Identification of Preoperative Variables Needed for Risk Adjustment of Short-Term Mortality After Coronary Artery Bypass Graft Surgery

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Objectives. **The purpose of this consensus effort was to define and prioritize the importance of a set of clinical variables useful for monitoring and improving the short-term mortality of patients undergoing coronary artery bypass graft surgery (CABG).**

Background. **Despite widespread use of data bases to monitor the outcome of patients undergoing CABG, no consistent set of clinical variables has been defined for risk adjustment of observed outcomes for baseline differences in disease severity among patients.**

Methods. **Experts with a background in epidemiology, biostatistics and clinical care with an interest in assessing outcomes of CABG derived from previous work with professional societies, government or academic institutions volunteered to participate in this unsponsored consensus process. Two meetings of this ad hoc working group were required to define and prioritize clinical variables into core, level 1 or level 2 groupings to reflect their importance for relating to short-term mortality after CABG. Definitions of these 44 variables were simple and specific to enhance objectivity of the 7 core, 13 level 1 and 24 level 2 variables. Core and level 1 variables were evaluated using data from five existing data bases, and core variables only were examined in an additional two data bases to confirm the consensus opinion of the relative prognostic power of each variable.**

Results. **Multivariable logistic regression models of the seven core variables showed all to be predictive of bypass surgery mortality in some of the seven existing data sets. Variables relating to acuteness, age and previous operation proved to be the most important in all data sets tested. Variables describing coronary anatomy appeared to be least significant. Models including both the 7 core and 13 level 1 variables in five of the seven data sets showed the core variables to reflect 45% to 83% of the predictive information. However, some level 1 variables were stronger than some core variables in some data sets.**

Conclusions. **A relatively small number of clinical variables provide a large amount of prognostic information in patients undergoing CABG.**

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Coronary artery bypass graft surgery (CABG) has been used for treatment of patients with coronary artery disease with increasing frequency over the past 25 years (1). Both quality of care and severity of illness influence the observed outcomes of CABG, and observed outcomes must be adjusted for severity of illness to be useful for evaluating and improving quality of care (2). Moreover, accurate preoperative characterization of the impact of severity of illness on the risk of adverse outcomes after CABG is important for patients and their physicians when considering alternate treatment strategies for coronary artery disease. The deceptively simple-appearing task of achieving widespread consensus on variables that relate strongly to short-term mortality after CABG has in the past proved difficult to achieve. Different lists and definitions of variables used to categorize perioperative risk have evolved among the many cardiovascular data bases established to monitor CABG outcomes (3). This consensus report of the working group is intended to develop a standard of practice by identifying variables that should be captured by data bases designed to assess CABG mortality.

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Abbreviations and Acronyms
CABG = coronary artery bypass graft surgery
CCS = Canadian Cardiovascular Society

Methods

Recognition of the need for a core set of well defined variables to prospectively collect severity of illness data on all patients before CABG led representatives of seven large cardiovascular data bases and other experienced investigators to enter the Cooperative CABG Database Project (Appendix). The working group convened included recognized experts with expertise in epidemiology, biostatistics and clinical care who shared a common background and interest in assessing outcomes of patients undergoing CABG. The organizations listed in the Appendix contributed to conference and travel expenses. However, participants shared knowledge as individuals, and the purpose of this conference was not to replace all previous work by the organizations represented, nor to seek endorsement from these organizations with which individual panel members were affiliated. Therefore, the validity of conclusions of this consensus effort must be judged by the process and evidence alone. No endorsement of conclusions is implied from any of the academic, professional society or government organizations that permitted affiliated investigators to join the consensus panel or that shared data used for testing consensus opinion.

The first phase of work on the Cooperative CABG Database Project was begun at a consensus conference on December 2, 1993. Participants drew on their knowledge of published scientific reports and their own extensive experience with data bases on patients undergoing CABG to identify variables describing clinical characteristics considered useful for monitoring the quality of care of patients undergoing CABG.

Short-term mortality, defined as in-hospital death from all causes after a CABG procedure, was identified as the primary end point of interest. The strength of this end point is its general availability. A more inclusive end point of all-cause death, occurring either during the hospital period for CABG or within 30 days of the procedure, was recognized as a preferable end point, but practical constraints often limit ascertainment of cause of death that occurs after hospital discharge. The use of cardiac death in place of all-cause mortality was rejected because of the subjectivity in assigning cause of death in the patient undergoing CABG with a complicated clinical course.

The occurrence of CABG was defined as the intention to perform operative myocardial revascularization as indicated by transport of the patient into an operating room environment even if the operation was aborted. The term CABG, as used in this document, is strictly defined as isolated CABG and does not include myocardial revascularization performed in association with other procedures, such as cardiac valve replacement or repair, resection of left ventricular aneurysm or other cardiac operations. Many of the variables defined as important for isolated CABG are likely to also relate to short-term mortality when CABG is combined with other cardiac operations. However, the many additional variables that might be needed to accurately risk stratify patients with more complex operations than isolated CABG were not addressed in this effort.

Variables were assigned by consensus to one of three groups to reflect relative level of importance in predicting short-term mortality after CABG. The following criteria were used to define the three groups:

Core = variables shown to be unequivocally related to operative mortality. These variables *should* be in the data base record of every patient undergoing CABG.

Level 1 = variables shown to have a likely relation to short-term CABG mortality. These variables are *suggested* for inclusion in the data base record of every patient undergoing CABG.

