

Appendix

STS Mitral Valve Repair/Replacement (MVRR) + Coronary Artery Bypass Graft (CABG) Composite Score

S.4. – S.11. Measure Specifications

Due to the complex methodology used to construct the composite measure, it is impractical to separately discuss the numerator and denominator. The following discussion describes how each domain score is calculated and how these are combined into an overall composite score.

The STS Mitral Valve Repair/Replacement (MVRR) Composite Score comprises two domains consisting of six measures:

Domain 1 – Absence of Operative Mortality

Proportion of patients (risk-adjusted) who do not experience operative mortality. Operative mortality is defined as death before hospital discharge or within 30 days of the operation.

Domain 2 – Absence of Major Morbidity

Proportion of patients (risk-adjusted) who do not experience any major morbidity. Major morbidity is defined as the occurrence of any one or more of the following major complications:

1. Prolonged ventilation,
2. Deep sternal wound infection,
3. Permanent stroke,
4. Renal failure, and
5. Reoperations for bleeding, coronary graft occlusion, prosthetic or native valve dysfunction, and other cardiac reasons, but not for other non-cardiac reasons.

Participants receive a score for each of the two domains, plus an overall composite score. The overall composite score was created by “rolling up” the domain scores into a single number. In addition to receiving a numeric score, participants are assigned to rating categories designated by the following:

- 1 star – lower-than-expected performance
- 2 stars – as-expected performance
- 3 stars – higher-than-expected performance

Patient Population: The analysis population consists of patients aged 18 years or older who MVRR + CABG with or without concomitant Atrial Septal Defect (ASD) and Patent Foramen Ovale (PFO) closures, tricuspid valve repair (TVr), or surgical ablation for atrial fibrillation (AF).

Time Window: 3 years

Data Completeness Requirement: Participants are excluded from the analysis if they have fewer than 25 MVRR + CABG procedures in the patient population.

Estimation of Composite Scores and Star Ratings:

To be consistent with the conventions of previous composite measures, risk-adjusted event rates were first converted into risk-adjusted absence-of-event rates. To calculate the composite, participant-specific absence of mortality rates and absence of morbidity rates were weighted inversely by their respective standard deviations across participants. This procedure was equivalent to first rescaling the absence of mortality rates and absence of morbidity rates by their respective standard deviations across participants, and then assigning equal weighting to the rescaled rates. Finally, in order to draw statistical inferences about participant performance, a Bayesian credible interval surrounding each participant’s composite score was calculated. Unlike frequentist confidence intervals, Bayesian credible intervals have an intuitively direct interpretation as an interval containing the true value of the composite score with a specified probability (e.g., 95%). To determine star ratings for each participant, the credible interval of its composite score was compared with the

STS average. Participants whose intervals were entirely above the STS average were classified as 3-star (higher than expected performance), and participants whose intervals were entirely below the STS average were classified as 1-star (lower than expected performance). Credible intervals based on different probability levels (90%, 95%, 98%) were explored, and the resulting percentages of 1, 2, and 3-star programs were calculated.

S.14. Identify the statistical risk model method and variables (Name the statistical method - e.g., logistic regression and list all the risk factor variables. Note - risk model development and testing should be addressed with measure testing under Scientific Acceptability)

AND

S.15. Detailed risk model specifications

To adjust for case mix, logistic regression models for operative mortality and major complications were estimated using covariates from published STS 2008 risk models [1,2], augmented by inclusion of treated endocarditis; severe tricuspid insufficiency; and indicators for TVr. Discretionary procedures such as concomitant TVr are usually not included in risk models. However, we did so in this instance for two specific reasons. First, it may serve as an additional marker, beyond severity of tricuspid regurgitation, of more advanced tricuspid disease and possible right ventricular dysfunction. Second, TVr may confer long-term benefits that outweigh potential increases in some short-term outcomes, and we did not want to discourage its performance by not adjusting for any potential impact on early risk.

Each model's fit to the data was assessed by comparing observed versus expected mortality rates overall and within subgroups based on quintiles of predicted risk. After confirming satisfactory calibration, the models were used to calculate each participant's expected operative mortality and major complication rates. The expected rates then were entered as risk scores in a Bayesian hierarchical model that simultaneously estimated risk-adjusted operative mortality and major morbidity rates for each participant.

References

1. Rankin JS, Badhwar V, He X, Jacobs JP, Gammie JS, Furnary AP, Fazzalari FL, Han J, O'Brien SM, Shahian DM. The Society of Thoracic Surgeons Mitral Valve Repair/Replacement plus Coronary Artery Bypass Grafting Composite Score: A Report of The Society of Thoracic Surgeons Quality Measurement Task Force – This manuscript is currently being prepared for submission to The Annals of Thoracic Surgery.
2. Shahian DM, O'Brien SM, Filardo G, Ferraris VA, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: part 3--valve plus coronary artery bypass grafting surgery. Ann Thorac Surg 2009 Jul;88(1 Suppl):S43-62.

Definitions of Variables Appearing in 2008 STS Valve + CABG Models

| Variable | Definition |
|---------------------------------------|--|
| Intercept | = 1 for all patients |
| Preoperative AFib | = 1 if patient has history of preoperative atrial fibrillation, = 0 otherwise |
| Age function 1 | = max (age - 50, 0) |
| Age function 3 | = max (age - 75, 0) |
| Age by reop function | = Age function 1 if surgery is a reoperation, = 0 otherwise |
| Age by status function | = Age function 1 if status is emergent or salvage, = 0 otherwise |
| Age by MVR function | = Age function 1 if operation is MVR, = 0 otherwise |
| Age by MVRepair function | = Age function 1 if operation is MVRepair, = 0 otherwise |
| BSA function 1 | = max (1.4, min [2.6, BSA]) - 1.8 |
| BSA function 2 | = (BSA function 1) ² |
| CHF but not NYHA IV | = 1 if patient has CHF and is not NYHA class IV, = 0 otherwise |
| CHF and NYHA IV | = 1 if patient has CHF and is NYHA class IV, = 0 otherwise |
| CHF by MVR function | = 1 if patient has CHF and operation is MVR, = 0 otherwise |
| CHF by MVRepair function | = 1 if patient has CHF and operation is MVRepair, = 0 otherwise |
| CLD function | = 0 if no CLD, = 1 if mild CLD, = 2 if moderate CLD, = 3 if severe CLD |
| CLD by MVR function | = CLD function if operation is MVR, = 0 otherwise |
| CLD by MVRepair function | = CLD function if operation is MVRepair, = 0 otherwise |
| Creatinine function 1 | = max (0.5, min [creatinine, 5.0]) if patient is not on dialysis, = 0 otherwise |
| Creatinine by MVR function | = Creatinine function 1 if valve operation is MVR, = 0 otherwise |
| Creatinine by MVRepair function | = Creatinine function 1 if valve operation is MVRepair, = 0 otherwise |
| CVD without prior CVA | = 1 if patient has history of CVD and no prior CVA, = 0 otherwise |
| CVD and prior CVA | = 1 if patient has history of CVD and a prior CVA, = 0 otherwise |
| Diabetes, noninsulin | = 1 if patient has diabetes not treated with insulin, = 0 otherwise |
| Diabetes, insulin | = 1 if patient has diabetes treated with insulin, = 0 otherwise |
| Dialysis | = 1 if patient requires dialysis preoperatively, = 0 otherwise |
| Dialysis by MVR function | = 1 if patient has history of dialysis and operation is MVR, = 0 otherwise |
| Dialysis by MVRepair function | = 1 if patient has history of dialysis and operation is MVRepair, = 0 otherwise |
| Ejection fraction function | = max (50 - ejection fraction, 0) |
| EF by MVR function | = Ejection fraction function if valve operation is MVR, = 0 otherwise |
| EF by MVRepair function | = Ejection fraction function if valve operation is MVRepair, = 0 otherwise |
| Endocarditis, active | = 1 if patient has active endocarditis, = 0 otherwise |
| Endocarditis by MVR function | = 1 if patient has active endocarditis and valve operation is MVR, = 0 otherwise |
| Endocarditis by MVRepair function | = 1 if patient has active endocarditis and valve operation is MVRepair, = 0 otherwise |
| Female | = 1 if patient is female, = 0 otherwise |
| Female by MVR function | = 1 if female and operation is MVR, = 0 otherwise |
| Female by MVRepair function | = 1 if female and operation is MVRepair, = 0 otherwise |
| Female by BSA function 1 | = BSA function 1 if female, = 0 otherwise |
| Female by BSA function 2 | = BSA function 2 if female, = 0 otherwise |
| Hypertension | = 1 if patient has hypertension, = 0 otherwise |
| IABP or inotropes | = 1 if patient requires IABP or inotropes preoperatively, = 0 otherwise |
| IABP by MVR function | = 1 if patient requires preop IABP or inotropes and operation is MVR, = 0 otherwise |
| IABP by MVRepair function | = 1 if patient requires preop IABP or inotropes and operation is MVRepair, = 0 otherwise |
| Immunosuppressive treatment | = 1 if patient has received immunosuppressive therapy within 30 days, = 0 otherwise |
| Insufficiency, mitral | = 1 if patient has at least moderate mitral insufficiency, = 0 otherwise |
| Insufficiency, tricuspid | = 1 if patient has at least moderate tricuspid insufficiency, = 0 otherwise |
| Left main disease | = 1 if patient has left main disease, = 0 otherwise |
| MI 1-21 days | = 1 if history of MI 1 to 21 days prior to surgery, = 0 otherwise |
| MI ≤ 21 days ^a | = 1 if patient has history of MI within 21 days prior to surgery, = 0 otherwise (for CVA and PLOS; coded as < 24 hours and 1-21 days for others) |
| MI < 24 hours | = 1 if history of MI < 24 hours prior to surgery, = 0 otherwise |
| MVR | = 1 if valve operation is mitral valve replacement, = 0 otherwise |
| MVRepair | = 1 if valve operation is mitral valve repair, = 0 otherwise |
| No. diseased coronary vessel function | = 2 if triple-vessel disease, = 1 if double-vessel disease, = 0 otherwise |

| | |
|------------------------------------|--|
| Peripheral vascular disease | = 1 if patient has peripheral vascular disease, = 0 otherwise |
| Race black | = 1 if patient is black, = 0 otherwise |
| Race Hispanic | = 1 if patient is nonblack Hispanic, = 0 otherwise |
| Reop, 1 previous operation | = 1 if patient has had exactly 1 previous CV surgery, = 0 otherwise |
| Reop, ≥ 2 previous operations | = 1 if patient has had 2 or more previous CV surgeries, = 0 otherwise |
| Reop by MVR function | = 1 if surgery is a reoperation and operation is MVR, = 0 otherwise |
| Reop by MVRepair function | = 1 if surgery is a reoperation and operation is MVRepair, = 0 otherwise |
| Shock | = 1 if patient was in shock at time of procedure, = 0 otherwise |
| Shock by MVR function | = 1 if shock and operation is MVR, = 0 otherwise |
| Shock by MVRepair function | = 1 if shock and operation is MVRepair, = 0 otherwise |
| Status urgent | = 1 if status is urgent, = 0 otherwise |
| Status emergent | = 1 if status is emergent (but not resuscitation), = 0 otherwise |
| Status salvage | = 1 if status is salvage (or emergent plus resuscitation), = 0 otherwise |
| Status by MVR function | = 1 if status is emergent or salvage and operation is MVR, = 0 otherwise |
| Status by MVRepair function | = 1 if status is emergent or salvage and operation is MVRepair, = 0 otherwise |
| Stenosis, mitral | = 1 if patient has mitral stenosis, = 0 otherwise |
| Unstable angina | = 1 if patient has unstable angina and no MI within 7 days of surgery, = 0 otherwise |

2008 STS Valve + CABG Models Regression Coefficients

| Variable | Mort | CVA | RF | Vent | DSWI | Reop |
|---------------------------------------|----------|----------|----------|----------|----------|----------|
| Intercept | -5.24391 | -5.14546 | -5.32535 | -3.63438 | -6.50043 | -3.16980 |
| Preoperative AFib | 0.18430 | 0.04634 | 0.16567 | 0.12059 | 0.00000 | 0.14910 |
| Age function 1 | 0.02560 | 0.02487 | 0.03268 | 0.02106 | 0.00545 | 0.01715 |
| Age function 3 | 0.02758 | -0.00709 | 0.00671 | 0.00791 | -0.00985 | -0.00021 |
| Age by reop function | -0.00861 | 0.00458 | 0.00077 | -0.00673 | 0.00314 | -0.00399 |
| Age by status function | -0.00507 | -0.01979 | -0.00178 | -0.00750 | 0.01627 | -0.00029 |
| Age by MVR function | 0.01564 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Age by MVRRepair function | 0.01240 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| BSA function 1 | -1.14176 | -0.81169 | -0.41848 | -0.66843 | 0.86401 | -0.51266 |
| BSA function 2 | 2.25471 | 0.94689 | 1.84088 | 1.80467 | 0.42453 | 0.70024 |
| CHF but not NYHA IV | 0.21206 | -0.01726 | 0.17460 | 0.20063 | 0.00000 | 0.00000 |
| CHF and NYHA IV | 0.39457 | 0.14109 | 0.30146 | 0.38383 | 0.00000 | 0.14499 |
| CHF by MVR function | -0.31077 | -0.20917 | -0.25767 | -0.18455 | 0.00000 | 0.00000 |
| CHF by MVRRepair function | -0.24791 | 0.06897 | -0.18667 | -0.10484 | 0.00000 | 0.00000 |
| CLD function | 0.17713 | 0.00000 | 0.11379 | 0.23345 | 0.27571 | 0.09280 |
| CLD by MVR function | 0.00000 | 0.00000 | 0.00000 | -0.06780 | 0.00000 | 0.00000 |
| CLD by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | -0.04014 | 0.00000 | 0.00000 |
| Creatinine function 1 | 0.44794 | 0.23545 | 0.81612 | 0.38147 | 0.00000 | 0.24620 |
| Creatinine by MVR function | 0.00000 | 0.00000 | -0.21574 | 0.00000 | 0.00000 | 0.00000 |
| Creatinine by MVRRepair function | 0.00000 | 0.00000 | -0.18787 | 0.00000 | 0.00000 | 0.00000 |
| CVD without prior CVA | 0.00000 | 0.24847 | 0.13299 | 0.09769 | 0.00000 | 0.00000 |
| CVD and prior CVA | 0.19754 | 0.54344 | 0.11571 | 0.23581 | 0.19686 | 0.10974 |
| Diabetes, noninsulin | 0.11060 | 0.14576 | 0.24490 | 0.10365 | 0.26281 | 0.00000 |
| Diabetes, insulin | 0.26870 | 0.14582 | 0.48504 | 0.27893 | 0.68330 | 0.00000 |
| Dialysis | 1.61151 | 0.58833 | 0.00000 | 1.20290 | 0.61527 | 0.74332 |
| Dialysis by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | -0.30339 |
| Dialysis by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.13058 |
| Ejection fraction function | 0.00989 | 0.00000 | 0.00534 | 0.01113 | 0.00000 | 0.00703 |
| EF by MVR function | 0.01056 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| EF by MVRRepair function | -0.00117 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Endocarditis, active | 0.71327 | 0.60657 | 0.41797 | 0.67172 | 0.00000 | 0.44757 |
| Endocarditis by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Endocarditis by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Female | 0.30852 | 0.17170 | 0.16668 | 0.41874 | 0.10654 | -0.08221 |
| Female by MVR function | 0.00000 | 0.00000 | 0.00000 | -0.25972 | 0.00000 | 0.00000 |
| Female by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | -0.19373 | 0.00000 | 0.00000 |
| Female by BSA function 1 | 0.51233 | 0.07575 | 0.76032 | 0.48032 | 0.80594 | 0.16701 |
| Female by BSA function 2 | -0.27980 | -0.88628 | -0.57622 | -0.49740 | 0.58767 | 0.52524 |
| Hypertension | 0.00000 | 0.17080 | 0.22638 | 0.09581 | 0.28851 | 0.00000 |
| IABP or inotropes | 0.36025 | 0.00000 | 0.23674 | 0.77918 | 0.00000 | 0.15075 |
| IABP by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| IABP by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Immunosuppressive treatment | 0.29654 | 0.00000 | 0.26400 | 0.24814 | 0.00000 | 0.24041 |
| Insufficiency, mitral | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Insufficiency, tricuspid | 0.24006 | 0.00000 | 0.22040 | 0.13606 | 0.00000 | 0.00000 |
| Left main disease | 0.11450 | 0.00000 | 0.00000 | 0.06181 | 0.00000 | 0.00000 |
| MI 1-21 days | 0.17038 | 0.00000 | 0.16476 | 0.24560 | 0.00000 | 0.00000 |
| MI ≤ 21 days | 0.00000 | 0.19671 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| MI < 24 hours | 0.49918 | 0.00000 | 0.26240 | 0.34321 | 0.00000 | 0.13716 |
| MVR | 0.14888 | 0.32659 | 0.90926 | 0.76504 | 0.28437 | 0.41642 |
| MVRRepair | -0.07374 | 0.06933 | 0.51275 | 0.28204 | 0.19499 | 0.07390 |
| No. diseased coronary vessel function | 0.13746 | 0.18243 | 0.15791 | 0.17277 | 0.24582 | 0.08187 |
| Peripheral vascular disease | 0.25173 | 0.13776 | 0.14995 | 0.16591 | 0.00000 | 0.14312 |
| Race black | 0.00000 | 0.00000 | 0.14301 | 0.26900 | 0.00000 | 0.17364 |
| Race Hispanic | 0.00000 | 0.00000 | 0.18384 | 0.15363 | 0.00000 | 0.08065 |
| Reop, 1 previous operation | 0.78624 | 0.00000 | 0.25782 | 0.60179 | 0.00000 | 0.33209 |
| Reop, ≥ 2 previous operations | 0.90015 | 0.00000 | 0.38499 | 0.78263 | 0.00000 | 0.39502 |
| Reop by MVR function | 0.00000 | 0.00000 | 0.00000 | -0.27846 | 0.00000 | -0.19608 |
| Reop by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | -0.16306 | 0.00000 | 0.06985 |
| Shock | 0.51917 | 0.17321 | 0.15810 | 0.65653 | 0.00000 | 0.21271 |
| Shock by MVR function | 0.00000 | 0.00000 | 0.02883 | 0.00000 | 0.00000 | 0.00000 |
| Shock by MVRRepair function | 0.00000 | 0.00000 | 0.36429 | 0.00000 | 0.00000 | 0.00000 |
| Status urgent | 0.22591 | 0.00000 | 0.16451 | 0.22905 | 0.00000 | 0.12800 |
| Status emergent | 0.75852 | 0.79460 | 0.56854 | 0.99818 | 0.00000 | 0.34063 |
| Status salvage | 1.51811 | 0.95665 | 0.61798 | 0.75178 | 0.00000 | 0.00000 |
| Status by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Status by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Stenosis, mitral | 0.09879 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| Unstable angina | 0.10722 | -0.11292 | 0.11597 | 0.05762 | 0.00000 | 0.00000 |

