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Risk factors adversely impacting post coronary artery bypass grafting longer-term *vs.* shorter-term clinical outcomes

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Abstract

Aim: Coronary artery bypass grafting (CABG) patients' characteristics and surgical techniques associated with short-term (ST; < 1 year) mortality are well documented; however, the literature pinpointing factors predictive of longer-term (LT; ≥ 1 year) death rates are more limited. Thus, the CABG factors associated with ST *vs.* LT mortality were compared.

Methods: Using advanced PubMed search techniques, the factors associated with improved post-CABG mortality were compared for ST *vs.* LT prediction models; ST *vs.* LT models' results were compared across three time periods: until 1997, 1998-2007, and 2007-2017.

Results: Of 156 post-CABG mortality risk models (*n* = 125 publications), 133 ST and 23 LT models were evaluated. Important predictors consistently included age, ejection fraction, and renal dysfunction/dialysis. The ST models more commonly identified surgical priority, gender, and prior cardiac surgery; however, the LT models more frequently included diabetes and peripheral arterial disease. Compared to ST mortality, patterns also emerged for cerebrovascular disease and chronic lung disease predicting LT mortality. As modifiable risks, body mass index or another marker of body habitus appeared in 31/133 (23%) of ST models; smoking or tobacco use was considered in only 4/133 (3%). No models evaluated compliance with ischemic heart disease guidelines. No time period-related differences were found.

Conclusion: Different risk factors predicted ST *vs.* LT post-CABG mortality; for LT death, debilitating chronic/complex comorbidities were more often reported. As few models focused on identifying modifiable patient risks or ischemic heart disease guideline compliance, future CABG LT risk modeling should address these knowledge gaps.

Keywords: Coronary artery bypass graft surgery, risk assessment, outcomes research, survival, mortality

INTRODUCTION

Over the past 60 years, much has changed in the healthcare field. Increasingly, attention is being paid to healthcare quality with the goals of improving clinical outcomes and increasing value of care delivered. A special emphasis in quality improvement has been placed on high volume procedures such as coronary artery bypass grafting (CABG). Although CABG volumes have declined from ~213,700 procedures (2011) to ~156,900 procedures (2016), it remains the most common cardiac surgical procedure performed in the United States[1-3]. To evaluate the true value of CABG, longer-term outcomes are necessary to establish the durability of the procedure. Accordingly, the baseline patient risk factors associated with short-term (< 1 year) and longer-term (≥ 1 year) CABG mortality were compared.

Interpreting CABG clinical outcomes data can often be challenging, as there may be a wide range in pre-CABG patient's severity of coronary disease or comorbidity-related disease complexity, variations in CABG operative techniques used or post-CABG pre-discharge patient care management, as well as provider-based variations for annual CABG volumes performed. In 1972, the Department of Veterans Affairs (VA) healthcare system began internally reporting national unadjusted outcome rates (e.g., "observed" in-hospital mortality rates) for patients undergoing cardiac surgery at its institutions; these first VA reports focused upon observed CABG mortality and post-CABG complication rates[4].

After US hospitals' CABG mortality reports were made publicly available by the Department of Health and Human Services in 1985, Congress in 1986 mandated that the VA report risk-adjusted cardiac surgery mortality rates and compare these VA rates to national standards[5]. Given these legislation-driven mandates, VA clinicians and scientists began looking for ways to "level the playing field" using statistical risk models to permit more meaningful comparisons between centers and surgeons; these risk-adjusted outcome reports were used in their local VA medical centers' quality improvement endeavors.

Initiated in April 1987, the VA Continuous Improvement in Cardiac Surgery Program (CICSP) was founded; CICSP was one of the first registries to report risk-adjusted CABG 30-day operative mortality and major morbidity across all participating VA hospitals[4]. The VA CICSP identified a set of Veteran risk characteristics associated with CABG adverse outcomes; based on gathering 54 patients' risk, cardiac surgical procedural details, and hospital-related outcomes, the VA CICSP calculated the "expected" mortality occurrence for each Veteran undergoing a CABG procedure. Across providers and "high-risk" patient sub-groups, therefore, "observed" to "expected" outcome rates were compared to identify opportunities to improve their local VA cardiac surgical care[6].

Some of the earliest lists of pre-CABG patient risk factors associated with mortality were developed entirely based on expert consensus. As different national, regional, and state-wide databases originally gathered different sets of patient risk factors, an early consensus conference was held to identify the minimal set of "core" risk variables required to be captured[7,8]. Given challenges encountered with CABG records' data completeness, however, these earliest mathematical approaches to calculate risk-adjusted outcome rates made use of Bayes theorem[9]. Since the VA's programmatic expansions in 1992, dramatic improvements were made in the VA completeness of CABG data captured; thus, logistic regression emerged as the most common analytical approach used. Other approaches have been reported, including applications of neural networks and Cox regression[10,11]. Given both the ease of clinical interpretation and superior statistical model performance, however, logistic regression remains the standard analytical approach used to predict post-CABG short-term (ST) and longer-term (LT) mortality[12-14].

Historically, the process of choosing logistic regression eligible ("candidate") risk variables was different for each CABG registry. As this pre-selection candidate variable approach may have introduced subjectivity and biased model results, CABG risk models (such as those developed by the VA, Society of Thoracic Surgeons, and EuroSCORE teams) have been derived in recent years using a standardized approach with a core set of model eligible variables. Beyond this core set, however, each database incorporates an expanded set of population-specific risk variables in their risk modeling processes.

Over the past 30 years, nearly countless CABG risk models with various designs and complexity have been developed to predict the likelihood of death at pre-specified time periods. As the standard ST endpoint used, operative mortality was defined as death within 30 days or within the index hospitalization. As operative mortality avoids any potential post-discharge referral bias (e.g., post-CABG hospital discharge to a separate sub-acute care facility), this endpoint was determined to be the most clinically relevant performance metric; it is commonly used to assess the quality of the surgical procedure. Other models have considered LT death during longer periods of follow-up, investigating the durability of the CABG procedure and importance of other risk factors. For ST and LT published risk models, therefore, this study describes the patterns in pre-CABG factors differentially impacting ST *vs.* LT mortality. Until this report, these patterns had not been previously described. Moreover, this novel report identifies additional opportunities to improve future CABG risk models.

METHODS

An advanced literature review was undertaken to document published risk factors associated with post-CABG mortality. In February 2019, PubMed was searched for all Medline publications using the following terms: "CABG" (Title) OR "coronary artery bypass" (Title) AND "mortality" (Title) OR "risk" (Title) OR "death" (Title) OR "survival" (Title). This yielded 1904 publications. Following a review of all articles for pre-stated inclusion/exclusion criteria, there were a total of 125 included articles with 156 CABG mortality models. Only papers reporting risk models for mortality after an isolated CABG procedure were included; inclusion criteria were otherwise left intentionally broad so as to gather a wide variety of models. Models requiring data from the postoperative period were excluded for the purpose of this review, whereas those employing only preoperative variables [as opposed to preoperative and intraoperative variables (e.g., cardiopulmonary bypass time)] were identified for sub-analysis review. For the 125 publications meeting all inclusion/exclusion criteria, their reference lists were also carefully reviewed for relevant publications to augment the original search strategy's findings.

Working collaboratively under the senior co-authors' guidance, the majority of literature search screening and data extraction were performed primarily by one author (BC). To permit meaningful model comparisons, risks were classified into 91 different common clinical categories. Clinically relevant composite variables were reported based upon database-specific definitions (e.g., "critical preoperative state" and "extra-cardiac arteriopathy"). Named risk indices (e.g., "Elixhauser Comorbidity Index") were analyzed using their assigned name as a group, rather than being recorded based upon the indices' subcomponents. For the 125 publications evaluated, the set of risk factors identified to be associated with post-CABG ST or LT mortality were compared. Time trends in models' risk factors reported were evaluated across three time periods until 1997, 1998-2007, and 2007-2017.

RESULTS

One hundred fifty-six post-CABG mortality risk models were identified within 125 different papers. In Appendix A, the full listing of these papers and models can be found in Supplementary Tables 1 and 2.

Of these models, 133 predicted ST CABG mortality. Operative mortality was the most commonly reported ST endpoint, defined as death occurring during the index hospitalization and/or up to 30 days after the index surgical procedure. Twenty-three LT CABG mortality models were identified. The longest period of follow-up was seven years, reported by Wu *et al.*[15] When looking at those models considering only preoperative (i.e., not intraoperative) risk factors, there were 75 ST models and 14 LT models (total = 89). As a pre-planned sub-analysis, risk models considering on-pump *vs.* off-pump CABG and only preoperative risk factors were also compared separately. This identified three ST and one LT models (total = 4). The complete listing of variables for the ST *vs.* LT models with frequency counts is included in Table 1.

Overwhelmingly, age was the most common preoperative variable identified to be predictive of ST post-CABG mortality, reported in 115 of 125 (86%) of those models. Of the articles summarized, 22/156 (14.1%) did not report age as a risk factor. Across these 22 publications, the age-related variability in reporting observed appears to be due in part to their study-specific populations' inherent risk profile. For example, articles focused upon higher risk patient sub-groups (e.g., emergent CABG patients or those experiencing an acute myocardial infarction) commonly did not report age as a post-CABG mortality model finding. Despite this observed pattern, however, there was not a single, simple explanation for the observed inconsistency in age not being reported across all models.

Age was followed by left ventricular ejection fraction (included in 64% of ST mortality models), surgical case priority or status (59%), patient gender (57%), and having undergone a prior cardiac surgical procedure before the index procedure (55%); these represented the top five most common preoperative variables for predicting ST post-CABG mortality. For LT models, the top five risk factors were age, ejection fraction, diabetes mellitus, peripheral arterial disease, and renal failure. There appeared to be a trend toward cerebrovascular disease and lung disease being more commonly reported by CABG risk models focused upon mortality beyond one year (compared with other variables within that same subset of models), perhaps suggesting debilitating chronic and complex comorbidities are more useful in prediction of LT mortality.

