Determinants of operative mortality in valvular heart surgery

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Objective: In some respects, outcome reporting in valvular surgery has been hampered by focusing on specific populations, reluctance to publish high-risk subgroups, and possibly skewed or inadequate samples. The goal of this study was to evaluate risk factors for operative mortality comprehensively across the entire spectrum of cardiac valvular procedures over the past decade.

Methods: All 409,904 valve procedures in the Society of Thoracic Surgeons database performed between 1994 and 2003 were assessed, and Society of Thoracic Surgeons preoperative and operative variables were related to operative mortality by using a multivariable logistic regression model. Data were greater than 95% complete, and the relative importance of relevant risk factors was determined by ranking odds ratios. The analysis had a high predictive power, with a C statistic of 0.735.

Results: In the model, 19 variables independently influenced operative mortality (all $P < .01$). The most significant was nonelective (acute) presentation (odds ratios, 2.11), followed by advanced age (odds ratios, 1.88), reoperation (odds ratios, 1.61), endocarditis (odds ratios, 1.59), and coronary disease (odds ratios, 1.58). Generally, valve replacement was associated with higher mortality than repair (odds ratios, 1.52). Overall, female gender was very important (odds ratios, 1.37), and earlier year of operation increased risk (odds ratios, 1.34), implying improving outcomes over time. Although any single comorbidity, on average, was only moderately contributory (odds ratios, 1.19), specific comorbidities, such as renal failure, or multiple comorbidities in a given patient could be very significant. Aortic root reconstruction carried the highest risk (odds ratios, 2.78), followed by tricuspid valve surgery (odds ratios, 2.26), multiple valve procedures (odds ratios, 2.06), and then isolated mitral (odds ratios, 1.47), pulmonic (odds ratios, 1.29), and aortic (reference procedure) operations. Reduced ejection fraction and severity of valve lesion were relatively less important (odds ratios, 1.34 and 0.83, respectively).

Conclusions: These data illustrate the significance of acute presentation in determining operative risk, and earlier surgical intervention under elective conditions might be emphasized for all types of significant valve lesions. Because aortic root reconstruction doubles mortality compared with simple aortic valve procedures, root replacement should be reserved for specific root pathology. Finally, issues related to reoperation, endocarditis, valve repair, gender, and the various procedures deserve more detailed examination.

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Scientific understanding of how baseline patient variables influence operative mortality in cardiac valvular surgery may have been limited by several factors. Most studies have reviewed small series from single centers and have focused on highly specific and usually low-risk subgroups. Complex valvular procedures are not available in sufficient numbers in most hospitals to allow a comprehensive analysis, and because the more complicated cases tend to have

Abbreviations and Acronyms

IABP = intra-aortic balloon pumping
 LV = left ventricular
 OR = odds ratio
 STS = Society of Thoracic Surgeons

higher operative mortalities, many investigators may have been reluctant to publish high-mortality data from complex categories. Confusion occasionally has existed regarding patient classification, and analyses sometimes have been so detailed as to limit clinical utility. Finally, results tend to change over time, and data regarding contemporary outcomes, as well as how prognosis has evolved in recent years, would be useful. As a result of all these issues, current prognostic effects of adverse baseline characteristics, such as advanced age, left ventricular (LV) dysfunction, and acute presentation, are poorly understood, especially as related to the entire spectrum of valve surgery. For example, one recent series of mitral valve repairs for ischemic mitral regurgitation found that severe LV dysfunction was no longer a prognostic factor.¹ Such a finding could be spurious because of limited sample size, focus on one procedure, or assessment from a single center, the results of which might not be representative. The goal of the present study was to clarify this topic by generating a simple but comprehensive risk factor analysis of operative mortality in the entire Society of Thoracic Surgeons (STS) valve surgery registry. Because many centers are represented and because all valvular procedures are present in ample numbers, it was anticipated that a more complete view of contemporary valve surgery might be obtained.

Patients and Methods**Data Source**

The STS national database was established in 1989 by North American heart surgeons to collect and assess cardiac surgical results in a valid and consistent manner.^{2,3} The STS database currently records the results of more than 70% of US adult cardiac surgical procedures annually. Clinical patient data are entered at sites using uniform definitions and certified software systems. Detailed definitions for preoperative risk factors, as well as complications, have been established by the STS and can be viewed online (<http://www.sts.org>). Data from individual centers are harvested semiannually and sent to the STS data warehouse and analysis center at the Duke Clinical Research Institute. A series of data quality checks are performed before data are aggregated into the national sample. Since 1994, the variables entered and definitions used have been changed in minor ways, but for this study, consistent baseline variables were available in every category for the entire 10-year period, with an overall missing rate of 3.85%. The frequency of missing data ranged from 0.0% for patient gender to 16.5% for ejection fraction. The accuracy and com-