Estimated odds ratios from the modified STS 2008 models are summarized in the table below.

| Effect | Morbidity | | Mortality | |
|---|-------------------|---------|-------------------|---------|
| | OR (95% CI) | P-value | OR (95% CI) | P-value |
| Effects that do not interact with MV repair/replacements | | | | |
| Preoperative atrial fibrillation | 1.09 (1.02, 1.17) | 0.0125 | 1.04 (0.92, 1.18) | 0.4926 |
| Race (v. others) | | | | |
| Black | 1.21 (1.08, 1.35) | 0.0007 | NA | . |
| Hispanic | 1.16 (1.00, 1.35) | 0.0529 | NA | . |
| CVD (v. no) | | | | |
| CVD with CVA | 1.21 (1.10, 1.33) | 0.0001 | 1.01 (0.86, 1.19) | 0.9223 |
| CVD without CVA | 1.09 (0.98, 1.21) | 0.1264 | NA | . |
| Number Diseased Vessels (3 v. 2, 2 v. 1/0) | 1.16 (1.11, 1.21) | <.0001 | 1.16 (1.08, 1.26) | <.0001 |
| Pre-op IABP or inotrope | 2.21 (1.98, 2.47) | <.0001 | 1.43 (1.22, 1.69) | <.0001 |
| Hypertension | 1.11 (1.02, 1.20) | 0.0189 | NA | . |
| Immunosuppressive treatment | 1.17 (1.02, 1.34) | 0.0264 | 1.29 (1.02, 1.63) | 0.0303 |
| Peripheral vascular disease | 1.08 (1.00, 1.17) | 0.0536 | 1.28 (1.11, 1.48) | 0.0007 |
| MI (v. no recent MI) | | | | |
| 1-21 days | 1.32 (1.23, 1.42) | <.0001 | 1.30 (1.13, 1.50) | 0.0002 |
| <=24 hrs | 1.48 (1.16, 1.89) | 0.0015 | 1.76 (1.28, 2.40) | 0.0004 |
| Number of previous operations (v. 0) | | | | |
| 1 previous operation | 1.45 (1.15, 1.83) | 0.0017 | 2.79 (1.88, 4.14) | <.0001 |
| 2 or more previous operations | 1.50 (1.00, 2.24) | 0.0485 | 2.68 (1.41, 5.06) | 0.0025 |
| Diabetes (v. no) | | | | |
| Non-insulin diabetes | 1.22 (1.12, 1.32) | <.0001 | 1.35 (1.17, 1.57) | <.0001 |
| Insulin diabetes | 1.08 (1.01, 1.16) | 0.0233 | 1.10 (0.97, 1.24) | 0.1565 |
| Chronic lung disease (severe v moderate, or moderate v none-mild) | 1.10 (1.07, 1.14) | <.0001 | 1.16 (1.10, 1.22) | <.0001 |
| Dialysis v. no dialysis & creatinine = 1.0 | 2.17 (1.88, 2.50) | <.0001 | 2.66 (2.19, 3.23) | <.0001 |
| Creatinine per 1 unit increase | 1.62 (1.51, 1.73) | <.0001 | 1.46 (1.33, 1.61) | <.0001 |
| Female (at BSA=1.8) v. male (at BSA=2.0) | 1.20 (1.11, 1.29) | <.0001 | 1.39 (1.21, 1.59) | <.0001 |
| Status (v. elective) | | | | |
| Urgent | 1.26 (1.18, 1.36) | <.0001 | 1.09 (0.96, 1.24) | 0.1821 |
| Emergent - no resuscitation | 2.53 (1.75, 3.65) | <.0001 | 1.74 (1.12, 2.73) | 0.0148 |
| Emergent+resuscitation/Emergent Salvage | 1.90 (1.07, 3.38) | 0.0292 | 5.13 (2.83, 9.31) | <.0001 |
| Active infections endocarditis | 1.48 (1.20, 1.83) | 0.0003 | 1.63 (1.18, 2.24) | 0.0027 |
| Treated infections endocarditis | 0.91 (0.72, 1.16) | 0.4538 | 0.57 (0.33, 0.97) | 0.0393 |
| Body surface area, m ² | | | | |
| 1.6 v. 2.0 in male | 1.16 (1.01, 1.34) | 0.0354 | 1.32 (1.02, 1.72) | 0.0354 |
| 1.8 v. 2.0 in male | 1.02 (0.97, 1.08) | 0.4400 | 1.07 (0.97, 1.17) | 0.1703 |
| 2.2 v. 2.0 in male | 1.09 (1.05, 1.14) | <.0001 | 1.08 (1.01, 1.16) | 0.0234 |
| 1.6 v. 1.8 in female | 1.12 (1.06, 1.18) | 0.0002 | 1.24 (1.12, 1.36) | <.0001 |
| 2.0 v. 1.8 in female | 1.06 (1.00, 1.12) | 0.0360 | 1.03 (0.94, 1.12) | 0.5595 |
| 2.2 v. 1.8 in female | 1.33 (1.15, 1.54) | 0.0002 | 1.34 (1.06, 1.68) | 0.0133 |
| Time trend (half year increase) | 0.98 (0.96, 1.00) | 0.0541 | 1.03 (1.00, 1.06) | 0.0440 |
| Left main disease | NA | . | 1.09 (0.96, 1.24) | 0.1778 |
| Unstable angina (no MI < 8days) | NA | . | 1.01 (0.87, 1.17) | 0.9382 |
| Mitral stenosis | NA | . | 1.21 (1.01, 1.46) | 0.0399 |
| Mitral insufficiency (>= moderate) | 0.95 (0.86, 1.05) | 0.3396 | NA | . |
| Moderate tricuspid insufficiency (v. no-mild) | 1.10 (1.02, 1.20) | 0.0189 | 1.10 (0.96, 1.26) | 0.1618 |
| Severe tricuspid insufficiency (v. no-mild) | 1.12 (0.98, 1.29) | 0.1051 | 1.12 (0.89, 1.41) | 0.3448 |
| Mitral valve repair (v. replacement) | 0.69 (0.59, 0.81) | <.0001 | 0.81 (0.59, 1.10) | 0.1784 |
| Tricuspid valve repair (v. none) | 1.33 (1.19, 1.49) | <.0001 | 1.04 (0.85, 1.27) | 0.7010 |
| Effects that interacts with procedure groups and were modeled separately for MV replacement and MV repairs | | | | |
| In MV replacements + CABG | | | | |
| Age | | | | |
| 60 v. 50 (no reoperations, non-emergent) | 1.16 (1.09, 1.23) | <.0001 | 1.70 (1.51, 1.91) | <.0001 |
| 70 v. 50 (no reoperations, non-emergent) | 1.35 (1.20, 1.52) | <.0001 | 2.88 (2.28, 3.64) | <.0001 |
| 80 v. 50 (no reoperations, non-emergent) | 1.57 (1.34, 1.84) | <.0001 | 4.84 (3.62, 6.49) | <.0001 |

| | | | | |
|--|-------------------|--------|-------------------|--------|
| Congestive heart failure (v. no) | | | | |
| CHF not NYHA IV | 1.15 (1.04, 1.28) | 0.0063 | 1.14 (0.94, 1.37) | 0.1794 |
| CHF NYHA IV | 1.36 (1.18, 1.55) | <.0001 | 1.49 (1.21, 1.83) | 0.0002 |
| Ejection fraction per 10-unit decrease | 1.12 (1.09, 1.16) | <.0001 | 1.04 (0.96, 1.14) | 0.3436 |
| Shock | 2.07 (1.59, 2.69) | <.0001 | 1.89 (1.49, 2.39) | <.0001 |
| In MV repairs + CABG | | | | |
| Age | | | | |
| 60 v. 50 (no reoperations, non-emergent) | 1.16 (1.10, 1.21) | <.0001 | 1.45 (1.31, 1.61) | <.0001 |
| 70 v. 50 (no reoperations, non-emergent) | 1.34 (1.21, 1.47) | <.0001 | 2.11 (1.72, 2.60) | <.0001 |
| 80 v. 50 (no reoperations, non-emergent) | 1.55 (1.36, 1.76) | <.0001 | 3.04 (2.35, 3.92) | <.0001 |
| Congestive heart failure (v. no) | | | | |
| CHF not NYHA IV | 1.15 (1.05, 1.27) | 0.0027 | 1.27 (1.06, 1.51) | 0.0087 |
| CHF NYHA IV | 1.32 (1.18, 1.49) | <.0001 | 1.40 (1.14, 1.73) | 0.0016 |
| Shock | 1.97 (1.56, 2.47) | <.0001 | 1.89 (1.49, 2.39) | <.0001 |
| Ejection fraction per 10-unit decrease | 1.12 (1.09, 1.16) | <.0001 | 1.13 (1.06, 1.21) | 0.0002 |

CHF = congestive heart failure; CVA = cerebrovascular accident (stroke); CVD = cardiovascular disease; EF = ejection fraction; IABP = intra-aortic balloon pump; MI = myocardial infarction; NA = variable not used in model and estimate not available; NYHA = New York Heart Association.

1b.2. Provide performance scores on the measure as specified (current and over time) at the specified level of analysis. (This is required for endorsement maintenance. Include mean, std dev, min, max, interquartile range, scores by decile. Describe the data source including number of measured entities; number of patients; dates of data; if a sample, characteristics of the entities include). This information also will be used to address the subcriterion on improvement (4b.1) under Usability and Use.

The measure was calculated using STS Adult Cardiac Surgery Database data for patients undergoing mitral valve repair/replacement (MVRR) +CABG in two consecutive overlapping 3-year time periods, January 2016 – December 2018 and January 2017 – December 2019. For each time period, we provide the number of measured entities (# participants), the number of eligible patient records (# operations), and the distribution of composite score estimates by percentiles and geographic region. Participants with at least 10 eligible records in a 3-year time period were included in the hierarchical model for estimating composite scores in that time period. While participants with 10 eligible cases are included in the hierarchical model procedure, composite scores will typically only be reported by STS for participants with at least 25 cases during a 3-year time period. Thus, we present results for the set of participants with at least 10 eligible cases and the subset with at least 25 eligible cases.

| | January 2016-December 2018 | | January 2017-December 2019 | |
|---------------|--|--|--|--|
| Distribution | Participants with ≥10 Eligible Cases | Participants with ≥25 Eligible Cases | Participants with ≥10 Eligible Cases | Participants with ≥25 Eligible Cases |
| # Participant | 625 | 289 | 605 | 272 |
| # Operations | 21383 | 16175 | 20403 | 15087 |
| Mean | 0.863 | 0.866 | 0.860 | 0.864 |
| STD | 0.02575 | 0.02745 | 0.02428 | 0.02595 |
| IQR | 0.0317 | 0.0352 | 0.0319 | 0.0328 |
| 0% | 0.741 | 0.741 | 0.768 | 0.768 |
| 10% | 0.830 | 0.831 | 0.829 | 0.831 |
| 20% | 0.843 | 0.845 | 0.841 | 0.844 |
| 30% | 0.852 | 0.854 | 0.849 | 0.854 |
| 40% | 0.859 | 0.863 | 0.857 | 0.861 |
| 50% | 0.865 | 0.869 | 0.862 | 0.866 |
| 60% | 0.871 | 0.875 | 0.867 | 0.871 |
| 70% | 0.877 | 0.882 | 0.872 | 0.878 |
| 80% | 0.884 | 0.889 | 0.879 | 0.885 |
| 90% | 0.892 | 0.897 | 0.887 | 0.894 |
| 100% | 0.936 | 0.936 | 0.921 | 0.921 |
| CANADA | 4 | 2 | 2 | 1 |
| MIDWEST | 167 | 66 | 156 | 59 |
| NORTHEAST | 100 | 62 | 99 | 60 |
| SOUTH | 220 | 115 | 216 | 108 |
| WEST | 134 | 44 | 132 | 44 |

1b.4. Provide disparities data from the measure as specified (current and over time) by population group, e.g., by race/ethnicity, gender, age, insurance status, socioeconomic status, and/or disability. (This is required for endorsement maintenance. Describe the data source including number of measured entities; number of patients; dates of data; if a sample, characteristics of the entities include.) This information also will be used to address the subcriterion on improvement (4b.1) under Usability and Use.