When the results were grouped into early, mid, and late subgroups by year of publication [Tables 2-4], age and ejection fraction remained among the most common risk factors for models throughout those time periods. No definite trends over time were observed in risk factor prevalence for the overall group or the ST or LT model subgroups, although sample size may have impacted the ability to detect such trends, particularly within the subgroups. Results were also similar when considering models that included only preoperative risk factors [Table 5] or those that considered on-pump *vs.* off-pump CABG [Table 6].

DISCUSSION

Across the post-CABG follow-up periods, different pre-CABG risk factors predictive of mortality were documented. This literature search revealed dozens of logistic regression models, each reporting different patient risk factors associated with time-varying post-CABG mortality endpoints. As documented by the tables, the ST models found the patient's risk variables related to their severity of coronary disease (e.g., more commonly reported be important predictors), whereas patient's chronic comorbidities (e.g., diabetes, cerebrovascular disease, or pulmonary disease) appeared to be more frequently associated with LT post-CABG mortality. Following one-year post-CABG, life expectancy appears to be most strongly impacted by non-cardiac comorbidities than cardiac factors or surgical processes of care. While optimizing CABG patient selection and surgical techniques may be important ST, optimal management of non-cardiac comorbidities may improve post-CABG patients' LT survival. Moreover, across all follow-up time periods, a patient's age, ejection fraction, and renal function (e.g., creatinine or dialysis dependence) were important predictors of post-CABG mortality; these were consistently reported for the ST and LT mortality time periods.

A special sub-analysis was performed for the sub-group of models comprised of preoperative risk factors along with a variable indicating the on-pump *vs.* off-pump surgical technique. Although there were

Table 1. All data

All models			Short-term models			Long-term models		
Variable	***n* = 156**	**%**	**Variable**	***n* = 133**	**%**	**Variable**	***n* = 23**	**%**
Age	134	86%	Age	115	86%	Age	12	52%
Left ventricular function	104	67%	Left ventricular function	85	64%	Left ventricular function	12	52%
Renal failure	88	56%	Urgency	78	59%	Comb. arterial disease	9	39%
Comb. heart failure variables	84	54%	Gender	76	57%	Diabetes	8	35%
Urgency	84	54%	Renal failure	73	55%	Peripheral arterial disease	8	35%
Gender	83	53%	Comb. heart failure variables	69	52%	Renal failure	7	30%
Comb. arterial disease	76	49%	Repeat operation	68	51%	Comb. heart failure variables	7	30%
Comb. CHF or NYHA	74	47%	Comb. arterial disease	61	46%	Comb. CHF or NYHA	7	30%
Repeat operation	73	47%	Comb. any MI variable	60	45%	Lung disease	5	22%
Comb. any MI variable	65	42%	Comb. CHF or NYHA	60	45%	Neurologic disease	5	22%
History of MI	63	40%	History of MI	59	44%	Congestive heart failure	5	22%
Comb. critical state	62	40%	Comb. critical state	58	44%	Comb. graft variables	5	22%
Peripheral arterial disease	62	40%	Peripheral arterial disease	49	37%	Postoperative variables	5	22%
Diabetes	54	35%	Lung disease	43	32%	Body size measurements	4	17%
Lung disease	52	33%	Comb. vessel disease	43	32%	Comb. vessel disease	4	17%
Comb. vessel disease	51	33%	Diabetes	40	30%	Type of graft(s)	4	17%
Neurologic disease	49	31%	Neurologic disease	39	29%	Smoking status	4	17%
Congestive heart failure	47	30%	Congestive heart failure	37	28%	Gender	3	13%
Body size measurements	39	25%	Body size measurements	31	23%	Urgency	3	13%
Left main disease	36	23%	Cardiogenic shock	30	23%	Comb. any MI variable	3	13%
Cardiogenic shock	34	22%	NYHA class	29	22%	Left main disease	3	13%
NYHA class	33	21%	Left main disease	29	22%	Repeat operation	2	9%
Number of diseased vessels	30	19%	Number of diseased vessels	27	20%	NYHA class	2	9%
Comb. ECG or arrhythmia variables	29	19%	Comb. ECG or arrhythmia variables	26	20%	History of MI	2	9%
Preoperative IABP use	27	17%	Concurrent procedure	26	20%	Valve disease	2	9%
Concurrent procedure	26	17%	Preoperative IABP use	24	18%	Hypertension	2	9%
Angina	26	17%	Angina	23	17%	Comb. HTN or BP	2	9%
Comb. HTN or BP	25	16%	Comb. HTN or BP	21	16%	Atrial arrhythmia	2	9%
Comb. PCI variables	24	15%	Comb. PCI variables	21	16%	Hypercholesterolemia	2	9%
Hypertension	24	15%	Hypertension	20	15%	Intraoperative variables	2	9%
Postoperative variables	22	14%	Pulmonary hypertension	19	14%	Ventricular wall motion	1	4%
Comb. graft variables	20	13%	Non-CABG surgery	18	14%	Calcified aorta	1	4%
Pulmonary hypertension	19	12%	Postoperative variables	17	13%	Angina	1	4%
Valve disease	19	12%	Any arrhythmia	16	12%	Active MI	1	4%
Non-CABG surgery	18	12%	Valve disease	15	11%	Number of diseased vessels	1	4%
Any arrhythmia	17	11%	Comb. graft variables	14	11%	Diffuse/severe disease	1	4%
Inotropic medication	15	10%	Extracardiac arteriopathy	12	9%	Number of grafts	1	4%
Prior/recent PCI or PTCA	15	10%	Inotropic medication	12	9%	Race or ethnicity	1	4%

Atrial arrhythmia	13	8%	Cardiopulmonary bypass time	12	9%	Preoperative IABP use	1	4%
Type of graft(s)	13	8%	Prior/recent PCI or PTCA	12	9%	Inotropic medication	1	4%
Extracardiac arteriopathy	13	8%	Nitroglycerin use	10	8%	Comb. critical state	1	4%
Cardiopulmonary bypass time	12	8%	Critical state	10	8%	Cardiogenic shock	1	4%
Race or ethnicity	11	7%	Preoperative diuretic use	9	7%	Immunosuppression	1	4%
Ventricular or unstable arrhythmia	10	6%	Type of graft(s)	9	7%	Date or order of surgery	1	4%
Preoperative diuretic use	10	6%	Liver disease	9	7%	Aortic cross-clamp duration	1	4%
Critical state	10	6%	Cardiomegaly	9	7%	On- *vs.* off-pump CABG	1	4%
Liver disease	10	6%	Atrial arrhythmia	9	7%	Prior/recent PCI or PTCA	1	4%
Smoking status	10	6%	Diffuse/severe disease	8	6%	Comb. PCI variables	1	4%
Nitroglycerin use	10	6%	PTCA failure/emergency	8	6%	Ventricular or unstable arrhythmia	1	4%
Diffuse/severe disease	9	6%	Ventricular or unstable arrhythmia	8	6%	Comb. ECG or arrhythmia variables	1	4%
Immunosuppression	9	6%	Preop intubation	8	6%	Preoperative thrombolysis	1	4%
Cardiomegaly	9	6%	Race or ethnicity	7	5%	Left ventricular hypertrophy	1	4%
PTCA failure/emergency	8	5%	On- *vs.* off-pump CABG	7	5%	Cachexia or malnutrition	0	0%
Preop intubation	8	5%	Endocarditis	7	5%	Pulmonary hypertension	0	0%
On- *vs.* off-pump CABG	8	5%	Dyspnea	6	5%	Extracardiac arteriopathy	0	0%
Number of grafts	8	5%	Number of grafts	6	5%	Dyspnea	0	0%
Intraoperative variables	7	4%	Immunosuppression	6	5%	Type of MI	0	0%
Endocarditis	7	4%	Aortic cross-clamp duration	5	4%	Pulmonary rales	0	0%
Aortic cross-clamp duration	7	4%	Intraoperative variables	5	4%	Preoperative diuretic use	0	0%
Dyspnea	6	4%	Pulmonary rales	4	3%	Killip classification	0	0%
Date or order of surgery	6	4%	Smoking status	4	3%	Blood pressure	0	0%
Digoxin or digitalis use	5	3%	Anticoagulation or antiplatelet use	4	3%	Nitroglycerin use	0	0%
Hypercholesterolemia	5	3%	Disaster, catastrophic state	4	3%	Liver disease	0	0%
Disaster, catastrophic state	4	3%	Anemia (hemoglobin, hematocrit)	4	3%	Cardiopulmonary bypass time	0	0%
Pulmonary rales	4	3%	Digoxin or digitalis use	4	3%	Cardiomegaly	0	0%
Active MI	4	3%	A published comorbidity index	4	3%	Preoperative CPR/cardiac arrest	0	0%
Ventricular wall motion	4	3%	Other preoperative comorbidities	4	3%	Location or type of surgical center	0	0%
Other preoperative comorbidities	4	3%	Ventricular wall motion	3	2%	Center's case frequency	0	0%
A published comorbidity index	4	3%	Active MI	3	2%	Endocarditis	0	0%
Anemia (hemoglobin, hematocrit)	4	3%	Preoperative CPR/cardiac arrest	3	2%	Abdominal aortic aneurysm	0	0%
Anticoagulation or antiplatelet use	4	3%	Location or type of surgical center	3	2%	PTCA failure/emergency	0	0%
Serum albumin	3	2%	Hypercholesterolemia	3	2%	Stent thrombosis	0	0%
Other preoperative labs	3	2%	Refused blood products	3	2%	Any family history variable	0	0%
Refused blood products	3	2%	Other preoperative labs	3	2%	Any arrhythmia	0	0%
Location or type of surgical center	3	2%	Serum albumin	3	2%	Antiarrhythmic agents	0	0%
Preoperative CPR/cardiac arrest	3	2%	Cachexia or malnutrition	2	2%	Other ECG abnormalities	0	0%
Preoperative thrombolysis	2	1%	Type of MI	2	2%	Non-CABG surgery	0	0%
Other ECG abnormalities	2	1%	Date or order of surgery	2	2%	Anticoagulation or antiplatelet use	0	0%
Stent thrombosis	2	1%	Abdominal aortic aneurysm	2	2%	PT or INR	0	0%