TABLE 1. Distribution of valve procedures

		% Concomitant		Unadjusted mortality
	No.	CAB	"Other"	
Single valve				
A	216,245	50.0%	11.7%	5.7%
M	132,641	44.8%	11.6%	7.7%
T	3688	20.5%	41.9%	10.7%
P	819	16.1%	41.1%	4.4%
R	11,545	20.9%	64.5%	11.1%
Double valve				
A, M	24,608	38.3%	13.0%	11.5%
A, T	1183	29.6%	24.8%	14.0%
A, P	2574	10.2%	25.0%	3.1%
M, T	11,532	29.0%	23.4%	10.8%
M, P	43	27.9%	16.3%	9.3%
R, M	729	31.1%	52.3%	17.4%
T, P	186	9.1%	50.0%	6.0%
R, T	69	20.3%	40.6%	18.8%
R, P	248	10.9%	43.5%	2.8%
Triple valve				
A, M, T	3121	27.1%	20.5%	15.3%
A, M, P	92	20.7%	18.5%	5.4%
A, T, P	23	17.4%	26.1%	4.4%
M, T, P	33	39.4%	24.2%	9.1%
R, M, T	87	25.3%	49.4%	23.0%
R, M, P	6	0.0%	16.7%	0.0%
R, T, P	3	33.3%	33.3%	66.7%
Quadruple valve				
A, M, T, P	47	61.7%	27.7%	8.5%
R, M, T, P	2	0.0%	50.0%	100.0%
Total	409,524			

CAB, Coronary artery bypass; A, aortic valve; M, mitral valve; T, tricuspid valve; P, pulmonic valve; R, aortic root reconstruction.

ability of STS results have been confirmed by comparison with other mandatory and audited cardiac databases.⁴

Patient Population

The population for this study included all 409,904 cardiac valvular procedures in the STS database recorded over the 10-year period between January 1, 1994, and December 31, 2003. From this total, 322 procedures were omitted for "resection of sub-aortic stenosis," and 58 procedures were excluded from one site with unacceptable mortality data, resulting in 409,524 procedures in the study. An additional 424 were missing gender information, leaving 409,100 for inclusion in the statistical model. The individual procedures and sample sizes are shown in Table 1. The most common operations were isolated aortic valve procedures (n = 216,245), followed by mitral valve procedures (n = 132,641) and then aortic-mitral double-valve (n = 24,607), aortic root replacement (n = 11,545), and mitral-tricuspid double-valve (n = 11,532) operations. There were 3121 aortic-mitral-tricuspid triple valves. The incidence of concomitant coronary bypass and "other" procedures also is shown. The types of "other" cases are shown in Table 2. In general, these operations represent a small fraction of the overall group and are composed of highly diverse populations. Ablation

TABLE 2. Concurrent nonvalvular procedures

Procedure	No.
AICD	366
ASD	6188
Batista	172
Congenital	2410
Heart transplantation	130
LVA	1587
TMR	321
Pacemaker	2031
SVR	178
Cardiac trauma	212
VSD	1033
Ascending aortic replacement	19,143
Carotid endarterectomy	2257
Other, thoracic	1932
Other, vascular	3134
Other, cardiac	19,386

AICD, Automatic internal cardiac defibrillator; *ASD*, atrial septal defect closure; *LVA*, left ventricular aneurysm resection; *TMR*, transmyocardial revascularization; *SVR*, surgical ventricular restoration; *VSD*, ventricular septal defect closure.

procedures for atrial fibrillation were not recorded until recently and are omitted. Baseline characteristics of the overall series are presented in Table 3. Preoperative variables remained fairly constant over the decade, except that obesity increased from 6% to 11%, diabetes increased from 17% to 23%, hypertension increased from 46% to 66%, cerebrovascular disease increased from 8% to 15%, and minor increases were observed in age (65.1 years to 66.3 years, mean), peripheral vascular disease (9% to 13%), and renal failure (6% to 8%). Because this study also focused on elective versus acute presentation, baseline data are given additionally for these subgroups.

Selection of Variables for Analysis

In order to compare quantitatively the relative importance of preoperative patient characteristics in the risk factor analysis, variables were simplified as much as possible and, except for number of comorbidities, were dichotomized so that each could be evaluated as a single degree of freedom. Decisions in this process were made prospectively before the analysis began and were influenced by perceived clinical relevance and the results of previous similar clinical research. The risk factors that were selected included the following: acute presentation (nonelective vs elective); age (≥ 70 years vs < 70 years); reoperation (yes/no); etiology endocarditis (yes/no); presence of coronary disease, performance of coronary bypass (yes-no); the decision for valve replacement versus repair (for multiple valves, any valve repaired = repair group); New York Heart Association class III or IV congestive heart failure preoperatively (yes/no); gender (female vs male); severe LV dysfunction (ejection fraction < 0.35 vs ≥ 0.35); earlier year of operation (first 5-year period vs second 5-year period); presence and number of comorbidities (range, 0-10); hemodynamically severe valve lesion (vs mild to moderate); and valve procedure required (referenced to single aortic valve repair or replace-

