A Decade of Change—Risk Profiles and Outcomes for Isolated Coronary Artery Bypass Grafting Procedures, 1990–1999: A Report From the STS National Database Committee and the Duke Clinical Research Institute

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***Background*. The Society of Thoracic Surgeons National Adult Cardiac Database is the largest voluntary clinical database in medicine. Using this database we examined changes in the risk profile of patients undergoing isolated coronary artery bypass grafting (CABG) and their outcomes during the decade 1990 to 1999.**

***Methods*. Trends in 23 preoperative risk factors were tracked for CABG cases during this decade. Using a multivariate logistic risk model, we also determined the degree to which operative risk and risk-adjusted operative mortality changed during this 10-year interval.**

***Results*. Between 1990 and 1999, 1,154,486 patient records were harvested by the Society of Thoracic Surgeons National Adult Cardiac Database for isolated CABG procedures performed at 522 Society of Thoracic Surgeons participant sites in the United States and Canada. Over time, CABG patients were more likely to be older (mean age 63.7 in 1990, 65.1 in 1999), of female gender (25.7% women in 1990, 28.7% in 1999), and have a history of smoking, diabetes mellitus, renal failure, hypertension, stroke, chronic lung disease, New York Heart Association functional class IV, and three-vessel disease ($p < 0.0001$). Patients' predicted operative risk increased by 30.1%, from 2.6% in 1990 to 3.4% in 1999. Despite higher risk, observed operative mortality decreased by 23.1%, from 3.9% in 1990 to 3.0% in 1999 ($p < 0.0001$). During the decade, a Medicare-aged subset (n = 629,174) experienced similar increases in risk and declines in mortality.**

***Conclusions*. Patients referred for isolated CABG are significantly older, sicker, and have a higher risk than a decade ago. Despite this, CABG mortality rates have declined substantially. These results highlight the excellent progress in the care of CABG patients achieved during the past decade.**

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Cardiothoracic surgeons have the impression that the patients now referred for surgical revascularization procedures are substantially "older and sicker" than those on whom they performed coronary artery bypass grafting (CABG) a decade ago (1990 to 1999). Several reasons for this include: (1) documentation during the decade that surgical procedures can be safely performed on extremely aged [1] and high-risk [2] subsets; (2) documentation that patients with impaired ventricular function but reversible ischemia often benefit the most from surgical intervention [3]; (3) selective referral of lower risk patients (including single- and two-vessel disease patients) to percutaneous cardiovascular intervention or medical therapy, resulting in a greater percentage of surgical candidates with triple-vessel disease [3], and (4) compelling data from clinical trials documenting that patients with a higher baseline risk (including more extensive coronary disease and diabetic patients) are better treated by surgical rather than percutaneous intervention or medicine [4].

Empiric data to support this impression have come from single-institution studies, but multisite analyses are lacking. We used the Society of Thoracic Surgeons National Cardiac Database (STS NCD) [5] to examine the changes in risk profile for patients undergoing isolated CABG during the past decade as determined by the changes in risk factor trends. These changes were then compared with the changes in actual operative mortality for isolated CABG between 1990 and 1999. We also examined the change in major postoperative morbidities during the decade. Finally, because the Medicare population is America's largest healthcare payment outlay, we

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examined the changes in risk profiles and outcomes in this population as well.

Material and Methods

The Society of Thoracic Surgeons National Cardiac Database

Currently, patient data are harvested semiannually from the individual participant site providers contributing to the NCD [5]. Data are uploaded to a central warehouse facility, the Duke Clinical Research Institute. Certain data quality standard benchmarks need to be met both locally and nationally before a site's data are included on the aggregate national set. Aggregate data are analyzed twice a year for site-specific feedback reporting, and benchmarked against regional and national standards. These reports are designed for use in local and regional CABG Quality Improvement efforts by identifying areas for process improvement. An Executive Summary of the Semi-Annual report is posted at http://www.sts.org/database.

Outcomes performance measures are risk-adjusted using a series of statistical models developed by the STS National Database Committee [6–10]. Current models include mortality and major morbidity for CABG, valve and CABG/valve procedures, as well as risk-adjusted postoperative length of stay for each procedure classification.

Study Population

Between 1990 and 1999, a total of 1,517,715 adult cardiac procedures were harvested into the STS NCD from patients in the United States and Canada. A total of 522 sites contributed data to the STS NCD over this time interval. From this total, we excluded those patients undergoing isolated valve or other cardiac procedures, combined (CABG + valve, CABG + other) procedures, or data that failed to meet the data quality standards for inclusion in the NCD. This left a subset of isolated CABG patients that were used for the present analysis (n = 1,154,486).

Data Definitions

The elements and definitions used in the STS NCD have remained generally constant across this entire 10-year period [5, 7]. Detailed definitions for these outcomes can be found on the Society's web page (http://www.sts.org/database).

For this analysis, operative mortality included all in-hospital deaths as well as all out-of-hospital deaths occurring within 30 days of the procedure.

Analysis

Initial data descriptions included means for continuous risk variables and percentages for discrete variables. The statistical significance of time trends in risk factor prevalence during the 10-year period was determined by linear regression for continuous variables and logistic regression for discrete variables.

Table 1. Annual Harvest Data for the Total Population, Isolated CABG Population, and Medicare-Age Subset

Year	Total No. Patients	Isolated CABG Patients	Isolated CABG Patients 65+ (yr)	Cumulative No. of Sites
1990	31,444	22,945	11,770	106
1991	52,027	38,678	20,509	152
1992	80,250	60,544	32,220	209
1993	104,643	79,265	42,344	266
1994	148,519	113,617	61,014	340
1995	198,691	152,325	82,563	409
1996	233,400	181,467	99,209	461
1997	250,054	190,552	104,369	493
1998	236,280	178,763	99,657	519
1999	182,407	136,330	75,519	522
Total	1,517,715	1,154,486	629,174	

CABG = coronary artery bypass grafting.