Type of MI	2	1%	Stent thrombosis	2	2%	Critical state	0	0%
Calcified aorta	2	1%	Any family history variable	2	2%	Disaster, catastrophic state	0	0%
Cachexia or malnutrition	2	1%	Other ECG abnormalities	2	2%	Anemia (hemoglobin, hematocrit)	0	0%
Recent admissions	2	1%	Steroid use	2	2%	Transfusion	0	0%
Patient education level/literacy	2	1%	Preoperative cardiac biomarkers	2	2%	Refused blood products	0	0%
Preoperative cardiac biomarkers	2	1%	Patient education level/literacy	2	2%	Digoxin or digitalis use	0	0%
Steroid use	2	1%	Calcified aorta	1	1%	Preop intubation	0	0%
Heart rate	2	1%	Killip classification	1	1%	Concurrent procedure	0	0%
Any family history variable	2	1%	Blood pressure	1	1%	A published comorbidity index	0	0%
Abdominal aortic aneurysm	2	1%	Center's case frequency	1	1%	Heart rate	0	0%
Transfusion	1	1%	Antiarrhythmic agents	1	1%	Steroid use	0	0%
PT or INR	1	1%	Preoperative thrombolysis	1	1%	Preoperative cardiac biomarkers	0	0%
Antiarrhythmic agents	1	1%	PT or INR	1	1%	Other preoperative labs	0	0%
Center's case frequency	1	1%	Transfusion	1	1%	Serum albumin	0	0%
Blood pressure	1	1%	Heart rate	1	1%	Other preoperative comorbidities	0	0%
Killip classification	1	1%	ACE inhibitor use	1	1%	ACE inhibitor use	0	0%
Acute mental status changes	1	1%	ASA classification	1	1%	Functional state	0	0%
Time from admission to procedure	1	1%	Insurance type or status	1	1%	Patient education level/literacy	0	0%
Left ventricular hypertrophy	1	1%	Recent admissions	1	1%	ASA classification	0	0%
Insurance type or status	1	1%	Time from admission to procedure	1	1%	Insurance type or status	0	0%
ASA classification	1	1%	Acute mental status changes	1	1%	Recent admissions	0	0%
Functional state	1	1%	Functional state	0	0%	Time from admission to procedure	0	0%
ACE inhibitor use	1	1%	Left ventricular hypertrophy	0	0%	Acute mental status changes	0	0%
Total variables (excl. combinations)	92		Total variables (excl. combinations)	90		Total variables (excl. combinations)	42	

Comb: combination variable; CHF: congestive heart failure; NYHA: New York Heart Association; MI: myocardial infarction; ECG: electrocardiogram; IABP: intra-aortic baloon pump; HTN: hypertension; BP: blood pressure; PCI: percutaneous coronary intervention; PTCA: percutaneous transluminal coronary angioplasty; CPR: cardiopulmonary resuscitation; ASA: American Society of Anethesiology; ACE: angiotensin converting enzyme; INR: international normalized ratio; PT: prothromin time

Table 2. All risk models by publication year

≤ 1997			1998-2007				2008-2017				
Variable	***n* = 41**	**%**	**Variable**	***n* = 54**	**%**	**Δa**	**Variable**	***n* = 61**	**%**	**Δa**	**Δb**
Age	37	90%	Age	44	81%	-9%	Age	53	87%	-3%	5%
Repeat operation	24	59%	Left ventricular function	40	74%	18%	Left ventricular function	41	67%	11%	-7%
Comb. heart failure variables	24	59%	Renal failure	36	67%	25%	Renal failure	35	57%	16%	-9%
Left ventricular function	23	56%	Gender	31	57%	11%	Urgency	34	56%	7%	0%
History of MI	22	54%	Urgency	30	56%	7%	Gender	33	54%	8%	-3%
Comb. any MI variable	22	54%	Comb. heart failure variables	30	56%	-3%	Comb. arterial disease	32	52%	13%	1%
Comb. CHF or NYHA	21	51%	Comb. arterial disease	28	52%	13%	Comb. heart failure variables	30	49%	-9%	-6%
Urgency	20	49%	Repeat operation	25	46%	-12%	Comb. critical state	30	49%	20%	12%
Gender	19	46%	Comb. any MI variable	25	46%	-7%	Comb. CHF or NYHA	28	46%	-5%	0%
Renal failure	17	41%	Comb. CHF or NYHA	25	46%	-5%	Peripheral arterial disease	25	41%	2%	2%

Peripheral arterial disease	16	39%	Diabetes	24	44%	22%	Repeat operation	24	39%	-19%	-7%
Comb. arterial disease	16	39%	History of MI	24	44%	-9%	Diabetes	21	34%	12%	-10%
Lung disease	15	37%	Lung disease	22	41%	4%	Comb. any MI variable	18	30%	-24%	-17%
Comb. vessel disease	15	37%	Neurologic disease	21	39%	5%	History of MI	17	28%	-26%	-17%
Neurologic disease	14	34%	Peripheral arterial disease	21	39%	0%	Cardiogenic shock	16	26%	12%	4%
Congestive heart failure	14	34%	Comb. vessel disease	21	39%	2%	Lung disease	15	25%	-12%	-16%
Angina	13	32%	Comb. critical state	20	37%	8%	NYHA class	15	25%	0%	10%
Comb. critical state	12	29%	Congestive heart failure	19	35%	1%	Comb. vessel disease	15	25%	-12%	-14%
Body size measurements	11	27%	Body size measurements	18	33%	7%	Neurologic disease	14	23%	-11%	-16%
Left main disease	11	27%	Left main disease	18	33%	7%	Congestive heart failure	14	23%	-11%	-12%
Comb. ECG or arrhythmia variables	11	27%	Comb. HTN or BP	14	26%	11%	Number of diseased vessels	12	20%	3%	-1%
NYHA class	10	24%	Hypertension	13	24%	9%	Preoperative IABP use	12	20%	3%	5%
Diabetes	9	22%	Cardiogenic shock	12	22%	8%	Concurrent procedure	11	18%	3%	1%
Number of diseased vessels	7	17%	Postoperative variables	12	22%	15%	Body size measurements	10	16%	-10%	-17%
Preoperative IABP use	7	17%	Number of diseased vessels	11	20%	3%	Comb. PCI variables	10	16%	2%	2%
Valve disease	6	15%	Comb. ECG or arrhythmia variables	11	20%	-6%	Atrial arrhythmia	10	16%	14%	13%
Hypertension	6	15%	Pulmonary hypertension	10	19%	9%	Valve disease	9	15%	0%	7%
Nitroglycerin use	6	15%	Concurrent procedure	9	17%	2%	Inotropic medication	9	15%	7%	9%
Cardiomegaly	6	15%	NYHA class	8	15%	-10%	Angina	8	13%	-19%	4%
Cardiogenic shock	6	15%	Preoperative IABP use	8	15%	-2%	Race or ethnicity	7	11%	11%	4%
Non-CABG surgery	6	15%	Comb. graft variables	8	15%	0%	Left main disease	7	11%	-15%	-22%
Concurrent procedure	6	15%	Comb. PCI variables	8	15%	0%	Postoperative variables	7	11%	4%	-11%
Diffuse/severe disease	6	15%	Preoperative diuretic use	7	13%	6%	Extracardiac arteriopathy	7	11%	11%	0%
Comb. graft variables	6	15%	Any arrhythmia	7	13%	1%	Comb. ECG or arrhythmia variables	7	11%	-15%	-9%
Comb. HTN or BP	6	15%	Prior/recent PCI or PTCA	6	11%	4%	On- *vs*. off-pump CABG	6	10%	10%	6%
Comb. PCI variables	6	15%	Non-CABG surgery	6	11%	-4%	Prior/recent PCI or PTCA	6	10%	3%	-1%
Cardiopulmonary bypass time	5	12%	Intraoperative variables	6	11%	11%	Non-CABG surgery	6	10%	-5%	-1%
Any arrhythmia	5	12%	Extracardiac arteriopathy	6	11%	11%	Critical state	6	10%	10%	2%
Pulmonary hypertension	4	10%	Type of graft(s)	6	11%	4%	Comb. graft variables	6	10%	-5%	-5%
Pulmonary rales	4	10%	Angina	5	9%	-22%	Pulmonary hypertension	5	8%	-2%	-10%
Number of grafts	3	7%	Endocarditis	5	9%	4%	Hypertension	5	8%	-6%	-16%
Liver disease	3	7%	Ventricular or unstable arrhythmia	5	9%	2%	Smoking status	5	8%	6%	1%
Aortic cross-clamp duration	3	7%	Valve disease	4	7%	-7%	Immunosuppression	5	8%	6%	3%
Prior/recent PCI or PTCA	3	7%	Race or ethnicity	4	7%	7%	Comb. HTN or BP	5	8%	-6%	-18%
Anemia (hemoglobin, hematocrit)	3	7%	Smoking status	4	7%	5%	Any arrhythmia	5	8%	-4%	-5%
Preop intubation	3	7%	Liver disease	4	7%	0%	Date or order of surgery	4	7%	7%	3%
Postoperative variables	3	7%	Cardiopulmonary bypass time	4	7%	-5%	Type of graft(s)	4	7%	-1%	-5%
Ventricular wall motion	3	7%	Aortic cross-clamp duration	4	7%	0%	Liver disease	3	5%	-2%	-2%
Preoperative diuretic use	3	7%	Hypercholesterolemia	4	7%	7%	Cardiopulmonary bypass time	3	5%	-7%	-2%
Type of graft(s)	3	7%	Critical state	4	7%	7%	Other preoperative labs	3	5%	5%	5%
Inotropic medication	3	7%	Preop intubation	4	7%	0%	Number of grafts	2	3%	-4%	-2%