ment procedure): aortic root reconstruction, tricuspid valve procedure, multiple valve procedure (≥ 2 valves operated), mitral valve procedure, pulmonic valve procedure, valve plus other major operation (eg, ascending aortic replacement, LV aneurysm resection, and septal defect closure; see Table 2), and aortic valve procedure. There were 303,043 procedures in the elective group, and the nonelective (acute presentation) group contained 106,481 divided into 3 categories: urgent ($n = 90,956$), emergency ($n = 12,867$), and salvage ($n = 2658$). The current STS operational definition of urgent status is as follows: "All of the following conditions are met: Not elective status. Not emergency status. Procedure required during same hospitalization in order to minimize chance of further clinical deterioration. Worsening, sudden chest pain, congestive heart failure, acute myocardial infarction, precarious anatomy, IABP, unstable angina with intravenous nitroglycerin or rest angina may be included." The definition for emergency is as follows: "The patient's clinical status includes any of the following: Ischemic dysfunction: 1. Ongoing ischemia including resting angina despite maximal medical therapy (medical and/or IABP); 2. Acute evolving myocardial infarction within 24 hours before surgery; or 3. Pulmonary edema requiring intubation. Mechanical dysfunction (either of the following): 1. Shock with circulatory support; or 2. Shock without circulatory support." The definition for salvage is as follows: "The patient was undergoing cardiopulmonary resuscitation en route to the operating room or prior to anesthesia induction." The STS definition for mortality is death during the same hospitalization as the valve surgery or after discharge but within 30 days of the operation. Again, other definitions are given at <http://www.sts.org>. In the analysis, comorbidities included morbid obesity (body mass index ≥ 35), smoker, diabetes, renal failure, dialysis, hypertension, hyperlipidemia, immunosuppressive therapy, cerebrovascular disease, and peripheral vascular disease. Missing categoric variables were imputed by assigning the modal value, and missing continuous variables were assigned the median value. Again, less than 5% of data were missing overall.

Statistical Analysis

A multivariable logistic regression model was used to quantify the association between each explanatory variable and operative mortality in a manner that partially adjusted for the confounding effects of other variables. The form of the logistic regression equation was as follows:

$$\log \left\{ \frac{\theta_i}{1 - \theta_i} \right\} = \alpha + x'_i \beta,$$

where θ_i is the probability of mortality for the i th patient, α is the model intercept term, β is the vector of regression parameters, and x_i is the vector of explanatory variables for the i th patient. This type of logistic methodology has been shown to be superior to other techniques for the purpose of risk factor analysis.^{5,6} The magnitude of the effect of each explanatory variable in the logistic model was quantified by using 2 statistics: the odds ratio (OR) and the adjusted mortality difference. The latter is defined as the difference between the average predicted risk of mortality in the study population if each subject had the risk factor in question minus the average predicted risk of mortality in the study population if no subject had the risk factor in question, holding all other

TABLE 3. Baseline patient characteristics

Variable	Overall	Elective	Nonelective	P value
No.	409,524	303,043	106,481	
Age (y)				<.0001
Mean	66.1	65.7	67.4	
Median	69.0	69.0	70.0	
Age ≥70 y	48%	47%	53%	<.0001
Gender				<.0001
Male	57%	57%	56%	
Female	43%	43%	44%	
Race				<.0001
White	87%	87%	85%	
Black	5%	5%	6%	
Other-unknown	8%	8%	8%	
No. of comorbidities				<.0001
0	13%	14%	10%	
1	26%	27%	22%	
2	27%	27%	26%	
3	19%	18%	20%	
4	10%	9%	12%	
Obesity (BMI >35)	9%	9%	9%	.2706
Smoker	48%	48%	50%	<.0001
Current smoker	14%	13%	16%	<.0001
Diabetes	20%	18%	25%	<.0001
Hyperlipidemia	37%	36%	38%	<.0001
Renal failure	7%	5%	12%	<.0001
Dialysis-dependent RF	2%	1%	3%	<.0001
Last creatinine preoperatively				<.0001
Mean	1.3	1.2	1.5	
Median	1.0	1.0	1.1	
Hypertension	58%	56%	62%	<.0001
CVA	8%	7%	10%	<.0001
COPD	13%	12%	17%	<.0001
Immunosuppressive treatment	3%	2%	4%	<.0001
PVD	12%	11%	16%	<.0001
CVD	12%	11%	15%	<.0001
Prior MI	19%	15%	31%	<.0001
MI within 7 d	5%	2%	13%	
MI within 8-21 d	2%	1%	4%	
MI within >21 d	11%	11%	13%	
Reoperation	19%	18%	21%	<.0001
Prior PCI	7%	6%	9%	<.0001
Endocarditis	5%	4%	9%	<.0001
Any severe lesion	79%	80%	75%	<.0001
NYHA class				<.0001
I	10%	11%	7%	
II	18%	21%	10%	
III	39%	41%	33%	
IV	21%	14%	40%	
CHF	34%	29%	49%	<.0001
Angina type				<.0001
No angina	63%	66%	53%	
Stable	22%	24%	18%	
Unstable	15%	10%	29%	
Cardiogenic shock	3%	1%	9%	<.0001

