± 0.023 versus 0.645 ± 0.032; $P<0.0001$), in the validation cohort (0.806 ± 0.034 versus 0.608 ± 0.056; $P<0.001$), and in the subset of patients undergoing vascular surgery (0.774 ± 0.032 versus 0.683 ± 0.046; $P<0.05$). Neither of these indexes performed well among patients undergoing abdominal aortic aneurysm surgery (0.543 ± 0.092 for Revised Cardiac Risk Index versus 0.484 ± 0.074 for the vascular surgery index; $P=0.30$).

Finally, a version of the Revised Cardiac Risk Index with only the 4 variables with independent associations with complications in the validation cohort (excluding diabetes and renal function) yielded slightly superior diagnostic performance compared with the 6-variable model. Complication rates in patients with none, 1, 2, or more of these variables were 0.4% (2/493), 1.0% (6/579), 7% (19/270), and 11% (9/80).

Performance by Procedure Type

Patients from both the derivation and validation cohorts were pooled for an analysis of the performance of the Revised Cardiac Risk Index within types of procedures (Figure). Except for patients undergoing abdominal aortic aneurysm surgery, there were significant ($P<0.05$) trends toward greater rates of cardiac complications within higher-risk classes within all procedure types.

Discussion

In this report of the risk of major cardiac complications with major nonemergent noncardiac surgery, 6 factors with approximately equal prognostic importance were identified. The presence of ≥2 of these factors identified patients with moderate (7%) and high (11%) complication rates in prospective evaluation among 1422 patients in the validation cohort.

These findings are consistent with prior research and guidelines[5,8] that have emphasized the value of clinical data in perioperative risk stratification. Other investigations have also found increased risk among patients with cardiovascular disease or diabetes mellitus[1,2,8,11] or with certain classes of procedures.[6] However, several previously identified risk factors, including advanced age, critical aortic valvular stenosis, and abnormal cardiac rhythms, did not correlate with complications in the present study. This finding may reflect patient selection and increased attention to these issues. Therefore, the absence of these factors from the Revised Cardiac Risk Index should not be taken as evidence that they are not worrisome prognostic factors; indeed, they might be important predictors in patients undergoing emergent operations.

There was no relationship between risk class and major cardiac complications among the patients who underwent abdominal aortic aneurysm surgery. Because there were only 110 patients who underwent this procedure in the derivation cohort, statistical power was limited in these analyses.

The form and content of the Revised Cardiac Risk Index reflect the goal of this investigation: to derive a simple index that might influence and be readily incorporated into routine practice (eg, on forms for preoperative evaluations). We therefore emphasized in the analyses dichotomous variables that were either present or absent and used a scoring system that assigned 1 point to each variable. A more complex index might have achieved greater accuracy but at the expense of ease of use.

How the Revised Cardiac Risk Index should be used by clinicians remains to be defined. One approach is to confine routine use of noninvasive testing to patients with moderate risk for complications (eg, classes III or IV).[3] An alternative strategy has been suggested by Bodenheimer,[12] who argues that improved outcomes are more likely to result from controlling postoperative oxygen demand than additional risk stratification. This approach would support use of this index to identify patients who should be treated with strategies to reduce oxygen consumption rather than undergo additional noninvasive testing.

The findings from the present report should be interpreted in the context of the study design. The data were collected from patients undergoing nonemergent operations at a single teaching hospital. The Revised Cardiac Risk Index is of uncertain generalizability in lower-risk populations, such as patients who undergo more minor procedures, or in high-risk populations, such as those who undergo emergency operations. However, patients undergoing major nonemergent procedures constitute the population in which physicians most often have to consider additional testing or other strategies before the patient proceeds to surgery. Other clinical factors not included in this index may be important for predicting long-term prognosis and warrant attention by clinicians. Finally, although this cohort is perhaps the largest to be studied prospectively for predictors of cardiac complications associated with noncardiac surgery, the statistical power to identify predictors of complications among specific patient subsets was limited.

Nevertheless, these findings are consistent with prior research, and the Revised Cardiac Risk Index appears simple enough for easy application in patient care. Previously published data on a subset of this cohort demonstrate that patients with at least 3 of the factors in the Revised Cardiac Risk Index (history of ischemic heart disease, history of congestive heart failure, and diabetes mellitus) have an increased risk for cardiovascular complications during the next 6 months, even if they do not have major perioperative cardiac complications.[13] Hence, patients with increased perioperative risk probably warrant closer clinical attention well beyond their hospital admission.

Acknowledgment

This study was supported by a grant from the Agency for Health Care Policy and Research, Rockville, Md (RO1-HS06573).

References

1. L'Italien GJ, Paul SD, Hendel RC, Leppo JA, Cohen MC, Fleisher LA, Brown KA, Zarich SW, Cambria RP, Cutler BS, Eagle KA. Development and validation of a Bayesian model for perioperative cardiac risk assessment in a cohort of 1,081 vascular surgery patients. *J Am Coll Cardiol.* 1996;27:779–786.
2. Mangano DT, Layug UL, Wallace A, Tateo I. Effect of atenolol on mortality and cardiovascular morbidity after noncardiac surgery. *N Engl J Med.* 1996;335:1713–1720.
3. Mangano DT, Goldman L. Preoperative assessment of patients with known or suspected coronary disease. *N Engl J Med.* 1995;333: 1750–1756.
4. Guidelines for perioperative cardiovascular evaluation for noncardiac surgery: report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation.* 1996;93: 1278–1317.
5. Eagle KA, Froehlich JB. Reducing cardiovascular risk in patients undergoing noncardiac surgery. *N Engl J Med.* 1996;335:1761–1763.
6. Goldman L, Caldera DL, Nussbaum SR, Southwick FS, Krogstad D, Murray B, Burke DS, O'Malley TA, Goroll AH, Caplan CH, Nolan J, Carabello B, Slater EE. Multifactorial index of cardiac risk in noncardiac surgical procedures. *N Engl J Med.* 1977;297:845–850.
7. Detsky AS, Abrams HB, McLaughlin JR, Drucker DJ, Sasson Z, Johnston N, Scott JG, Forbath N, Hilliard JR. Predicting cardiac complications in patients undergoing noncardiac surgery. *J Gen Intern Med.* 1986;1: 211–219.
8. American College of Physicians. Guidelines for assessing and managing the perioperative risk from coronary artery disease associated with major noncardiac surgery. *Ann Intern Med.* 1997;127:309–312.
9. Palda VA, Detsky AS. Perioperative assessment and management of risk from coronary artery disease. *Ann Intern Med.* 1997;127:313–328.
10. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology.* 1982;143:29–36.
11. Bartels C, Bechtel JFM, Hossman V, Horsch S. Cardiac risk stratification for high-risk vascular surgery. *Circulation.* 1997;95:2473–2475.
12. Bodenheimer M. Noncardiac surgery in the cardiac patient: what is the question? *Ann Intern Med.* 1996;124:763–766.
13. Lopez-Jimenez, F, Goldman L, Sacks DB, Thomas EJ, Johnson PA, Cook EF, Lee TH. Prognostic value of cardiac troponin T after noncardiac surgery: 6-month follow-up data. *J Am Coll Cardiol.* 1997;29:1241–1245.