Reprinted from THE JOURNAL OF THORACIC AND CARDIOVASCULAR SURGERY, St. Louis
Vol. 100, No. 4, pp. 595-605, October, 1990, (Printed in the U.S.A.)

Prediction of risk in noncardiac operations after cardiac operations

To determine the preoperative variables affecting the mortality rate and the development of severe complications in patients who have had myocardial revascularization or a valve replacement and who then undergo a noncardiac operation, we retrospectively studied data from 120 such patients over the 5 years from 1982 through 1986. Thirty-six percent of patients had a noncardiac operation during the first month after the cardiac operation. The mortality rate was 11%, and the morbidity rate was 56%. The statistical comparison of the predictive accuracy of postoperative complications of three simple, widely used classifications (American Society of Anesthesiologists physical status, New York Heart Association classification, Massachusetts General Hospital cardiac risk index) demonstrated the superiority of the simplified three-class cardiac risk index (Massachusetts General Hospital–cardiac risk index; predictive accuracy of 84%). In a multivariate discriminant analysis of 21 variables in this population, five variables (myocardial infarction in previous 6 months, S_3 gallop or jugular vein distention, arrhythmia on last preoperative electrocardiogram, emergency operation, delay between cardiac and noncardiac operation) were identified as being the most predictive of a postoperative complication. When these variables were used in the function (DF3) obtained by linear discriminant analysis, the prediction accuracy of a postoperative complication reached 83%. Performance of the new models in a prospective validation population remained satisfactory (75% for Massachusetts General Hospital–cardiac risk index three-class index and 72% for DF3). Extensive statistical analysis of our data tested by a validation study provided simple predictive models based on clinical variables easily available even in emergency situations.

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Approximately 1% of the 250,000 patients annually undergoing cardiac operations in the United States require a second, noncardiac operation at the same hospital admission or within the next 6 months.[1-10] Although only 2500 patients are at risk, their mortality rates range from 12.5% to 63%.[1-10] This high risk of death after noncardiac operations is in sharp contrast to the low prevalence (0% to 1%) of postoperative myocardial infarction when noncardiac procedures are electively performed after coronary bypass grafts, as assessed in retrospective studies.[11-15]

At least three retrospectively derived rating scales have been invoked to predict the likelihood of fatal and nonfatal complications in cardiac patients who undergo noncardiac operations.[16-24] They are as follows:

1. The most widely used estimate must be the physical status scale of the American Society of Anesthesiologists (ASA) (Appendix A, I). This scale was actually designed to assess physical status, however, not to predict fate.[16-18, 25, 26] Nonetheless, in predicting the chance of survival after splenorenal and portacaval shunts,[27] for example, it is as accurate as more elaborate methods.[28] Although the ASA scale was not intended as a predictor of perioperative risk, several studies have demonstrated it as a reliable predictor of overall outcome.[29-33]

2. The empiric scale of assessing risks according to elements of the physical examination and symptoms

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Supported in part by a North Atlantic Treaty Organization (NATO) grant and a Fulbright scholarship to L. A. Michel, MD.

Received for publication May 1, 1989.

Accepted for publication Nov. 22, 1989.

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12/1/18503

Table I. *Preoperative assignment risk according to NYHA, ASA classification, and MGH-CRI*

	No. of patients				
	Class 1	*Class 2*	*Class 3*	*Class 4*	*Class 5*
NYHA	1	38	62	19	—
ASA	1	33	57	27	3
MGH-CRI	13	35	51	21	—

related to the degree of congestive heart failure (Appendix A, II) proposed by the New York Heart Association (NYHA) is useful,[34] but it is neither specific nor easily amenable to objective quantitation.[19, 20, 35]

3. From a multivariate discriminant analysis, Goldman and his colleagues[36] at the Massachusetts General Hospital (MGH) identified nine independent correlates of life-threatening and fatal cardiac complications (Appendix A, III). This method of analysis was used because specious relationships may be defined by subjective classifications and by univariate correlations of single risk, such as obesity, heart failure, diabetes, cigarette smoking, and hypertension.

Since the urgent nature of the noncardiac surgical problem arising after a cardiac operation often precludes comprehensive preoperative assessment, the first purpose of the present study is to compare the validity and the utility of simple clinical classifications, such as the ASA, the NYHA, and the MGH scales, in predicting complications after noncardiac operations in postoperative cardiac patients. The second purpose is to examine our data by multivariate analysis to determine whether the existing risk scales could be improved with regard to their predictive accuracy, and to identify the relative importance of variables that relate to an unfavorable outcome in this population of patients.

Patients and methods

Population. Records were reviewed of 120 patients who underwent one or several cardiac surgical procedures followed by noncardiac surgical procedures at the Massachusetts General Hospital in the 5 years from Jan. 1, 1982, through Dec. 31, 1986.