TABLE 3. Continued

Variable	Overall	Elective	Nonelective	P value
Resuscitation	1%	0%	3%	<.0001
Arrhythmia	27%	26%	30%	<.0001
Acuity of presentation				<.0001
Elective	74%	100%	0%	
Urgent	22%	0%	85%	
Emergency	3%	0%	12%	
Salvage	1%	0%	2%	
PA mean pressure				<.0001
Mean	25.5	24.5	28.0	
Median	24.0	24.0	27.0	
Pulmonary hypertension	12%	11%	16%	<.0001
Ejection fraction				<.0001
Mean	0.51	0.52	0.48	
Median	0.50	0.50	0.50	
Ejection fraction ≥ 0.35	89%	91%	83%	<.0001
No. of diseased vessels				<.0001
0	53%	56%	42%	
1	13%	13%	12%	
2	13%	13%	15%	
3	21%	18%	30%	
Left main disease	7%	5%	11%	<.0001
Any valve replaced	81%	82%	79%	<.0001
Isolated valve procedure				
Aortic	53%	54%	49%	<.0001
Mitral	32%	31%	35%	<.0001
Tricuspid	0.90%	0.87%	1.00%	.0001
Pulmonic	0.20%	0.23%	0.11%	<.0001
Aortic root reconstruction	3%	2%	4%	<.0001
Multiple valve procedure	10.89%	10.76%	11.24%	<.0001
Concurrent CAB	46%	42%	56%	<.0001
Concurrent non-CAB procedure	14%	13%	17%	<.0001

BMI, Body mass index; RF, renal failure; CVA, cerebral vascular accident; COPD, chronic obstructive pulmonary disease; PVD, peripheral vascular disease; CVD, cerebral vascular disease; MI, myocardial infarction; PCI, percutaneous coronary intervention; NYHA, New York Heart Association; CHF, congestive heart failure; PA, pulmonary artery; CAB, coronary artery bypass.

variables constant. Independent effects of individual variables on mortality were assessed by comparing ORs. To examine differences in patient characteristics between elective and acute presentation groups, χ^2 statistics were used for categorical variables, and Wilcoxon rank sum statistics were used for continuous variables. All analyses were performed with SAS version 8.2 software.

Results

Raw unadjusted mortality rates for each of the procedures are listed in Table 1. Table 3 shows patient characteristics in the overall group and also for the elective and acute presentation subgroups. In general, acute patients had a higher incidence of adverse risk factors and, overall, were sicker on admission. In Table 4 outcome variables are presented in 3 ways. First, unadjusted mortality rates are given for each subpopulation defined by the explanatory variables. The univariable magnitude of effect of a given risk factor on raw

mortality is evident. Then adjusted mortality differences are presented, examining the effect of the variable under consideration, with the others held fixed. This is important, for example, because one variable (eg, acute presentation) often is associated with a higher incidence of other adverse risk factors, such as advanced age or comorbidities. Finally, the ORs quantify the relative effects of each independent variable on mortality within the multivariable logistic regression model. With the large sample size, virtually all variables are highly statistically significant, but using adjusted risk differences and ORs, relative magnitudes are more easily assessed. The C statistic of the model was 0.735, indicating high predictive power.

Of baseline characteristics, acute presentation proved to be the most important determinant of mortality, and the incidence appeared to accelerate over time (Figure 1). Acute