We specifically considered the 28 risk variables that had been previously identified as independent predictors for operative mortality in any of the previous CABG models. Of these 28 variables, 23 had consistent definitions during the entire decade. We also calculated absolute and relative percentage changes in these risk factors between 1990 and 1999.

We developed a new, composite risk-adjusted logistic model based on the entire data set. This model allowed one to calculate a patient's summary predicted risk based on all 23 preoperative risk factors. These model estimates were also used to calculate the annual observed-to-expected (O/E) ratios for mortality as well as risk-adjusted mortality rates observed for the decade. Finally, results were analyzed to determine whether the time trend from 1990 to 1999 was statistically significant.

For purposes of the overall dataset analysis, missing data (data value for element not recorded) were assigned a null value (normal, absent) for all 23 variables used in the risk model.

Given that the quantity of missing data were not constant over time, as a secondary analysis we recalculated these temporal changes among a subset of isolated CABG patients, subject to the following rules: (1) for discrete variables, more than 20% missing for any variable disqualified that site's data for that year; (2) exceptions included data for child variables (eg, intraaortic balloon pump timing, myocardial infarction timing), and New York Heart Association functional classification; in these instances, if these variables were 100% missing, these sites were excluded; and (3) variables for ejection fraction and body surface area were not subject to any threshold because these continuous variables were imputed to means in the model.

Results

Table 1 documents the annual harvest data for the entire patient dataset from 1990 to 1999. A total of 1,154,486

CABG patient records were included in this analysis. Both the cumulative aggregate total record numbers and the aggregate Medicare population numbers are shown (n = 629,174). The cumulative aggregate number of harvest sites has grown fivefold during this decade.

Table 2 displays the changes in risk factor frequency during this time interval. For display purposes, we concentrated on the years 1990 and 1999, although time trends demonstrated consistent changes throughout the entire period. Table 2 also displays the relative and absolute change that occurred during this time period for each risk factor. Overall, the percentage of missing data (referred to as unknown in the Table) declined significantly during the decade. By 1999, the only variables with more than 6% missing data included pulmonary hypertension (14.7%), chronic obstructive pulmonary disease (14.4%), ejection fraction (13.3%), and New York Heart Association functional classification (14.7%).

The mean age of patients undergoing CABG increased from 63.7 years in 1990 to 65.1 years in 1999 ($p < 0.0001$ for the decade time trend) as did the percentage of women (25.7% versus 28.7%, $p < 0.0001$). The frequency of comorbid conditions including diabetes, renal failure, hypertension, preoperative stroke, chronic obstructive pulmonary disease, cardiogenic shock, and triple vessel disease all increased ($p < 0.0001$ for the time trend). Preoperative intraaortic balloon pump use increased by 33.9% as well. A decline in reoperations (before CABG or combined procedure) and a decline in emergent and salvage procedures occurred by the end of the decade.

Table 3 shows the similarly formatted data for the Medicare population. Again, univariate analysis documented that the change in the incidence of these risk factors was significant ($p < 0.0001$) for all variables during the time trend 1990 to 1999 except for previous cardiac operations ($p = 0.0054$), myocardial infarction timing more than 21 days ($p = 0.0022$), and salvage status ($p = 0.0067$).

To address the issue of missing data trends over time, a subanalysis of the entire dataset was performed as outlined above. Table 4 illustrates the number of isolated CABG patients (overall and Medicare-aged) and number of sites per year after the missing data criteria had been applied. The percentage of sites that dropped out of the analysis due to these rules declined substantially from 65% in 1990 to only 15% in 1999.

Table 5 presents this subset analysis formatted as in Table 2, for the entire population. By design, the percentage of missing data is dramatically reduced and is consistent across the time trend. The univariate trends, however, are similar in the subanalysis to the overall dataset ($p < 0.0001$ for the decade trend except for the variables noted) for the entire population. Similarly, the univariate trends for the missing data subanalysis of the Medicare subset were significant ($p < 0.0001$ except for salvage status ($p = 0.0051$), preoperative intraaortic balloon pump ($p = 0.06$) and New York Heart Association functional class IV ($p = 0.0681$)) (data not shown).

For the overall population, Figure 1 displays the changes in expected (predicted risk) mortality, in observed operative mortality, and risk-adjusted mortality during the decade using the model developed for this analysis. During this time interval, the observed operative mortality declined by 0.9%, a relative decrease of 23.1% ($p < 0.0001$ for the time trend). Risk-adjusted operative mortality similarly declined from 4.8% to 2.9% during the decade, also highly significant. In contrast, patient's predicted relative risk for operative mortality increased by 30%, from 2.6% in 1990 to 3.4% in 1999 ($p < 0.0001$ for the time trend).

Figure 2 shows the O/E ratio trend during the decade for the overall analysis (total isolated CABG group) and for the missing data subanalysis. The observed and expected data for each year for both analyses are shown in the Appendix. Although elimination of missing data from the analysis reduced the number of patients and sites available for the analysis, primarily in the early years (compare Table 1 and Table 4), the O/E trend was similar and both trends were significant for the decade analyzed. In addition, the O/E ratio data for the Medicare subgroup are shown, and tracked the "All CABG" and subanalysis curves.