Level 2 = variables not clearly shown to relate directly to short-term CABG mortality but with potential research or administrative interest. These variables are *optional* for inclusion in the data base record of patients undergoing CABG.

Objective and discrete criteria were used to simplify and standardize definitions for variables judged to be important. Information needed for these definitions was that commonly acquired during routine clinical care. The intent was also to create practical descriptors that could not be easily manipulated to overstate or understate the predicted risk of patient populations. Explicit and objective definitions lessen unintentional confusion or intentional gaming during data entry.

The preliminary variable lists were circulated more widely among personnel in each group represented, and priorities and definitions were refined at a second conference on March 13, 1994. Consensus in this endeavor required considerable discussion, especially concerning variables known from previous personal experience to be especially susceptible to subjectivity and variability in coding. The Canadian Cardiovascular Society (CCS) angina class and descriptors of acuteness were identified as the two variables of greatest concern. In some practice settings, the quality of information on these and other potentially gameable variables may need consistent monitoring to ensure accuracy. Definitions of variables included in this report reflect subtleties of data acquisition in different clinical environments tempered by the experience of recognized leaders in this field of outcomes research. Some participants recognized other variables than those included by the group to have value in their data bases. Clear and practical definitions are likely to improve the observed predictive power of the corresponding variable. Examples of variables better defined in some data sets and therefore considered more important by some panel members than reflected by group opinion included cardiomegaly, rales and preoperative diuretic use. Uncertainty among the entire panel about the importance of these variables if properly defined resulted in exclusion of these variables from the lists.

Table 1. Core, Level 1 and Level 2 Variables

Information Category	Core Variables	Level 1 Variables	Level 2 Variables
Demographics	Age Gender	Height Weight	Race Educational level Marital status Location of residence
Administrative			Institution where CABG performed Surgeon responsible for CABG Payment source
History	Previous heart operation	PTCA on current admission Date of most recent myocardial infarction Angina history	Date of last cardiac operation Number of previous CABGs Angina on admission Number of previous PTCAs Date of most recent PTCA Number of previous myocardial infarctions
Left ventricular function	Left ventricular ejection fraction		Left ventricular end-diastolic pressure
Left main disease	% stenosis of left main coronary artery		
Other coronary disease	No. of major coronary arteries with stenosis >70%		
Other cardiac conditions		Serious ventricular arrhythmias Congestive heart failure Mitral regurgitation	
Cardiovascular risk factors		Diabetes Cerebrovascular disease Peripheral vascular disease	Smoking Hypertension Diabetes sequelae
Comorbid conditions		Chronic obstructive pulmonary disease Creatinine levels	Cardiac pacemaker Refusal of blood products Substance abuse Liver disease Malignancy Immunosuppressed state
Acuity/priority/hierarchy	Elective Urgent Emergent/ongoing ischemia Emergent/hemodynamic instability Emergent/salvage		Hospital location before operation

CABG = coronary artery bypass grafting; PTCA = percutaneous transluminal coronary angioplasty.

At the conclusion of the second consensus panel meeting, a final list of 44 variables considered important were prioritized as *core* (7 variables) and *level 1* (13 variables) or *level 2* (24 variables) (Table 1). Data collection forms with definitions are provided for core and level 1 variables (Fig. 1) and for all 44 variables (Fig. 2). Core and level 1 variables were tested for their relative strength in predicting short-term mortality after CABG using existing data from the seven data bases represented. Because the only data available for testing had been acquired before variables had been selected by consensus, data were not adequate to test all variables in all data bases. Moreover, the definitions previously used to collect data were not always identical to those resulting from the consensus effort. This variation precludes a rigorous quantitative comparison of odds ratios to define the incremental information contributed to short-term mortality prediction by each of these variables among the seven data bases of patients undergoing CABG. The only purpose of the comparative analysis was to validate the panel judgment of the general level of importance assigned to each variable by the consensus process.

The short-term mortality end point available for the testing phase of this project was in-hospital death after CABG in five data bases and 30-day mortality in two data bases. Univariable logistic modeling was first conducted for each of the core and level 1 variables present in individual data bases. A multivariable logistic model was developed in each of the seven data sets to assess the level of independent information contributed by each of the core variables. For each data set, the relative

Patient ID ____________ (SSN Preferred)