TABLE 4. Effects of baseline variables on outcome

Variable	Unadjusted mortality (%)	Unadjusted mortality difference	Adjusted mortality (%)	Adjusted mortality difference	Adjusted odds ratio	χ^2	Parameter estimate	P value
Acute presentation	12.9	—	10.7	—	2.11	3244	0.7445	<.001
Elective	5.1	7.8	5.5	5.2				
Age ≥ 70 y	9.4	—	9.1	—	1.88	2150	0.6322	<.001
Age <70 y	5.0	4.4	5.2	3.9				
Reoperation, yes	11.3	—	9.7	—	1.61	1123	0.4762	<.001
Reoperation, no	6.2	5.1	6.4	3.3				
Endocarditis, yes	10.6	—	10.3	—	1.59	338	0.4614	<.001
Endocarditis, no	6.9	3.7	7.0	3.3				
CAD, yes	9.3	—	8.4	—	1.58	1024	0.4552	<.001
CAD, no	5.0	4.3	5.6	2.8				
Valve replacement	7.2	—	7.4	—	1.52	408	0.4158	<.001
Valve repair	6.8	0.4	5.1	2.3				
CHF, yes	10.5	—	8.3	—	1.39	605	0.3262	<.001
CHF, no	5.4	5.1	6.3	2.0				
Female gender	8.4	—	8.3	—	1.37	590	0.3139	<.001
Male gender	6.2	2.2	6.3	1.9				
EF ≥ 0.35	6.6	—	6.9	—	1.34	280	0.2944	<.001
EF <0.35	11.1	4.5	8.9	−2.0				
Year ≥ 1999	6.9	—	6.4	—	1.34	511	0.2945	<.001
Year <1999	7.5	−0.6	8.3	−1.9				
0 Comorbidities	4.5	—	5.0	—	1.19	1586	0.1716	<.001
1 Comorbidity	5.5	1.0	5.8	0.8	(Average per comorbidity)			
2 Comorbidities	6.4	1.9	6.8	1.8				
3 Comorbidities	8.1	3.6	7.9	2.9				
4 Comorbidities	10.5	6.0	9.1	4.1				
Severe Lesion, yes	6.8	—	6.9	—	0.83	151	−0.1880	<.001
Severe Lesion, no	8.4	−1.6	8.1	−1.2				
Overall	7.1	—	7.1	—				
Procedures (referenced to AVR)								
Aortic root	11.1	5.4	13.5	7.9	2.78	650	1.0227	<.001
Isolated tricuspid	10.7	5.0	11.4	5.8	2.26	199	0.8173	<.001
Multiple valve	11.2	5.5	10.5	4.9	2.06	1440	0.7203	<.001
Isolated mitral	7.7	2.0	7.9	2.3	1.47	578	0.3880	<.001
Isolated pulmonic	4.4	−1.3	7.1	1.5	1.29	2	0.2556	.141
Isolated aortic	5.7	—	5.6	—	1.00	—	—	—
Concurrent operation, yes	10.0	—	9.9	—	1.58	736	0.4568	<.001
Concurrent operation, no (referenced to valve-only procedure)	6.7	3.3	6.7	3.2				

The regression intercept was −4.3817. CAD, Coronary artery disease; CHF, congestive heart failure; EF, ejection fraction; AVR, aortic valve replacement.

presentation was present in 22.4% of procedures in 1994 versus 31.7% in 2003 (a 42% increase over the decade). To illustrate the effects of acute presentation on mortality, the raw elective mortality was 5.1% versus 12.9% for acute presentation (a 253% increment). Within acute categories, the raw mortality for urgent status was 10.4%, for emergency status was 23.8%, and for salvage status was 44.8%. The next most important variable was advanced age, followed by reoperation, endocarditis, etc. (listed in descending order in Table 1). Patients selected for valve repair

generally had better survival than those receiving replacement, and female gender was associated with a higher mortality. Operative results appeared to improve over time, and although the average effect of a single comorbidity was modest, multiple morbidities or specific morbidities, such as renal failure, could produce major effects. Having a hemodynamically severe valve lesion seemed to be protective.

With regard to individual procedures, aortic root reconstruction appeared to have the highest risk, followed by tricuspid valve procedures and multiple valve procedures,

Figure 1. The incidence of acute presentation increased steadily over the decade.

etc. (Table 1). The ORs in this analysis are referenced to the lowest-risk operation, aortic valve procedures. Focusing on root reconstructions ($n = 11,545$), 10,724 were listed as having valve conduits, and 821 had valve-sparing root replacements. Of the entire group, 6044 (52%) were performed for ascending aortic aneurysms, 435 (4%) for aortic dissections, and 5066 (44%) had no aortic root pathology documented. The majority of the latter group was listed as having aortic stenosis (42.3%) and/or aortic insufficiency (50.7%) only. In the latter group 2152 patients had stentless porcine or homograft root replacement, 545 had mechanical valve composite grafts, and the remainder had a plethora of other prostheses. The raw mortality for root reconstruction for aortic aneurysms was 10.5%, for aortic dissection was 23.7%, and for root replacement without root pathology was 9.5%. In the valve plus "other" category, 9877 patients had aortic valve and noncomposite ascending aortic replacement procedures, with a raw mortality of 9.2%. In the entire data set, addition of an "other" cardiac or noncardiac operation increased average risk appreciably (Table 1), although there was likely significant variation between "other" categories (Table 2). In the "other" analysis, the OR was referenced to the same valve procedure but without the "other" component. Lastly, the primary causes of death for the study group are shown in Table 5. This primary designation refers to the single problem that initiated the fatal outcome, understanding that additional problems likely occurred during the hospital course. The most important initiating factor was cardiac, followed by pulmonary and neurologic, as listed in Table 5. Also documented are the incidences of complications occurring in the data set. Atrial fibrillation was most common, followed by pulmonary and renal complications, and the remainder are shown in Table 5. In this analysis patients could have more than one complication.

TABLE 5. Causes of mortality and morbidity

Primary cause of mortality	
Cardiac	60.3%
Pulmonary	8.9%
Neurologic	8.2%
Infection	6.4%
Renal	3.3%
Vascular	2.0%
Valvular	1.1%
"Other"	9.8%
Complications	
Atrial fibrillation	27.0%
Prolonged ventilation	14.0%
Renal failure	7.1%
Reoperation for bleeding	5.5%
Heart block	5.2%
Pneumonia	4.5%
Gastrointestinal	4.3%
Noncardiac reoperation	3.5%
Cardiac arrest	3.3%
"Other" cardiac reoperation	3.1%
Urinary tract infection	2.9%
Permanent stroke	2.8%
Septicemia	2.5%
Multiorgan failure	2.1%
Anticoagulation complication	2.0%
Transient stroke	1.5%
Tamponade	1.4%
Coma >24 h	1.1%
Leg infection	1.0%

Other complications occurred in less than 1.0%.