Preoperative and perioperative data. In each case an assignment of risk for noncardiac surgery based on evaluation of data available beforehand was estimated according to the ASA and NYHA classifications, as well as by the criteria used to determine the MGH cardiac risk index (MGH-CRI) (Table I). The scores assigned were the preoperative scores previously reported in the chart by the involved anesthesiologist and cardiologist. Intraobserver and interobserver variability was not considered. Twenty-one preoperative variables were also analyzed (Table II). The first nine variables were those specifically defined by Goldman and colleagues[36] and selected to compute the CRI. An emergency procedure was defined as a procedure performed during the first 12 hours after urgent general operation consult. A number of classic risk factors, such as obesity, diabetes, impaired renal function, hypertension, cigarette smoking, hyperlipidemia, alcohol abuse, chronic lung disease, cerebrovascular disease, and peripheral atherosclerotic vascular disease, were determined for each patient by reviewing in detail the preoperative note of the cardiology consultant. From this note it was possible to elicit any history of risk factors. A weighted score was impossible to allocate each risk factor in this retrospective series. This is the reason the number of risk factors per patient was analyzed as a numerical variable.

Postoperative data. All cardiac and noncardiac complications that developed before hospital discharge were recorded. A cardiac death was defined as one in a patient who died either of an arrhythmia or of a refractory low-flow state that was the consequence of a postoperative myocardial infarction or of an inexorable downhill course primarily caused by the cardiac condition. A noncardiac death was defined as one resulting from any other cause, regardless of whether there was progressive or persistent cardiac failure or ischemia.

Data analysis. The correlation between the three predictive indices (ASA, NYHA, and MGH-CRI) was measured by the Spearman rank correlation coefficient[37] on both the whole group of 120 patients and the eight subgroups defined by the presence or the absence of each of four outcomes considered: a cardiac death, a life-threatening cardiac complication, a death from any cause, and a life-threatening complication of any nature.

Receiver operating characteristic curves (Appendix B) were constructed for assessing the value of each index (ASA, NYHA, MGH-CRI) in the prediction of the various outcomes[38, 39] (Figs. 1 and 2). Receiver operating characteristic curves assessing the predictive value of crude MGH-CRI score (score ranges from 1 to 53 points) for each outcome (Figs. 3 and 4) were also drawn.[40, 41]

The influence on the outcome of the 21 variables specified in the section on preoperative and perioperative data was assessed by univariate and multivariate methods (Appendix C). For each of the 21 variables, comparisons between patients who survived or died and between patients with or without life-theatening complications were made with use of the χ^2 test or Fisher's exact test when appropriate for categoric variables and use of Wilcoxon's rank sum test for numeric variables. For numeric variables mean values are reported with standard deviations. Various functions were also derived from these data by linear discriminant analysis with use of the numeric value of the variable or the values 1 and 0 for categoric parameters. They were computed with various statistical selection procedures of the variables with use of SPSS/PC software.[42, 43]

Results

Patients. During the 5 years studied, 5688 patients underwent cardiac procedures with a mortality rate of 3.8% (215/5688). During the same period, 120 patients with a previous cardiac surgical procedure underwent subsequent noncardiac surgical procedures with a mortality rate of 11% (13/120). The sex ratio was skewed to men (95/25). The mean age of the population was 62 ± 9 years (median 62 years; range 35 to 81 years).

Cardiac procedures. Of the 120 patients who underwent cardiac operations, 77 had myocardial revascular-

Table II. *Incidence of preoperative and perioperative variables in different postoperative outcomes*

	Whole group (n = 120)	Cardiac complication but alive (n = 25)	Cardiac death (n = 9)	Any complication but alive (n = 54)	Any death (n = 13)
Categoric variables (numbers)					
Age >70 yr	27	7	4	15	7
MI in previous 6 mo	22	7	5	14	5
S_3 gallop or JVD	34	12	8	23	9
Important VAS	9	2	1	6	1
Last preop. ECG	62	18	7	34	10
>5 PVC on any preop. ECG	6	2	0	3	1
General status parameters	88	17	8	39	12
Intraperitoneal, intrathoracic, or aortic operation	84	18	9	42	13
Emergency operation	41	10	9	26	12
Sex (M/F)	95/25	21/4	8/1	42/12	10/3
Gastric operation	15	5	1	9	3
Biliary operation	32	4	3	13	3
Small bowel operation	10	3	4	4	5
Colonic operation	23	3	1	12	1
Coronary artery bypass	92	17	7	41	10
Aortic valve operation	28	8	3	14	5
Mitral valve operation	24	6	1	12	1
Intraaortic balloon	26	7	5	14	5
Numeric variable (mean ± SD)					
Age in years	62 ± 9	63 ± 9	67 ± 9	63 ± 9	68 ± 8
Delay between cardiac and noncardiac operation in months	12 ± 14	11 ± 12	2 ± 5	7 ± 11	5 ± 10
Number of risk factors	3.6 ± 1.7	4.2 ± 1.7	3.0 ± 1.4	3.6 ± 1.5	3.7 ± 2.2

ECG, Electrocardiogram; JVD, jugular vein distention; MI, myocardial infarction; PVC, premature ventricular contractions; SD, standard deviation; VAS, valvular aortic stenosis.

ization, 15 had a mitral valve replacement, 4 had an aortic valve replacement, 9 had replacement of both the aortic and the mitral valves, and 15 had myocardial revascularization accompanied by an aortic valve replacement.