Figure 3 demonstrates data similar to Figure 1 for the Medicare-aged population. Observed operative mortality rates in patients 65 years and older undergoing CABG declined from 5.4% to 4.1%, a relative decrease of 24.1%. The risk-adjusted mortality also declined from 5.2% to 3.1%, a relative decrease of 41%. In contrast, the predicted operative mortality risk for those aged 65 years and older increased by 33.3%, from 3.3% in 1990% to 4.4% in 1999 ($p < 0.0001$ for the time trend).

In addition, Figure 3 is a composite benchmarking the overall analysis mortality trend data (expected and risk-adjusted) for the Medicare-aged subset against average Medicare reimbursement for a standard three-vessel bypass procedure (current procedural terminology (CPT) code 33512 in 1990 to 1992, CPT code 33533 + 33518 in 1993 to 1999). During the decade, predicted reimbursement declined from $3,698 to $2,276 on average per case, a relative percentage decline of 38.4%. This occurred although mortality outcomes improved during the decade despite a significant increase in predicted risk.

Comment

Operative Mortality Trends Over Time

The present study is the first published report from a multisite national dataset (in contrast to reports from large, single-institution databases [11–15]) analyzing trends in CABG mortality. These results confirm that during the past decade patients undergoing CABG are older and with more comorbidities. Despite this, there has been a significant decline in overall operative mortality and risk-adjusted mortality for CABG during the decade from 1990 to 1999 (Fig 1).

Changing Risk Profile in CABG

The present study also importantly evaluates concomitant changes in the risk profile of patients undergoing

Table 2. Univariate Data for Variables Used in the Risk Adjustment, 1990–1999: All CABG Patients (n = 1,154,486) and Absolute and Relative Changes in Selected Risk-Adjustment Variables, 1990 Versus 1999[a]

Risk Factor	1990	1999	Absolute Change	Relative % Change
Demographics				
Patient age (y)				
Mean	63.7	65.1	1.4	
Median	65	66		
Gender				
Female (%)	25.7	28.7	3.0	11.6
Unknown (%)	0.0	0.4		
Race				
Non-Caucasian (%)	5.6	10.2	4.6	82.1
Unknown (%)	17.7	4.7		
Comorbidities				
Body surface area (m^2)				
Mean	1.90	1.95	0.05	
Median	1.92	1.96		
Unknown (%)	41.0	2.3		
Diabetes mellitus				
Yes (%)	21.4	32.7	11.3	52.7
Unknown (%)	17.6	2.6		
Renal failure				
Yes (%)	3.0	4.6	1.6	51.8
Unknown (%)	18.0	3.6		
Hypertension				
Yes (%)	50.7	68.9	18.2	35.9
Unknown (%)	14.1	2.1		
Pulmonary hypertension				
Yes (%)	0.8	3.0	2.2	275.0
Unknown (%)	38.4	14.7		
Cerebrovascular accident				
Yes (%)	3.8	7.1	3.2	84.9
Unknown (%)	31.4	3.4		
COPD				
Yes (%)	8.2	14.0	5.8	71.0
Unknown (%)	31.2	14.4		
Previous interventions				
Prior cardiac operations				
Yes (%)	10.6	8.4	−2.2	−21.0
Unknown (%)	1.2	2.4		
Cardiac status				
Cardiogenic shock				
Yes (%)	1.3	4.4	3.1	243.0
Unknown (%)	24.1	3.6		
MI timing				
0–21 days	16.2	23.7	7.5	46.3
> 21 days	20.5	21.9	1.4	6.8
Unknown (%)	22.3	3.4		
Unstable angina				
Yes (%)	55.8	43.2	−12.6	−22.6
Unknown (%)	6.3	1.6		
Arrhythmia				
Yes (%)	14.9	11.8	−3.1	−20.8
Unknown (%)	21.4	3.5		
NYHA class IV				
Yes (%)	13.2	23.1	9.9	75.0
Unknown (%)	57.2	14.7		
Hemodynamics and Cath				
Triple vessel disease				
Yes (%)	55.8	68.5	12.6	22.7
Unknown (%)				
Left main > 50% stenosis				
Yes (%)	15.6	23.4	7.8	50.0
Unknown (%)	30.2	3.4		
Ejection fraction (%)				
Mean	52.7	50.7	−2.0	−3.8
Median	54	50		
Unknown (%)	31.4	13.3		
Operative				
Procedure status				
Elective	67.3	60.8	−6.5	−9.7
Urgent	17.6	32.9	15.3	86.9
Emergent	7.1	5.5	−1.6	−22.7
Salvage	0.6	0.5	−0.2	−28.1
Unknown (%)	7.5	0.4		
CPB and support				
Preoperative IABP				
Yes (%)	4.9	6.5	1.7	33.9
Unknown (%)	6.2	2.6		

[a] Trends in all variables were statistically significant (at the $p < 0.0001$ level) over the decade, except salvage status ($p = 0.0003$).

COPD = chronic obstructive pulmonary disease; IABP = intraaortic balloon pump; MI = myocardial infarction; NYHA = New York Heart Association.

surgical intervention in a large, nationwide dataset. We used statistical modeling techniques that permit a longitudinal time trend analysis of the change in surgical risk over time, based on preoperative risk factors. Table 2 illustrates the preoperative risk factor trends during the decade. These trends include increasing age, increased female patient cohort, more comorbidities, more extensive surgical disease, and more patients with abnormal ventricular function. Interestingly, the incidence of emergent and salvage patients declined, in part probably due to the use of coronary stents for acute intervention and for vein graft restenosis, and perhaps due to more aggressive use of preoperative intraaortic balloon pump placement. In summary, this risk profile change resulted in a 30% increase in expected risk during the decade, highly significant for the time trend.