Preoperative CPR/cardiac arrest	3	7%	Dyspnea	4	7%	7%	A published comorbidity index	2	3%	1%	1%
PTCA failure/emergency	3	7%	Number of grafts	3	6%	-2%	Preoperative cardiac biomarkers	2	3%	3%	3%
Ventricular or unstable arrhythmia	3	7%	Nitroglycerin use	3	6%	-9%	Patient education level/literacy	2	3%	3%	3%
Disaster, catastrophic state	3	7%	Cardiomegaly	3	6%	-9%	Recent admissions	2	3%	3%	3%
Serum albumin	3	7%	Immunosuppression	3	6%	3%	Dyspnea	2	3%	3%	-4%
Endocarditis	2	5%	Active MI	3	6%	6%	PTCA failure/emergency	2	3%	-4%	-2%
Anticoagulation or antiplatelet use	2	5%	Inotropic medication	3	6%	-2%	Stent thrombosis	2	3%	3%	3%
Digoxin or digitalis use	2	5%	Location or type of surgical center	3	6%	6%	Ventricular or unstable arrhythmia	2	3%	-4%	-6%
Cachexia or malnutrition	2	5%	PTCA failure/emergency	3	6%	-2%	Nitroglycerin use	1	2%	-13%	-4%
Smoking status	1	2%	Refused blood products	3	6%	6%	Hypercholesterolemia	1	2%	2%	-6%
Immunosuppression	1	2%	Date or order of surgery	2	4%	4%	Anticoagulation or antiplatelet use	1	2%	-3%	0%
Any family history variable	1	2%	On- *vs.* off-pump CABG	2	4%	4%	Digoxin or digitalis use	1	2%	-3%	-2%
A published comorbidity index	1	2%	Abdominal aortic aneurysm	2	4%	4%	Preop intubation	1	2%	-6%	-6%
Other preoperative comorbidities	1	2%	Digoxin or digitalis use	2	4%	-1%	Other preoperative comorbidities	1	2%	-1%	-2%
ACE inhibitor use	1	2%	Heart rate	2	4%	4%	Insurance type or status	1	2%	2%	2%
Type of MI	1	2%	Steroid use	2	4%	4%	Time from admission to procedure	1	2%	2%	2%
Atrial arrhythmia	1	2%	Other preoperative comorbidities	2	4%	1%	Intraoperative variables	1	2%	2%	-9%
Antiarrhythmic agents	1	2%	Calcified aorta	2	4%	4%	Active MI	1	2%	2%	-4%
Other ECG abnormalities	1	2%	Diffuse/severe disease	2	4%	-11%	Diffuse/severe disease	1	2%	-13%	-2%
Race or ethnicity	0	0%	Atrial arrhythmia	2	4%	1%	Center's case frequency	1	2%	2%	2%
Date or order of surgery	0	0%	Preoperative thrombolysis	2	4%	4%	PT or INR	1	2%	2%	2%
On- *vs.* off-pump CABG	0	0%	Any family history variable	1	2%	-1%	Disaster, catastrophic state	1	2%	-6%	2%
Abdominal aortic aneurysm	0	0%	Anticoagulation or antiplatelet use	1	2%	-3%	Transfusion	1	2%	2%	2%
Hypercholesterolemia	0	0%	Anemia (hemoglobin, hematocrit)	1	2%	-5%	Cardiomegaly	0	0%	-15%	-6%
Critical state	0	0%	A published comorbidity index	1	2%	-1%	Aortic cross-clamp duration	0	0%	-7%	-7%
Heart rate	0	0%	Functional state	1	2%	2%	Endocarditis	0	0%	-5%	-9%
Steroid use	0	0%	ASA classification	1	2%	2%	Abdominal aortic aneurysm	0	0%	0%	-4%
Preoperative cardiac biomarkers	0	0%	Left ventricular hypertrophy	1	2%	2%	Any family history variable	0	0%	-2%	-2%
Functional state	0	0%	Acute mental status changes	1	2%	2%	Anemia (hemoglobin, hematocrit)	0	0%	-7%	-2%
Patient education level/literacy	0	0%	Ventricular wall motion	1	2%	-5%	Heart rate	0	0%	0%	-4%
ASA classification	0	0%	Type of MI	1	2%	-1%	Steroid use	0	0%	0%	-4%
Insurance type or status	0	0%	Killip classification	1	2%	2%	ACE inhibitor use	0	0%	-2%	0%
Recent admissions	0	0%	Blood pressure	1	2%	2%	Functional state	0	0%	0%	-2%
Left ventricular hypertrophy	0	0%	Other ECG abnormalities	1	2%	-1%	ASA classification	0	0%	0%	-2%
Time from admission to procedure	0	0%	Preoperative cardiac biomarkers	0	0%	0%	Left ventricular hypertrophy	0	0%	0%	-2%
Acute mental status changes	0	0%	ACE inhibitor use	0	0%	-2%	Acute mental status changes	0	0%	0%	-2%
Intraoperative variables	0	0%	Patient education level/literacy	0	0%	0%	Cachexia or malnutrition	0	0%	-5%	0%
Extracardiac arteriopathy	0	0%	Insurance type or status	0	0%	0%	Ventricular wall motion	0	0%	-7%	-2%
Calcified aorta	0	0%	Recent admissions	0	0%	0%	Calcified aorta	0	0%	0%	-4%
Dyspnea	0	0%	Time from admission to procedure	0	0%	0%	Type of MI	0	0%	-2%	-2%
Active MI	0	0%	Cachexia or malnutrition	0	0%	-5%	Pulmonary rales	0	0%	-10%	0%

Killip classification	0	0%	Pulmonary rales	0	0%	-10%	Preoperative diuretic use	0	0%	-7%	-13%
Blood pressure	0	0%	Preoperative CPR/cardiac arrest	0	0%	-7%	Killip classification	0	0%	0%	-2%
Location or type of surgical center	0	0%	Center's case frequency	0	0%	0%	Blood pressure	0	0%	0%	-2%
Center's case frequency	0	0%	Stent thrombosis	0	0%	0%	Preoperative CPR/cardiac arrest	0	0%	-7%	0%
Stent thrombosis	0	0%	Antiarrhythmic agents	0	0%	-2%	Location or type of surgical center	0	0%	0%	-6%
Preoperative thrombolysis	0	0%	PT or INR	0	0%	0%	Antiarrhythmic agents	0	0%	-2%	0%
PT or INR	0	0%	Disaster, catastrophic state	0	0%	-7%	Other ECG abnormalities	0	0%	-2%	-2%
Transfusion	0	0%	Transfusion	0	0%	0%	Preoperative thrombolysis	0	0%	0%	-4%
Refused blood products	0	0%	Other preoperative labs	0	0%	0%	Refused blood products	0	0%	0%	-6%
Other preoperative labs	0	0%	Serum albumin	0	0%	-7%	Serum albumin	0	0%	-7%	0%
Total variables (excl. combinations)	60		Total variables (excl. combinations)	75			Total variables (excl. combinations)	64			

Δa: change from < 1998; Δb: change from 1998-2007. Comb: combination variable; CHF: congestive heart failure; NYHA: New York Heart Association; MI: myocardial infarction; ECG: electrocardiogram; IABP: intra-aortic baloon pump; HTN: hypertension; BP: blood pressure; PCI: percutaneous coronary intervention; PTCA: percutaneous transluminal coronary angioplasty; CPR: cardiopulmonary resuscitation; ASA: American Society of Anethesiology; ACE: angiotensin converting enzyme; INR: international normalized ratio; PT: prothromin time

Table 3. Short-term risk model variables by publication year

≤ 1997			1998-2007				2008-2017				
Variable	***n* = 39**	**%**	**Variable**	***n* = 45**	**%**	**Δa**	**Variable**	***n* = 49**	**%**	**Δa**	**Δb**
Age	36	92%	Age	36	80%	-12%	Age	43	88%	-5%	8%
Repeat operation	24	59%	Left ventricular function	32	71%	15%	Left ventricular function	31	63%	7%	-8%
Comb. heart failure variables	23	59%	Gender	30	67%	20%	Urgency	29	59%	10%	-5%
Left ventricular function	22	56%	Renal failure	30	67%	25%	Gender	27	55%	9%	-12%
History of MI	22	54%	Urgency	29	64%	16%	Renal failure	27	55%	14%	-12%
Comb. any MI variable	22	54%	Comb. any MI variable	25	56%	2%	Comb. critical state	26	53%	24%	9%
Urgency	20	49%	Repeat operation	24	53%	-5%	Comb. arterial disease	24	49%	10%	0%
Comb. CHF or NYHA	20	51%	History of MI	24	53%	0%	Comb. heart failure variables	23	47%	-12%	-4%
Gender	19	46%	Comb. heart failure variables	23	51%	-7%	Comb. CHF or NYHA	21	43%	-8%	1%
Renal failure	16	41%	Comb. arterial disease	22	49%	10%	Repeat operation	20	41%	-18%	-13%
Lung disease	15	37%	Comb. critical state	20	44%	15%	Peripheral arterial disease	18	37%	-2%	1%
Peripheral arterial disease	15	39%	Comb. CHF or NYHA	19	42%	-9%	Diabetes	14	29%	7%	-11%
Comb. arterial disease	15	39%	Comb. vessel disease	19	42%	6%	History of MI	13	27%	-27%	-27%
Comb. vessel disease	14	37%	Diabetes	18	40%	18%	Comb. any MI variable	13	27%	-27%	-29%
Neurologic disease	13	34%	Lung disease	18	40%	3%	Cardiogenic shock	12	24%	10%	-2%
Angina	13	32%	Neurologic disease	17	38%	4%	NYHA class	11	22%	-2%	5%
Congestive heart failure	13	34%	Peripheral arterial disease	16	36%	-3%	Congestive heart failure	11	22%	-12%	-6%
Comb. critical state	12	29%	Left main disease	16	36%	9%	Concurrent procedure	11	22%	8%	2%
Body size measurements	11	27%	Body size measurements	14	31%	4%	Lung disease	10	20%	-16%	-20%
Comb. ECG or arrhythmia variables	11	27%	Congestive heart failure	13	29%	-5%	Comb. vessel disease	10	20%	-16%	-22%
NYHA class	10	24%	Comb. HTN or BP	13	29%	14%	Neurologic disease	9	18%	-16%	-19%
Left main disease	10	27%	Hypertension	12	27%	12%	Number of diseased vessels	9	18%	1%	-6%
Diabetes	8	22%	Cardiogenic shock	12	27%	12%	Preoperative IABP use	9	18%	1%	1%