Noncardiac procedures. Forty-three patients (36%) underwent noncardiac operations during the first month after cardiac operations. The range of the interval between cardiac and noncardiac operations was large: 1 day to 52 months; mean 12 months; median 6 months.

A total of 82 patients had intraperitoneal operations; two were operated on through a thoracoabdominal approach. There were 41 emergency operations and 79 elective procedures. The distribution of procedures by types was as follows: 15, gastric; 23, colonic; 10, small bowel; 32, general surgery (perineal, hernia, breast, thyroid); 8, urologic; and 32, biliary. Six of the biliary procedures were performed for acute acalculous cholecystitis (three deaths) and two for acute necrotizing pancreatitis.

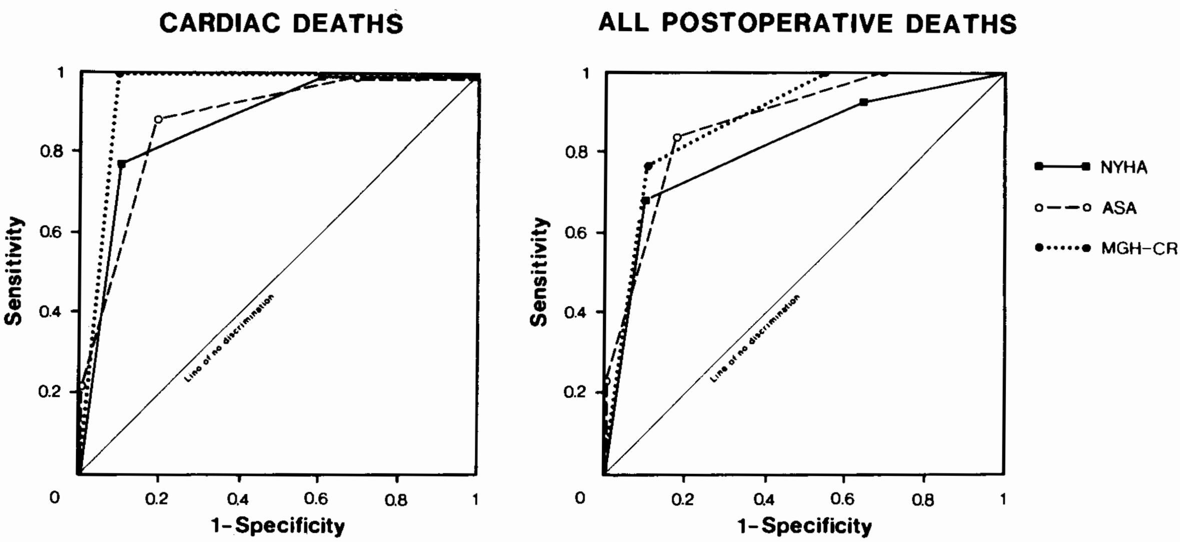
Mortality and morbidity. After their noncardiac operations, life-threatening complications were manifest in 56% of the patients (67/120). Thirteen (11%) died of postoperative complications. If the group of patients operated on during the first 3 months after cardiopulmonary bypass operation is considered alone, the mortality rate was 19.6% ($p < 0.01$).

Sixteen patients who had cardiac complications exclusively when first seen by the physician had a mortality rate of 19% (3/16). Thirty-three with noncardiac complications exclusively had a mortality rate of 6% (2/33), and 18 with simultaneous cardiac and noncardiac complications had a mortality rate of 44% (8/18).

Thirty-four of the 67 patients (51%) who manifested life-threatening complications had some form of serious cardiac complication. Twenty-five of them survived. Therefore, 9 of 13 deaths (69%) were cardiac related.

The main types of cardiac complications were prolonged low-flow state ($n = 5$), ventricular tachycardia ($n = 10$), postoperative myocardial infarction ($n = 1$), symptomatic supraventricular arrhythmia ($n = 6$), congestive heart failure ($n = 6$), endocarditis ($n = 4$), and postoperative hypertensive crisis ($n = 2$).

The main types of noncardiac complications were



	Cardiac deaths A ± SE(A)		All postoperative deaths A ± SE(A)
(1) MGH-CRI	0.946 ± 0.021	(1) MGH-CRI	0.885 ± 0.042
(2) ASA	0.880 ± 0.051	(2) ASA	0.879 ± 0.047
(3) NYHA	0.874 ± 0.056	(3) NYHA	0.820 ± 0.070

(1 vs 2: NS; 2 vs 3: NS; 1 vs 3: NS — for both outcomes)

Fig. 1. Receiver operating characteristic curves assessing predictive value of MGH-CRI, ASA, and NYHA scales for cardiac deaths and all postoperative deaths. *A* ± *SE* refers to area under receiver operating characteristic curve for each scale.

severe bleeding from perioperative dicumarol treatment (10 cases), acute tubular necrosis (five), adult respiratory distress syndrome (seven), sepsis (six), neurologic impairment (seven), delirium tremens (two), pulmonary embolism (one), small bowel infarction (one), necrotizing pancreatitis (two), acalculous cholecystitis (two), and severe gastrointestinal bleeding (eight).