Increased Risk Versus Decreased Mortality

Figure 2 demonstrates a significant decrease in the observed mortality/expected mortality ratio (O/E ratio) for the overall and Medicare analysis groups during the decade. In the overall population the O/E ratio decreased below 1.0 in 1995, whereas it declined below this benchmark in 1998 for the Medicare-aged subset. Because

Table 3. Univariate Data for Variables Used in the Risk Adjustment, 1990–1999: Medicare-Age Subset (n = 629,174) and Absolute and Relative Changes in Selected Risk-Adjustment Variables, 1990 Versus 1999[a]

Risk Factor	1990	1999	Absolute Change	Relative % Change
Demographics				
Patient age (y)				
Mean	71.7	73.1	1.4	
Median	71	73		
Gender				
Female (%)	31.3	33.7	2.3	7.5
Unknown (%)	0.0	0.4		
Race				
Non-Caucasian (%)	4.6	8.6	4.0	87.0
Unknown (%)	17.7	4.7		
Comorbidities				
Body surface area (m^2)				
Mean	1.85	1.90	0.05	
Median	1.87	1.91		
Unknown (%)	41.9	2.3		
Diabetes mellitus				
Yes (%)	22.3	32.5	10.2	45.5
Unknown (%)	18.2	2.6		
Renal failure				
Yes (%)	4.3	5.4	1.2	27.3
Unknown (%)	18.2	3.6		
Hypertension				
Yes (%)	53.3	72.2	18.9	35.4
Unknown (%)	14.2	1.9		
Pulmonary hypertension				
Yes (%)	1.0	3.5	2.5	250.0
Unknown (%)	38.8	15.0		
Cerebrovascular accident				
Yes (%)	4.5	8.9	4.3	95.1
Unknown (%)	32.0	3.3		
COPD				
Yes (%)	8.9	15.4	6.5	73.0
Unknown (%)	31.6	14.6		
Previous interventions				
Prior cardiac operations				
Yes (%)	10.8	10.0	−0.8	−7.7
Unknown (%)	1.8	6.0		
Cardiac status				
Cardiogenic shock				
Yes (%)	1.4	4.5	3.1	222.6
Unknown (%)	24.7	3.6		
MI timing				
0–21 Days	15.3	23.2	7.9	51.6
> 21 Days	20.6	21.9	1.3	6.3
Unknown %	23.5	3.4		
Unstable angina				
Yes (%)	55.9	43.3	−12.6	−22.5
Unknown (%)	6.1	1.5		
Arrhythmia				
Yes (%)	17.7	15.2	−2.5	−14.1
Unknown (%)	21.8	3.4		
NYHA class IV				
Yes (%)	14.3	23.4	9.1	63.4
Unknown (%)	57.9	14.5		

Table 3. Continued

Risk Factor	1990	1999	Absolute Change	Relative % Change
Hemodynamics and Cath				
Triple vessel disease				
Yes (%)	58.1	70.8	12.7	21.8
Unknown (%)	17.1	4.9		
Left main > 50% Stenosis				
Yes (%)	15.6	23.4	7.8	50.0
Unknown (%)	30.2	3.4		
Ejection fraction (%)				
Mean	52.4	50.4	−2.0	−3.8
Median	51	50		
Unknown (%)	31.8	13.3		
Operative				
Procedure status				
Elective	67.3	60.8	−6.5	−9.7
Urgent	17.6	32.9	15.3	86.9
Emergent	7.1	5.3	−1.7	−24.3
Salvage	0.7	0.5	−0.2	−28.7
Unknown (%)	7.5	0.4		
CPB and support				
Preoperative IABP				
Yes (%)	5.4	6.4	1.1	19.8
Unknown (%)	6.2	2.6		

[a] Trends in all variables were statistically significant (at the $p < 0.0001$ level) over the decade, except prior cardiac operations ($p = 0.0054$), MI timing >21 days ($p = 0.0022$), and salvage status ($p = 0.0067$).

Abbreviation as in Table 2.

during the decade this baseline mortality risk in fact increased in severity, this outcomes benchmark not only improved but improved against a negative trend in preoperative surgical risk.

This measurement of outcomes evaluation (O/E ratio) has been used in a number of other analyses from both

Table 4. Annual Harvest Data Results After Subjecting the Isolated CABG Dataset to the Missing Data Selection Rules Process

Year	All Patients	Patients 65+ Yrs	Cumulative No. of Sites	% Total Sites
1990	8,432	4,052	38	35%
1991	18,579	9,443	66	43%
1992	30,718	16,018	104	50%
1993	46,908	24,878	156	59%
1994	70,746	37,871	218	64%
1995	98,378	53,281	282	69%
1996	132,894	72,420	357	77%
1997	140,817	76,614	396	80%
1998	127,403	64,529	434	84%
1999	91,136	33,820	443	85%
Total	766,011	392,926		

Same format as in Table 1. The number of sites expressed as a percentage of the total number of sites for that year, and increased from 35% in 1990 to 85% in 1999.