Number of diseased vessels	7	17%	Number of diseased vessels	11	24%	7%	Comb. PCI variables	7	14%	0%	-3%
Preoperative IABP use	7	17%	Pulmonary hypertension	10	22%	12%	Body size measurements	6	12%	-15%	-19%
Valve disease	6	15%	Comb. ECG or arrhythmia variables	10	22%	-5%	Valve disease	6	12%	-2%	6%
Hypertension	6	15%	Concurrent procedure	9	20%	5%	Non-CABG surgery	6	12%	-2%	-1%
Nitroglycerin use	6	15%	NYHA class	8	18%	-7%	Critical state	6	12%	12%	3%
Cardiomegaly	6	15%	Preoperative IABP use	8	18%	1%	Postoperative variables	6	12%	5%	-6%
Cardiogenic shock	6	15%	Postoperative variables	8	18%	10%	Extracardiac arteriopathy	6	12%	12%	-1%
Non-CABG surgery	6	15%	Comb. PCI variables	8	18%	3%	Inotropic medication	6	12%	5%	6%
Concurrent procedure	6	15%	Any arrhythmia	7	16%	3%	Atrial arrhythmia	6	12%	10%	8%
Diffuse/severe disease	6	15%	Prior/recent PCI or PTCA	6	13%	6%	Pulmonary hypertension	5	10%	0%	-12%
Comb. graft variables	6	15%	Non-CABG surgery	6	13%	-1%	Angina	5	10%	-22%	-1%
Comb. HTN or BP	6	15%	Extracardiac arteriopathy	6	13%	13%	On- *vs*. off-pump CABG	5	10%	10%	6%
Comb. PCI variables	6	15%	Preoperative diuretic use	6	13%	6%	Comb. ECG or arrhythmia variables	5	10%	-17%	-12%
Cardiopulmonary bypass time	5	12%	Angina	5	11%	-21%	Comb. graft variables	4	8%	-6%	-1%
Any arrhythmia	5	12%	Endocarditis	5	11%	6%	Any arrhythmia	4	8%	-4%	-7%
Pulmonary hypertension	4	10%	Intraoperative variables	5	11%	11%	Race or ethnicity	3	6%	6%	-3%
Pulmonary rales	4	10%	Race or ethnicity	4	9%	9%	Left main disease	3	6%	-21%	-29%
Number of grafts	3	7%	Liver disease	4	9%	2%	Cardiopulmonary bypass time	3	6%	-6%	-3%
Liver disease	3	7%	Cardiopulmonary bypass time	4	9%	-3%	Prior/recent PCI or PTCA	3	6%	-1%	-7%
Prior/recent PCI or PTCA	3	7%	Critical state	4	9%	9%	Type of graft(s)	3	6%	-1%	-1%
Anemia (hemoglobin, hematocrit)	3	7%	Preop intubation	4	9%	2%	Other preoperative labs	3	6%	6%	6%
Preop intubation	3	7%	Dyspnea	4	9%	9%	Hypertension	2	4%	-11%	-23%
Postoperative variables	3	7%	Comb. graft variables	4	9%	-6%	Smoking status	2	4%	2%	2%
Preoperative diuretic use	3	7%	Ventricular or unstable arrhythmia	4	9%	2%	Liver disease	2	4%	-3%	-5%
Type of graft(s)	3	7%	Valve disease	3	7%	-8%	Immunosuppression	2	4%	2%	-3%
Inotropic medication	3	7%	Nitroglycerin use	3	7%	-8%	A published comorbidity index	2	4%	2%	2%
Preoperative CPR/cardiac arrest	3	7%	Cardiomegaly	3	7%	-8%	Preoperative cardiac biomarkers	2	4%	4%	4%
PTCA failure/emergency	3	7%	Immunosuppression	3	7%	4%	Patient education level/literacy	2	4%	4%	4%
Ventricular or unstable arrhythmia	3	7%	Aortic cross-clamp duration	3	7%	-1%	Dyspnea	2	4%	4%	-5%
Disaster, catastrophic state	3	7%	Active MI	3	7%	7%	Comb. HTN or BP	2	4%	-11%	-25%
Serum albumin	3	7%	Type of graft(s)	3	7%	-1%	PTCA failure/emergency	2	4%	-3%	-3%
Aortic cross-clamp duration	2	7%	Inotropic medication	3	7%	-1%	Stent thrombosis	2	4%	4%	4%
Endocarditis	2	5%	Location or type of surgical center	3	7%	7%	Number of grafts	1	2%	-5%	-2%
Anticoagulation or antiplatelet use	2	5%	PTCA failure/emergency	3	7%	-1%	Nitroglycerin use	1	2%	-13%	-5%
Digoxin or digitalis use	2	5%	Refused blood products	3	7%	7%	Date or order of surgery	1	2%	2%	0%
Cachexia or malnutrition	2	5%	Number of grafts	2	4%	-3%	Hypercholesterolemia	1	2%	2%	-2%
Ventricular wall motion	2	7%	On- *vs*. off-pump CABG	2	4%	4%	Anticoagulation or antiplatelet use	1	2%	-3%	0%
Smoking status	1	2%	Abdominal aortic aneurysm	2	4%	4%	Digoxin or digitalis use	1	2%	-3%	0%
Immunosuppression	1	2%	Hypercholesterolemia	2	4%	4%	Preop intubation	1	2%	-5%	-7%
Any family history variable	1	2%	Steroid use	2	4%	4%	Other preoperative comorbidities	1	2%	0%	-2%
A published comorbidity index	1	2%	Other preoperative comorbidities	2	4%	2%	Insurance type or status	1	2%	2%	2%

Other preoperative comorbidities	1	2%	Diffuse/severe disease	2	4%	-10%	Recent admissions	1	2%	2%	2%
ACE inhibitor use	1	2%	Atrial arrhythmia	2	4%	2%	Time from admission to procedure	1	2%	2%	2%
Type of MI	1	2%	Smoking status	1	2%	0%	Center's case frequency	1	2%	2%	2%
Atrial arrhythmia	1	2%	Date or order of surgery	1	2%	2%	Ventricular or unstable arrhythmia	1	2%	-5%	-7%
Antiarrhythmic agents	1	2%	Any family history variable	1	2%	0%	PT or INR	1	2%	2%	2%
Other ECG abnormalities	1	2%	Anticoagulation or antiplatelet use	1	2%	-3%	Disaster, catastrophic state	1	2%	-5%	2%
Race or ethnicity	0	0%	Anemia (hemoglobin, hematocrit)	1	2%	-5%	Transfusion	1	2%	2%	2%
Date or order of surgery	0	0%	Digoxin or digitalis use	1	2%	-3%	Cardiomegaly	0	0%	-15%	-7%
On- *vs.* off-pump CABG	0	0%	A published comorbidity index	1	2%	0%	Aortic cross-clamp duration	0	0%	-7%	-7%
Abdominal aortic aneurysm	0	0%	Heart rate	1	2%	2%	Endocarditis	0	0%	-5%	-11%
Hypercholesterolemia	0	0%	ASA classification	1	2%	2%	Abdominal aortic aneurysm	0	0%	0%	-4%
Critical state	0	0%	Acute mental status changes	1	2%	2%	Any family history variable	0	0%	-2%	-2%
Heart rate	0	0%	Ventricular wall motion	1	2%	-5%	Anemia (hemoglobin, hematocrit)	0	0%	-7%	-2%
Steroid use	0	0%	Calcified aorta	1	2%	2%	Heart rate	0	0%	0%	-2%
Preoperative cardiac biomarkers	0	0%	Type of MI	1	2%	0%	Steroid use	0	0%	0%	-4%
Functional state	0	0%	Killip classification	1	2%	2%	ACE inhibitor use	0	0%	-2%	0%
Patient education level/literacy	0	0%	Blood pressure	1	2%	2%	Functional state	0	0%	0%	0%
ASA classification	0	0%	Other ECG abnormalities	1	2%	0%	ASA classification	0	0%	0%	-2%
Insurance type or status	0	0%	Preoperative thrombolysis	1	2%	2%	Left ventricular hypertrophy	0	0%	0%	0%
Recent admissions	0	0%	Preoperative cardiac biomarkers	0	0%	0%	Acute mental status changes	0	0%	0%	-2%
Left ventricular hypertrophy	0	0%	ACE inhibitor use	0	0%	-2%	Intraoperative variables	0	0%	0%	-11%
Time from admission to procedure	0	0%	Functional state	0	0%	0%	Cachexia or malnutrition	0	0%	-5%	0%
Acute mental status changes	0	0%	Patient education level/literacy	0	0%	0%	Ventricular wall motion	0	0%	-7%	-2%
Intraoperative variables	0	0%	Insurance type or status	0	0%	0%	Calcified aorta	0	0%	0%	-2%
Extracardiac arteriopathy	0	0%	Recent admissions	0	0%	0%	Type of MI	0	0%	-2%	-2%
Calcified aorta	0	0%	Left ventricular hypertrophy	0	0%	0%	Active MI	0	0%	0%	-7%
Dyspnea	0	0%	Time from admission to procedure	0	0%	0%	Pulmonary rales	0	0%	-10%	0%
Active MI	0	0%	Cachexia or malnutrition	0	0%	-5%	Preoperative diuretic use	0	0%	-7%	-13%
Killip classification	0	0%	Pulmonary rales	0	0%	-10%	Killip classification	0	0%	0%	-2%
Blood pressure	0	0%	Preoperative CPR/cardiac arrest	0	0%	-7%	Diffuse/severe disease	0	0%	-15%	-4%
Location or type of surgical center	0	0%	Center's case frequency	0	0%	0%	Blood pressure	0	0%	0%	-2%
Center's case frequency	0	0%	Stent thrombosis	0	0%	0%	Preoperative CPR/cardiac arrest	0	0%	-7%	0%
Stent thrombosis	0	0%	Antiarrhythmic agents	0	0%	-2%	Location or type of surgical center	0	0%	0%	-7%
Preoperative thrombolysis	0	0%	PT or INR	0	0%	0%	Antiarrhythmic agents	0	0%	-2%	0%
PT or INR	0	0%	Disaster, catastrophic state	0	0%	-7%	Other ECG abnormalities	0	0%	-2%	-2%
Transfusion	0	0%	Transfusion	0	0%	0%	Preoperative thrombolysis	0	0%	0%	-2%
Refused blood products	0	0%	Other preoperative labs	0	0%	0%	Refused blood products	0	0%	0%	-7%
Other preoperative labs	0	0%	Serum albumin	0	0%	-7%	Serum albumin	0	0%	-7%	0%
Total variables (excl. combinations)	60		Total variables (excl. combinations)	73			Total variables (excl. combinations)	61			