Validity of ASA, NYHA, and MGH-CRI scales for prediction of postoperative outcome. Classification of patients according to the three indices is given in Table I. Although these indices were correlated, the intensity of the correlation differed in the three 2 × 2 comparisons. It was stronger between the NYHA and the ASA classifications ($r = 0.783$) than between the NYHA and the MGH-CRI scores ($r = 0.617$) and between the ASA and the MGH-CRI scores ($r = 0.521$). Moreover, the decreasing order of intensities of correlation remained unchanged when the correlations were assessed in each of the eight subgroups defined by the presence or the absence of each outcome.

Figs. 1 and 2 show the receiver operating characteristic curves (Appendix B) for the three predictive indices. Whatever the outcomes considered (cardiac or noncardiac deaths; cardiac or general complications), the area under the curve was larger for the MGH-CRI classification than for both of the other classifications. The superiority of that index was statistically significant for the prediction of both a cardiac complication ($p < 0.03$) and of any life-threatening complication ($p < 0.03$). It did not reach a significant level for death outcomes, but the number of patients with such an outcome was much smaller.

Receiver operating characteristic curves of crude MGH-CRI scores in each outcome are plotted in Figs. 3 and 4, with values of the areas under the curves and with cutoff levels maximizing Youden's index for a dichotomous prediction.[41] The thresholds obtained for both death outcomes (≥26) correspond exactly to the limit between classes III and IV of the MGH-CRI index. Moreover, by considering simultaneously the results for the four outcomes, we can propose a three-class index derived from the MGH-CRI index for predicting the postoperative evolution of a patient (Table III). The accuracy of this three-class index is 84% for prediction of complications and 88% for prediction of death from any cause.

Identification of the preoperative variables most predictive of operative outcome. Table II shows the distribution of the 21 preoperative variables for the whole group and for the postoperative outcomes. The eight categoric and numeric variables univariately related to operative complication and their canonical function coef-

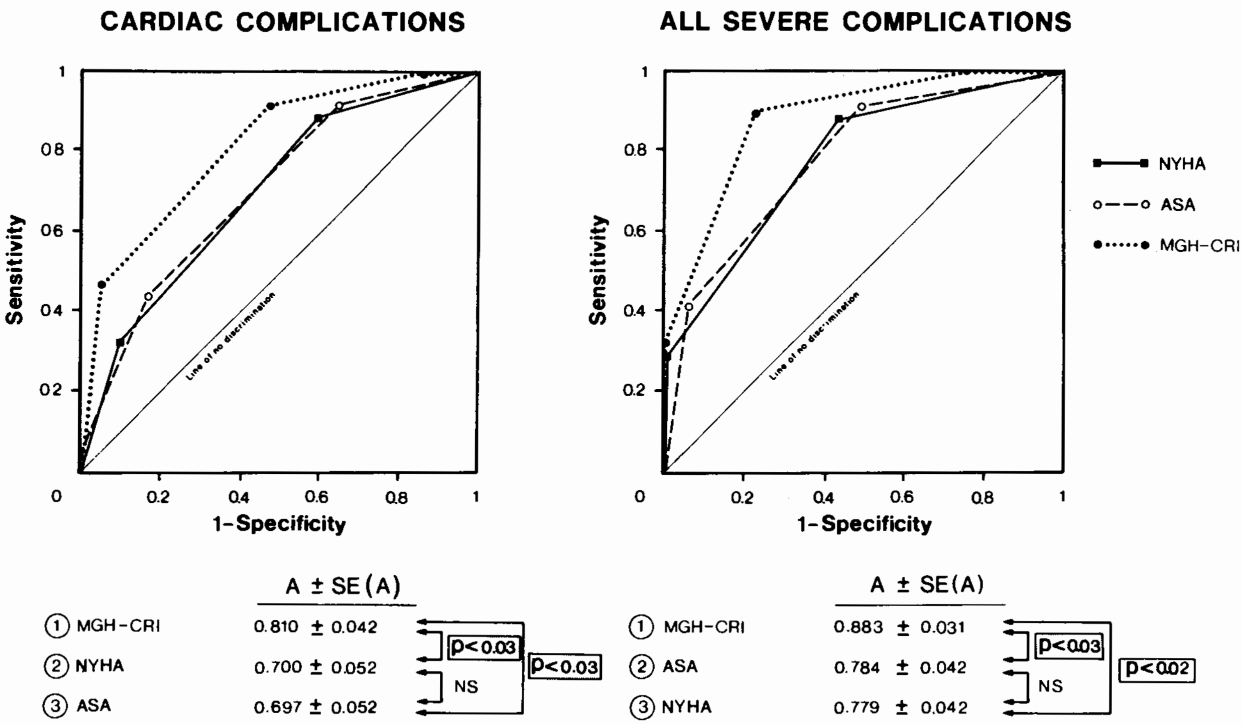


Fig. 2. Receiver operating characteristic curves assessing predictive value of MGH-CRI, ASA, and NYHA scales for cardiac complications and for all severe complications.