Discussion

Improvements in cardiac surgery over the past half century at times have been rapid and at others have been slow and incremental. It is reasonable to state, however, that the current aggregate ability to surgically manage heart disease has been one of the medical success stories of all time. The first step in quality improvement is defining a problem area, which requires data collection and analysis, and then strategies are implemented to overcome specific deficiencies.⁷ As a final step, data again are collected to verify the efficacy of therapeutic interventions. Cardiac valve surgery presents special difficulties in following this process. Most studies from single centers have evaluated small series of patients and focused on highly specific subgroups. Often, a center is motivated to publish only good results, so that problem areas can be overlooked. Because outcomes can represent a moving target, assessment over time is important, and confusion has existed regarding patient classification in some categories. Adverse characteristics, such as advanced age, low ejection fraction, hemodynamic severity, and acute presentation, probably affect prognosis more than in coronary surgery,⁸ but the exact magnitudes are unclear. This study was designed to evaluate comprehensively the mor-

tality characteristics of the entire STS valve surgery database over the past 10 years and potentially to overcome many of the methodologic deficiencies outlined above. The overall goal was to define current problem areas in valve surgery for future innovation and quality improvement. A secondary goal was to better understand how variables interrelate to produce an overall mortality figure.

The most striking problem area in the current analysis was acute presentation. Similar to other studies and with all other variables being constant, acute presentation was associated with a 2-fold increase in operative mortality, which was more than any other risk factor.⁹⁻¹² Less than a quarter were “obligatory” emergencies (eg, acute myocardial infarction, endocarditis, and aortic dissection), so that most might have been candidates for earlier intervention. Although definitive conclusions about the timing of the operation are difficult to make from data such as these, it is plausible that referring patients with significant valve lesions under elective conditions before severe refractory symptoms convert the operation to urgent status could affect overall operative mortality in a positive manner. It is disconcerting that the incidence of acute presentation increased by 42% over the decade. One could hypothesize that cardiology practice has preferentially emphasized acute coronary disease during this period, and perhaps some of this acute focus has carried over to valvular patients. On the other hand, the concept of earlier referral is now well accepted for mitral regurgitation, and perhaps with documentation of acute presentation risks, a similar principle could be established for all of valve surgery. The best results are obtained with elective referral, and procrastinating until urgent or emergency intervention is required seems to double operative risk.

The other surprising finding of this study was the high relative risk of aortic root replacement. It appeared that this was not due to a predominance of aortic dissections in the population (mortality, 23.7%) because dissection comprised only 4% of cases. Although composite aortic valve and ascending aortic replacement for root aneurysm was associated with a 10.5% mortality and noncomposite replacement had a 9.2% mortality, all of these results might not be out of line.¹³⁻¹⁵ The high mortality for root replacement for standard aortic valve disease without root pathology, however, deserves special attention. It seemed that almost half of the aortic root reconstructions were performed in the absence of aneurysms, and this might reflect the recent trend toward using freestyle or homograft prostheses as root replacements for isolated aortic valve disease. Although this group comprised less than 3% of aortic valve procedures (without root pathology), the mortality was close to 10%. It should be emphasized that simple aortic valve replacement in this series was the lowest-risk valve surgery (5.7% raw mortality) and that standard valve replacement probably

should be used preferentially when the root is normal. In fact, most authorities would agree that root replacement should be reserved for patients with complex dissections, annuloaortic ectasia, or true root aneurysms,^{14,15} and the trend toward inappropriate root replacement should be discouraged.

To experienced valve surgeons, it is not surprising that isolated tricuspid valve procedures carried such a high risk. These patients often present with advanced sequelae of chronic systemic venous hypertension, such as liver or renal failure, and can pose difficult management problems. The effects of chronic tricuspid regurgitation can be subtle and insidious, and a message of careful monitoring and early referral for this disorder also would be appropriate. Usually, in any single center only a small number of isolated tricuspid procedures are available for analysis, and this group represents one example for which the STS data set could be useful. It is clear from this study that isolated tricuspid procedures constitute one of the high-risk categories. Multiple valve surgery also is a complex topic.¹⁶ Each of the different valve combinations likely represents differing pathologies; for example, the aortic-pulmonic valve procedures might be predominantly Ross operations. With such a large number of multiple valve procedures, the STS registry might be uniquely positioned to better understand this diverse topic, and more detailed analyses seem indicated.