ADMINISTRATIVE AND DEMOGRAPHIC	
Age ____	Calculated from date of birth or stated by patient or family
Sex 0 = male 1 = female	As stated by patient
Height ____ (cm)	In order of preference: measured, reported, or estimated
Weight ____ (kg)	In order of preference: measured, reported, or estimated
HISTORY	
Angina ≤2 weeks prior to surgery? 0 = no 1 = yes CCS class: I II III IV	Highest Canadian Cardiovascular Society angina class within 2 weeks before surgery (I= No limitation in physical activity, II= Slight limitation, III= Marked limitation, IV= Complete limitation)
Date of most recent MI: ___/___/___ mm/dd/yy	As available from most reliable source
PTCA on current admission? 0 = no 1 = yes	Catheter inserted into the right or left main coronary artery orifice for the purpose of coronary revascularization by any endovascular technique
Prior cardiopulmonary bypass? 0 = no 1 = yes	Any surgery for which the patient was placed on cardiopulmonary bypass using intrathoracic cannulation
OTHER CARDIAC CONDITIONS	
Ventricular arrhythmias: 0 = no 1 = yes	Cardioversion for ventricular tachycardia or fibrillation within 2 weeks before surgery
Congestive heart failure: 0 = no 1 = yes If yes, NYHA class: I II III IV	Highest New York Heart Association class within 2 weeks before surgery (I= No limitation in physical activity, II= Slight limitation, III= Marked limitation, IV= Complete limitation)
Mitral insufficiency: ___ none ___ mild ___ moderate ___ severe	Classified by none, mild, moderate, or severe in a semi-quantitative scale on echocardiogram or contrast ventriculogram
LEFT VENTRICULAR FUNCTION	
Left ventricular ejection fraction ______ %	Most recent measurement before CABG. Method of LVEF measurement in descending order of preference: contrast ventriculography, radionuclide ventriculography, echocardiogram
CORONARY ANATOMY	
Left main disease, % stenosis ____ (%)	% stenosis, % luminal diameter narrowing. Measurement preferred over estimation
Number of stenoses > 70% ____ (0-3)	Number of major coronary arteries obstructed by a determined stenosis ≥70% in one or more branches of the three major coronary systems defined by the CASS classification (left anterior descending, circumflex, or right) (≥50% Left main=LAD and Circumflex)
CARDIOVASCULAR RISK FACTORS	
Diabetes? 0 = no 1 = yes	Clinical diagnosis of diabetes treated either with oral agents or insulin with or without sequelae
Cerebrovascular disease? 0 = no 1 = yes	History of stroke or documentation of prior TIA or RIND, or prior carotid surgery
Peripheral vascular disease? 0 = no 1 = yes	Diagnosis based on history of claudication, absent pedal pulses, positive noninvasive tests, abnormal arteriograms, or prior vascular operations
COMORBID CONDITIONS	
Severe COPD? 0 = no 1 = yes	COPD resulting in functional disability, hospitalization, requiring chronic bronchodilator therapy, or FEVI <75% of predicted
Creatinine value before surgery: _____ Dialysis within last month? 0 = no 1 = yes	Defined by most recent creatinine value measured before operation
ACUTENESS INDICATOR	
Priority at operation (circle one): 1 = Elective 2 = Urgent 3 = Emergent/Ongoing ischemia 4 = Emergent/Hemodynamic instability 5 = Emergent/salvage	Elective: Unstable angina defined by progressive and/or new onset angina but without ongoing rest pain or ischemic ECG change; Stable angina; No angina. Urgent: Unstable angina with ischemia resolving on intra-aortic balloon pump or intravenous nitroglycerin. Emergent/ongoing ischemia: Ongoing ischemia including rest angina despite maximal therapy (medical or intra-aortic balloon pump) or acute evolving MI within 24 hours prior to surgery. Pulmonary edema requiring intubation. Emergent/ hemodynamic instability: Shock with or without circulatory support (STS Definition of Cardiogenic Shock). Emergent/salvage: Arrest with CPR (immediately prior to entering the operating room)

Figure 1. Data collection form for core and level 1 variables. CASS = Coronary Artery Surgery Study; COPD = chronic obstructive pulmonary disease; CPR = cardiopulmonary resuscitation; ECG = electrocardiographic; FEVI = forced expiratory volume (in 1 s); ID = identification; LAD = left anterior descending coronary artery; LVEF = left ventricular ejection fraction; MI = myocardial infarction; NYHA = New York Heart Association; PTCA = percutaneous transluminal coronary angioplasty; RIND = reversible ischemic neurologic deficit; SSN = social security number; STS = Society of Thoracic Surgeons; TIA = transient ischemic attack.

contribution of each of the individual core variables was calculated by dividing its chi-square value by the total chi-square value for the core variable model. In the five data sets with both core and level 1 variables, separate multivariable models were developed to assess the additional contribution of the level 1 variables. In this analysis, the sum of the chi-square values for all the core variables was divided by the total chi-square value for the model to reflect the total information of the core variables to compare with individual information contributed by level 1 variables.

Receiver operating characteristic curves were calculated for all core models and for all models containing both core and level 1 variables. The area under the receiver operating characteristic curve, denoted by the c-index, was derived to compare information content of these models. The c-index represents the percent of patient pairs, one of whom died and

Patient ID: ________ (SSN Preferred)