Δa: change from < 1998; Δb: change from 1998-2007. Comb: combination variable; CHF: congestive heart failure; NYHA: New York Heart Association; MI: myocardial infarction; ECG: electrocardiogram; IABP: intra-aortic baloon pump; HTN: hypertension; BP: blood pressure; PCI: percutaneous coronary intervention; PTCA: percutaneous transluminal coronary angioplasty; CPR: cardiopulmonary resuscitation; ASA: American Society of Anethesiology; ACE: angiotensin converting enzyme; INR: international normalized ratio; PT: prothromin time

Table 4. Long-term risk model variables by publication year

≤ 1997			1998-2007				2008-2017				
Variable	***n* = 2**	**%**	**Variable**	***n* = 9**	**%**	**Δa**	**Variable**	***n* = 12**	**%**	**Δa**	**Δb**
Age	1	50%	Age	8	89%	39%	Age	5	42%	-8%	-47%
Diabetes	1	50%	Left ventricular function	8	89%	39%	Left ventricular function	5	42%	-8%	-47%
Renal failure	1	50%	Comb. heart failure variables	7	78%	28%	Gender	3	25%	25%	14%
Left ventricular function	1	50%	Diabetes	6	67%	17%	Diabetes	3	25%	-25%	-42%
Neurologic disease	1	50%	Renal failure	6	67%	17%	Renal failure	3	25%	-25%	-42%
Peripheral arterial disease	1	50%	Congestive heart failure	6	67%	17%	Peripheral arterial disease	3	25%	-25%	-31%
Congestive heart failure	1	50%	Comb. arterial disease	6	67%	17%	Comb. arterial disease	3	25%	-25%	-42%
Left main disease	1	50%	Comb. CHF or NYHA	6	67%	17%	Comb. any MI variable	3	25%	25%	25%
Aortic cross-clamp duration	1	50%	Peripheral arterial disease	5	56%	6%	Comb. heart failure variables	3	25%	-25%	-53%
Ventricular wall motion	1	50%	Body size measurements	4	44%	44%	Comb. CHF or NYHA	3	25%	-25%	-42%
Comb. arterial disease	1	50%	Lung disease	4	44%	44%	Urgency	2	17%	17%	6%
Comb. heart failure variables	1	50%	Neurologic disease	4	44%	-6%	Lung disease	2	17%	17%	-28%
Comb. CHF or NYHA	1	50%	Postoperative variables	4	44%	44%	Neurologic disease	2	17%	-33%	-28%
Comb. vessel disease	1	50%	Comb. graft variables	4	44%	44%	NYHA class	2	17%	17%	17%
Total variables (excl. combinations)	10		Smoking status	3	33%	33%	History of MI	2	17%	17%	17%
			Type of graft(s)	3	33%	33%	Comb. vessel disease	2	17%	-33%	-6%
			Left main disease	2	22%	-28%	Comb. graft variables	2	17%	17%	-28%
			Hypercholesterolemia	2	22%	22%	Atrial arrhythmia	2	17%	17%	17%
			Comb. vessel disease	2	22%	-28%	Body size measurements	1	8%	8%	-36%
			Gender	1	11%	11%	Repeat operation	1	8%	8%	-3%
			Urgency	1	11%	11%	Angina	1	8%	8%	8%
			Repeat operation	1	11%	11%	Congestive heart failure	1	8%	-42%	-58%
			Number of grafts	1	11%	11%	Number of diseased vessels	1	8%	8%	8%
			Valve disease	1	11%	11%	Number of grafts	1	8%	8%	-3%
			Hypertension	1	11%	11%	Valve disease	1	8%	8%	-3%
			Date or order of surgery	1	11%	11%	Hypertension	1	8%	8%	-3%
			Aortic cross-clamp duration	1	11%	-39%	Race or ethnicity	1	8%	8%	8%
			Digoxin or digitalis use	1	11%	11%	Preoperative IABP use	1	8%	8%	8%
			Heart rate	1	11%	11%	Smoking status	1	8%	8%	-25%
			Functional state	1	11%	11%	Left main disease	1	8%	-42%	-14%
			Left ventricular hypertrophy	1	11%	11%	Cardiogenic shock	1	8%	8%	8%
			Intraoperative variables	1	11%	11%	Immunosuppression	1	8%	8%	8%
			Calcified aorta	1	11%	11%	Date or order of surgery	1	8%	8%	-3%
			Preoperative diuretic use	1	11%	11%	On- *vs.* off-pump CABG	1	8%	8%	8%
			Comb. HTN or BP	1	11%	11%	Prior/recent PCI or PTCA	1	8%	8%	8%
			Ventricular or unstable arrhythmia	1	11%	11%	Intraoperative variables	1	8%	8%	-3%
			Comb. ECG or arrhythmia variables	1	11%	11%	Postoperative variables	1	8%	8%	-36%

Preoperative thrombolysis	1	11%	11%	Active MI	1	8%	8%	8%
Total variables (excl. combinations)	31			Diffuse/severe disease	1	8%	8%	8%
				Type of graft(s)	1	8%	8%	-25%
				Comb. HTN or BP	1	8%	8%	-3%
				Inotropic medication	1	8%	8%	8%
				Comb. critical state	1	8%	8%	8%
				Comb. PCI variables	1	8%	8%	8%
				Total variables (excl. combinations)	35			

Δa: change from < 1998; Δb: change from 1998-2007. Comb: combination variable; CHF: congestive heart failure; NYHA: New York Heart Association; MI: myocardial infarction; ECG: electrocardiogram; IABP: intra-aortic baloon pump; HTN: hypertension; BP: blood pressure; PCI: percutaneous coronary intervention; PTCA: percutaneous transluminal coronary angioplasty; CPR: cardiopulmonary resuscitation; ASA: American Society of Anethesiology; ACE: angiotensin converting enzyme; INR: international normalized ratio; PT: prothromin time

Table 5. Models containing only preoperative data

All models			Short-term models			Long-term models		
Variable	***n* = 89**	**%**	**Variable**	***n* = 75**	**%**	**Variable**	***n* = 14**	**%**
Age	79	89%	Age	68	91%	Age	11	79%
Left ventricular function	62	70%	Left ventricular function	52	69%	Renal failure	11	79%
Renal failure	54	61%	Urgency	46	61%	Left ventricular function	10	71%
Comb. arterial disease	52	58%	Gender	45	60%	Diabetes	9	64%
Comb. heart failure variables	52	58%	Repeat operation	44	59%	Comb. arterial disease	9	64%
Gender	51	57%	Renal failure	43	57%	Comb. heart failure variables	9	64%
Urgency	50	56%	Comb. arterial disease	43	57%	Peripheral arterial disease	8	57%
Repeat operation	48	54%	Comb. heart failure variables	43	57%	Comb. CHF or NYHA	8	57%
Peripheral arterial disease	45	51%	History of MI	38	51%	Lung disease	7	50%
Comb. CHF or NYHA	44	49%	Comb. any MI variable	38	51%	Gender	6	43%
History of MI	42	47%	Peripheral arterial disease	37	49%	Neurologic disease	6	43%
Comb. any MI variable	42	47%	Comb. CHF or NYHA	36	48%	Comb. vessel disease	6	43%
Lung disease	41	46%	Comb. critical state	36	48%	Body size measurements	5	36%
Comb. critical state	40	45%	Lung disease	34	45%	Congestive heart failure	5	36%
Diabetes	37	42%	Comb. vessel disease	31	41%	Left main disease	5	36%
Comb. vessel disease	37	42%	Diabetes	28	37%	Urgency	4	29%
Neurologic disease	32	36%	Neurologic disease	26	35%	Repeat operation	4	29%
Left main disease	28	31%	Left main disease	23	31%	History of MI	4	29%
Congestive heart failure	27	30%	Cardiogenic shock	23	31%	Comb. any MI variable	4	29%
Cardiogenic shock	27	30%	Congestive heart failure	22	29%	Hypertension	4	29%
Body size measurements	26	29%	Body size measurements	21	28%	Comb. HTN or BP	4	29%
Number of diseased vessels	23	26%	Number of diseased vessels	20	27%	Race or ethnicity	4	29%
NYHA class	21	24%	NYHA class	18	24%	Comb. critical state	4	29%
Hypertension	19	21%	Comb. ECG or arrhythmia variables	17	23%	Smoking status	4	29%
Comb. HTN or BP	19	21%	Hypertension	15	20%	Cardiogenic shock	4	29%
Comb. ECG or arrhythmia variables	19	21%	Comb. HTN or BP	15	20%	NYHA class	3	21%