In order to shed light on disparities, we used logistic regression to study the associations of race, ethnicity and insurance status with operative mortality and major morbidity while adjusting for covariates included in this measure's risk adjustment model (see other sections for details of covariate adjustment – we used the most recent 2017 valve+CABG models for mortality and major morbidity). Odds ratios with 95% confidence intervals (CI's) and p-values are summarized in the table below.

| | Mortality | | Major Morbidity | |
|--|-------------------------|---------|-------------------------|---------|
| | Adjusted OR (95% CI) | p-value | Adjusted OR (95% CI) | p-value |
| Insurance status among patients age≥65 | | | | |
| Medicare without Medicaid/Commercial-HMO | (ref) | | (ref) | |
| Medicare + Medicaid dual eligible | 0.94(0.71, 1.24) | 0.6578 | 0.81(0.68, 0.98) | 0.0287 |
| Medicare + Commercial-HMO without Medicaid | 0.97(0.84, 1.13) | 0.7131 | 0.98(0.90, 1.07) | 0.6597 |
| Commercial-HMO without Medicare | 0.84(0.64, 1.09) | 0.1880 | 1.04(0.88, 1.22) | 0.6680 |
| | | | | |
| Insurance status among patients age<65 | | | | |
| Commercial-HMO without Medicare/Medicaid | (ref) | | (ref) | |
| Medicare or Medicaid | 1.17(0.96, 1.42) | 0.1265 | 1.09(0.98, 1.22) | 0.1148 |
| None/Self Paid | 0.97(0.65, 1.45) | 0.8796 | 1.02(0.83, 1.25) | 0.8393 |
| Other | 1.23(0.77, 1.97) | 0.3833 | 1.00(0.76, 1.31) | 0.9743 |
| | | | | |
| Black Race | 0.91(0.75, 1.11) | 0.3471 | 1.28(1.15, 1.43) | <.0001 |
| Hispanic ethnicity | 1.13(0.92, 1.39) | 0.2510 | 1.10(0.97, 1.24) | 0.1558 |



The Society of Thoracic Surgeons Mitral Valve Repair/Replacement Plus Coronary Artery Bypass Grafting Composite Score: A Report of The Society of Thoracic Surgeons Quality Measurement Task Force

J. Scott Rankin, MD, Vinay Badhwar, MD, Xia He, MS, Jeffrey P. Jacobs, MD, James S. Gammie, MD, Anthony P. Furnary, MD, Frank L. Fazzalari, MD, Jane Han, MSW, Sean M. O'Brien, PhD, and David M. Shahian, MD

Division of Cardiothoracic Surgery, West Virginia University, Morgantown, West Virginia; Duke Clinical Research Institute, Durham, North Carolina; Johns Hopkins All Children's Heart Institute, All Children's Hospital, Johns Hopkins University School of Medicine, Saint Petersburg, Florida, and Baltimore, Maryland; Department of Cardiac Surgery, University of Maryland, Baltimore, Maryland; Starr-Wood Cardiac Group, Portland, Oregon; Section of Cardiac Surgery, University of Michigan, Ann Arbor, Michigan; The Society of Thoracic Surgeons, Chicago, Illinois; and Department of Surgery, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts

Background. The Society of Thoracic Surgeons (STS) Quality Measurement Task Force has developed a composite performance measure for mitral repair/replacement (MVRR) with concomitant coronary artery bypass grafting (CABG).

Methods. Data were acquired from the STS Adult Cardiac Surgery Database for 26,463 patients undergoing MVRR + CABG operations between July 1, 2011, and June 30, 2014. Established STS risk models were applied, along with modifications enabling the inclusion of patients with concomitant closures of atrial septal defects and patent foramen ovale, surgical ablation for atrial fibrillation, and tricuspid valve repair (TVR). Participants with fewer than 10 eligible cases over 3 years were excluded. The MVRR + CABG composite consisted of two domains: risk-adjusted mortality and the any-or-none occurrence of major morbidity (prolonged ventilation, deep sternal infection, permanent stroke, renal failure, and reoperation). Composite performance scores were calculated with the use of hierarchic regression

models, and high-performing and low-performing outliers were determined with the use of 95% Bayesian credible intervals.

Results. There were 24,740 patients at 703 participant sites after exclusions. Two percent (14/703) of programs were classified as 1-star (lower than expected performance), 95% (666/703) were classified as 2-star (as-expected performance), and 3% (23/703) were classified as 3-star (higher than expected performance). The average unadjusted operative mortality was 6.2% (1,532/24,740), and a monotonic decline in both mortality and morbidity was observed as star rating scores increased.

Conclusions. An STS composite performance measure was developed for MVRR + CABG operations. This measure may be useful for outcome assessment, quality improvement, patient counseling, clinical research, and public reporting.

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The Society of Thoracic Surgeons (STS) has developed operative risk models and composite performance measures for isolated coronary artery bypass grafting (CABG), isolated aortic valve replacement (AVR), and AVR + CABG [1–7]. The CABG composite measure consists of four domains: (1) risk-adjusted mortality, (2) risk-adjusted any-or-none major morbidity (renal failure, permanent stroke, reoperation, deep sternal infection, prolonged ventilation), (3) use of at least one internal mammary artery bypass graft, and (4) use of all perioperative medications endorsed by the National Quality

Forum. The two AVR composite measures consist of only the first two of those domains because widely accepted process measures are not available. These STS composite

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Address correspondence to Dr Rankin, Professor of Surgery, WVU Heart and Vascular Institute, Morgantown, WV; email: jsrankinmd@cs.com.

measures have been useful for quality assessment, practice improvement, patient counseling, research, and public reporting.

A composite performance measure for isolated mitral valve repair or replacement (MVRR) recently was developed in a companion study [8]. A clinically related procedure, MVRR + CABG, constitutes an increasing proportion of cardiac surgical practice, and mortality risk is higher than for isolated MVRR [9–13]. An STS composite performance measure for MVRR + CABG has been developed to enable benchmark comparisons among STS participants and to facilitate outcome assessment and quality improvement.

Material and Methods

Patient Population

The study population consisted of 26,463 adult patients undergoing MVRR + CABG in North America between July 1, 2011, and June 30, 2014. Data were collected by use of the STS Adult Cardiac Surgery Database (ACSD) version 2.73, and all patients receiving MVRR + CABG were initially included. Patients who had arrhythmia devices (eg, internal cardiac defibrillators), transmyocardial revascularization, concomitant vascular or pulmonary procedures, prior mitral clip, and missing age, sex, or both were subsequently excluded, as were STS participants outside the United States or those with fewer than 10 eligible cases over 3 years. The study population included patients with any acuity status (including emergency and salvage), those with closure of atrial septal defects or patent foramen ovale, operations for endocarditis (active or treated), reoperations, surgical ablation procedures (both intracardiac and extracardiac) for atrial fibrillation (AF), and concomitant tricuspid valve repair (TVR). These inclusion and exclusion criteria differ slightly from the STS 2008 risk models [1–3] and were selected to better reflect evolving science and practice trends. For example, discretionary procedures such as concomitant TVR are usually not included in risk models. However, we did so in this instance for two reasons. First, TVR may serve as an additional marker beyond severity of tricuspid regurgitation for more advanced tricuspid disease and right ventricular dysfunction. Second, TVR may confer long-term benefits that outweigh some potential short-term risks, and we did not want to discourage TVR by failing to adjust for any potential impact on early risk. The final study population comprised 24,740 operations among 703 STS participating centers.

Estimation of Risk-Adjusted Outcome Measures

The composite measure is a weighted combination of a participant's risk-adjusted operative mortality (OM) and risk-adjusted major morbidity rates. Operative mortality was defined as death before hospital discharge or within 30 days of operation. Major morbidity (an any-or-none outcome) included postoperative prolonged ventilation, deep sternal infection, permanent stroke, renal failure,

and reoperations. To adjust for case mix, logistic regression models for operative mortality and major adverse events were estimated by the use of covariates from published STS 2008 risk models [2, 3]. The etiologies of mitral valve disease were not included in the final model because of unacceptably high missing data rates (24.7%).

Each model's fit to the data was assessed by a comparison of observed versus expected outcomes within subgroups and across deciles of predicted risk. The subgroups were based on presence of a tricuspid procedure and amount of tricuspid insufficiency (none to mild, moderate, severe). After confirmation of satisfactory calibration, the models were used to calculate each participant's expected rates of OM and major adverse events. The expected rates then were entered as risk scores in a Bayesian hierarchical model that simultaneously estimated rates of OM and major morbidity for each participant.

Estimation of the Composite Measure Score and Star Ratings

Consistent with previous composite measures, risk-adjusted event rates first were converted into risk-adjusted absence-of-event rates. To calculate the composite score, participant-specific absence of mortality rates and absence of morbidity rates were weighted inversely by their respective standard deviations across participants. This procedure was equivalent to first rescaling the absence of mortality rates and absence of morbidity rates by their respective standard deviations across participants, and then assigning equal weighting to the rescaled rates. Finally, to draw statistical inferences about participant performance, a Bayesian credible interval surrounding each participant's composite score was calculated. Unlike frequentist confidence intervals, a Bayesian credible interval has an intuitively direct interpretation as an interval containing the true value of the composite score with a specified probability (eg, 95%).

To determine star ratings for each participant, the credible interval of its composite score was compared with the STS average. Participants whose intervals were entirely above the STS average were classified as 3-star (higher than expected performance), and participants whose intervals were entirely below the STS average were classified as 1-star (lower than expected performance). Credible intervals based on different probability levels (90%, 95%, 98%) were explored, and the resulting percentages of 1-star, 2-star, and 3-star programs were calculated.

The reliability of the composite score was estimated as the squared correlation between the calculated composite score and the true score as described previously [7]. Briefly, reliability may be interpreted as the proportion of variation in a measure that is attributable to true differences between the measured units (ie, signal) as opposed to random statistical fluctuations (ie, noise). As in previous STS composite measure development, our goal was to achieve as high a reliability as possible (at least 0.50), which generally required establishing a minimum number of procedures performed over a 3-year period for

eligibility. This goal had to be balanced by the competing goal of providing a score to as many centers as possible.

Sensitivity Analysis: Mitral Disease Etiology

Etiology was not included as a covariate in the risk model, mainly because 24.7% of patients had etiology listed as “other” or “missing” ([Supplemental Table A](#)). The model development team hypothesized that other consistently collected risk variables in the model were the underlying factors leading to the apparent association of etiology with outcomes, as shown previously [10, 14, 15], and that the absence of a specific etiologic variable would not affect model performance. To further explore whether mitral disease etiology was an independent risk predictor (thus compromising a model that did not include it), we examined the degree to which outcome comparisons between STS participants and the national benchmark might be confounded by unadjusted differences in the mix of mitral disease etiologies. A sensitivity analysis was conducted with the records of patients with nonmissing etiologies (75.3%). An “augmented” operative mortality model was estimated by adding recorded mitral disease etiology as a categorical variable. We calculated participant-specific expected mortality rates and risk-adjusted OM rates by use of the final STS model and the augmented model and compared the MVRR + CABG results from these two models among participants having at least 30 eligible cases with nonmissing mitral disease etiologies.

Sensitivity Analysis: Expanded Inclusion Criteria

To evaluate the effect of the expanded patient inclusion criteria for this measure compared with prior STS mitral models, a sensitivity analysis was performed by excluding the “active endocarditis” patients from the model and by documenting the absolute differences in composite scores. Pearson and Spearman rank correlations then were estimated between the two sets of scores.

The Duke University Institutional Review Board granted a waiver of informed consent for use of these registry data for quality assurance.

Results

The baseline characteristics for the 24,740 patients are shown in [Supplemental Table A](#). The median age was 69 years. The etiology of mitral disease was classified as degenerative in 51.8% (12,807/24,740), ischemic in 13.3% (3,300/24,740), rheumatic in 4.6% (1,129/24,740), endocarditis in 2.6% (643/24,740), and “other” or missing in 24.7% patients. Mitral repair was performed in 16,300 (65.9%) of patients, and 8,440 had valve replacement (34.1%), which was more common in the rheumatic and endocarditis categories. Concomitant TVR was performed in 2,712 (11.0%), and the incidence was 1.6% higher in the mitral replacement than in the mitral repair subgroups. The overall unadjusted OM was 6.2% (1,532/24,740), and one or more major morbidities occurred in 30.8% (7,620/24,740), with prolonged ventilation being the most common (26%) ([Table 1](#)). When prolonged ventilation was

Table 1. Number of Participants, Operations, and Events

| Variable | N |
|----------------------------|--------------|
| Time duration of data set | 3 years |
| Participants, n | 703 |
| Operations, n | 24,740 |
| Mortality, n (%) | 1,532 (6.2) |
| Any major morbidity, n (%) | 7,620 (30.8) |
| Prolonged ventilation | 6,428 (26.0) |
| Deep sternal infection | 102 (0.4) |
| Permanent stroke | 684 (2.8) |
| Renal failure | 1,601 (6.5) |
| Reoperations ^a | 1,350 (5.5) |

^a Reoperation (1) for bleeding, (2) for intervention of coronary graft occlusion because of acute closure, thrombosis, technical, or embolic origin, (3) for prosthetic or native valve dysfunction, and (4) for other cardiac reasons.

observed, the associated unadjusted OM increased from 2.4% to 17.1% ([Supplemental Table B](#)). The occurrence of any major morbidity was associated with an increased unadjusted OM to 15.7% of patients, compared with 2.0% without major adverse events. Thus, pulmonary complications proved to be the major driver of morbidity-associated mortality.

The distributions of adjusted mortality and morbidity and estimated composite scores across the 703 STS participant centers are presented in [Figures 1 and 2](#). The weights of mortality and morbidity domains in the composite score calculation were 0.78 and 0.22, respectively. The numbers and percentages of 1-star, 2-star, and 3-star programs for various Bayesian credible intervals are displayed in [Table 2](#), and a 95% credible interval was selected. By use of this criterion, 14 of 703 centers (2%) were assigned a 1-star rating (lower than expected performance), 23 of 703 (3%) were 3-star (better than expected performance), and the remaining 666 (95%) were 2-star (as-expected performance).

The aggregate adjusted OM and morbidity rates by star rating category are shown in [Table 3](#). In comparison with centers in the “as expected” 2-star category, adjusted OM approximately doubled and halved for the 1-star and 3-star categories, respectively. The morbidity rate differences across star rating categories were directionally similar but slightly less in magnitude. These findings provided internal validation that the performance score measured what it purported: the overall quality of MVRR + CABG.

The overall composite measure reliability was greater than 0.50 in the 341 centers performing 25 cases or more over 3 years. Thus, about half of the total number of programs would be eligible to receive a star rating ([Supplemental Table C](#)). Higher reliability could be achieved by further substantial reductions in the number of eligible programs, but that was thought to be counterproductive.