This study produced many more questions than it answered. The risk of advanced age is ubiquitous in surgical articles,^{11,17-19} but the importance of reoperation recently has been de-emphasized.^{9,20-22} As the third most important preoperative variable over the past decade, reoperation certainly deserves more careful examination. Perhaps reoperation is of minimal importance for simple isolated procedures, but with more complex lesions (that are less frequently reported), the risk is amplified. Reoperation could be a fruitful topic for future study, including formal analysis of statistical interactions of variables. Similarly, the topics of endocarditis and valve repair versus replacement should be further investigated, as well as that of female gender. As in other studies,²³⁻²⁶ coronary disease and LV dysfunction increased risk.

Similar to previous analyses,²⁷ adjusted mortality decreased by almost 25% over the decade, almost certainly because of refinements in surgical technique and postoperative care. Was this a general phenomenon or a specific function of certain procedures? Did the emergence of minimally invasive valve surgery or the increasing use of valve repair contribute to this effect?²⁸⁻³² Parenthetically, and perhaps disturbingly, unadjusted mortality decreased by only 8%. The difference was largely due to increased rates of acute presentation, and reversal of the acute presentation trend could allow relative improvements in valve surgery results to become more evident in everyday practice. Co-

morbidity effects in this study were assessed in a fairly rudimentary way. It would be useful to apply a weighted comorbidity index to take into account the more pronounced effects of certain comorbidities, such as renal failure.³³ Finally, hemodynamically severe valve lesions seemed to have a protective effect on operative mortality. Perhaps this finding is a function of immediate and profound hemodynamic improvement postoperatively, although again, further analysis will be required to clarify this point.

One function of a database is to define problem areas so that potential solutions can be considered. It is interesting that cardiac issues remain the initiators of mortality in more than half of operative deaths. Although the exact types of cardiac problems are not documented, one can surmise that low cardiac output or other manifestations of inadequate myocardial protection might still be occurring in some complex valve cases requiring longer clamp times. Cardiac arrhythmias also might be contributing to mortality and constitute the most common complication. Lastly, pulmonary problems remain the most frequent noncardiac cause of morbidity and mortality,^{34,35} and effective innovations in each of these areas will likely produce further improvements in the future.

This attempt at a comprehensive analysis of overall valve surgery mortality should not be construed as a substitute for detailed assessment of individual procedures. Rather, this study poses a different question: What are the aggregate risk factors for all types of valve surgery? With current trends toward publication of overall valve mortality figures from center to center, an improved general understanding of relationships between baseline risk and mortality will be important.³⁶ Especially because baseline characteristics influence valve mortality to a greater extent than coronary surgery, further illumination seems indicated. This study can be viewed as a first draft of such an analysis and produced several surprising results. Each of these findings, however, is dependent on the quality of data recording, and coding errors are possible, even though many audits have shown STS data to be very accurate. Other limitations of the data set exist, such as the 5% of patients listed as having “other” cardiac procedures, the exact nature of which is unknown. Each of these issues is being addressed, and hopefully, the STS database will continue as a prime example of physician-initiated evidence-based medicine.

In conclusion, this study illustrates the power of multicenter collaboration in generating a clinical database in adult cardiac surgery. Complex or unusual valve procedures can be investigated in a valid and comprehensive manner, and concepts can be developed that are difficult to perceive in any single center. A major finding of this study was the high mortality in possibly inappropriate aortic root reconstructions. The data suggest that simple aortic valve replacement (the lowest-risk procedure) should be favored for all

but the most compelling aortic root pathology. Finally, the most important observations of this study are the accelerating trend toward acute presentation over the past decade and the primary importance of this variable in increasing operative risk. Cardiac clinicians should redouble their efforts to emphasize earlier surgical referral for all types of severe valve lesions before urgent or emergency intervention is required.

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Discussion

Dr James I. Fann (*Stanford, Calif*). Scott, you and your colleagues have performed a comprehensive analysis of the determinants of operative mortality in patients undergoing valve surgery using what has become a tremendous resource, the STS database. The importance of this study is that it is an unbiased look at a group of more than 400,000 patients over a 10-year period. Although this is a retrospective analysis and in a somewhat selected group of patients, it is perhaps the most reliable statistical analysis to date directed at independent risk factors in patients undergoing valve surgery. As you mentioned, this analysis is important because it is not subject to sampling bias or the results of a single center or surgeon. It does not focus on one specific procedure and is not compiled over an inordinately long period of time.

In this study acute presentation was the most important risk factor for operative mortality. This variable is well recognized in its association with a worse outcome, and you mentioned that it is important to refer patients with severe valve lesions under elective and not emergency conditions. What is more important is the

underlying problem that caused the patient to present acutely. My first question is this: How did these acute or emergency patients present? As background, I notice that 14% of the patients in the acute category were operated on for emergency or salvage indications, whereas the other 85% were in the urgent subgroup. Were the emergency and salvage patients with operative mortality rates of 24% and 45%, respectively, patients presenting with acute myocardial infarction, congestive heart failure, and/or endocarditis, because these are significant risk factors that you mentioned, and they also are variables that might not be directly affected by earlier valvular intervention?