ADMINISTRATIVE	
Provider ID code ______	Identification number of institution providing surgery
Surgeon ID code ______	Physician ID
Payor ID code ______	Type of insurance
DEMOGRAPHIC	
Age: ____	Calculated from date of birth or stated by patient or family
Sex: 0 = male 1 = female	As stated by patient
Height ____ (cm)	In order of preference: measured, reported, or estimated
Weight ____ (kg)	In order of preference: measured, reported, or estimated
Race: ___ White ___ Black ___ American Indian, Aleut, Eskimo ___ Asian or Pacific Islander ___ Other, specify ______	Self reported
Highest year of education completed: ____	Highest educational level attained as number of years of formal education
Marital status: ___ Single ___ Married ___ Widowed/Divorced	Self reported
Zip code of patient's home residence: ______	Postal zip code of patient's residence
HISTORY	
Angina ≤2 weeks prior to surgery? 0 = no 1 = yes CCS class: I II III IV	Highest Canadian Cardiovascular Society angina class within 2 weeks before surgery (I= No limitation in physical activity, II= Slight limitation, III= Marked limitation, IV= Complete limitation)
Angina on day of hospital admission? 0 = no 1 = yes CCS class: I II III IV	CCS angina class on day of hospital admission
Prior MI? 0 = no 1 = yes Number of prior MIs: ____	The number of prior MI available from patients, family, or chart, or prior ECG reading
Date of most recent MI: __/__/__ mm/dd/yy	As available from most reliable source
Prior PTCA? 0 = no 1 = yes Number of prior PTCAs: ____	The number of prior PTCA in which a catheter designed for performing PTCA was inserted into the right or left main coronary artery orifice
Date of most recent PTCA: __/__/__ mm/dd/yy	Date of most recent procedure during which a catheter designed for performing PTCA was inserted into the right or left main coronary artery orifice
PTCA on current admission? 0 = no 1 = yes	Catheter inserted into the right or left main coronary artery orifice for the purpose of coronary revascularization by any endovascular technique
Number of operations requiring cardiopulmonary bypass: ____	Include all operations for which the patient was actually placed on cardiopulmonary bypass using intrathoracic cannulation
Date of last cardiac operation: __/__/__ mm/dd/yy	Date of most recent heart operation during which cannulae were inserted for cardiopulmonary bypass
Prior CABG? 0 = no 1 = yes Number of prior CABGs: ____	The number of prior heart operations during which at least one coronary arteriotomy was performed
OTHER CARDIAC CONDITIONS	
Ventricular arrhythmias 0 = no 1 = yes	Cardioversion for ventricular tachycardia or fibrillation within 2 weeks before surgery
Congestive heart failure. 0 = no 1 = yes If yes, NYHA class: I II III IV	Highest New York Heart Association class within 2 weeks before surgery (I= No limitation in physical activity, II= Slight limitation, III= Marked limitation, IV= Complete limitation)
Mitral insufficiency ___ none ___ mild ___ moderate ___ severe	Classified by none, mild, moderate, or severe in a semi-quantitative scale on echocardiogram or contrast ventriculogram
LEFT VENTRICULAR FUNCTION	
Left ventricular ejection fraction ____ %	Most recent measurement before CABG. Method of LVEF measurement in descending order of preference. contrast ventriculography, radionuclide ventriculography, echocardiogram
Left ventricular end-diastolic pressure ____ mmHg	Direct intracavity left ventricular end-diastolic pressure measurement

Figure 2. Data collection form for core, level 1 and level 2 variables. lab = laboratory; mm/dd/yy = month/day/year; other abbreviations as in Figure 1.

the other of whom did not die, in which the estimated probability of death for the patient who died exceeded the estimated probability of death for the patient who did not die. This concordance measure has a maximal value of 1 and reflects the discriminatory ability of the model.

Results of testing were reviewed by the panel at a third consensus meeting on November 15, 1994. At this meeting the decision was reached not to change the priority given to variables by consensus to reflect power of these variables as shown by model testing. Testing was considered to substantiate general consensus conclusions, and the observed variability among models was considered to relate most to different variable definitions and differences in the rigor with which the original data had been acquired among the different data bases. These final panel conclusions form the basis of this written report. Production and revision of this document represent the final task of this consensus process.

CORONARY ANATOMY		
Left main disease, % stenosis ____ (%)		% stenosis, % luminal diameter narrowing. Measurement preferred over estimation
Number of stenoses > 70% ____ (0-3)		Number of major coronary arteries obstructed by a determined stenosis ≥70% in one or more branches of the three major coronary systems defined by the CASS classification (left anterior descending, circumflex, or right)
CARDIOVASCULAR RISK FACTORS		
Diabetes?	0 = no 1 = yes	Clinical diagnosis of diabetes treated either with oral agents or insulin with or without sequelae
Diabetes sequelae present?	0 = no 1 = yes	Charlson definition of diabetes sequelae
Cerebrovascular disease?	0 = no 1 = yes	History of stroke or documentation of prior TIA or RIND, or prior carotid surgery
Peripheral vascular disease?	0 = no 1 = yes	Diagnosis based on history of claudication, absent pedal pulses, positive noninvasive tests, abnormal arteriograms, or prior vascular operations
Current or former smoker?	0 = no 1 = yes	Active smoking of any amount or prior history defined as at least one pack/year total cigarette use
Hypertension?	0 = no 1 = yes	Diastolic blood pressure consistently greater than 90 mmHg or history of hypertension requiring treatment
COMORBID CONDITIONS		
Severe COPD?	0 = no 1 = yes	COPD resulting in functional disability, hospitalization, requiring chronic bronchodilator therapy, or FEVI <75% of predicted
Creatinine value before surgery ____ Dialysis within last month?	0 = no 1 = yes	Defined by most recent creatinine value measured before operation
Permanent cardiac pacemaker?	0 = no 1 = yes	Permanent cardiac pacemaker in place
Substance abuse?	0 = no 1 = yes	History or active abuse of an addictive substance by patient history or family
Liver dysfunction?	0 = no 1 = yes	Clinical diagnosis of acute or chronic liver dysfunction
Malignancy?	0 = no 1 = yes	Solid organ malignancy or leukemia/lymphoma requiring treatment ≤ 5 years
Immunosupression?	0 = no 1 = yes	Immunosupressed state or history of major transplantation
Refused blood products during surgery?	0 = no 1 = yes	Patient refusal/nonconsent to use of blood products during surgery
ACUTENESS INDICATOR		
Priority at operation (circle one): 1 = Elective 2 = Urgent 3 = Emergent/Ongoing ischemia 4 = Emergent/Hemodynamic instability 5 = Emergent/salvage		Elective: Unstable angina defined by progressive and/or new onset angina but without ongoing rest pain or ischemic ECG change; Stable angina; No angina. Urgent: Unstable angina with ischemia resolving on intra-aortic balloon pump or intravenous nitroglycerin. Emergent/ongoing ischemia: Ongoing ischemia including rest angina despite maximal therapy (medical of intra-aortic balloon pump) or acute evolving MI within 24 hours prior to surgery. Pulmonary edema requiring intubation. Emergent/ hemodynamic instability: Shock with or without circulatory support (STS Definition of Cardiogenic Shock). Emergent/salvage: Arrest with CPR (immediately prior to entering the operating room)
Location prior to surgery: ___ Emergency department ___ Cardiac interventional lab ___ Intensive/cardiac care unit ___ Other		Emergency department, cardiac catheterization or interventional laboratory, intensive/cardiac care unit, or other