As shown in [Figure 3](#), the adjusted OM rates calculated with and without adjustment for etiology of mitral disease were nearly identical, with a Pearson correlation coefficient of 0.9985. The ratio of risk-adjusted OM rates

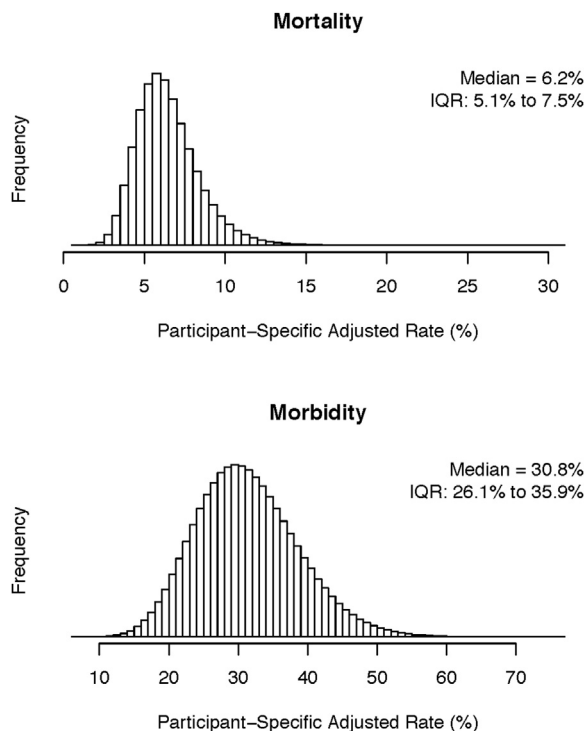


Fig 1. Distributions of risk-adjusted mortality and morbidity rates (N = 703 participants). (IQR = interquartile range.)

calculated with versus without adjustment for etiology of mitral disease ranged from 0.934 to 1.140 (interquartile range [IQR] 0.988 to 1.008) in the MVR + CABG population. On the absolute scale, the difference in risk-

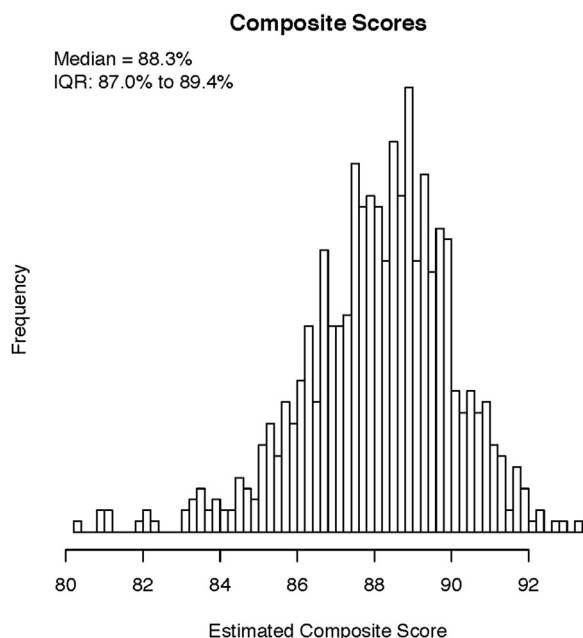


Fig 2. Distribution of estimated composite scores (N = 703 participants). (IQR = interquartile range.)

Table 2. Star Rating Distributions for Various Bayesian Credible Intervals

| CrI | Rating | | |
|-----------------------------------|---------------|---------------|---------------|
| | 1 star, n (%) | 2 star, n (%) | 3 star, n (%) |
| Overall composite score (N = 703) | | | |
| 90% CrI | 23 (3.3) | 647 (92.0) | 33 (4.7) |
| 95% CrI | 14 (2.0) | 666 (94.7) | 23 (3.3) |
| 98% CrI | 9 (1.3) | 682 (97.0) | 12 (1.7) |
| Mortality domain (N = 703) | | | |
| 90% CrI | 1 (0.1) | 700 (99.6) | 2 (0.3) |
| 95% CrI | 0 (0.0) | 702 (99.9) | 1 (0.1) |
| 98% CrI | 0 (0.0) | 702 (99.9) | 1 (0.1) |
| Morbidity domain (N = 703) | | | |
| 90% CrI | 24 (3.4) | 648 (92.2) | 31 (4.4) |
| 95% CrI | 14 (2.0) | 672 (95.6) | 17 (2.4) |
| 98% CrI | 7 (1.0) | 687 (97.7) | 9 (1.3) |

CrI = Bayesian credible intervals.

adjusted OM estimates based on the final versus augmented model was always less than 0.1 of the width of the 95% confidence interval.

In the sensitivity analysis for inclusion of active endocarditis cases, the average absolute difference between the original composite score and the composite score without 416 active endocarditis patients was 0.0015 (IQR 0.0008 to 0.0018). On the relative scale, the median relative change from the original to the new score was 0.05% (IQR 0.03% to 1.13% (relative change was defined as new score – original score / original score)). The Pearson correlation between the two sets of scores was 0.995, and the Spearman rank correlation was 0.993.

Comment

The STS performance measures have been developed from the STS ACS, a clinical registry with nearly 95% national penetration among adult cardiac surgery centers. Through annual external audits of 10% of participant

Table 3. Mortality and Morbidity for Each Composite Star Rating and Bayesian Credible Intervals

| CrI | Rating | | | | | |
|---------------|---------------|--------|--------|---------------|--------|--------|
| | 1-star | 2-star | 3-star | 1-star | 2-star | 3-star |
| | Mortality (%) | | | Morbidity (%) | | |
| Observed | | | | | | |
| 90% CrI | 11.6 | 6.3 | 3.5 | 52.6 | 31.1 | 21.0 |
| 95% CrI | 11.6 | 6.3 | 3.3 | 53.9 | 31.1 | 21.6 |
| 98% CrI | 11.6 | 6.3 | 2.9 | 55.3 | 30.8 | 22.0 |
| Risk-adjusted | | | | | | |
| 90% CrI | 11.2 | 6.1 | 3.3 | 51.0 | 31.0 | 20.3 |
| 95% CrI | 11.2 | 6.1 | 3.0 | 52.3 | 31.0 | 20.9 |
| 98% CrI | 11.1 | 6.1 | 2.6 | 53.3 | 30.7 | 21.3 |

CrI = Bayesian credible interval.

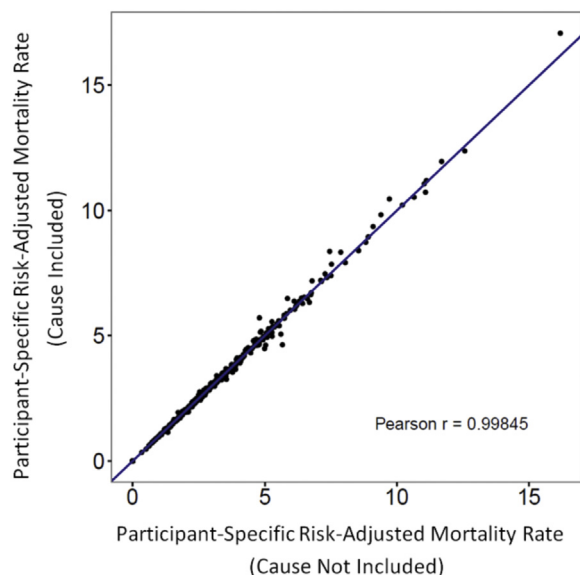


Fig 3. Correlation of risk-adjusted operative mortality rates estimated with and without inclusion of mitral etiology as a variable.

programs, the STS ACSD also has been shown to contain highly accurate data (96% to 97% congruence with medical record abstractions). On the basis of these findings and with the use of appropriate statistical modeling, an extensive portfolio of risk models and performance measures for the outcomes of five specific operations have been developed: isolated CABG, isolated AVR, AVR + CABG, isolated MVRR, and now MVRR + CABG. Importantly, the conceptual and technical details of these models and measures are fully transparent and have been published in their entirety in the peer-reviewed literature [1–8].

Compared with single-outcome metrics, such as mortality, composite performance measures have proved to be even more valuable tools for contemporary outcome assessment and quality improvement [4–7]. The advantages of composite measures include higher effective sample sizes / event rates compared with single outcomes, and more comprehensive evaluation of performance than could be achieved with the use of mortality alone. Finally, the inclusion of higher-risk categories, such as active endocarditis, made the current analysis more comprehensive but did not appreciably influence results.

The findings of this study provide interesting clinical insights into what has been one of the historically higher-mortality procedures in cardiac surgery [9]. Outcomes have improved in recent years as a result of innovations in surgical technique and patient care. For example, the data in the current study revealed contemporary unadjusted OM of 4.9% for mitral repair plus CABG and 8.7% for mitral replacement plus CABG (6.2% overall) (Supplemental Table 1). Although comparative analysis is difficult, it is likely that the transition of two thirds of MVRR + CABG patients from replacement to lower-risk mitral repair is a major factor responsible for the overall

outcome improvement [9–13]. Better processes of care also have contributed, including augmented myocardial protection, improved cardiopulmonary bypass, and numerous innovations in intraoperative and postoperative management. In the present study, the degree to which pulmonary adverse events contributed to increased mortality and morbidity in the MVRR + CABG population was impressive. From previous STS ACSD work, pulmonary complications seem to vary widely between centers [16] and are increasing over time [17]. Thus, better processes of care in this one area could improve the overall results significantly [18, 19], and they represent an opportunity for near-term quality improvement.

The current 65.9% mitral repair rate for MVRR + CABG patients is increased over that observed a decade ago [20], but the denominator of this rate also includes patients undergoing reoperation who may not be candidates for repair. If reoperations after previous mitral replacement were removed, then the primary mitral repair rate approximated 75% of candidates and represents a substantive increase. A similar repair rate of greater than 70% was observed for isolated MVRR in a companion study derived from the same 2.73 data set [8]. With better early and late results uniformly observed after mitral repair [9–13], conversion to predominant valve reconstruction should be encouraged.

Several other findings also merit discussion. Half of the MVRR + CABG patients had degenerative causes of disease. Ninety-five percent of repair patients had annuloplasty, 16% had leaflet resection, 8% had artificial chordal replacement, and only 1.3% had leaflet augmentation patches. The increasing application of adjunctive repair techniques may further expand the proportion of cases resulting in effective and durable repair [21]. Interestingly, the baseline characteristics and procedural incidences in the MVRR + CABG population differed little from isolated mitral surgical procedures [8]. However, mortalities and morbidities were higher with the addition of ischemic heart disease to the pathophysiology.

The results of concomitant TVR appear to be improving. In previous reports, performance of a tricuspid procedure independently increased short-term risk [22–25], although late outcomes probably were better. In a separate analysis of the current data set [26], short-term mortality for mitral procedures with concomitant TVR was not statistically significantly higher, regardless of the degree of tricuspid regurgitation [26]. This finding is possibly due to advancing surgical techniques and to better operative and postoperative management. Improving results also may reflect increasing experience with TVR, now approaching 95% of all tricuspid cases [25]. Conversion to more effective tricuspid annuloplasty, such as geometric rings, may have contributed [27, 28]. Surgical ablation for AF has not been associated with higher early mortality [29], as also was the case in the current series. In fact, effective surgical ablation in patients with preoperative AF currently may be protective [30]. This finding would support more liberal

application of concomitant ablation procedures, although long-term data are still required.

Finally, the nearly perfect correlation between adjusted OM rates with the “augmented” model (including the recorded variable in etiology of disease) and adjusted OM rates without etiology suggested that no significant information was added by including etiology, consistent with previous studies [10, 14, 15]. Thus, the apparent influence of etiology of ischemic disease on OM seem mediated by the effects of other included risk factors, rather than assignment of etiology per se. Similarly, the inclusion of high-risk categories, such as endocarditis, in the model did not diminish predictive accuracy and could even improve discrimination by increasing events.

Limitations

The combination of high center penetrance [31], a 10% annual center audit rate, large sample sizes, and linkages to other databases [32] have made the STS ACSD a valuable resource for the study of cardiothoracic procedures. However, it must be acknowledged that because participation in the STS ACSD remains voluntary, the results could be skewed toward better-performing centers. This seems unlikely, given the high national participation in the STS ACSD (90% to 95%).

Data from 703 sites were used to develop the MVRR + CABG measure. However, to achieve a reliability of 0.50, it was necessary to require a minimum volume of 25 cases over 3 years for centers to be eligible to receive composite scores, and this threshold was met by only 341 programs. The proportion of participant centers eligible to receive a MVRR + CABG composite score was smaller than for previous STS composite measures because of the generally lower case volumes per center for this procedure. For example, the total number of MVRR + CABG procedures available for model development was 24,740, compared with CABG (774,881), AVR (67,138), AVR + CABG (53,827), and isolated MVRR (61,201). By requiring a minimum volume threshold, we assure that those programs receiving an STS MVRR + CABG score can have confidence in its reliability.

Conclusion

In summary, an STS composite performance measure incorporating adjusted OM and morbidity has been developed for MVRR + CABG operations. Based on 3-year STS data samples and 95% Bayesian credible intervals, 2% of STS ACSD participants had worse than expected performance, 95% had “as expected” performance, and 3% had better than expected performance. STS composite measures may be useful for outcome assessment, quality improvement, public reporting, and future clinical investigation.

References

- Shahian DM, O'Brien SM, Filardo G, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: Part 1—coronary bypass grafting surgery. *Ann Thorac Surg* 2009;88:S2–22.
- O'Brien SM, Shahian DM, Filardo G, et al. The Society of Thoracic Surgeons 2008 Cardiac Surgery Risk Models: Part 2—isolated valve surgery. *Ann Thorac Surg* 2008;88:S23–42.
- Shahian DM, O'Brien SM, Filardo G, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: Part 3—valve plus coronary artery bypass grafting surgery. *Ann Thorac Surg* 2009;88:S43–62.
- Shahian DM, Edwards FH, Ferraris VA, et al. Society of Thoracic Surgeons Quality Measurement Task Force. Quality measurement in adult cardiac surgery: Part 1—conceptual framework and measure selection. *Ann Thorac Surg* 2007;83:S3–12.
- O'Brien SM, Shahian DM, Delong ER, et al. Quality measurement in adult cardiac surgery: Part 2—statistical considerations in composite measure scoring and provider rating. *Ann Thorac Surg* 2007;83:S13–26.
- Shahian DM, He X, Jacobs JP, et al. The Society of Thoracic Surgeons isolated aortic valve replacement (AVR) composite score: a report of the STS Quality Measurement Task Force. *Ann Thorac Surg* 2012;94:2166–71.
- Shahian DM, He X, Jacobs JP, et al. The STS AVR+CABG composite score: a report of the STS Quality Measurement Task Force. *Ann Thorac Surg* 2014;97:1604–9.
- Badhwar V, Rankin JS, He M, et al. The Society of Thoracic Surgeons mitral repair/replacement composite score: a report of the Society of Thoracic Surgeons Quality Measurement Task Force. *Ann Thorac Surg* 2016;101:2265–71.
- Rankin JS, Feneley MP, Hickey M StJ, et al. A clinical comparison of mitral valve repair versus valve replacement in ischemic mitral regurgitation. *J Thorac Cardiovasc Surg* 1988;95:165–77.
- Glower DD, Tuttle RH, Shaw LK, et al. Patient survival characteristics after routine mitral valve repair for ischemic mitral regurgitation. *J Thorac Cardiovasc Surg* 2005;129:860–8.
- Milano CA, Daneshmand MA, Rankin JS, et al. Survival prognosis and surgical management of ischemic mitral regurgitation. *Ann Thorac Surg* 2008;86:735–44.
- Daneshmand MA, Milano CA, Rankin JS, et al. Mitral valve repair for degenerative disease: a 20-year experience. *Ann Thorac Surg* 2009;88:1828–37.
- Daneshmand MA, Milano CA, Rankin JS, et al. Influence of patient age on procedural selection in mitral valve surgery. *Ann Thorac Surg* 2010;90:1479–86.
- Gillinov AM BE, Rajeswaran J, et al. Ischemic versus degenerative mitral regurgitation: does etiology affect survival? *Ann Thorac Surg* 2005;80:811–9.
- Gazoni LM, Kern JA, Swenson BR, et al. A change in perspective: results for ischemic mitral valve repair are similar to mitral valve repair for degenerative disease. *Ann Thorac Surg* 2007;84:750–7; discussion 758.
- Likosky DS, Wallace AS, Prager RL, et al. Sources of variation in hospital-level infection rates after coronary artery bypass grafting: an analysis of The Society of Thoracic Surgeons Adult Heart Surgery Database. *Ann Thorac Surg* 2015;100:1570–5; discussion 1575–6.
- Lee R, Li S, Rankin JS, et al. Fifteen-year outcome trends for valve surgery in North America. *Ann Thorac Surg* 2011;91:677–84.
- Labelle A, Kollef MH. Healthcare-associated pneumonia: approach to management. *Clin Chest Med* 2011;32:507–15.
- Rankin JS, Oguntolu O, Binford RS, et al. Management of immune dysfunction after adult cardiac surgery. *J Thorac Cardiovasc Surg* 2011;142:575–80.
- Gammie JS, Sheng S, Griffin BP, et al. Trends in mitral valve surgery in the United States: results from the Society of Thoracic Surgeons database. *Ann Thorac Surg* 2009;87:1431–9.
- Rankin JS, Gaca JG, Brunsting LA, et al. Increasing mitral valve repair rates with non-resectional techniques. *Innovations* 2011;6:209–20.
- Rankin JS, Hammill BG, O'Brien SM, et al. Determinants of operative mortality in valvular heart surgery. *J Thorac Cardiovasc Surg* 2006;131:547–57.