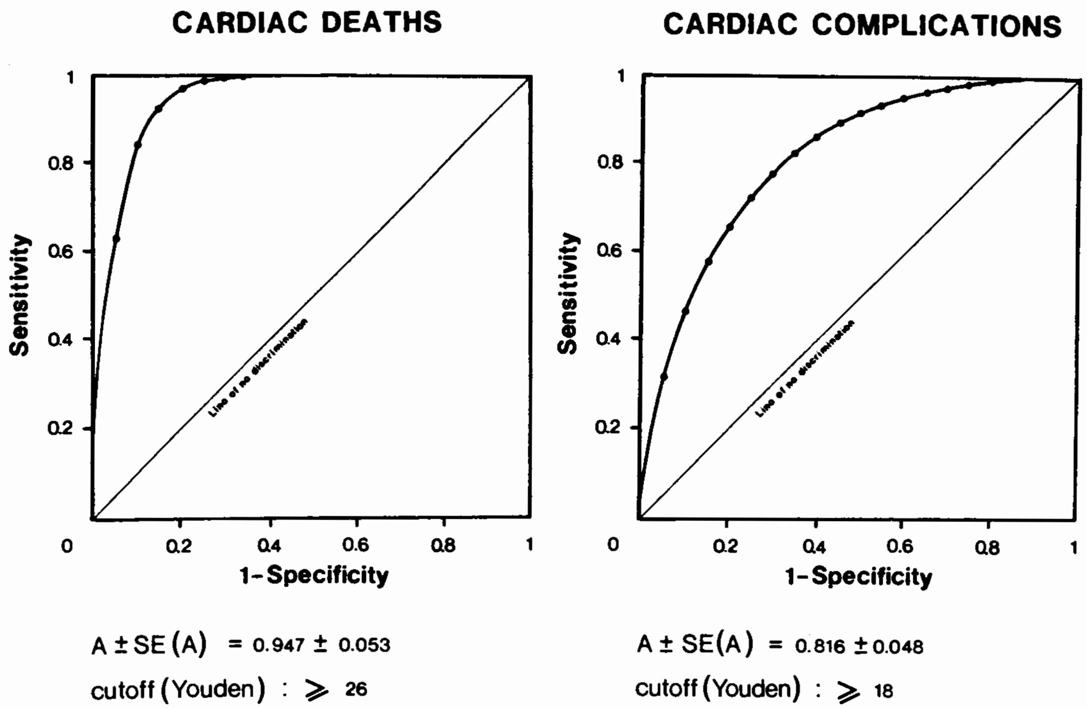


Fig. 3. Receiver operating characteristic curves assessing predictive value of crude MGH-CRI score for cardiac deaths and cardiac complications. Cutoff point determined by maximizing Youden's index[39] indicates score above which death or complication can be predicted with accuracy.