Figure 2. *Continued.*

Results

Table 2 summarizes characteristics of the 172,184 patients with data recorded in the seven data sets used to test core and level 1 variables identified as important by group consensus (4–21). Patient data bases had similar population characteristics of age, gender (except for the Veterans Affairs data base), body size, ejection fraction, left main coronary artery stenosis and previous myocardial infarction. Less similarity was apparent in variables related to symptoms, such as congestive heart failure and angina classification, and in the recorded prevalence of associated conditions, such as mitral regurgitation, ventricular arrhythmias, diabetes, cerebral and peripheral vascular disease and pulmonary dysfunction. Figure 3 illustrates the relative contribution of the seven core variables entered into multivariable logistic regression models to predict hospital death after CABG in the seven data sets. Acuteness, history of previous cardiac operation and age are the three predominant core variables that account for the majority of total information in most of the data bases.

Figure 4 compares data from multivariable logistic regression models including level 1 with core variables. Data were available in only five data bases to adequately characterize all level 1 variables for testing, but these represent four of the largest of the seven data sets. The amount of incremental information contributed by level 1 variables was <25% of the total from both sets of variables in the Duke and Society of Thoracic Surgeons data bases but substantial (e.g., >40% of the total) in the New York and Veterans Affairs data bases. The following level 1 variables contributed at least 2% of the total model chi-square in two or more of the four data bases: cerebrovascular disease, number of previous myocardial infarctions, congestive heart failure (New York Heart Association functional class), peripheral vascular disease, previous ventricular arrhythmia, chronic obstructive pulmonary disease and angina (CCS class).

Table 2. Prevalence of Core and Level 1 Variables in Tested Data Sets

	Data Base (ref no)						
	STS (4–7)	NY (8–11)	VA (12,13)	Duke (14–17)	NNE (18,19)	MN (20)	NJ (21)
Years of data entry	1/91–12/93	1/92–12/92	10/91–9/93	1/86–12/92	6/87–4/89	1/85–12/90	6/91–12/94
Total no. of patients	132,882	16,028	11,474	5,447	3,055	1,521	1,777
Mortality	Both	In-hosp	30-day	30-day	In-hosp	30-day	30-day
Core Variables							
Mean age (yr)	64	65	64	62	64	63	65
Male	73%	73%	99%	74%	73%	67%	69%
Prior heart operations							
No	90%	91.6%	89%	91%	94%	92%	94%
Yes	10%	8%	11%	8%	6%	8%	6%
Mean LV ejection fraction (%)	52	45	50	51	58	57	46
Left main disease (>50% stenosis)	20%	20%	22%	24%	21%	20%	17%*
No. of major coronary arteries with >70% stenosis							
1	7%	9%	5%	12%	12%	11%	NA†
2	22%	26%	22%	31%	35%	31%	
>3	70%	62%	73%	56%	53%	56%	
Acuity							
Elective	82%	36%	76%	92%	51%	NA†	23%
Urgent	10%	56%	17%	4%	42%		72%
Emergent		9%	7%	2%	7%		5%
Emergency	7%			2%			
Salvage	1%						
Level 1 Variables							
Height (cm)	168	170	175	172	1.92 (BSA)	171	NA
Weight (kg)	82	80	84	80	NA	80	NA
PTCA on current admission	3%	NA	3%	8%	NA	7%	5.5%
Myocardial infarction							
None	54%	39%	40%	40%	NA	NA	NA
≤24 h	3%	2%		2%			
24–48 h		1%		1%			
2–7 days		6%	5%	7%			
>1 wk	43%	52%	55%	50%			
Angina class (CCS)							
I	2%	2%	5%	43%	NA	NA	NA
II	15%	6%	12%	17%			
III	46%	39%	39%	14%			
IV	38%	53%	44%	26%			
Ventricular arrythmias	6%	3%	NA	NA	NA	0.1%	2.5%
Congestive heart failure (NYHA)							
I	NA		65%	93%	NA		
II	NA	Any: 15%	22%	3%		Any: 8%	Any: 7%
III	NA		10%	2%			
IV	NA		3%	1%			
Mitral regurgitation							
None	98%	NA	NA	87%	NA	47%	NA
Mild	1%			7%		10%	
Moderate	0.2%			1%		9%	
Severe	0.1%			0.3%		1%	
Missing	0%			4.7%		38%	
Diabetes	25%	24%	25%	23%	18%	21%	35%
Cerebrovascular disease	4%‡	12%	17%	10%	NA	NA	3%
Peripheral vascular disease	NA	15%	21%	13%	6%	NA	8%
COPD	11%	17%	21%	NA	11%	NA	4%
Creatinine (mg/dl)	NA	NA	1.2	NA	NA	NA	NA