23. Rankin JS, Thourani VH, Suri RM, et al. Associations between valve repair and reduced operative mortality in mitral/tricuspid double valve surgery. *Eur J Cardiothorac Surg* 2013;44:472–7.
24. Vassileva CM, Li S, Thourani VH, et al. Outcome characteristics of multiple-valve surgery: comparison with single valve procedures. *Innovations* 2014;9:27–32.
25. Kilic A, Saha-Chaudhuri P, Rankin JS, et al. Trends and outcomes of tricuspid valve surgery in North America. *Ann Thorac Surg* 2013;96:1546–52.
26. Badhwar V, Rankin JS, He M, et al. Performing concomitant tricuspid valve repair at the time of mitral operations is not associated with increased mortality. *Ann Thorac Surg* 2016 Aug 25. <http://dx.doi.org/10.1016/j.athoracsur.2016.06.004>. [Epub ahead of print].
27. Rankin JS. Current techniques of tricuspid valve repair. http://www.ctsnet.org/sections/videosection/videos/vg2012_RankinS_TVR.html. Accessed October 15th, 2016.
28. Ghoreishi M, Cheema FH, Laschinger M, et al. Functional tricuspid regurgitation repair solved: undersized rigid annuloplasty insertion assures effective and durable repair. *Ann Thorac Surg*; in press.
29. Gammie JS, Haddad M, Milford-Beland S, et al. Atrial fibrillation correction surgery: lessons from the Society of Thoracic Surgeons national cardiac database. *Ann Thorac Surg* 2008;85:909–15.
30. Rankin JS, He X, O'Brien SM, et al. The Society of Thoracic Surgeons risk model for operative mortality after multiple valve surgery. *Ann Thorac Surg* 2013;95:1484–90.
31. Jacobs JP, Shahian DM, He X, et al. Successful linkage of STS and CMS Medicare data to examine the penetration, completeness, and representativeness of the STS adult cardiac surgery database. *Ann Thorac Surg* 2016;101:33–41.
32. Badhwar V, Peterson ED, Jacobs JP, et al. Longitudinal outcome of isolated mitral repair in older patients: results from 14,604 procedures performed from 1991 to 2007. *Ann Thorac Surg* 2012;94:1870–9.

The Society of Thoracic Surgeons 2008 Cardiac Surgery Risk Models: Part 3—Valve Plus Coronary Artery Bypass Grafting Surgery

David M. Shahian, MD,^a Sean M. O'Brien, PhD,^b Giovanni Filardo, PhD, MPH,^c Victor A. Ferraris, MD,^d Constance K. Haan, MD,^e Jeffrey B. Rich, MD,^f Sharon-Lise T. Normand, PhD,^g Elizabeth R. DeLong, PhD,^b Cynthia M. Shewan, PhD,^h Rachel S. Dokholyan, MPH,^b Eric D. Peterson, MD, MPH,^b Fred H. Edwards, MD,^e and Richard P. Anderson, MD^{i†}

^aMassachusetts General Hospital, Boston, Massachusetts; ^bDuke Clinical Research Institute, Durham, North Carolina; ^cInstitute for Health Care Research and Improvement, Baylor Health Care System, Dallas, Texas; ^dUniversity of Kentucky Chandler Medical Center, Division of Cardiovascular and Thoracic Surgery, Lexington, Kentucky; ^eUniversity of Florida, Division of Cardiothoracic Surgery, Jacksonville, Florida; ^fSentara Cardiovascular Research Institute, Norfolk, Virginia; ^gDepartment of Health Care Policy, Harvard Medical School, and Department of Biostatistics, Harvard School of Public Health, Boston, Massachusetts; ^hThe Society of Thoracic Surgeons, Chicago, Illinois; and ⁱSeattle, Washington

Background. Since 1999, The Society of Thoracic Surgeons (STS) has published two risk models that can be used to adjust the results of valve surgery combined with coronary artery bypass graft surgery (CABG). The most recent was developed from data for patients who had surgery between 1994 and 1997 using operative mortality as the only endpoint. Furthermore, this model did not specifically consider mitral valve repair plus CABG, an increasingly common procedure. Consistent with STS policy of periodically updating and improving its risk models, new models for valve surgery combined with CABG have been developed. These models specifically address both perioperative morbidity and mitral valve repair, and they are based on contemporary data.

Methods. The final study population consisted of 101,661 procedures, including aortic valve replacement (AVR) plus CABG, mitral valve replacement (MVR) plus CABG, or mitral valve repair (MVRRepair) plus CABG between January 1, 2002, and December 31, 2006. Model outcomes included operative mortality, stroke, deep sternal wound infection, reoperation, prolonged ventilation, renal failure, composite major morbidity or mortality, prolonged postoperative length of stay, and short postoperative length of stay. Candidate variables were screened for frequency of missing data, and imputation techniques were used where appropriate. Stepwise variable selection was employed, supplemented by advice from an expert panel of cardiac surgeons and biostatisticians. Several variables were forced into models to insure face validity (eg, atrial

fibrillation for the permanent stroke model, sex for all models). Based on preliminary analyses of the data, a single model was employed for valve plus CABG, with indicator variables for the specific type of procedure. Interaction terms were included to allow for differential impact of predictor variables depending on procedure type. After validating the model in the 40% validation sample, the development and validation samples were then combined, and the final model coefficients were estimated using the overall 100% combined sample. The final logistic regression model was estimated using generalized estimating equations to account for clustering of patients within institutions.

Results. The c-index for mortality prediction for the overall valve plus CABG population was 0.75. Morbidity model c-indices for specific complications (permanent stroke, renal failure, prolonged ventilation > 24 hours, deep sternal wound infection, reoperation for any reason, major morbidity or mortality composite, and prolonged postoperative length of stay) for the overall group of valve plus CABG procedures ranged from 0.622 to 0.724, and calibration was excellent.

Conclusions. New STS risk models have been developed for heart valve surgery combined with CABG. These are the first valve plus CABG models that also include risk prediction for individual major morbidities, composite major morbidity or mortality, and short and prolonged length of stay.

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Risk models for cardiac surgery were first developed almost 2 decades ago, and most of these early models focused on isolated coronary artery bypass graft surgery (CABG) [1–4]. The results of this frequently performed

surgical procedure have often been used as the sole marker to assess the quality of care delivered by cardiac surgical programs. Risk-adjusted results for CABG have been used

†This author is deceased. Former Chair, Quality, Research and Patient Safety Council, The Society of Thoracic Surgeons, Chicago, IL.

Address correspondence to Dr Shahian, Massachusetts General Hospital, 55 Fruit St, Boston, MA 02114; e-mail: dshahian@partners.org.

Drs Shahian, O'Brien, Filardo, Ferraris, Haan, Rich, Normand, DeLong, Shewan, Peterson, Edwards, Anderson, and Ms Dokholyan, have no conflicts of interest to declare regarding this work.

Abbreviations and Acronyms

| | |
|----------|---|
| AVR | = aortic valve replacement |
| CABG | = coronary artery bypass graft surgery |
| MI | = myocardial infarction |
| MVR | = mitral valve replacement |
| MVRepair | = mitral valve repair |
| NCD | = National Adult Cardiac Surgery Database |
| QMTF | = Quality Measurement Task Force |
| STS | = The Society of Thoracic Surgeons |

for hospital and regional quality improvement initiatives, public reporting, pay for performance reimbursement programs, decision support, patient counseling, and clinical research. Earlier models focused primarily on mortality prediction, but subsequent models have been developed for both risk-adjusted morbidity and length of stay [5].

The other commonly performed category of cardiac surgery consists of operations on the heart valves, either alone or in combination with CABG. Relative to isolated CABG procedures, which are declining in frequency, the proportion of valve cases is steadily increasing. To better assess the overall performance of cardiac surgery programs, to discern the factors that are most significantly related to patient outcomes, and to aid in physician and patient decision-making, risk models have now also been developed for heart valve surgery [6–18].

Unlike risk models for isolated CABG, a relatively standardized procedure, valve surgery encompasses a much more diverse group of operations. There are four cardiac valves, and they may malfunction in a number of quite different ways (eg, stenosis, regurgitation, infection, and so forth). The valves may be repaired or replaced with a wide range of techniques and prosthetics. In some cases, procedures may be performed on multiple valves, or the valve procedure may be combined with CABG.

Given the heterogeneity of heart valve surgery, it is not surprising that a variety of risk-modeling techniques has been applied. At one extreme, the European System for Cardiac Operative Risk Evaluation (EuroSCORE) algorithm, developed by a European consortium, groups all cardiac operations together in a single risk model with indicator variables included to account for valve procedures [14, 18]. Although this approach is simple and easy to apply, recent studies by van Gameren and associates [19] have suggested that a dedicated valve risk model may have better discrimination and calibration than the EuroSCORE algorithm when applied to valve surgery patients. Combined models for aortic and mitral valve procedures with or without CABG have been developed by Jin and colleagues [12] and by Ambler and associates [13]. The 2001 valve models developed by The Society of Thoracic Surgeons (STS) [6] consisted of one model for all isolated valve procedures and one model for valve procedures combined with CABG, and a 2007 risk model derived from the New York Cardiac Surgery Reporting System used a similar stratification [8].

Unified valve models reflect the fact that many risk factors are common to both aortic and mitral valve surgery. They offer simplicity, and they also permit larger sample sizes for development and validation [12]. However, there are significant differences between aortic and mitral valvular disease in both pathophysiology and outcomes, and both also differ substantially from isolated CABG [11]. Some investigators advocate separate aortic and mitral valve models to have more homogeneous patient populations. Examples include models developed by STS, the New York Cardiac Surgery Reporting System, and the Northern New England Cardiovascular Disease Study Group [7, 9, 10]. Some of these models have been developed solely for isolated valve replacement, some have included CABG as a separate predictor variable in the isolated valve model, and some models have focused specifically on valve plus CABG. All these decisions involve a tradeoff—the more homogeneous the study group, the fewer patients are available for model development and validation [12].

Because of the large number of valve surgery patients available for analysis in the STS National Adult Cardiac Surgery Database (NCD), our approach has favored separate models for valve plus CABG versus isolated valve surgery. The STS Quality Measurement Task Force (QMTF) presumes that when adequate numbers of patients are available for study, relatively homogeneous operative categories result in more accurate risk prediction. Furthermore, recent studies by van Gameren and colleagues [19] suggest that the valve plus CABG group may be the most difficult to model accurately, thus meriting its own algorithm.

Several new features were added to the 2008 valve plus CABG models described in this report. First, recognizing that mitral valve repair is often different in both etiology and outcomes than replacement, the QMTF has included interactions between surgery type and several key predictor variables. Fitting a single model with several such interactions is useful. It allows for pooling information across related groups of valve procedures without making an *a priori* assumption that the effect of key risk factors is constant across these groups. Finally, new models have been developed for specific major complications of each valve plus CABG procedure, as well as for composite morbidity, mortality, and for both short and prolonged postoperative length of stay.

The authors of this report are members of the STS QMTF who were involved in this risk model development project.

Study Population and Endpoints

Our general approaches to variable selection and risk model development have been described in the companion articles on isolated CABG (Part 1) and isolated valve surgery (Part 2). Details specific to the valve plus CABG models are included in this report.

Study Population

The study population for this analysis consisted of single aortic or mitral valve surgical procedures combined with

CABG performed on adult patients between January 1, 2002, and December 31, 2006. Only the following procedures were included: (1) isolated aortic valve replacement (AVR) plus CABG; (2) isolated mitral valve replacement (MVR) plus CABG; and (3) isolated mitral valve repair (MVRRepair) plus CABG.

Because of the relatively small number of pulmonic, tricuspid, multiple valve procedures, and aortic repairs, these cases were not included in the current models. Patients undergoing isolated valve surgery without CABG were excluded from the current analysis, but these cases are the focus of a separate model described in Part 2 of this three-part series. Patients with missing sex data ($n = 17$) were excluded because these patients are not allowed in the analysis dataset used for creating STS database participant feedback reports. Patients on dialysis preoperatively ($n = 2,443$) were excluded when developing the risk model for prediction of postoperative renal failure. The final study population comprised 101,661 patient operations (66,074 AVR plus CABG; 13,663 MVR plus CABG; and 21,924 MVRRepair plus CABG) from 814 STS NCD participating groups.

Characteristics of the study population are summarized in Table 1.

Training and Validation Samples

The study population was randomly divided into a 60% training (development) sample and a 40% test (validation) sample. The development sample was used to identify predictor variables and estimate model coefficients. Data from the validation sample were used to assess model fit, discrimination, and calibration. After choosing variables and assessing model fit, the development and validation samples were subsequently combined, and the final model coefficients were estimated using the combined (development plus validation) data.

Endpoints

In developing the valve plus CABG risk models, we used the same nine endpoints that were analyzed in the STS isolated CABG (Part 1) and the STS isolated valve (Part 2) models. Morbidities in all three models are recorded only in-hospital, in contrast to the operative mortality endpoint defined below (although beginning with version 2.61, sternal infection will be recorded at 30 days): (1) operative mortality: death during the same hospitalization as surgery, regardless of timing or within 30 days of surgery regardless of venue; (2) permanent stroke (CVA): a central neurologic deficit persisting longer than 72 hours; (3) renal failure: a new requirement for dialysis or an increase of the serum creatinine to more than 2.0 mg/dL and double the most recent preoperative creatinine level; (4) prolonged ventilation (> 24 hours); (5) deep sternal wound infection; (6) reoperation for any reason; (7) major morbidity or mortality, a composite defined as the occurrence of any of the above endpoints; (8) prolonged postoperative length of stay (PLOS): length of stay (LOS) more than 14 days (alive or dead); and (4) short postoperative length of stay (SLOS): LOS less than 6 days and patient alive at discharge.

Endpoint frequencies in the study population are presented in Table 2.

Separate Versus Combined Models

Given the variety of approaches used in previous models by STS and other developers, we investigated the option of developing separate models for the AVR plus CABG and MVR plus CABG populations, and we also studied how best to subdivide the mitral plus CABG population into repair versus replacement. Although we had a large study population available, many of the individual outcomes were relatively rare. We were concerned that the number of events would be too small to permit reliable estimation of the model coefficients in separate models for each valve. Thus, in theory, the development of separate custom models for each valve type could be inferior to a single combined model because the custom models would have a smaller sample size and hence larger variance.