Table 5. Univariate Data for Variables Used in the Risk Adjustment, 1990–1999, After Missing Data Subanalysis and Absolute and Relative Changes in Selected Risk-Adjustment Variables, 1990–1999[a,b]

Risk Factor	1990	1999	Absolute Change	Relative % Change
Demographics				
Patient age (y)				
Mean	63.4	65.1	1.7	
Median	65	66		
Gender				
Female (%)	25.8	28.7	2.9	11.2
Unknown (%)	0.0	0.1		
Race				
Non-Caucasian (%)	6.3	11.0	4.7	74.6
Unknown (%)	0.8	0.7		
Comorbidities				
Body surface area (m^2)				
Mean	1.89	1.96	0.1	
Median	1.92	1.96		
Unknown (%)	0.8	0.7		
Diabetes mellitus				
Yes (%)	24.6	32.5	7.9	32.1
Unknown (%)	0.5	0.2		
Renal failure				
Yes (%)	2.8	4.6	1.8	64.3
Unknown (%)	0.5	0.4		
Hypertension				
Yes (%)	58.4	70.2	11.8	20.2
Unknown (%)	0.5	0.2		
Pulmonary hypertension				
Yes (%)	1.3	3.7	2.4	184.6
Unknown (%)	0.6	1.8		
Cerebrovascular accident				
Yes (%)	3.6	7.4	3.8	105.6
Unknown (%)	0.6	0.3		
COPD				
Yes (%)	11.3	16.5	5.2	46.0
Unknown (%)	0.5	0.4		
Previous interventions				
Prior cardiac operations				
Yes (%)	10.5	8.3	−2.2	−21.0
Unknown (%)	0.0	0.2		
Cardiac Status				
Cardiogenic shock				
Yes (%)	1.5	4.4	2.9	193.3
Unknown (%)	0.2	0.3		
MI timing				
0–21 days	22.0	24.7	2.7	12.3
> 21 days	26.3	22.3	−4.0	−15.2
Unknown (%)	7.8	2.1		
Unstable angina				
Yes (%)	44.1	42.8	−1.3	−2.9
Unknown (%)	4.7	0.7		
Arrhythrnia				
Yes (%)	18.5	12.4	−6.1	−33.0
Unknown (%)	1.6	0.8		
NYHA class IV				
Yes (%)	22.4	23.3	0.9	4.0
Unknown (%)	31.0	9.9		
Hemodynamics and Cath				
Triple vessel disease				
Yes (%)	64.9	71.6	6.7	10.3
Unknown (%)	2.0	1.8		
Left main > 50% stenosis				
Yes (%)	16.5	21.8	5.3	32.1
Unknown (%)	0.9	0.4		
Ejection fraction (%)				
Mean	52.3	50.8	−1.5	−2.9
Median	55	50		
Unknown (%)	18.3	10.0		
Operative				
Procedure status				
Elective	72.3	58.7	−13.6	−18.8
Urgent	18.4	35.1	16.7	90.8
Emergent	8.3	5.7	−2.6	−31.3
Salvage	0.7	0.5	−0.2	−28.6
Unknown (%)	0.4	0.2		
CPB and support				
Preoperative IABP				
Yes (%)	6.1	6.6	0.5	8.2
Unknown (%)	1.7	0.7		

[a] The stable missing data values across the decade for all variables except for child discrete variables of MI timing and IABP timing and for NYHA class. Body surface area and ejection fraction are continuous variables imputed to the means in the model and not subjected to threshold of completeness. Abbreviations are the same as in Table 2.

[b] Trends in all variables were statistically significant (at the $p < 0.0001$ level) over the decade, except salvage status ($p = 0.0051$), preoperative IABP ($p = 0.0600$), and NYHA class IV ($p = 0.0681$).

voluntary and mandatory databases (Shroyer ALW, personal communication, October 2000) [16–20]. Time trend data similar to that reported here from the STS have been collected but not reported from the VA Cardiac Surgical Program, also a nationwide, multisite but mandatory cardiac surgery database (Shroyer ALW, personal communication, October 2000) [21]. In this VA analysis, a significant decrease in the O/E ratio was demonstrated for the 13-year interval between 1988 and 1999, using a slightly different time trend analysis than the present study (Shroyer ALW, personal communication, October 2000). Thus, the two nationwide cardiac surgical databases, one voluntary (STS) and one mandatory (VA), have demonstrated a decline in operative mortality in the face of increased surgical risk during the decade of the 1990s. The similarity of results from the STS and VA analyses suggests again that voluntary data collection and analysis programs can yield results that are of quite similar validity and scientific merit as compared to mandatory programs for collection and analysis, provided the