Dr Rankin. Thank you, Jim, and I would like to also first recognize the many individuals who have contributed to the development of the STS database, many of whom are in this room. As you said, this has become an important resource for all of us; it was quite a good idea.

It is clear that the acute presentation group is a heterogeneous group, and there are patients with, let us say, obligatory acute presentation (eg, aortic dissections and endocarditis) that are at higher risk and require operations with no opportunity for intervention. But if we look at the overall numbers of those patients, they are the minority, accounting for less than a fourth of the population. The majority of patients are potential candidates for earlier referral. If we correlate to our own clinical practices, I think we have seen in recent years that patients are being referred later, perhaps "worked up a year ago, decided against surgery," and then a year later, all of a sudden they are in the hospital with pulmonary edema requiring an emergency operation. Therefore I think there is probably a definite majority of the acute presentation patients who might have been evaluated earlier and perhaps could have been operated on earlier. It has been so successful in mitral valve repair to convince the cardiologists to refer the patients earlier, and earlier referral has really improved the outcomes. I think we now need to extend that concept to all of valvular surgery: if a patient has a severe valve lesion, there is really no advantage to waiting.

Dr Fann. Just as interesting is your finding that aortic root reconstruction was the highest-risk procedure, with an OR of more than 2.7 referenced to aortic valve replacement. What is important to realize is that in this group, 5066 patients had no aortic root pathology, and more than 2100 of them had a stentless porcine or homograft root replacement. The mortality for reconstruction without root pathology is more than 9%. Your conclusion that root replacement should be considered only for specific root pathology needs to be emphasized. There are numerous reports of substantially lower operative mortality rates than what was found in the series of patients undergoing stentless valve implant. Why do you think that the operative mortality rate in this group is so much higher than the rate that has been reported, other than a mere reality check?

Dr Rankin. I think it is also important to emphasize that there is no such thing as perfect methodology in clinical research. In some ways, if I present a series of 120 mitral valve repairs, advantages exist, because I took care of all those patients. I really knew everything that happened with them, but the disadvantage is the small sample size. Here we have the opposite extreme, a large sample size as an advantage but a large distance from these patients as a disadvantage, and we do not quite understand what was going on with all of them or what the exact pathology was. But there is a definite suggestion in these data that there are a lot of

patients now undergoing root replacement with no root pathology, and I think this correlates with some of the articles describing freestyle root replacement as a routine. The STS data suggest that, in the national data set with the real world of all the surgeons doing this in the country, the mortality with this approach is higher than we might think. Given this information, it seems prudent to consider going back to performing just simple aortic valve replacement in these patients.

Dr Fann. Reoperation was a risk factor for operative mortality, with an OR of 1.61. Interestingly, it also comprised a statistically higher proportion of patients in the nonelective category. One question is, how do you define reoperation? Is it redo sternotomy or reoperation for a degenerated or otherwise dysfunctional valve? If it is the latter, and based on the data presented, do you personally think that the argument for placing a bioprosthesis to avoid thromboembolic and anticoagulation-related complications in the younger patient with the intention of future reoperation is justified?

Dr Rankin. Well, I will go back to say that we are in the early stages of looking at the entire data set, and it was a bit of a surprise to us to see that reoperation was so important. I would suggest that any of you who are interested turn in a proposal to the STS publications committee to study the reoperation factor as determining operative mortality—we need to get into those data more. The definition was any previous sternotomy, coronary bypass or valve. Now this finding does not correlate well with all of our articles in the current literature examining isolated aortic or mitral valve procedures in which reoperation is no longer a risk factor. My personal bias is that the reoperation risk probably is related more to the multiple valve procedures and that reoperation be-

comes much more important when we get into the more complex operations. I think this is something that needs to be addressed.

Dr Fann. One group of patients that warrants further investigation is comprised of those who underwent mitral valve procedures. Dr Glower and you have previously reported that survival after mitral valve repair for ischemic mitral regurgitation is more influenced by patient characteristics and comorbidity than by the ischemic cause of mitral regurgitation. What was important in that study was the consistent surgical techniques and the undersizing of the annuloplasty ring. In the current study the presence of coronary artery disease was a significant independent risk factor for operative mortality. Do you think that this finding is suggestive that patients who undergo surgical intervention for ischemic mitral regurgitation do worse in terms of operative outcome regardless of comorbidity?

Dr Rankin. One of the problems in the STS data set is that there are a handful of definitions that are lacking. For example, cause of valve disease is not recorded, and therefore it is difficult to say much about ischemic mitral regurgitation. One thing that is clear, however, from Don's recent article, the recent Cleveland Clinic article, and David Adams' work is that the results with routine repair in ischemic mitral regurgitation are a lot better now. Ischemic cause, per se, is likely not a prominent risk factor. The other general impression that is evident in the national cardiac surgery data set is that the quality of cardiac surgery throughout the United States is at an extremely high level. If we look at average mortalities for any procedure and so on, they are only a couple points higher than the very best ones reported in the literature, and therefore I think we can all be proud of our specialty and what has happened over the past decades.

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