As described in detail in Part 2 of this series (isolated valve surgery), we performed preliminary empirical analyses to compare two alternative strategies (separate versus combined AVR plus CABG and MVR/Repair plus CABG) for developing these risk models. We first developed separate models for the three subpopulations (AVR plus CABG, MVR plus CABG, and MVRRepair plus CABG), then modeled all three subpopulations together in a single model. In the latter approach, we included several interaction terms to allow the effect of certain risk factors to differ across the specific valve subpopulations. These strategies were used to develop risk models for operative mortality and permanent stroke, using a 60% development sample and a separate 40% validation sample. The performance of the combined model was then assessed separately within each subpopulation and compared to the model that was developed specifically for that subpopulation. In the case of mortality, the combined model had better discrimination (larger c-index) than the corresponding custom model in each of the three subpopulations (AVR plus CABG, MVR plus CABG, MVRRepair plus CABG). For stroke, the combined model had better discrimination in two of the three populations (all except AVR plus CABG). Finally, when explained variation was quantified by the generalized R^2 index of Nagelkerke [20], the combined model had greater explained variation than the custom model in each subpopulation for each endpoint. These results provide empirical support for the use of a single model with several interactions, which allows pooling of information across valve groups without assuming that the effect of risk factors is constant.

Selection of Candidate Predictor Variables

The candidate variables for the STS valve plus CABG models were identical to those in the STS isolated valve models, described in Part 2 of this series. They differed from the isolated CABG model variables in the following specific areas: (1) Percutaneous coronary intervention (PCI) occurring 6 hours or less before surgery was present in only 315 patients (0.3%) in the valve plus CABG study population, and was not included as a candidate variable. (2) Infectious endocarditis was not included in the isolated CABG model but was considered for the valve plus CABG model. Although this risk factor was rarely present (0.8% active

Table 1. Distribution of Risk Factors in Overall Study Population 2002 to 2006

| Variable | Overall Valve + CABG (n = 101,661) | | AVR + CABG (n = 66,074) | | MVR + CABG (n = 13,663) | | MVRRepair + CABG (n = 21,924) | |
|------------------------------------|---------------------------------------|------|----------------------------|-------|----------------------------|-------|----------------------------------|-------|
| | N | % | N | % | N | % | N | % |
| Demographics | | | | | | | | |
| Age, years | | | | | | | | |
| < 55 | 6,693 | 6.6 | 2,983 | 4.51 | 1,309 | 9.58 | 2,401 | 10.95 |
| 55–64 | 17,188 | 16.9 | 9,132 | 13.82 | 2,790 | 20.42 | 5,266 | 24.02 |
| 65–74 | 33,628 | 33.1 | 21,313 | 32.26 | 4,667 | 34.16 | 7,648 | 34.88 |
| ≥ 75 | 44,152 | 43.4 | 32,646 | 49.41 | 4,897 | 35.84 | 6,609 | 30.15 |
| Sex | | | | | | | | |
| Male | 65,588 | 64.5 | 44,619 | 67.53 | 7,348 | 53.78 | 13,621 | 62.13 |
| Female | 36,073 | 35.5 | 21,455 | 32.47 | 6,315 | 46.22 | 8,303 | 37.87 |
| Race | | | | | | | | |
| Caucasian | 90,572 | 89.1 | 60,121 | 90.99 | 11,765 | 86.11 | 18,686 | 85.23 |
| Black | 4,534 | 4.5 | 2,094 | 3.17 | 914 | 6.69 | 1,526 | 6.96 |
| Hispanic | 2,487 | 2.4 | 1,487 | 2.25 | 354 | 2.59 | 646 | 2.95 |
| Asian | 1,083 | 1.1 | 542 | 0.82 | 191 | 1.40 | 350 | 1.60 |
| Other | 2,295 | 2.3 | 1,402 | 2.12 | 331 | 2.42 | 562 | 2.56 |
| Missing | 690 | 0.7 | 428 | 0.65 | 108 | 0.79 | 154 | 0.70 |
| Risk factors | | | | | | | | |
| Body surface area, m ² | | | | | | | | |
| < 1.50 | 3,340 | 3.3 | 1,985 | 3.00 | 638 | 4.67 | 717 | 3.27 |
| 1.50–1.74 | 20,779 | 20.4 | 12,580 | 19.04 | 3,500 | 25.62 | 4,699 | 21.43 |
| 1.75–1.99 | 40,017 | 39.4 | 25,814 | 39.07 | 5,440 | 39.82 | 8,763 | 39.97 |
| ≥ 2.00 | 36,956 | 36.4 | 25,361 | 38.38 | 3,996 | 29.25 | 7,599 | 34.66 |
| Missing | 569 | 0.6 | 334 | 0.51 | 89 | 0.65 | 146 | 0.67 |
| Body mass index, kg/m ² | | | | | | | | |
| < 25 | 29,353 | 28.9 | 17,712 | 26.81 | 4,787 | 35.04 | 6,854 | 31.26 |
| 25–29 | 39,345 | 38.7 | 25,692 | 38.88 | 4,951 | 36.24 | 8,702 | 39.69 |
| 30–34 | 21,063 | 20.7 | 14,447 | 21.86 | 2,507 | 18.35 | 4,109 | 18.74 |
| ≥ 35 | 11,165 | 11.0 | 7,785 | 11.78 | 1,299 | 9.51 | 2,081 | 9.49 |
| Missing | 735 | 0.7 | 438 | 0.66 | 119 | 0.87 | 178 | 0.81 |
| Diabetes mellitus | | | | | | | | |
| No diabetes | 68,112 | 67.0 | 44,489 | 67.33 | 9,517 | 69.66 | 14,106 | 64.34 |
| Diabetes, noninsulin | 23,383 | 23.0 | 15,705 | 23.77 | 2,642 | 19.34 | 5,036 | 22.97 |
| Diabetes, insulin | 9,848 | 9.7 | 5,677 | 8.59 | 1,463 | 10.71 | 2,708 | 12.35 |
| Diabetes, missing treatment | 167 | 0.2 | 105 | 0.16 | 20 | 0.15 | 42 | 0.19 |
| Missing | 151 | 0.1 | 98 | 0.15 | 21 | 0.15 | 32 | 0.15 |
| Hypertension | | | | | | | | |
| No | 22,709 | 22.3 | 13,944 | 21.10 | 3,482 | 25.48 | 5,283 | 24.10 |
| Yes | 78,823 | 77.5 | 52,050 | 78.78 | 10,163 | 74.38 | 16,610 | 75.76 |
| Missing | 129 | 0.1 | 80 | 0.12 | 18 | 0.13 | 31 | 0.14 |
| Hypercholesterolemia | | | | | | | | |
| No | 33,759 | 33.2 | 21,248 | 32.16 | 5,324 | 38.97 | 7,187 | 32.78 |
| Yes | 67,613 | 66.5 | 44,649 | 67.57 | 8,280 | 60.60 | 14,684 | 66.98 |
| Missing | 289 | 0.3 | 177 | 0.27 | 59 | 0.43 | 53 | 0.24 |
| Past or present smoker | | | | | | | | |
| No | 43,687 | 43.0 | 29,123 | 44.08 | 5,835 | 42.71 | 8,729 | 39.81 |
| Yes | 57,813 | 56.9 | 36,849 | 55.77 | 7,797 | 57.07 | 13,167 | 60.06 |
| Missing | 161 | 0.2 | 102 | 0.15 | 31 | 0.23 | 28 | 0.13 |
| Chronic lung disease | | | | | | | | |
| None | 76,803 | 75.5 | 50,632 | 76.63 | 9,756 | 71.40 | 16,415 | 74.87 |
| Mild | 12,157 | 12.0 | 7,658 | 11.59 | 1,853 | 13.56 | 2,646 | 12.07 |
| Moderate | 7,797 | 7.7 | 4,720 | 7.14 | 1,269 | 9.29 | 1,808 | 8.25 |
| Severe | 4,005 | 3.9 | 2,463 | 3.73 | 658 | 4.82 | 884 | 4.03 |
| Missing | 899 | 0.9 | 601 | 0.91 | 127 | 0.93 | 171 | 0.78 |

Table 1. Continued

| Variable | Overall Valve + CABG (n = 101,661) | | AVR + CABG (n = 66,074) | | MVR + CABG (n = 13,663) | | MVRRepair + CABG (n = 21,924) | |
|---------------------------------|---------------------------------------|------|----------------------------|-------|----------------------------|-------|----------------------------------|-------|
| | N | % | N | % | N | % | N | % |
| Peripheral vascular disease | | | | | | | | |
| No | 84,183 | 82.8 | 54,658 | 82.72 | 11,373 | 83.24 | 18,152 | 82.80 |
| Yes | 17,294 | 17.0 | 11,296 | 17.10 | 2,267 | 16.59 | 3,731 | 17.02 |
| Missing | 184 | 0.2 | 120 | 0.18 | 23 | 0.17 | 41 | 0.19 |
| Cerebrovascular disease | | | | | | | | |
| No | 83,284 | 81.9 | 53,509 | 80.98 | 11,304 | 82.73 | 18,471 | 84.25 |
| Yes | 18,202 | 17.9 | 12,449 | 18.84 | 2,335 | 17.09 | 3,418 | 15.59 |
| Missing | 175 | 0.2 | 116 | 0.18 | 24 | 0.18 | 35 | 0.16 |
| CVA | | | | | | | | |
| No CVA | 92,527 | 91.0 | 60,141 | 91.02 | 12,283 | 89.90 | 20,103 | 91.69 |
| Remote CVA (> 2 weeks) | 8,461 | 8.3 | 5,545 | 8.39 | 1,240 | 9.08 | 1,676 | 7.64 |
| Recent CVA (\leq 2 weeks) | 348 | 0.3 | 184 | 0.28 | 88 | 0.64 | 76 | 0.35 |
| CVA, missing timing | 114 | 0.1 | 62 | 0.09 | 23 | 0.17 | 29 | 0.13 |
| Missing | 211 | 0.2 | 142 | 0.21 | 29 | 0.21 | 40 | 0.18 |
| Endocarditis | | | | | | | | |
| No endocarditis | 99,517 | 97.9 | 65,023 | 98.41 | 12,914 | 94.52 | 21,580 | 98.43 |
| Treated endocarditis | 1,091 | 1.1 | 525 | 0.79 | 356 | 2.61 | 210 | 0.96 |
| Active endocarditis | 827 | 0.8 | 387 | 0.59 | 356 | 2.61 | 84 | 0.38 |
| Endocarditis, missing type | 24 | 0.0 | 11 | 0.02 | 8 | 0.06 | 5 | 0.02 |
| Missing | 202 | 0.2 | 128 | 0.19 | 29 | 0.21 | 45 | 0.21 |
| Renal failure | | | | | | | | |
| No | 92,592 | 91.1 | 60,880 | 92.14 | 12,037 | 88.10 | 19,675 | 89.74 |
| Yes | 8,888 | 8.7 | 5,072 | 7.68 | 1,605 | 11.75 | 2,211 | 10.08 |
| Missing | 181 | 0.2 | 122 | 0.18 | 21 | 0.15 | 38 | 0.17 |
| Renal function | | | | | | | | |
| Creatinine < 1.0 mg/dL | 30,178 | 29.7 | 20,297 | 30.72 | 3,672 | 26.88 | 6,209 | 28.32 |
| Creatinine 1.00–1.49 mg/dL | 52,008 | 51.2 | 34,054 | 51.54 | 6,758 | 49.46 | 11,196 | 51.07 |
| Creatinine 1.50–1.99 mg/dL | 11,469 | 11.3 | 7,151 | 10.82 | 1,732 | 12.68 | 2,586 | 11.80 |
| Creatinine 2.00–2.49 mg/dL | 2,711 | 2.7 | 1,554 | 2.35 | 498 | 3.64 | 659 | 3.01 |
| Creatinine \geq 2.5 mg/dL | 1,602 | 1.6 | 844 | 1.28 | 319 | 2.33 | 439 | 2.00 |
| Dialysis | 2,443 | 2.4 | 1,364 | 2.06 | 482 | 3.53 | 597 | 2.72 |
| Missing | 1,250 | 1.2 | 810 | 1.23 | 202 | 1.48 | 238 | 1.09 |
| Immunosuppressive treatment | | | | | | | | |
| No | 98,421 | 96.8 | 63,984 | 96.84 | 13,211 | 96.69 | 21,226 | 96.82 |
| Yes | 2,975 | 2.9 | 1,904 | 2.88 | 427 | 3.13 | 644 | 2.94 |
| Missing | 265 | 0.3 | 186 | 0.28 | 25 | 0.18 | 54 | 0.25 |
| Previous CV interventions | | | | | | | | |
| Previous CABG surgery | | | | | | | | |
| No | 91,657 | 90.2 | 59,583 | 90.18 | 12,057 | 88.25 | 20,017 | 91.30 |
| Yes | 9,615 | 9.5 | 6,257 | 9.47 | 1,540 | 11.27 | 1,818 | 8.29 |
| Missing | 389 | 0.4 | 234 | 0.35 | 66 | 0.48 | 89 | 0.41 |
| Previous valve surgery | | | | | | | | |
| No | 98,737 | 97.1 | 64,265 | 97.26 | 12,794 | 93.64 | 21,678 | 98.88 |
| Yes | 2,540 | 2.5 | 1,567 | 2.37 | 813 | 5.95 | 160 | 0.73 |
| Missing | 384 | 0.4 | 242 | 0.37 | 56 | 0.41 | 86 | 0.39 |
| Previous other cardiac surgery | | | | | | | | |
| No | 98,538 | 96.9 | 64,166 | 97.11 | 13,181 | 96.47 | 21,191 | 96.66 |
| Yes | 2,683 | 2.6 | 1,634 | 2.47 | 407 | 2.98 | 642 | 2.93 |
| Missing | 440 | 0.4 | 274 | 0.41 | 75 | 0.55 | 91 | 0.42 |
| Number of previous CV surgeries | | | | | | | | |
| No previous CV surgery | 89,419 | 88.0 | 58,161 | 88.02 | 11,530 | 84.39 | 19,728 | 89.98 |
| 1 prior CV surgery | 10,453 | 10.3 | 6,796 | 10.29 | 1,799 | 13.17 | 1,858 | 8.47 |
| \geq 2 prior CV surgeries | 1,200 | 1.2 | 766 | 1.16 | 231 | 1.69 | 203 | 0.93 |
| Missing | 589 | 0.6 | 351 | 0.53 | 103 | 0.75 | 135 | 0.62 |