*>90% stenosis. †Not available for tabulation available for multivariable model. ‡Stroke only. Both = in-hospital (hosp) and 30-day mortality; BSA = body surface area; CCS = Canadian Cardiovascular Society; COPD = chronic obstructive pulmonary disease; Duke = Duke University; LV = left ventricular; MN = Minnesota; NA = not available; NJ = New Jersey; NNE = Northern New England; NY = New York; NYHA = New York Heart Association classification; PTCA = percutaneous transluminal coronary angioplasty; STS = Society of Thoracic Surgeons; VA = Veterans Affairs. Unless otherwise indicated, data presented are percent of patients.

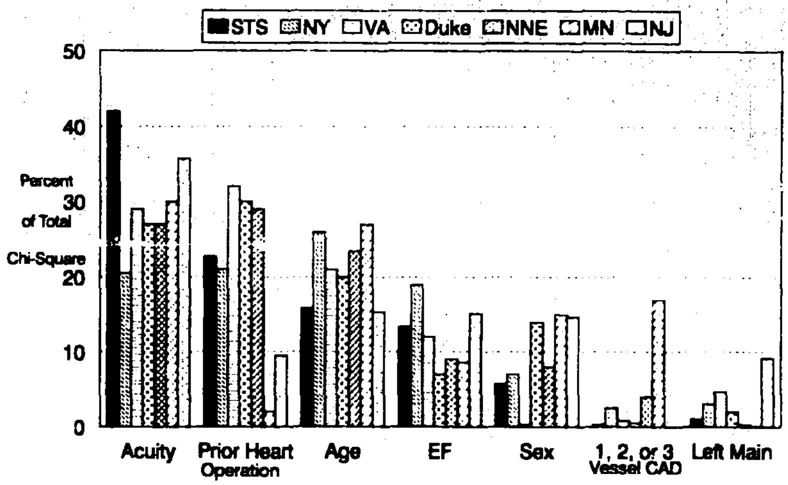

Figure 3. Percent of total chi-square contributed by each of the seven core variables in individual multivariable models from seven separate data bases reflects the relative importance of these core variables in predicting mortality 30 days after CABG. CAD = coronary artery disease; EF = ejection fraction; Duke = Duke University; MN = Minnesota; NJ = New Jersey; NNE = Northern New England; NY = New York; STS = Society of Thoracic Surgeons; VA = Veterans Affairs.

The first three of these variables were comparable in importance to the two least important core variables (left main coronary disease and number of diseased vessels). This variability is also reflected in the predictive ability of these models. Table 3 demonstrates that the c-index for the core variable model ranges from 0.722 in the Veterans Affairs data base to 0.789 in the Duke data base. Adding the level 1 variables brings the minimal c-index to 0.748 and adds between 0 and 0.071 to the discriminatory ability of the model.

Discussion

Need for standardization of data base variables. Optimization of information content in clinical data bases occurs incrementally through an iterative process characterized by alternate phases of information storage and system revision (22). Because data must be collected on a variable to determine its clinical importance, initial data bases commonly include a large number of variables that later prove to have little or no value. After a period of data collection by uniform methodology and assessment of the usefulness of the accumulated information, the efficiency of the data base may be enhanced by deleting unimportant variables and redefining or adding new ones that appear promising. Unfortunately, practical considerations often limit the frequency of revisions of data base content. Substantial effort is required to create a functional data base, and the added work of reeducating and maintaining the enthusiasm of all who contribute data often appears to outweigh the benefit of continual refinement and simplification of the approach for recording information. This