Angina	18	20%	Angina	15	20%	Angina	3	21%
Comb. PCI variables	18	20%	Comb. PCI variables	15	20%	Number of diseased vessels	3	21%
Valve disease	16	18%	Valve disease	13	17%	Valve disease	3	21%
Preoperative IABP use	15	17%	Preoperative IABP use	12	16%	Preoperative IABP use	3	21%
Prior/recent PCI or PTCA	14	16%	Prior/recent PCI or PTCA	11	15%	Inotropic medication	3	21%
Inotropic medication	13	15%	Any arrhythmia	11	15%	Immunosuppression	3	21%
Any arrhythmia	12	13%	Inotropic medication	10	13%	Date or order of surgery	3	21%
Pulmonary hypertension	10	11%	Pulmonary hypertension	10	13%	Prior/recent PCI or PTCA	3	21%
Race or ethnicity	10	11%	Nitroglycerin use	8	11%	Comb. PCI variables	3	21%
Preoperative diuretic use	8	9%	Preoperative diuretic use	7	9%	Atrial arrhythmia	3	21%
Nitroglycerin use	8	9%	Cardiomegaly	7	9%	Comb. ECG or arrhythmia variables	2	14%
Smoking status	8	9%	Race or ethnicity	6	8%	Extracardiac arteriopathy	1	7%
Atrial arrhythmia	8	9%	Extracardiac arteriopathy	6	8%	Preoperative diuretic use	1	7%
Extracardiac arteriopathy	7	8%	Liver disease	6	8%	Diffuse/severe disease	1	7%
Liver disease	7	8%	Atrial arrhythmia	5	7%	Liver disease	1	7%
Cardiomegaly	7	8%	Smoking status	4	5%	On- *vs.* off-pump CABG	1	7%
Immunosuppression	7	8%	Immunosuppression	4	5%	Any arrhythmia	1	7%
Diffuse/severe disease	5	6%	Diffuse/severe disease	4	5%	Ventricular or unstable arrhythmia	1	7%
Digoxin or digitalis use	5	6%	Digoxin or digitalis use	4	5%	Hypercholesterolemia	1	7%
Dyspnea	4	4%	Dyspnea	4	5%	Digoxin or digitalis use	1	7%
Pulmonary rales	4	4%	Pulmonary rales	4	5%	Functional state	1	7%
Date or order of surgery	4	4%	Critical state	4	5%	Recent admissions	1	7%
On- *vs.* off-pump CABG	4	4%	On- *vs.* off-pump CABG	3	4%	Cachexia or malnutrition	0	0%
Ventricular or unstable arrhythmia	4	4%	Ventricular or unstable arrhythmia	3	4%	Ventricular wall motion	0	0%
Critical state	4	4%	Ventricular wall motion	3	4%	Pulmonary hypertension	0	0%
Ventricular wall motion	3	3%	PTCA failure/emergency	3	4%	Calcified aorta	0	0%
PTCA failure/emergency	3	3%	Anticoagulation or antiplatelet use	3	4%	Dyspnea	0	0%
Hypercholesterolemia	3	3%	Anemia (hemoglobin, hematocrit)	3	4%	Type of MI	0	0%
Anticoagulation or antiplatelet use	3	3%	A published comorbidity index	3	4%	Active MI	0	0%
Anemia (hemoglobin, hematocrit)	3	3%	Other preoperative labs	3	4%	Pulmonary rales	0	0%
A published comorbidity index	3	3%	Hypercholesterolemia	2	3%	Killip classification	0	0%
Other preoperative labs	3	3%	Cachexia or malnutrition	2	3%	Number of grafts	0	0%
Cachexia or malnutrition	2	2%	Type of MI	2	3%	Type of graft(s)	0	0%
Type of MI	2	2%	Active MI	2	3%	Comb. graft variables	0	0%
Active MI	2	2%	Preoperative CPR/cardiac arrest	2	3%	Blood pressure	0	0%
Preoperative CPR/cardiac arrest	2	2%	Endocarditis	2	3%	Nitroglycerin use	0	0%
Endocarditis	2	2%	Stent thrombosis	2	3%	Cardiopulmonary bypass time	0	0%
Stent thrombosis	2	2%	Other ECG abnormalities	2	3%	Cardiomegaly	0	0%
Other ECG abnormalities	2	2%	Disaster, catastrophic state	2	3%	Preoperative CPR/cardiac arrest	0	0%
Disaster, catastrophic state	2	2%	Preop intubation	2	3%	Location or type of surgical center	0	0%
Preop intubation	2	2%	Steroid use	2	3%	Center's case frequency	0	0%

Steroid use	2	2%	Preoperative cardiac biomarkers	2	3%	Aortic cross-clamp duration	0	0%
Preoperative cardiac biomarkers	2	2%	Date or order of surgery	1	1%	Endocarditis	0	0%
Recent admissions	2	2%	Recent admissions	1	1%	Abdominal aortic aneurysm	0	0%
Calcified aorta	1	1%	Calcified aorta	1	1%	PTCA failure/emergency	0	0%
Killip classification	1	1%	Killip classification	1	1%	Stent thrombosis	0	0%
Location or type of surgical center	1	1%	Location or type of surgical center	1	1%	Any family history variable	0	0%
Any family history variable	1	1%	Any family history variable	1	1%	Antiarrhythmic agents	0	0%
Antiarrhythmic agents	1	1%	Antiarrhythmic agents	1	1%	Other ECG abnormalities	0	0%
Non-CABG surgery	1	1%	Non-CABG surgery	1	1%	Non-CABG surgery	0	0%
Preoperative thrombolysis	1	1%	Preoperative thrombolysis	1	1%	Anticoagulation or antiplatelet use	0	0%
PT or INR	1	1%	PT or INR	1	1%	Preoperative thrombolysis	0	0%
Transfusion	1	1%	Transfusion	1	1%	PT or INR	0	0%
Serum albumin	1	1%	Serum albumin	1	1%	Critical state	0	0%
ACE inhibitor use	1	1%	ACE inhibitor use	1	1%	Disaster, catastrophic state	0	0%
Functional state	1	1%	ASA classification	1	1%	Anemia (hemoglobin, hematocrit)	0	0%
ASA classification	1	1%	Insurance type or status	1	1%	Transfusion	0	0%
Insurance type or status	1	1%	Acute mental status changes	1	1%	Refused blood products	0	0%
Acute mental status changes	1	1%	Functional state	0	0%	Preop intubation	0	0%
Number of grafts	0	0%	Number of grafts	0	0%	Concurrent procedure	0	0%
Type of graft(s)	0	0%	Type of graft(s)	0	0%	A published comorbidity index	0	0%
Comb. graft variables	0	0%	Comb. graft variables	0	0%	Heart rate	0	0%
Blood pressure	0	0%	Blood pressure	0	0%	Steroid use	0	0%
Cardiopulmonary bypass time	0	0%	Cardiopulmonary bypass time	0	0%	Preoperative cardiac biomarkers	0	0%
Center's case frequency	0	0%	Center's case frequency	0	0%	Other preoperative labs	0	0%
Aortic cross-clamp duration	0	0%	Aortic cross-clamp duration	0	0%	Serum albumin	0	0%
Abdominal aortic aneurysm	0	0%	Abdominal aortic aneurysm	0	0%	Other preoperative comorbidities	0	0%
Refused blood products	0	0%	Refused blood products	0	0%	ACE inhibitor use	0	0%
Concurrent procedure	0	0%	Concurrent procedure	0	0%	Patient education level/literacy	0	0%
Heart rate	0	0%	Heart rate	0	0%	ASA classification	0	0%
Other preoperative comorbidities	0	0%	Other preoperative comorbidities	0	0%	Insurance type or status	0	0%
Patient education level/literacy	0	0%	Patient education level/literacy	0	0%	Left ventricular hypertrophy	0	0%
Left ventricular hypertrophy	0	0%	Left ventricular hypertrophy	0	0%	Time from admission to procedure	0	0%
Time from admission to procedure	0	0%	Time from admission to procedure	0	0%	Acute mental status changes	0	0%
Intraoperative variables	0	0%	Intraoperative variables	0	0%	Intraoperative variables	0	0%
Postoperative variables	0	0%	Postoperative variables	0	0%	Postoperative variables	0	0%
Total variables (excl. combinations)	76		Total variables (excl. combinations)	75		Total variables (excl. combinations)	39	

Comb: combination variable; CHF: congestive heart failure; NYHA: New York Heart Association; MI: myocardial infarction; ECG: electrocardiogram; IABP: intra-aortic baloon pump; HTN: hypertension; BP: blood pressure; PCI: percutaneous coronary intervention; PTCA: percutaneous transluminal coronary angioplasty; CPR: cardiopulmonary resuscitation; ASA: American Society of Anethesiology; ACE: angiotensin converting enzyme; INR: international normalized ratio; PT: prothromin time