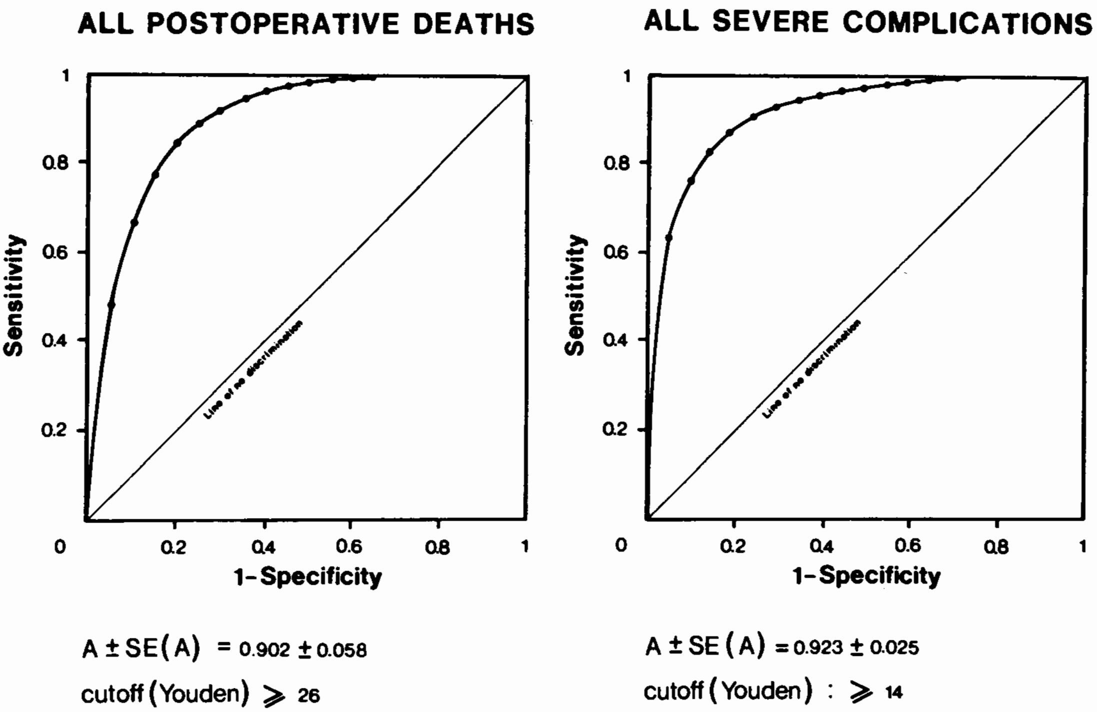


Fig. 4. Receiver operating characteristic curves assessing predictive value of crude MGH-CRI score for all postoperative deaths and for all severe complications.

Table III. *MGH-CRI four-class index and new modified three-class index*

MGH-CRI	*Scores*	*Cardiac complications (%)*
I	0-5	1
II	6-12	7
III	13-25	14
IV	≥26	78
Modified class for cardiac outcome	*Scores*	*Cardiac outcome*
I	≤17	No complication
II	18-25	Cardiac complication, no death
III	≥26	Cardiac death
Modified class for general outcome	*Scores*	*General outcome*
I	≤13	No complication
II	14-25	Any complication, no death
III	≥26	Death from any cause

ficient in a linear discriminant analysis (Appendix C) are reported in Tables IV and V. A high statistical significance level ($p < 0.01$) was reached for (1) age, expressed on a numerical or a dichotomous (<70 or >70 years) scale; (2) history of myocardial infarction in the previous 6 months; (3) presence of S_3 gallop or jugular vein distention; (4) rhythm other than sinus rhythm or premature atrial contractions on the last preoperative electrocardiogram; (5) intraperitoneal, intrathoracic, or aortic location of the operation; (6) the emergency character of the procedure; and (7) the delay between cardiac and noncardiac operations. In fact, six of these parameters are used for scoring the MGH-CRI score.

When the 21 variables were entered into the function (Appendix C), the discriminant equation obtained led to an 83.3% correct classification. The equation was difficult to use because of the number of criteria involved and the complexity of weights attributed to each, however. Table VI shows some alternative functions obtained by linear discriminant analysis. All these alternative funtions (DF1 to DF5) are based on some of only five variables, which appear therefore as the most important variables for predicting postoperative complications in the population studied. Once more, four of these variables are used for scoring the MGH-CRI index. Correct prediction of outcome by function DF3 was the highest (83%).

Performance of the MGH-CRI three-class index and the linear function (DF3) in a validation population. The concept of validation of prognostic indexes is widely accepted and should be a requirement before they are proposed. Thus we validated the new MGH-CRI three-class index and the best linear discriminant function (DF3) in an independent population from Mont-Godinne Academic Hospital at the University of Louvain

Table IV. *Categoric variables univariately related* ($p < 0.01$) *to postoperative complication and their canonical function coefficient in linear discriminant analysis*

	Variable not present		*Variable present*			
Variable	*No. of patients*	*Complications (%)*	*No. of patients*	*Complications (%)*	*p Value*	*Canonical coefficient*
Age >70 yr	93	45 (48)	27	22 (81)	$p < 0.01$	0.175
MI in previous 6 mo	98	48 (49)	22	19 (86)	$p < 0.01$	1.105
S_3 gallop or JVD	86	35 (41)	34	32 (94)	$p < 10^{-6}$	1.529
Last preoperative ECG (*cf.* Appendix A)	58	23 (40)	62	44 (71)	$p < 0.001$	1.214
Intraperitoneal, intrathoracic, aortic operation	36	12 (33)	84	55 (65)	$p < 0.01$	0.299
Emergency operation	79	29 (37)	41	38 (93)	$p < 10^{-8}$	1.184

ECG, Electrocardiogram; JVD, jugular vein distention; MI, myocardial infarction.

Table V. *Numeric variables univariately related* ($p < 0.01$) *to postoperative complication and their canonical function coefficient in a linear discriminant analysis*

*Variables**	*Without complication*	*Postoperative complication*	*p Value*	*Canonical coefficient*
Age (yr)	60 ± 10	64 ± 9	$p < 0.01$	0.004
Delay (mo) between cardiac and noncardiac operations	18 ± 15	7 ± 11	$p < 10^{-6}$	−0.007

*Mean ± standard deviation.