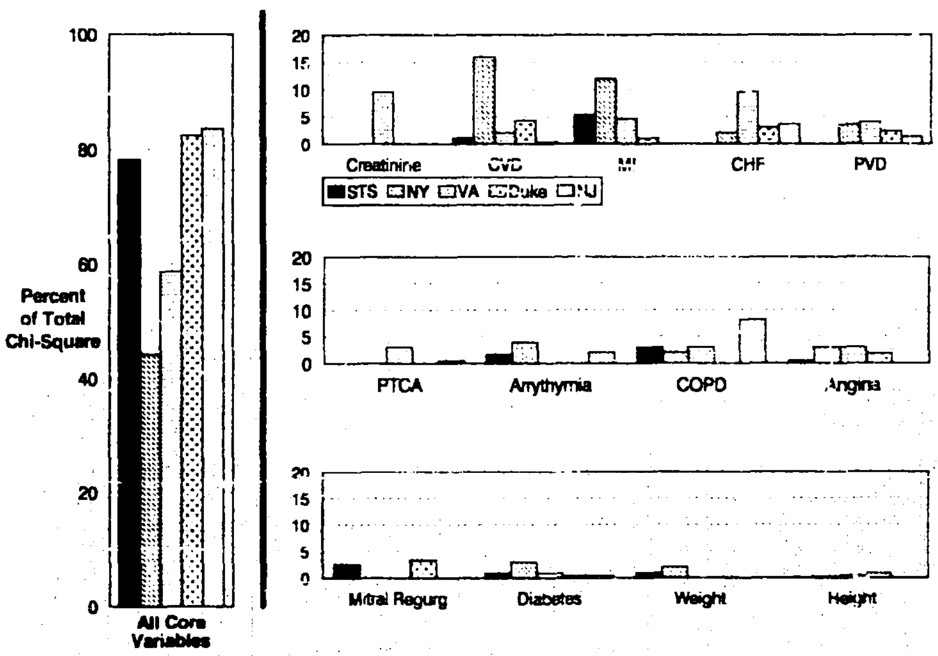

Figure 4. Percent of total chi-square contributed by the combined seven core variables and each of the 13 level 1 variables in individual multivariable models from five separate data bases reflects the relative importance of all core and individual level 1 variables in predicting mortality 30 days after CABG. CHF = congestive heart failure; CVD = cerebrovascular disease; PVD = peripheral vascular disease; Regurg = regurgitation; other abbreviations as in Figures 1 and 3.

Table 3. C-Index for Each Tested Data Set (core versus level 1 variables)

	STS	NY	VA	Duke	NNE	MN	NJ
Core only	0.759	0.768	0.722	0.789	0.780	0.752	0.782
Core + level 1	0.795	0.839	0.748	0.818	0.796	NA	0.782
Difference	0.036	0.071	0.026	0.029	0.016	NA	0

Abbreviations as in Table 2.

tendency to collect information of limited or no value is also fueled by the widespread conviction that all clinical information must somehow have use and therefore should be recorded even though this use cannot be defined.

Participants in this consensus effort, with extensive experience in collection of clinical information related to short-term mortality after CABG recognized a need for uniform definitions and statements of relative importance of those individual variables known to be related to mortality soon after CABG. Sharing of knowledge and comparison of information in existing data bases of patients undergoing CABG allowed participants to converge on a small number of useful variables among the many considered. Moreover, two or three core variables appear to reflect one-half or more of the total predictive information, and adding variables by level of importance in each data set showed each subsequent variable to contribute substantially less information predictive of short-term mortality. Therefore, short lists of variables could be constructed for each data set that contained most of the predictive power. This work supports the general conclusion that devoting effort to consistently collecting data on a small number of well defined variables is preferable to less focused attention to a wide range of clinical information.

Many existing data bases for monitoring short-term CABG mortality contain many more variables than those concluded to be important by this consensus effort. This list of most important variables with objective definitions provides a useful starting point to refine and simplify variable lists that may eliminate a large amount of work now devoted to the collection of unimportant data. Individuals and institutions desiring to start a new data base for monitoring short-term CABG mortality will benefit greatly by initially designing a simple data base to include a small set of the most important variables. After this initial information finds use in improving the quality of care for patients undergoing CABG, the data base can be expanded to include and test the added value of other variables. The process of converging on a uniform set of variables and definitions will facilitate future sharing of data among data bases. Future comparisons among data bases will further refine our understanding of important prognostic variables in CABG.

Clinical implications of this work. This consensus process did not address the multiple considerations for the patient, practitioner and society relating to the benefit or detriment of reporting risk-stratified mortality data for CABG (23). However, reporting CABG outcomes to the public is ongoing in many areas and appears to be increasingly used throughout the country (24,25). To increase the quality of health care in this country, it is equally important that high risk patients not be denied the potential benefit of CABG because of the negative impact on the mortality rate of a surgeon and that a surgeon not be able to hide an unacceptable mortality rate behind a risk stratification algorithm that can be easily manipulated. Identification and definition of a common set of variables are essential to make the process accurate and fair. Risk adjustment models carefully constructed with optimal derivation, definition and weight of variables still do not accurately describe risk in all patients. Models derived from important common variables do not accurately predict risk for patients with characteristics that occur infrequently in populations, yet are strongly related to short-term mortality in an individual patient after CABG. Examples of this type of variable include specific coagulopathy, constrictive pericarditis and calcification of the ascending aorta. These and other similar variables will not be identified as important for large populations because of their rare occurrence, but they represent important variables expressing risk when present in an individual patient. However, use of simple models emphasizing variables that reflect risk in most patients will facilitate identification and evaluation of the importance of other variables that occur only occasionally.

The purpose of this project was not to advocate immediate implementation of a common system of preoperative risk assessment for patients undergoing CABG. This set of variables and definitions provides uniform standards for data that can be collected for the purpose of reporting risk-adjusted outcomes of CABG for individual surgeons and institutions. However, the data describing the relative weights of these variables in existing data bases cannot be used for risk adjustment because of the retrospective review of data collected without uniform definitions. Appropriate models using these specific definitions will need to be prospectively developed for this purpose if this use is desired.

Appendix

Participants in the Cooperative CABG Database Project

Duke University Cardiovascular Database, Durham, North Carolina: Robert M. Califf, MD, Elizabeth R. DeLong, PhD, Robert H. Jones, MD, Karen Kesler, MS,* Lawrence H. Muhlbaier, PhD, Eric Peterson, MD, MPH, David B. Pryor, MD, Lynne Skaryak, MD, L. Richard Smith, PhD. **Health Care Financing Administration, Baltimore, MD:** Stephen Jencks, MD, R. Clifton Bailey, PhD. **Society of Cardiac Angiography and Interventions, St. Louis, MO:** Ronald J. Krone, MD. **New England Medical Center, Boston, MA:** Stephen G. Pauker, MD, John B. Wong, MD. **New York State Database, Rensselaer, NY:** Edward L. Hannan, PhD, Dinesh Kumar, MS.* **Northern New England Cardiovascular Disease Study Group, Hanover, NH:** Gerald T. O'Connor, PhD, DSc, Hebe Quinton, MS.* **St. Vincent Hospital and Medical Center, Portland, OR:** Peter C. Block, MD. **Society of Thoracic Surgeons Database, Chicago, IL:** Richard E. Clark, MD, Fred H. Edwards, MD, Marc Schwartz, BS.* **State of New Jersey Department of Health, Trenton, New Jersey:** Anne R. Davis, PhD. **Newark Beth**

*Participants providing statistical support.