Table 1. Continued

| Variable | Overall Valve + CABG (n = 101,661) | | AVR + CABG (n = 66,074) | | MVR + CABG (n = 13,663) | | MVRRepair + CABG (n = 21,924) | |
|-----------------------------|---------------------------------------|------|----------------------------|-------|----------------------------|-------|----------------------------------|-------|
| | N | % | N | % | N | % | N | % |
| Prior PCI | | | | | | | | |
| No PCI | 84,553 | 83.2 | 55,581 | 84.12 | 11,152 | 81.62 | 17,820 | 81.28 |
| PCI ≤ 6 hours | 315 | 0.3 | 151 | 0.23 | 89 | 0.65 | 75 | 0.34 |
| PCI > 6 hours | 16,158 | 15.9 | 9,946 | 15.05 | 2,321 | 16.99 | 3,891 | 17.75 |
| PCI, missing timing | 234 | 0.2 | 145 | 0.22 | 45 | 0.33 | 44 | 0.20 |
| Missing | 401 | 0.4 | 251 | 0.38 | 56 | 0.41 | 94 | 0.43 |
| Preoperative cardiac status | | | | | | | | |
| Acuity status | | | | | | | | |
| Elective | 62,298 | 61.3 | 43,682 | 66.11 | 7,277 | 53.26 | 11,339 | 51.72 |
| Urgent | 36,454 | 35.9 | 21,414 | 32.41 | 5,315 | 38.90 | 9,725 | 44.36 |
| Emergent | 2,479 | 2.4 | 763 | 1.15 | 945 | 6.92 | 771 | 3.52 |
| Emergent salvage | 258 | 0.3 | 97 | 0.15 | 104 | 0.76 | 57 | 0.26 |
| Missing | 172 | 0.2 | 118 | 0.18 | 22 | 0.16 | 32 | 0.15 |
| MI | | | | | | | | |
| No prior MI | 68,332 | 67.2 | 49,673 | 75.18 | 8,056 | 58.96 | 10,603 | 48.36 |
| MI ≤ 21 days | 16,934 | 16.7 | 9,308 | 14.09 | 2,621 | 19.18 | 5,005 | 22.83 |
| MI 8–21 days | 3,751 | 3.7 | 1,725 | 2.61 | 624 | 4.57 | 1,402 | 6.39 |
| MI 1–7 days | 10,458 | 10.3 | 4,514 | 6.83 | 1,741 | 12.74 | 4,203 | 19.17 |
| MI > 6 and < 24 hours | 1,113 | 1.1 | 367 | 0.56 | 341 | 2.50 | 405 | 1.85 |
| MI ≤ 6 hours | 531 | 0.5 | 178 | 0.27 | 192 | 1.41 | 161 | 0.73 |
| MI, missing timing | 355 | 0.3 | 184 | 0.28 | 59 | 0.43 | 112 | 0.51 |
| Missing | 187 | 0.2 | 125 | 0.19 | 29 | 0.21 | 33 | 0.15 |
| Angina | | | | | | | | |
| No | 42,542 | 41.8 | 28,032 | 42.43 | 6,248 | 45.73 | 8,262 | 37.68 |
| Yes | 58,967 | 58.0 | 37,945 | 57.43 | 7,394 | 54.12 | 13,628 | 62.16 |
| Missing | 152 | 0.1 | 97 | 0.15 | 21 | 0.15 | 34 | 0.16 |
| Cardiogenic shock | | | | | | | | |
| No | 98,743 | 97.1 | 65,219 | 98.71 | 12,590 | 92.15 | 20,934 | 95.48 |
| Yes | 2,719 | 2.7 | 720 | 1.09 | 1,055 | 7.72 | 944 | 4.31 |
| Missing | 199 | 0.2 | 135 | 0.20 | 18 | 0.13 | 46 | 0.21 |
| Resuscitation | | | | | | | | |
| No | 100,474 | 98.8 | 65,522 | 99.16 | 13,359 | 97.78 | 21,593 | 98.49 |
| Yes | 971 | 1.0 | 405 | 0.61 | 281 | 2.06 | 285 | 1.30 |
| Missing | 216 | 0.2 | 147 | 0.22 | 23 | 0.17 | 46 | 0.21 |
| Arrhythmia | | | | | | | | |
| No arrhythmia | 83,856 | 82.5 | 56,040 | 84.81 | 9,992 | 73.13 | 17,824 | 81.30 |
| AFib/flutter | 13,386 | 13.2 | 7,533 | 11.40 | 2,940 | 21.52 | 2,913 | 13.29 |
| Heart block | 1,975 | 1.9 | 1,311 | 1.98 | 289 | 2.12 | 375 | 1.71 |
| Sustained VT/VF | 1,513 | 1.5 | 614 | 0.93 | 299 | 2.19 | 600 | 2.74 |
| Arrhythmia, other | 483 | 0.5 | 305 | 0.46 | 63 | 0.46 | 115 | 0.52 |
| Arrhythmia, missing type | 242 | 0.2 | 135 | 0.20 | 59 | 0.43 | 48 | 0.22 |
| Missing | 206 | 0.2 | 136 | 0.21 | 21 | 0.15 | 49 | 0.22 |
| Preoperative IABP | | | | | | | | |
| No | 96,136 | 94.6 | 64,597 | 97.76 | 11,957 | 87.51 | 19,582 | 89.32 |
| Yes | 5,205 | 5.1 | 1,275 | 1.93 | 1,655 | 12.11 | 2,275 | 10.38 |
| Missing | 320 | 0.3 | 202 | 0.31 | 51 | 0.37 | 67 | 0.31 |
| NYHA class | | | | | | | | |
| I | 9,839 | 9.7 | 6,934 | 10.49 | 1,103 | 8.07 | 1,802 | 8.22 |
| II | 24,830 | 24.4 | 17,808 | 26.95 | 2,524 | 18.47 | 4,498 | 20.52 |
| III | 42,593 | 41.9 | 28,079 | 42.50 | 5,458 | 39.95 | 9,056 | 41.31 |
| IV | 20,571 | 20.2 | 10,808 | 16.36 | 3,882 | 28.41 | 5,881 | 26.82 |
| Missing | 3,828 | 3.8 | 2,445 | 3.70 | 696 | 5.09 | 687 | 3.13 |

Table 1. Continued

| Variable | Overall Valve + CABG (n = 101,661) | | AVR + CABG (n = 66,074) | | MVR + CABG (n = 13,663) | | MVRRepair + CABG (n = 21,924) | |
|-------------------------------------|---------------------------------------|------|----------------------------|-------|----------------------------|-------|----------------------------------|-------|
| | N | % | N | % | N | % | N | % |
| Congestive heart failure | | | | | | | | |
| No | 58,086 | 57.1 | 41,984 | 63.54 | 5,797 | 42.43 | 10,305 | 47.00 |
| Yes | 43,377 | 42.7 | 23,953 | 36.25 | 7,845 | 57.42 | 11,579 | 52.81 |
| Missing | 198 | 0.2 | 137 | 0.21 | 21 | 0.15 | 40 | 0.18 |
| Number of diseased coronary vessels | | | | | | | | |
| None | 2,362 | 2.3 | 1,786 | 2.70 | 281 | 2.06 | 295 | 1.35 |
| One | 22,718 | 22.3 | 16,934 | 25.63 | 3,040 | 22.25 | 2,744 | 12.52 |
| Two | 27,144 | 26.7 | 19,014 | 28.78 | 3,655 | 26.75 | 4,475 | 20.41 |
| Three | 49,060 | 48.3 | 28,107 | 42.54 | 6,623 | 48.47 | 14,330 | 65.36 |
| Missing | 377 | 0.4 | 233 | 0.35 | 64 | 0.47 | 80 | 0.36 |
| Left main disease \geq 50% | | | | | | | | |
| No | 84,025 | 82.7 | 55,292 | 83.68 | 11,503 | 84.19 | 17,230 | 78.59 |
| Yes | 17,175 | 16.9 | 10,512 | 15.91 | 2,072 | 15.17 | 4,591 | 20.94 |
| Missing | 461 | 0.5 | 270 | 0.41 | 88 | 0.64 | 103 | 0.47 |
| Ejection fraction, % | | | | | | | | |
| < 25 | 5,805 | 5.7 | 2,199 | 3.33 | 640 | 4.68 | 2,966 | 13.53 |
| 25–34 | 10,988 | 10.8 | 4,877 | 7.38 | 1,566 | 11.46 | 4,545 | 20.73 |
| 35–44 | 14,928 | 14.7 | 8,064 | 12.20 | 2,487 | 18.20 | 4,377 | 19.96 |
| 45–54 | 20,398 | 20.1 | 13,424 | 20.32 | 3,048 | 22.31 | 3,926 | 17.91 |
| \geq 55 | 43,556 | 42.8 | 32,973 | 49.90 | 5,209 | 38.12 | 5,374 | 24.51 |
| Missing | 5,986 | 5.9 | 4,537 | 6.87 | 713 | 5.22 | 736 | 3.36 |
| Aortic stenosis | | | | | | | | |
| No | 42,831 | 42.1 | 8,527 | 12.91 | 12,974 | 94.96 | 21,330 | 97.29 |
| Yes | 58,317 | 57.4 | 57,319 | 86.75 | 535 | 3.92 | 463 | 2.11 |
| Missing | 513 | 0.5 | 228 | 0.35 | 154 | 1.13 | 131 | 0.60 |
| Mitral stenosis | | | | | | | | |
| No | 95,696 | 94.1 | 63,862 | 96.65 | 11,166 | 81.72 | 20,668 | 94.27 |
| Yes | 4,993 | 4.9 | 1,542 | 2.33 | 2,366 | 17.32 | 1,085 | 4.95 |
| Missing | 972 | 1.0 | 670 | 1.01 | 131 | 0.96 | 171 | 0.78 |
| Tricuspid stenosis | | | | | | | | |
| No | 100,093 | 98.5 | 65,060 | 98.47 | 13,402 | 98.09 | 21,631 | 98.66 |
| Yes | 275 | 0.3 | 154 | 0.23 | 57 | 0.42 | 64 | 0.29 |
| Missing | 1,293 | 1.3 | 860 | 1.30 | 204 | 1.49 | 229 | 1.04 |
| Pulmonic stenosis | | | | | | | | |
| No | 99,484 | 97.9 | 64,693 | 97.91 | 13,348 | 97.69 | 21,443 | 97.81 |
| Yes | 122 | 0.1 | 85 | 0.13 | 14 | 0.10 | 23 | 0.10 |
| Missing | 2,055 | 2.0 | 1,296 | 1.96 | 301 | 2.20 | 458 | 2.09 |
| Aortic insufficiency | | | | | | | | |
| None | 57,561 | 56.6 | 28,972 | 43.85 | 10,821 | 79.20 | 17,768 | 81.04 |
| Trivial | 9,243 | 9.1 | 6,573 | 9.95 | 1,023 | 7.49 | 1,647 | 7.51 |
| Mild | 13,828 | 13.6 | 11,082 | 16.77 | 1,156 | 8.46 | 1,590 | 7.25 |
| Moderate | 10,195 | 10.0 | 9,581 | 14.50 | 232 | 1.70 | 382 | 1.74 |
| Severe | 8,686 | 8.5 | 8,580 | 12.99 | 49 | 0.36 | 57 | 0.26 |
| Missing | 2,148 | 2.1 | 1,286 | 1.95 | 382 | 2.80 | 480 | 2.19 |
| Mitral insufficiency | | | | | | | | |
| None | 41,756 | 41.1 | 38,790 | 58.71 | 1,297 | 9.49 | 1,669 | 7.61 |
| Trivial | 7,467 | 7.3 | 7,139 | 10.80 | 147 | 1.08 | 181 | 0.83 |
| Mild | 15,407 | 15.2 | 13,485 | 20.41 | 584 | 4.27 | 1,338 | 6.10 |
| Moderate | 14,987 | 14.7 | 4,842 | 7.33 | 2,790 | 20.42 | 7,355 | 33.55 |
| Severe | 20,516 | 20.2 | 527 | 0.80 | 8,743 | 63.99 | 11,246 | 51.30 |
| Missing | 1,528 | 1.5 | 1,291 | 1.95 | 102 | 0.75 | 135 | 0.62 |

Table 1. Continued

| Variable | Overall Valve + CABG (n = 101,661) | | AVR + CABG (n = 66,074) | | MVR + CABG (n = 13,663) | | MVRRepair + CABG (n = 21,924) | |
|-------------------------|---------------------------------------|------|----------------------------|-------|----------------------------|-------|----------------------------------|-------|
| | N | % | N | % | N | % | N | % |
| Tricuspid insufficiency | | | | | | | | |
| None | 74,774 | 73.6 | 49,614 | 75.09 | 9,758 | 71.42 | 15,402 | 70.25 |
| Trivial | 7,972 | 7.8 | 5,454 | 8.25 | 839 | 6.14 | 1,679 | 7.66 |
| Mild | 11,505 | 11.3 | 7,060 | 10.68 | 1,631 | 11.94 | 2,814 | 12.84 |
| Moderate | 4,119 | 4.1 | 1,919 | 2.90 | 874 | 6.40 | 1,326 | 6.05 |
| Severe | 636 | 0.6 | 237 | 0.36 | 186 | 1.36 | 213 | 0.97 |
| Missing | 2,655 | 2.6 | 1,790 | 2.71 | 375 | 2.74 | 490 | 2.23 |
| Pulmonic insufficiency | | | | | | | | |
| None | 91,715 | 90.2 | 59,891 | 90.64 | 12,275 | 89.84 | 19,549 | 89.17 |
| Trivial | 3,411 | 3.4 | 2,122 | 3.21 | 442 | 3.24 | 847 | 3.86 |
| Mild | 2,065 | 2.0 | 1,215 | 1.84 | 306 | 2.24 | 544 | 2.48 |
| Moderate | 326 | 0.3 | 165 | 0.25 | 70 | 0.51 | 91 | 0.42 |
| Severe | 49 | 0.0 | 25 | 0.04 | 11 | 0.08 | 13 | 0.06 |
| Missing | 4,095 | 4.0 | 2,656 | 4.02 | 559 | 4.09 | 880 | 4.01 |

AFib = atrial fibrillation; AVR = aortic valve replacement; CABG = coronary artery bypass graft; CV = cardiovascular; CVA = cerebrovascular accident (stroke); IABP = intra-aortic balloon pump; MI = myocardial infarction; MVR = mitral valve replacement; MVRRepair = mitral valve repair; NYHA = New York Heart Association; PCI = percutaneous coronary intervention; VF = ventricular fibrillation; VT = ventricular tachycardia.

endocarditis) in the overall valve plus CABG population, it was included for consistency with the isolated valve model. Active endocarditis was present in 2.6% of patients undergoing mitral replacement plus CABG. (3) Mitral stenosis was rarely present among isolated CABG patients (0.35%). However, it was not uncommon (4.9%) among patients undergoing valve plus CABG surgery and was included as a candidate variable. It was present in 17.3% of mitral replacements and 5.0% of mitral repairs.

An indicator for valve procedure (AVR, MVR, MVRRepair) was included in the combined valve plus CABG model, as previously noted.

Missing Data

Missing data are uncommon in the STS NCD, with a frequency of less than 1% missing for most variables. Model variables with more than 1% missing were ejection fraction

Table 2. Frequency of Endpoints in Overall Study Population 2002 to 2006

| | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
|--|---------|---------|--------|---------|---------|---------|---------|---------|---------|
| Overall (AVR + CABG, MVR + CABG, MVRRepair + CABG) | | | | | | | | | |
| N | 101,661 | 101,661 | 99,218 | 101,661 | 101,661 | 101,661 | 101,661 | 101,661 | 101,661 |
| Events | 6,919 | 2,935 | 9,097 | 21,561 | 684 | 12,117 | 30,580 | 15,594 | 22,534 |
| % | 6.8 | 2.9 | 9.0 | 21.2 | 0.7 | 11.9 | 30.1 | 15.3 | 22.2 |
| AVR + CABG | | | | | | | | | |
| N | 66,074 | 66,074 | 64,710 | 66,074 | 66,074 | 66,074 | 66,074 | 66,074 | 66,074 |
| Events | 3,718 | 1,751 | 5,032 | 11,608 | 394 | 7,090 | 17,343 | 8,412 | 16,961 |
| % | 5.6 | 2.7 | 7.6 | 17.6 | 0.6 | 10.7 | 26.3 | 12.7 | 25.7 |
| MVR + CABG | | | | | | | | | |
| N | 13,663 | 13,663 | 13,181 | 13,663 | 13,663 | 13,663 | 13,663 | 13,663 | 13,663 |
| Events | 1,590 | 499 | 1,829 | 4,469 | 114 | 2,274 | 5,897 | 3,277 | 1,512 |
| % | 11.6 | 3.7 | 13.6 | 32.7 | 0.8 | 16.6 | 43.2 | 24.0 | 11.1 |
| MVRRepair + CABG | | | | | | | | | |
| N | 21,924 | 21,924 | 21,327 | 21,924 | 21,924 | 21,924 | 21,924 | 21,924 | 21,924 |
| Events | 1,611 | 685 | 2,236 | 5,484 | 176 | 2,753 | 7,340 | 3,905 | 4,061 |
| % | 7.4 | 3.1 | 10.3 | 25.0 | 0.8 | 12.6 | 33.5 | 17.8 | 18.5 |

AVR = aortic valve replacement; CABG = coronary artery bypass graft surgery; Comp = composite adverse event (any); CVA = cerebrovascular accident (stroke); DS WI = deep sternal wound infection; Mort = mortality; MVR = mitral valve replacement; MVRRepair = mitral valve repair; PLOS = prolonged length of stay; Reop = reoperation; RF = renal failure; SLOS = short length of stay; Vent = prolonged ventilation.