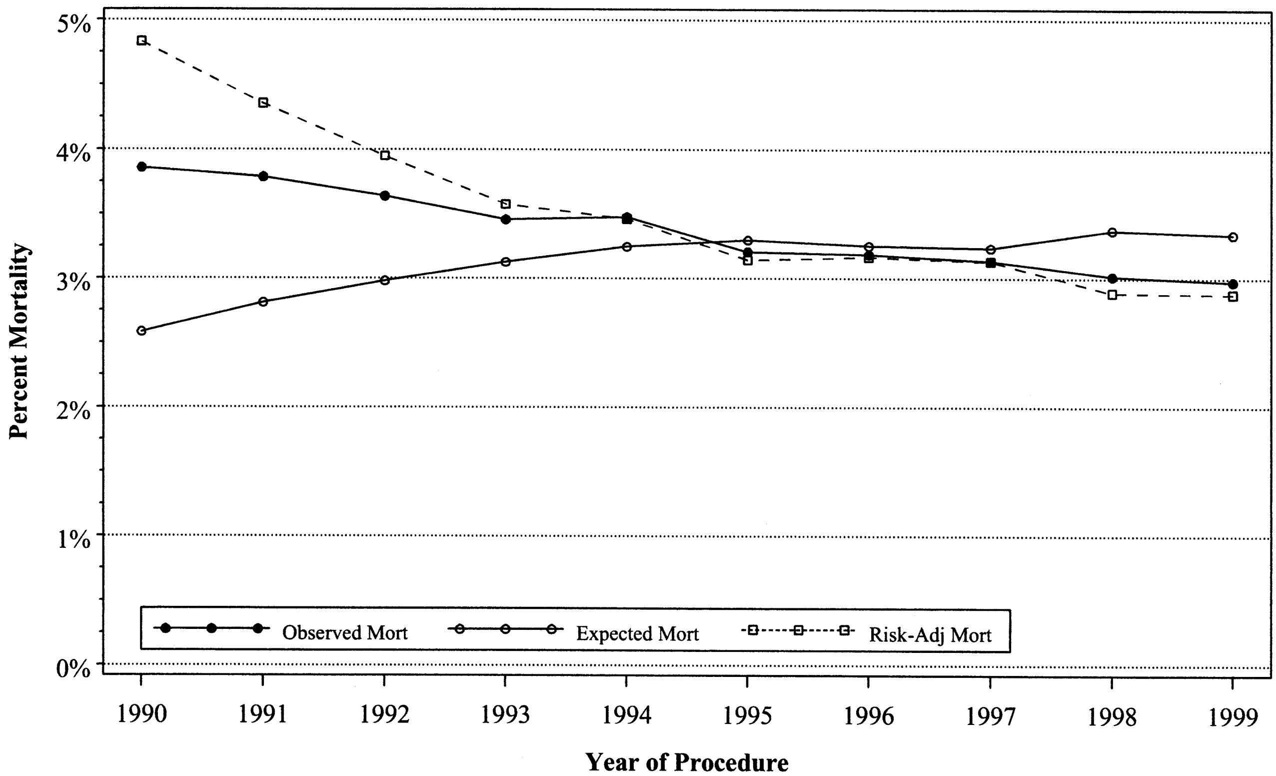

Fig 1. Observed, expected and risk-adjusted mortality, 1990 to 1999. Entire coronary artery bypass grafting population (n = 1,154,486).

data are collected by highly motivated physicians educated in the benefits of outcomes analyses.

Possible Reasons for the Improved Mortality Despite the Increased Risk

Efforts to continually improve the outcomes after CABG have been the hallmark of cardiothoracic surgeons for the past 30 years [5, 9, 17]. A number of reasons can be postulated for the continued improvement in operative mortality during the past decade. First, the *process* of CABG has undergone a significant evolution, with implementation of care paths and cardiac surgical service lines, both major efforts at improving the coordination of care for the CABG patient. Second, formation of cardiac surgical teams with dedicated cardiothoracic anesthesiologists, nursing personnel, and allied health personnel has greatly contributed to the efficiency of care. Third, technical improvements have occurred, both in cardiac surgery (eg, cardiopulmonary bypass and myocardial protection improvements) as well as in cardiology (eg, stenting of previous bypass grafts). Fourth, new pharmacologic agents and perioperative techniques have allowed for early extubation protocols and "fast-track" management of a majority of CABG patients [22]. Fifth, selection criteria and techniques have been developed to safely and successfully intervene in an increasingly elderly patient population [1, 2, 23].

Perhaps as important as these structural and technical changes, implementation of quality improvement programs has had a profound effect on improving mortality after CABG during the past decade. Physician-championed voluntary data collection and analysis efforts in northern New England [17], Minnesota [24], and Alabama [25] have demonstrated this, and the STS has recently embarked on a nationwide effort in quality improvement [5]. All these efforts have in common the feedback, local analysis of processes and outcomes, and regional information exchange that can favorably impact outcomes after CABG. It can be anticipated that continued efforts in quality improvement in CABG will produce sustained improvements in surgical outcomes after CABG during the first decade of the new millennium.

Missing Data in the STS NCD

As shown in Tables 2 and 3, the percentage of missing data was relatively high in the early years of the NCD. Importantly, the percentage of missing data declined during the decade to levels commensurate with other voluntary and mandatory database efforts. However, this change in the baseline level of missing data would be expected to affect the risk evaluation and expected mortality analyses in particular over time. Therefore, we repeated this analysis after exclusion of sites with more than 20% missing data for any of the 23 variables used in the trend mortality analyses. As shown in Table 4 this resulted in a smaller patient population, from a smaller number of participant sites. However, Table 5 shows that the variability in the percentage of missing data was