Table VI. *Results of linear discriminant analysis**

	Canonical discriminant function coefficients				
	DF1	*DF2*	*DF3*	*DF4*	*DF5*
MI previous 6 months	—	0.663	0.779	0.573	—
S_3 gallop or JVD (S_3)	1.517	1.457	1.473	1.559	1.552
Last preop. ECG (cf. Appendix A)	0.867	0.947	0.957	—	0.863
Emergency operation	1.356	1.251	1.478	1.704	1.668
Delay between cardiac and noncardiac operation (day)	−0.022	−0.018	—	—	—
Constant (K)	−1.083	−1.239	−1.560	−1.129	−1.455
Percentage of correct classification	80.8	80.8	83.3	82.5	82.5

ECG, Electrocardiogram; JVD, jugular vein distention; MI, myocardial infarction.
*The five functions are obtained by various statistical selection procedures of the variables, Appendix C.

(MGUL). Table VII details the characteristics of the retrospective population from the Massachusetts General Hospital (MGH) and the prospective validation population (MGUL).

Except for the total morbidity rate, both populations were comparable for the matching criteria. One of us (L.A.M.) followed all the patients in the validation population to avoid differences in surveillance strategies[44] and to respect definitions of outcome (e.g., definition of severe complication, such as cardiac death).

The proportion of patients accurately predicted as having or not having a severe postoperative complication (Table VIII) remained above 70% in the validation population. The accuracy of the prediction of the new discriminant function DF3 remained satisfactory (from 83% to 72%) and deteriorated even less for the MGH-CRI three-class index (from 84% to 75%). The accuracy of the latter index for prediction of death remained as good in the prospective validation population (90%), however, as in the retrospective population (88%).

Discussion

Preoperative assessment of the risk of patients who have had cardiac operations, but are also undergoing

Table VII. *Distribution of the retrospective (MGH) and the prospective (MGUL) populations according to the matching criteria*

Criteria	*MGH retrospective group (n = 120)*	*MGUL prospective group (n = 97)*	*p Value*
Age, mean ± SD (median; range)	62 ± 9 (62; 35-81)	60 ± 10 (62; 23-87)	NS
Sex (M/F)	95/25	70/27	NS
Total mortality rate (%)	13 (11%)	5 (5.2%)	NS
Total morbidity rate (%)	67 (50%)	31 (32%)	$p < 0.001$
Number of emergency operations	41 (31%)	27 (28%)	NS
Cardiac group index (group ≥III)	71 (59%)	46 (47%)	NS
ASA class (class ≥III)	87 (72%)	44 (45%)	NS
NYHA class (class ≥III)	81 (67%)	46 (47%)	NS
Type of operation			
Gastric	15 (12.5%)	6 (6.2%)	NS
Colonic	23 (19.1%)	15 (15.5%)	NS
Small bowel	10 (8.3%)	9 (9.3%)	NS
Biliary	32 (26.7%)	31 (32%)	NS
Urologic	8 (6.7%)	5 (5%)	NS
Miscellaneous	32 (26.7%)	31 (32%)	NS

NS, Not significant; SD, standard deviation.

Table VIII. *Proportion of patients who have been predicted as having or not having postoperative complications by the MGH-CRI three-class index and the linear discriminant function DF3*

Index	*MGH retrospective study (%) (n = 120)*	*MGUL prospective study (%) (n = 97)*
MGH-CRI three-class index	84	75
DF3 discriminant function	83	72

noncardiac operations on the same admission or within 6 months, is complicated by interposed problems. Some of these are diabetes, hypertension, use of anticoagulant medications, and a need for an emergency operation that precludes comprehensive preoperative assessment of risk. To eliminate these potential sources of error, statistically derived predictive models have been proposed to substitute for qualified surgical judgment.[20, 22-25, 31-36] Although clinical judgment can be reinforced by the use of statistical methods, predictive models cannot predict with certainty the outcome for an individual patient.[45-47]

Before proposing another prognostic model, we decided as a lead-in message to assess the predictive accuracy of three simple, widely used classifications (ASA, NYHA, MGH-CRI). We know that the ASA and NYHA scales were not intended as predictors of postoperative outcome, but are designed to assess physical status and severity of cardiac illness. Nevertheless, both scales are extensively used in the surgical literature as reliable predictors of overall outcome.[16-20, 25-34] Furthermore, in one study[33] classification of physical status (ASA) by experienced anesthesiologists correlated well with invasive preoperative monitoring of elderly patients. The comparison of these three classifications shows that the predictive accuracy of the MGH-CRI index is superior to that of the ASA and NYHA scales in our population of patients undergoing noncardiac operations after cardiac operations (Figs. 1 and 2). Performance of a simplified MGH-CRI three-class index (Table III) for predicting death and complication demonstrated an even greater accuracy.

The main message of this study is, however, that after linear discriminant analysis of 21 variables, five of them (Table IV) were identified as the most predictive of operative outcome in this population. These five variables are used in the equation of the alternative functions (Table VI) obtained by linear discriminant analysis (the most accurate being DF3). They are also among the variables identified to compute the MGH-CRI index. Each of these five variables can be obtained by gathering basic preoperative data, easily available even in emergency situations. The simplicity of our results leads us to propose DF3 as an alternative to the MGH-CRI index. Before doing so, we validated the new MGH-CRI three-class index and the DF3 discriminant function in an independent prospective series. Both models performed well in the validation population but require further assessment in other independent series and in different patient populations. DF3 and the MGH-CRI three-class index remain the most accurate models in our prospective study.