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References

1. Favaloro RG. Saphenous vein graft in the surgical treatment of coronary artery disease: operative technique. J Thorac Cardiovasc Surg 1969;58:178-85.
2. Jones RH. In search of the optimal surgical mortality. Circulation 1989;79 Suppl I:I-132-6.
3. Daley J. Criteria by which to evaluate risk-adjusted outcomes programs in cardiac surgery. Ann Thorac Surg 1994:58:1827-35.
4. Edwards FH, Clark RE, Schwartz M. Coronary artery bypass grafting: the Society of Thoracic Surgeons National Database experience. Ann Thorac Surg 1994;47:12-9.
5. Clark RE. The Society of Thoracic Surgeons National Database status report. Ann Thorac Surg 1994;57:20-6.
6. Clark RE. Definitions of terms of the Society of Thoracic Surgeons National Cardiac Surgery Database. Ann Thorac Surg 1994;58:271-3.
7. Clark RE, Edwards FH, Schwartz M. Profile of preoperative characteristics of patients having CABG over the past decade. Ann Thorac Surg 1994;58:1863-5.
8. Hannan EL, Kilburn H Jr, O'Donnell JF, Lukacik G, Shields EP. Adult open heart surgery in New York State: an analysis of risk factors and hospital mortality rates. JAMA 1990;264:2768-74.
9. Hannan EL, Kumar D, Racz M, Siu AL, Chassin MR. New York State's cardiac surgery reporting system: four years later. Ann Thorac Surg 1994:58:1852-7.
10. Hannan EL, Kilburn H Jr, Racz M, Shields E, Chassin MR. Improving the outcomes of coronary artery bypass surgery in New York State. JAMA 1994;271:761-6.
11. Hannan EL, Siu AL, Kumar D, Kilburn H Jr, Chassin MR. The decline in coronary artery bypass graft surgery mortality in New York State. JAMA 1995;273:209-13.
12. Grover FL, Hammermeister KE, Burchfiel C, and cardiac surgeons of the Department of Veterans Affairs. Initial report of the Veterans Administration preoperative risk assessment study for cardiac surgery. Ann Thorac Surg 1990;50:12-28.
13. Grover FL, Johnson RR, Marshall G, Hammermeister KE, and Department of Veterans Affairs cardiac surgeons. Factors predictive of operative mortality among coronary artery bypass subsets. Ann Thorac Surg 1993;56:1296-307.
14. Califf RM, Phillips HR III, Hindman MC, et al. Prognostic value of a coronary artery jeopardy score. J Am Coll Cardiol 1985;5:1055-63.
15. Mark DB, Nelson CL, Califf RM, et al. The continuing evolution of therapy for coronary artery disease: initial results from the era of coronary angioplasty. Circulation 1994;89:2015-25.
16. Smith LR, Harrell FE Jr, Rankin JS, et al. Determinants of early vs late cardiac death in patients undergoing coronary artery bypass surgery. Circulation 1991;84 Suppl III:III-245-53.
17. Jones RH, Kesler K, Phillips HR III, et al. Long-term survival benefits of coronary artery bypass grafting and percutaneous transluminal angioplasty in patients with coronary artery disease. J Thorac Cardiovasc Surg 1996;111:1013-25.
18. O'Connor GT, Plume SK, Olmstead EM, Coffin LH, et al. Multivariate prediction of inhospital mortality associated with coronary artery bypass graft surgery. Circulation 1992;85:2110-8.
19. O'Connor GT, Morton JR, Diehl MJ, Olmstead EM, et al. Differences between men and women in hospital mortality associated with coronary artery bypass graft surgery. Circulation 1993;88(Pt 1):2104-10.
20. Doliszny KM, Luepker RV, Burke GL, Pryor DB, Blackburn H. Estimated contribution of coronary artery bypass graft surgery to the decline in coronary heart disease mortality: the Minnesota Heart Survey. J Am Coll Cardiol 1994;24:95-103.
21. Parsonnet V, Dean D, Bernstein AD. A method of uniform stratification of risk for evaluating the results of surgery in acquired adult heart disease. Circulation 1989:79 Suppl I:I-3-12.
22. Steen PM. Approaches to predictive modeling. Ann Thorac Surg 1994:58:1836-40.
23. Topol EJ, Califf RM. Scorecard cardiovascular medicine. Ann Intern Med 1994;120:65-70.
24. A Consumer Guide to Coronary Artery Bypass Graft Surgery. Harrisburg (PA): The Pennsylvania Health Care Cost Containment Council, 1991.
25. Coronary Artery Bypass Graft Surgery. Hospital and Physician Comments. Vol. II. Harrisburg (PA): The Pennsylvania Health Care Cost Containment Council, 1994.