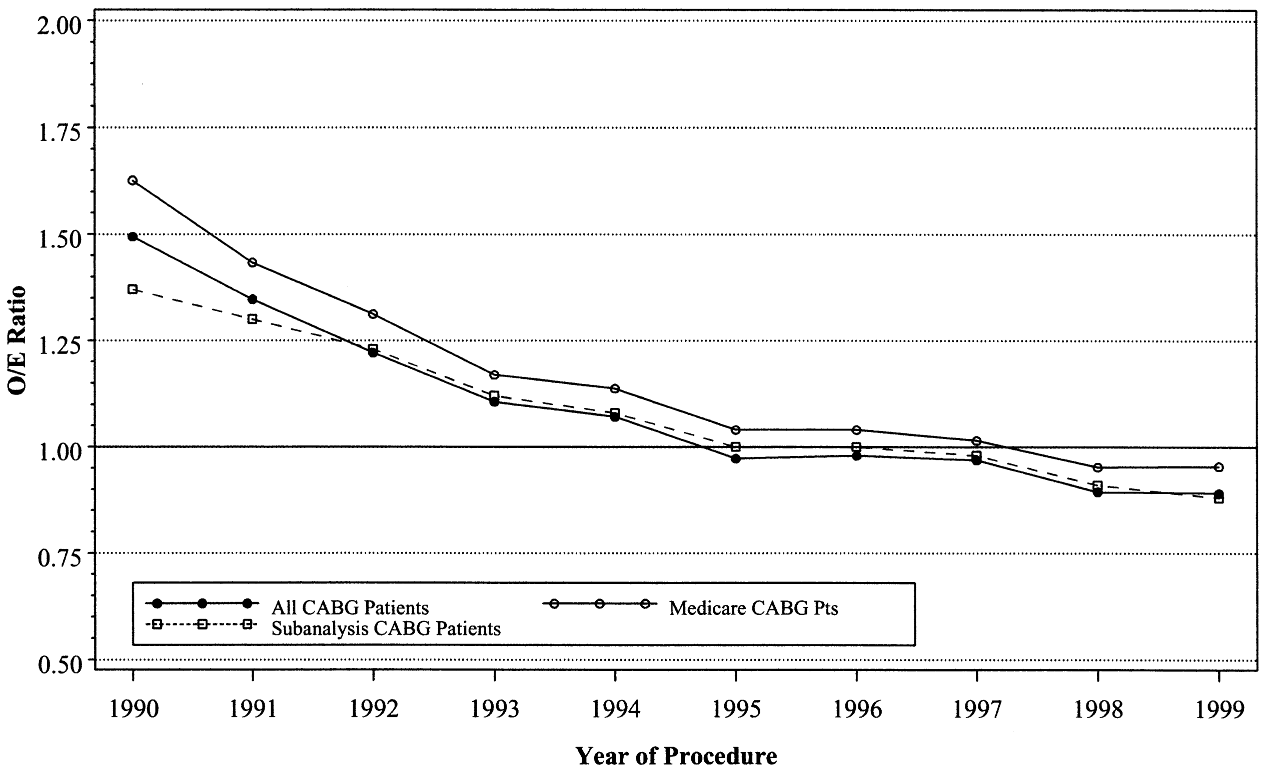

Fig 2. Observed mortality to expected mortality ratio (O/E), 1990 to 1999, for the entire coronary artery bypass grafting (CABG) population (n = 1,154,486), the Medicare-age subset (n = 629,174), and the missing data subanalysis subset of the entire coronary artery bypass grafting population (n = 766,011).

eliminated by this technique, while still leaving enough patients for trend analyses. Figure 3 demonstrates that the O/E ratio for this subanalysis was similar to the overall CABG and Medicare group analyses, and this decline in operative and risk-adjusted mortality as well as the increase in expected mortality were significant for the trend during 1990 to 1999 ($p < 0.0001$) for this missing data subanalysis as well. Thus, the seminal finding of this study, that there indeed has been an increase in expected mortality for CABG (increased surgical risk during the past decade, confirming surgeons' subjective impression that "patients today are sicker") is borne out in the overall dataset as well as both subanalyses.

The NCD has implemented a number of programs in the past several years to facilitate local data quality improvements [5], and the overall data quality in the NCD has improved substantially during the decade. Indeed, the decline in the percentage of missing data during the decade (Table 4) can be viewed as a surrogate for improved data quality in the NCB during this time frame.

Increased Risk Versus Decreased Mortality in the Elderly Population

In the patient group more than 65 years (n = 629,174), the mean age increased by 1.4 years also (71.7 versus 73.1 years) (Table 3; $p < 0.0001$). Numerous studies have documented acceptably higher mortality rates in elderly patients [1, 2]. This study reports similar mortality rates (Fig 3), and documents that the mortality for CABG in a subset of patients more than 65 years has declined significantly as well as during this past decade. Although this decline in this elderly subset is not as great as the overall population (Fig 1), it occurred during a decade where more and more elderly patients are considered acceptable candidates for elective and urgent surgical intervention. The O/E ratio has declined significantly during the decade in the Medicare population (Fig 2), and again this improvement in mortality outcome occurred in the face of an increasing, not static, baseline preoperative risk. The findings of this study support continued selected intervention in the elderly, including octogenarians and nonagenarians [1, 2].

Improved Outcomes Versus Declining Reimbursement for CABG (Fig 3)

During the decade of this analysis, the Medicare Part B reimbursement for CABG declined on average from \$3,698 for a three-vein procedure in 1990 to \$2,276 in 1999 for a more technically complicated standard left internal mammary artery/two-vein procedure. This represents a 38.4% decline in raw reimbursement during the decade, unadjusted for inflation (Fig 3). During this same time interval the surgical outcome for CABG improved by 41% despite the 33% increase in surgical risk. The findings from this scientific analysis should be used in establish-