Table 6. Models considering on- *vs.* off- pump CABG

All models			**Short-term models**			**Long-term models**		
Variable	***n* = 4**	**%**	**Variable**	***n* = 3**	**%**	**Variable**	***n* = 1**	**%**
Age	4	100%	Age	3	100%	Age	1	100%
On- *vs.* off-pump CABG	4	100%	On- *vs.* off-pump CABG	3	100%	History of MI	1	100%
Gender	2	50%	Gender	2	67%	Comb. any MI variable	1	100%
Renal failure	2	50%	Renal failure	2	67%	On- *vs.* off-pump CABG	1	100%
Urgency	2	50%	Urgency	2	67%	Total variables (excl. combinations)	3	
History of MI	2	50%	Comb. critical state	2	67%			
Comb. any MI variable	2	50%	Body size measurements	1	33%			
Comb. critical state	2	50%	Diabetes	1	33%			
Body size measurements	1	25%	Left ventricular function	1	33%			
Diabetes	1	25%	Lung disease	1	33%			
Left ventricular function	1	25%	Pulmonary hypertension	1	33%			
Lung disease	1	25%	Repeat operation	1	33%			
Pulmonary hypertension	1	25%	Neurologic disease	1	33%			
Repeat operation	1	25%	Peripheral arterial disease	1	33%			
Neurologic disease	1	25%	Comb. arterial disease	1	33%			
Peripheral arterial disease	1	25%	NYHA class	1	33%			
Comb. arterial disease	1	25%	History of MI	1	33%			
NYHA class	1	25%	Active MI	1	33%			
Active MI	1	25%	Comb. any MI variable	1	33%			
Preoperative diuretic use	1	25%	Preoperative diuretic use	1	33%			
Comb. heart failure variables	1	25%	Comb. heart failure variables	1	33%			
Comb. CHF or NYHA	1	25%	Comb. CHF or NYHA	1	33%			
Number of diseased vessels	1	25%	Number of diseased vessels	1	33%			
Comb. vessel disease	1	25%	Comb. vessel disease	1	33%			
Hypertension	1	25%	Hypertension	1	33%			
Comb. HTN or BP	1	25%	Comb. HTN or BP	1	33%			
Race or ethnicity	1	25%	Race or ethnicity	1	33%			
Preoperative IABP use	1	25%	Preoperative IABP use	1	33%			
Inotropic medication	1	25%	Inotropic medication	1	33%			
Left main disease	1	25%	Left main disease	1	33%			
Cardiogenic shock	1	25%	Cardiogenic shock	1	33%			
Any arrhythmia	1	25%	Any arrhythmia	1	33%			
Comb. ECG or arrhythmia variables	1	25%	Comb. ECG or arrhythmia variables	1	33%			
Steroid use	1	25%	Steroid use	1	33%			
Total variables (excl. combinations)	26		Total variables (excl. combinations)	26				

Comb: combination variable; CHF: congestive heart failure; NYHA: New York Heart Association; MI: myocardial infarction; ECG: electrocardiogram; IABP: intra-aortic baloon pump; HTN: hypertension; BP: blood pressure; PCI: percutaneous coronary intervention; PTCA: percutaneous transluminal coronary angioplasty; CPR: cardiopulmonary resuscitation; ASA: American Society of Anethesiology; ACE: angiotensin converting enzyme; INR: international normalized ratio; PT: prothromin time minor differences in the pre-CABG patients' risk factor frequency (which may have been associated with provider-based off-pump patient selection criteria), the pre-CABG patient risk factors identified were extremely similar to the overall findings, as reported above. Given the smaller number of on-pump *vs.* off-pump CABG mortality risk model comparisons reported, however, these findings may have limited generalizability.

When reviewing the frequency distribution of preoperative model risk variables, it is striking how very few modifiable (as opposed to non-modifiable) patient risk factors have been identified with a post-CABG mortality impact. As an inherently non-modifiable risk factor, the risk for post-CABG mortality increases as a patient's age increases. Perhaps by the time a patient is being evaluated for a CABG procedure, the negative prognostic impact for the most common preoperative risk factors, such as diabetes mellitus and poor left ventricular ejection fraction, may be difficult to reverse or otherwise counteract in the ST; however, these impacts can be seen in LT models.

In contrast, several of these reported patient risk factors have potential to be mitigated. As an example, body mass index or another marker of body habitus (e.g., height, weight, or body surface area) was included in 31/133 (23%) of ST models considering only preoperative risk factors. Similarly, a measure of smoking or tobacco use was considered in only 4/133 (3%). Although it is a well-known fact that these 2 risk factors represent important drivers for a patient developing ischemic heart disease, their significance in predicting post-CABG mortality risk appears likely confounded with presence of diabetes mellitus and poor renal function, which may also be sequela of obesity or diabetes.

Although these risk models may be helpful to enhance the providers' discussions with patients during the informed consent process or support provider discussions as to treatment-related risks for adverse events, the currently published CABG mortality risk models fall short of providing clinicians with useful information to optimize postoperative care consults, to ensure continuity of post-discharge care, or to enhance LT patients' survival. While it would likely not be surprising to most clinicians that these modifiable risk factors are important considerations, the manner presented in LT risks models may give the impression that LT post-CABG mortality risk is set in stone at the time of surgery, rather than an evolving risk that can be mitigated or exacerbated at any time. Using follow-up time-period-based risks (e.g., hemoglobin A1c management or continued tobacco use), therefore, future sequential modeling approaches may be needed to help better guide post-CABG follow-up care decisions and to optimize LT post-CABG survival.

One risk factor that is potentially modifiable, but not in the traditional sense, is operative urgency or priority, meaning whether a given procedure was performed in the elective *vs.* urgent or even emergent manner with an unstable patient. As clinically relevant examples, it is important to know when to intervene in patients with active angina or acute myocardial infarction. While operating in a time sensitive manner under potentially suboptimal conditions may be unavoidable, the fact that priority or status variables have been identified so frequently as ST mortality risk factors would suggest that future research funding should be prioritized to evaluate the impact of differential pre-CABG waiting periods[16].

A limited number of CABG mortality models found preoperative medications such as nitrates, anti-platelet agents, angiotensin converting enzyme inhibitor, or anti-arrhythmic medication were associated with mortality. Given risk assessment inconsistencies, some of these medications (e.g., nitrates) may have been markers for the severity of coronary disease or preoperative instability. Other medications may, in fact, be markers of optimal medical management during the pre- and postoperative periods[17].

Currently, no risk models incorporate direct measures of adherence with published clinical practice guidelines (e.g., the American College of Cardiology's guidelines for treatment of coronary artery disease) such as documenting the use of ischemic heart disease medications (e.g., pre-CABG statin use). As a potentially novel and important future enhancement to preoperative risk stratification, adherence to published guidelines should be considered. In general, adherence with published guidelines are increasingly becoming a marker used to identify high-quality, high-value care providers. Adherence to published guidelines has been shown to be suboptimal after CABG, yet adherence has been repeatedly associated with improved cardiovascular-related mortality in various populations[18-20]. Applied proactively, guideline adherence may provide a useful direction for future cardiac surgery mortality risk modeling endeavors.

Interestingly, none of these CABG mortality risk models identified mental health-related (e.g., psychiatric) or socioeconomic risk factors as predictive; however, preoperative depression has been associated with increased 5- and 10-year post-CABG mortality[21,22]. Similarly, one recent study showed a community-based marker of socioeconomic status (e.g., the Distressed Community Index) to be predictive of in-hospital mortality[23]. Hence, these types of non-traditional CABG risk factors may be worthy of future exploration.

Limitations

Conducted as an advanced PubMed literature review in February 2019, this summary has identified knowledge "gaps", which are intended to foster future CABG risk modeling research. With collaborative team member oversight and guidance, the majority of these data extractions were performed by a single author (BC). Substantial overlap was documented among several risk variables (e.g., left ventricular ejection fraction *vs.* congestive heart failure *vs.* pulmonary rales *vs.* diuretic use); therefore, the relative impact of any individual risk factor could not be easily quantified. If standardized CABG quality improvement database definitions (e.g., the Society of Thoracic Surgeons' definitions) were uniformly utilized in the future, however, comparing variable-specific relative rankings (e.g., identifying the "top five variables impacting mortality" across all published models) would become possible.

Inherently, all risk variables reported were limited to the sub-group of patients' risk characteristics uniquely captured by each database. Although a common core of risk variables was captured, each dataset may have contained unique risk factors relevant specifically to their patient populations. Additionally, different risk modeling approaches (e.g., descending stepwise logistic regression) may have contributed to the variations documented for the risk factors associated with post-CABG mortality.

In conclusion, CABG maintains an important role in the management of coronary artery disease; thus, understanding patients' ST and LT surgical risk and risk factors remains important to optimizing CABG patient's selection, treatment, and follow-up care. A wide array of CABG mortality model findings and an equally vast diversity of analytic approaches were used, each prediction model having population-specific benefits and drawbacks. Over the past 20 years, it appears that the majority of CABG registries have come to a general consensus to utilize at least a core pre-CABG risk factor set. Beyond this core dataset, however, population-relevant risk factors are commonly reported.

As always, research continues to identify new risk factors that may affect post-CABG patients' risk; based on these data-driven findings, areas warranting further research were identified - such as incorporating modifiable risk factors and ischemic heart disease guideline compliance. Additionally, a new focus appears warranted to evaluate pre-CABG wait time impacts upon surgical priority, as well as CABG risk-adjusted outcomes. Applying the lessons learned, post-CABG mortality risk model findings may be quite different in the future from current findings - as the post-CABG care continues to improve and the field of statistical risk modeling advances forward.

DECLARATIONS

Authors' contributions

Wrote the initial study protocol, under the oversight and leadership of Grover FL: Carr BM, Shroyer ALW
Prepared the research-related materials to obtain an official determination of "not research" by the Northport VA Medical Center's Research and Development office: Shroyer ALW
Performed the detailed data after implementing the advanced literature search strategy, acquisition with active involvement by Grover FL and Shroyer ALW: Carr BM
Ran the initial data analyses and prepared the initial set of tables and figures: Carr BM
Aided in the interpretation as well as the full co-author team worked collaboratively to assure a comprehensive search strategy: Grover FL, Shroyer ALW
The first draft of this article was written jointly by Carr BM and Shroyer ALW, with revisions provided by Grover FL, all co-authors provided their final approval.

Availability of data and materials

This study's data file, including data extracted for each reference listed, is available as an online-only supplement (Appendix A).

Financial support and sponsorship

None.

Conflicts of interest

All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

The Northport VA Medical Center's Research and Development Office determined that this study was "not research"; this "not research" determination was dated September 12, 2019.

Consent for publication

Not applicable.

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