Our results corroborate the danger that the clinician may become so bemused by analytical and statistical techniques applied to large amounts of data that sight of a simple rule will be lost: each patient should always be assessed individually by the clinician.

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Appendixes

Appendix A

I. ASA physical status classification[26]:

Class I: A normally healthy individual.
Class II: A patient with mild systemic disease.
Class III: A patient with severe systemic disease that is not incapacitating.
Class IV: A patient with incapacitating systemic disease that is a constant threat to life.
Class V: A moribund patient who is not expected to survive 24 hours with or without operation.
E: Added to any class for patient with emergency operations.

II. NYHA classification[34]:

Class I: No limitation of activity. Ordinary physical activity does not cause undue fatigue, dyspnea, or palpitation.
Class II: Slight limitation of physical activity. Such patients are comfortable at rest. Ordinary physical activity results in fatigue, palpitation, dyspnea, or angina.
Class III: Marked limitation of physical activity. Although patients are comfortable at rest, less than ordinary activity will lead to symptoms.
Class IV: Inability to carry out any physical activity without discomfort. Symptoms of congestive failure are present even at rest. With any physical activity, increased discomfort is experienced.

III. Multifactorial index of cardiac risk in noncardiac surgical procedures[36]:

Criteria	*Points*
1. Age >70 years.	5
2. Myocardial infarction in previous 6 months.	10
3. S_3 gallop or jugular vein distention.	11
4. Important valvular aortic stenosis.	3
5. Rhythm other than sinus or premature atrial contractions on last preoperative electrocardiogram.	7
6. Presence of more than five premature ventricular contractions per minute at any time before operation.	7
7. General status: Oxygen pressure (Po_2) <60 mm Hg or carbon dioxide pressure (Pco_2) <50 mm Hg; K^+ <3.0 mEq/L or bicarbonate (HCO_3) <20 mEq/L; blood urea nitrogen (BUN) >50 mg/dl or chronic liver disease or patient bedridden from noncardiac causes.	3
8. Intraperitoneal, intrathoracic, or aortic operation.	3
9. Emergency operation.	4
Total possible	53

Class	*Scores (points total)*
I	0-5
II	6-12
III	13-25
IV	>26

Appendix B. Receiver operating characteristic curves graph the function between the true positive rate (sensitivity) and the false positive rate (1 − specificity) for all possible cutoff values of the index studied (Figs. 1 and 2). The area *(A)* under the receiver operating characteristic curve is a measure of the global predictive value of the index. The more the curve diverges from the "line of no discrimination" the better is its performance. For each index and each outcome, areas (A ± standard error) under receiver operating characteristic curves were computed by the method derived from the Wilcoxon statistic[38] and were compared two by two with use of the procedure of Hanley and McNeil[39] and Spearman's coefficient as the correlation measure. Receiver operating curves assessing the predictive value of crude MGH-CRI score (score ranges from 1 to 53 points) for each outcome (Figs. 3 and 4) were also drawn. The greater number of possible cutoff levels allows graphing smoother curves from parameters of a straight line.[40] The best cutoff point of a curve for prediction of a dichotomous outcome was determined by maximizing Youden's index[41] (J = Sensitivity + Specificity − 1). This parameter was used to obtain a threshold independent of the respective proportions of patients having the expected outcome and to allow better reproducibility of predictive data in other populations.

Appendix C. The 21 variables, reported in Table II, were subjected to multivariate discriminant analysis with use of the numeric value of the variable or the values 1 and 0 for categoric parameters. Various functions labeled DF were derived by this linear discriminant analysis (Table VI) (1) by considering all the variables simultaneously, (2) by considering simultaneously the parameters that showed a statistically significant difference between both groups at the 0.01 level in univariate comparisons (DF1), (3) by a stepwise selection procedure minimizing Wilks' lambda criterion (DF2 and DF3),[42,43] and (4) by considering each subset of parameters resulting from elimination of one of the discriminant variables of the best function derived by the stepwise selection procedure (DF4 to DF7). All functions were computed with various statistical selection procedures of the variables using SPSS/PC software.[43] Proposed risk-index scores were finally derived from the canonical discriminant function coefficients by algebraic simplications. For example, the function DF3 from Table VI is:

$$Y = 0.799\ (M) + 1.473\ (S_3) + 0.957\ (ECG) + 1.478\ (E) - 1.560$$

where M is myocardial infarction in preceding 6 months, S_3 is gallop or jugular vein distention, ECG is rhythm other than sinus on preoperative electrocardiogram, and E is emergency operation. The risk of severe operative complication is high if $Y > 0$ and low if $Y < 0$. Table VI shows some alternative functions obtained by linear discriminant analysis and for which the percentage of correct prediction of complication was greater than 80% (DF6 and DF7 are not shown). The predicting accuracy of function DF3 is the best with 83%.