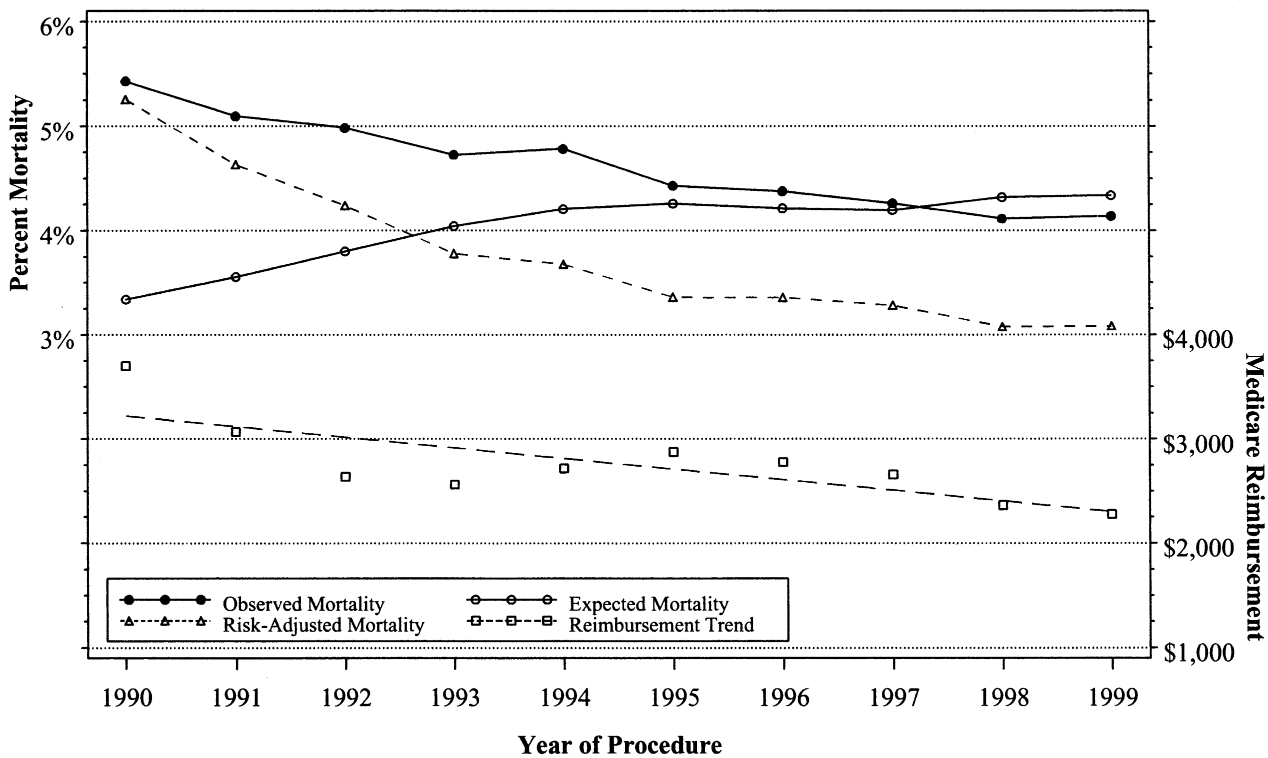

Fig 3. Composite of mortality statistics, Medicare-age subset and Medicare part B reimbursement, 1990 to 1999, Medicare-age subset (n = 629,491). Observed, expected and risk-adjusted mortality data are shown. In addition, Medicare part B reimbursement data from Health Care Financing Administration for current procedural terminology (CPT) 33512 (three veins) for 1990 to 1992 and for CPT 33518 + 33533 (left internal mammary artery + two veins) for 1993 to 1999 are shown. (HCFA is now known as CMS, Centers for Medicare and Medicaid Services.)

ing reimbursement levels to cardiothoracic surgeons for these more increasingly demanding clinical efforts. In particular, consideration should be given to the fact that these NCD participation activities are legitimate, reimbursable practice expenses that directly impact on the quality of care delivered to these patients.

Limitations

Although a substantial majority of US centers currently submit data to the STS NCD, participation is not ubiquitous among cardiac programs across the country; as such, the NCD data do not represent a truly comprehensive national experience. In addition, as the number of centers contributing to the STS has grown over time, it remains possible that some of the changes in risk factors and outcomes could be due to a change in the type or quality of centers represented in the STS NCD. A third potential limitation is that this study does not address perhaps the most important aspects of this analysis, namely why these improvements in mortality outcome occurred despite this increase in surgical risk.

In conclusion, this study documents a statistically significant increase in operative risk for patients undergoing isolated CABG during the past decade as documented in patient data from the STS National Cardiothoracic Surgical database. Importantly, despite this increase in expected mortality, the quality of care (as documented by decreased observed and risk-adjusted mortality) delivered by cardiothoracic surgeons and their colleagues to their patients was documented to have improved significantly during this time interval. Both of these time trends are highly statistically significant during the 10-year time interval. This analysis illustrates the powerful tool that the NCD represents, and clearly documents the value and "return on investment" of collecting and analyzing these outcomes data within organized medicine. Cardiothoracic surgeons should be extremely proud of the superb care delivered to their patients despite these increasingly complex and high-risk procedures.

The authors thank all STS participants who have contributed data to the STS National Database during the past decade. In addition, we extend our appreciation to the Society, the Officers, and the Members of the National Database Committee over the decade who have supported this National Database effort.

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Appendix

Mortality Data, 1990–1999

	Total Dataset		Missing Dataset	
Year	Expected	Observed	Expected	Observed
1990	2.58	3.85	2.75	3.78
1991	2.81	3.78	2.82	3.66
1992	2.97	3.63	2.90	3.58
1993	3.12	3.45	3.10	3.48
1994	3.24	3.47	3.18	3.44
1995	3.29	3.20	3.22	3.23
1996	3.25	3.18	3.18	3.19
1997	3.23	3.13	3.17	3.11
1998	3.37	3.01	3.33	3.03
1999	3.34	2.97	3.30	2.90

INVITED COMMENTARY

This manuscript has many features:

1. The Excellent: It has data from more than 1 million patients from 522 hospitals in the United States and Canada (2 Nations) from The Society of Thoracic Surgeons (STS) Database. It is, therefore, of great interest, is extremely valuable and documents that patient's risks (from cardiac disease and comorbidities) have increased from 1990 to 1999 but the observed and risk-adjusted mortality have decreased. These data are essential for monitoring the operative mortality of CABG surgery.
2. The Problems: (A) The actual mortality in each year is not listed; (B) A large amount of baseline data are missing. For example, excluding the data from a site with more than 20% data missing for any variable, results in 65% of sites being excluded in 1990, 36% in 1994 and even 15% in 1999, raising a concern about the risk-adjusted mortality. The authors' (indirect) suggestion that data are acceptable when 6% or less data are missing is reasonable and should be used in the future; (C) Data are not presented separately for patients less than 65 years of age. Data for the whole population and for those aged 65 or older are given.

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