Table 3. List of Candidate Variables and Their Coding for STS Valve Plus CABG Models

| Candidate Variables | Coding |
|--|--|
| Continuous variables | |
| Age ^a | Linear spline truncated from below at 50 with knot at 75. |
| Ejection fraction | Linear; values > 50 mapped to 50 |
| Body surface area ^a | Quadratic polynomial modeled separately for males and females. <i>Note: BSA < 1.4 and > 2.6 were mapped to those values, respectively.</i> |
| Creatinine | Linear (only for patients not on dialysis). <i>Note: Creatinine < 0.5 and > 5.0 mapped to those values, respectively.</i> |
| Time trend ^a | Ordinal categorical variable with separate category for each 6-month harvest interval. Modeled as linear across the categories. |
| Binary variables | |
| Active infectious endocarditis | Yes/no |
| Dialysis | Yes/no |
| Preoperative atrial fibrillation | Yes/no |
| Shock | Yes/no |
| Female ^a | Yes/no |
| Hypertension | Yes/no |
| Immunosuppressive treatment | Yes/no |
| Preop IABP or inotropes | Yes/no |
| Peripheral vascular disease | Yes/no |
| Unstable angina (no MI < 7 days) | Yes/no |
| Left main disease | Yes/no |
| Aortic stenosis | Yes/no |
| Mitral stenosis | Yes/no |
| Aortic insufficiency | Defined as at least moderate (yes/no) |
| Mitral insufficiency | Defined as at least moderate (yes/no) |
| Tricuspid insufficiency | Defined as at least moderate (yes/no) |
| Categorical variables | |
| Surgery type | 3 groups: AVR + CABG, MVR + CABG, MVRRepair + CABG |
| Chronic lung disease | Modeled as linear across categories (none, mild, moderate, severe) |
| CVD/CVA | 3 groups: no CVD, CVD no CVA, CVD + CVA |
| Diabetes mellitus | 3 groups: insulin diabetes, noninsulin diabetes, other or no diabetes |
| No. diseased coronary vessels | 3 groups: < 2-vessel disease; 2-vessel disease; 3-vessel disease. Modeled as linear across the categories |
| MI | 3 groups: < 24 hours, 1–21 days, > 21 days or no MI. <i>Note: groups 1 and 2 were subsequently collapsed for some models.</i> |
| Race | 3 groups: black, Hispanic, other including Caucasian |
| Status | 4 groups: elective, urgent, emergent no resuscitation, salvage or emergent with resuscitation |
| Previous cardiovascular operations | 3 groups: 0 previous, 1 previous, ≥ 2 previous |
| CHF and NYHA class | 3 groups: no CHF, CHF not NYHA IV, CHF and NYHA IV |
| Interaction terms | |
| Age by reoperation ^a | |
| Age by emergent status ^a | |
| Surgery type by each of the following: | Age, diabetes, dialysis, creatinine, reoperation, endocarditis, emergent status, CLD, CHF, EF, sex, shock, IABP/inotropes, mitral insufficiency, aortic insufficiency, mitral stenosis, aortic stenosis. |

^a These variables were forced into each model.

AVR = aortic valve replacement; CHF = congestive heart failure; CLD = chronic lung disease; CVA = cerebrovascular accident (stroke); CVD = cardiovascular disease; EF = ejection fraction; IABP = intra-aortic balloon pump; MI = myocardial infarction; MVR = mitral valve replacement; MVRRepair = mitral valve repair; NYHA = New York Heart Association.

(5.9%), New York Heart Association functional class (3.8%), tricuspid insufficiency (2.6%), aortic insufficiency (2.1%), mitral insufficiency (1.5%), and creatinine/dialysis (1.2%).

To make full use of the available data, binary risk factors were modeled as yes versus no or missing. Thus, missing

values were analyzed as if the endpoint did not occur. Missing data on categorical variables were imputed to the lowest risk value, which, in most instances, was the mode. Missing data on continuous variables were imputed to the conditional median. For ejection fraction, we conditioned

on congestive heart failure and sex. For body surface area, we conditioned on sex. For serum creatinine, we conditioned on renal failure.

Although multiple imputation is generally preferred on statistical grounds [21], we chose single imputation for this analysis based largely on practical considerations, including computational intensity. Furthermore, the fraction of missing data was small, and single and multiple imputation would give similar results. Finally, multiple imputation is primarily used for calculating appropriate standard error estimates, but an adjustment to the standard errors would not impact our study results or the published risk algorithms. In a separate sensitivity analysis, we compared predicted risk estimates from our final models to risk estimates that were derived from analogous models using multiple instead of single imputation. For each endpoint, the relative difference in predicted risk was less than 6% (eg, an absolute difference of 5.0% versus 5.3%) for all patients in the development and validation samples, and it was less than 2% (eg, an absolute difference of 5.0% versus 5.1%) for 99% of patients. A summary of these analyses including regression coefficients and covariance matrices is available at www.sts.org/riskmodels.

Final Variable Selection Procedure

Variables were initially selected using an automated stepwise model selection algorithm. The stepwise procedure began with a model that included all of the candidate variables except for interaction terms. Age, body surface area, and month of surgery were forced into each model. As in the isolated CABG and isolated valve models described in Parts 1 and 2 of this series, month of surgery was used only to adjust for time trends in the frequency of adverse outcomes over the 5-year study period. We adjusted for this to reduce potential confounding by time trends when estimating regression coefficients for the variables that are of primary interest (ie, patient preoperative risk factors—see example in Part 1). Surgery date was categorized into 6-month intervals and modeled as a linear trend across the ordinal categories. Surgery date is not included in the final risk prediction algorithm, and a patient's predicted risk does not depend on it. The published intercept parameter has been adjusted to incorporate the time trend, and this adjusted intercept reflects the baseline risk for a reference period of July to December 2006.

Other variables were selected in a stepwise fashion using a significance criterion of 0.05 for entry and removal. Ordinal categorical variables were initially coded such that removing an indicator variable caused a category to be combined with the lowest risk category (the reference group). In the case of myocardial infarction (MI), there were two outcomes (permanent stroke, prolonged length of stay) in which "MI 1 to 21 days" was retained but "MI less than 24 hours" was removed. For these two cases, the two MI categories were replaced by the single category "MI 21 days or less." The stepwise procedure was performed separately for each endpoint. Multiple interaction terms consisting of predictor variable and surgery type were also evaluated, and two additional interaction terms (age by reoperation

and age by emergent status) were forced into the models (see Tables 3 and 5).

The results of this initial selection process were then reviewed by surgeon members of the QMTF for face validity and consistency with previous STS or other valve models: (1) preoperative atrial fibrillation was forced into the model for permanent stroke; (2) an indicator variable for dialysis was forced into any model that included creatinine (this did not apply to the renal failure model, as patients with preoperative dialysis were excluded); (3) sex was forced into all models; and (4) each variable that interacted with surgery group was also included as a main effect.

After validating the model in the 40% validation sample, the development and validation samples were then rejoined, and the final model coefficients were estimated using the overall 100% combined sample. The final logistic regression model was estimated using generalized estimating equations with empirical (sandwich) standard error estimates to account for clustering of patients within institutions [22]. An independence working correlation matrix was used to apply the generalized estimating equations. With this approach, the estimated regression coefficients were identical to those obtained using ordinary logistic regression, but the standard errors were adjusted to account for the clustered data structure.

Results

Risk Factors, Outcomes, and Predictor Variables

Table 1 presents the distribution of risk factors and endpoints in the overall 2002 to 2006 study population. Because there are three valve plus CABG categories, space limitations prevent display of the bivariate relationships for each predictor variable, endpoint, and valve plus CABG group. These are available upon request from STS.

Table 2 summarizes the overall frequency of adverse outcomes as well as the outcomes for the three major valve groups. Table 3 lists the candidate predictor variables and their coding schemes.

Assessment of Model Fit and Discrimination

The Hosmer-Lemeshow test was not employed to assess overall calibration. Large sample sizes make a significant *p* value almost inevitable, as all risk models are only approximations of reality [23]. Rather, we assessed calibration graphically by plotting observed versus predicted event rates within deciles of predicted risk in the development and validation samples (Fig 1). These plots were constructed for the overall sample and for subgroups based on surgery type (AVR plus CABG, MVR plus CABG, MVR-repair plus CABG); age (< 60, 60 to 79, ≥ 80 years); sex (male, female); diabetes mellitus (yes/no); status (elective, non-elective); and ejection fraction (≤ 40, > 40). Because of space constraints, only the overall sample results in the validation sample are presented. Additional results are available at www.sts.org/riskmodels.

In general, the models were well calibrated in the validation sample. The average absolute difference between observed versus predicted event rates across the decile categories ranged from 0.1% for deep sternal wound infec-

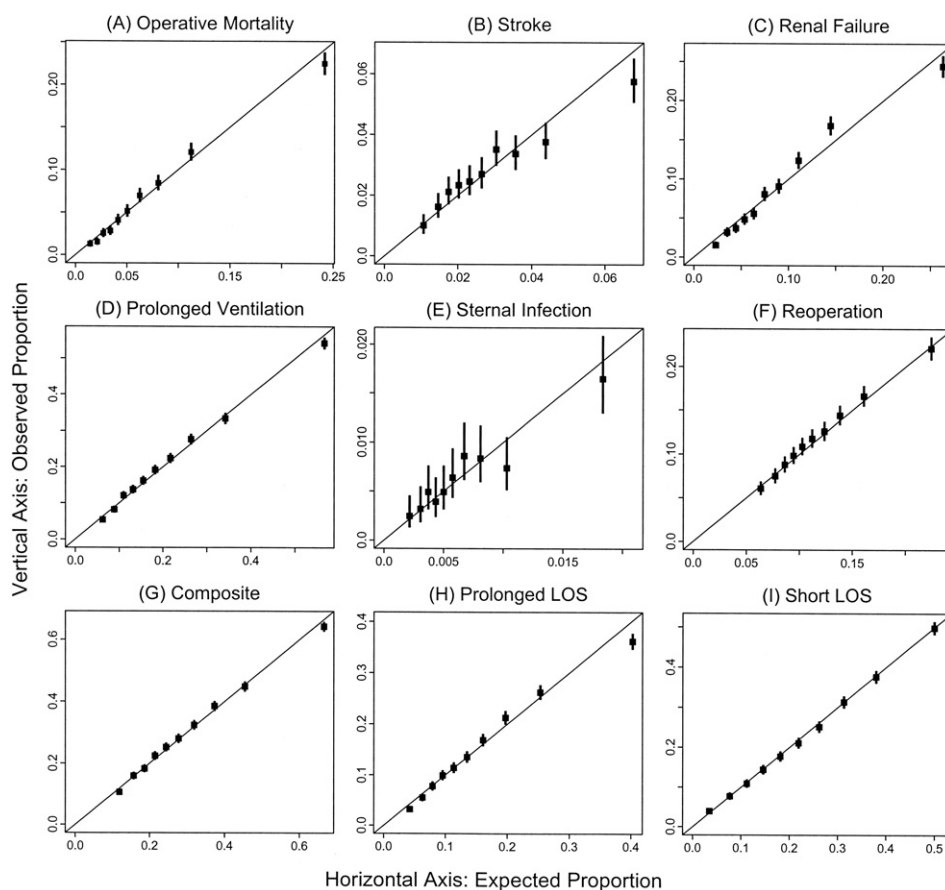


Fig 1. Plots of observed (O) versus expected (E) in validation sample

tion to 0.96% for prolonged length of stay. There was a very slight tendency for the models to overpredict risk in the highest decile. Although perfect prediction would be ideal, a slight overprediction implies that the model will give adequate credit to surgeons who take on patients with several model risk factors.

Discrimination was assessed by determining the c-

statistic, also known as the area under the receiver operating characteristic (ROC) curve. Table 4 presents the discrimination of the various models. In the validation sample, the c-index of the overall valve plus CABG operative mortality model was 0.750, and the c-indices of the morbidity models ranged from 0.617 for reoperation to 0.724 for renal failure and short length of stay.

Table 4. Discrimination of Models (C-Index) in Development and Validation Samples

| | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
|------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Overall | | | | | | | | | |
| Development sample | 0.754 | 0.656 | 0.729 | 0.730 | 0.670 | 0.623 | 0.704 | 0.719 | 0.726 |
| Validation sample | 0.750 | 0.622 | 0.724 | 0.720 | 0.646 | 0.617 | 0.698 | 0.710 | 0.724 |
| AVR + CABG | | | | | | | | | |
| Development sample | 0.737 | 0.648 | 0.720 | 0.706 | 0.639 | 0.607 | 0.678 | 0.705 | 0.700 |
| Validation sample | 0.736 | 0.609 | 0.718 | 0.697 | 0.657 | 0.604 | 0.673 | 0.699 | 0.698 |
| MVR + CABG | | | | | | | | | |
| Development sample | 0.764 | 0.665 | 0.712 | 0.746 | 0.713 | 0.608 | 0.725 | 0.694 | 0.726 |
| Validation sample | 0.739 | 0.611 | 0.701 | 0.733 | 0.580 | 0.599 | 0.714 | 0.680 | 0.733 |
| MVRepair + CABG | | | | | | | | | |
| Development sample | 0.746 | 0.650 | 0.727 | 0.725 | 0.692 | 0.624 | 0.707 | 0.712 | 0.738 |
| Validation sample | 0.755 | 0.652 | 0.715 | 0.716 | 0.644 | 0.623 | 0.705 | 0.702 | 0.733 |

AVR = aortic valve replacement; CABG = coronary artery bypass graft; Comp = composite adverse event (any); CVA = cerebrovascular accident (stroke); DSWI = deep sternal wound infection; Mort = mortality; MVR = mitral valve replacement; MVRepair = mitral valve repair; PLOS = prolonged length of stay; Reop = reoperation; RF = renal failure; SLOS = short length of stay; Vent = prolonged ventilation.

Table 5. Estimated Odds Ratios for CABG Mortality, Morbidity, and Length of Stay Models

| A. Odds ratios for variables that do not interact with surgery group | | | | | | | | | |
|--|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Variable | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
| Preoperative AFib | 1.20 (1.12, 1.29) | 1.05 (0.94, 1.17) | 1.18 (1.11, 1.26) | 1.13 (1.07, 1.19) | NA | 1.16 (1.10, 1.22) | 1.15 (1.10, 1.20) | 1.22 (1.15, 1.28) | 0.71 (0.67, 0.75) |
| BSA 1.6 versus 2.0 among females | 1.29 (1.19, 1.39) | 1.34 (1.18, 1.52) | 0.87 (0.81, 0.94) | 1.08 (1.02, 1.14) | 0.51 (0.39, 0.67) | 1.13 (1.07, 1.23) | 1.12 (1.07, 1.18) | 0.97 (0.92, 1.03) | 1.03 (0.96, 1.10) |
| BSA 1.6 versus 2.0 among males | 1.58 (1.41, 1.77) | 1.38 (1.17, 1.64) | 1.18 (1.07, 1.31) | 1.31 (1.21, 1.41) | 0.71 (0.49, 1.03) | 1.18 (1.12, 1.34) | 1.32 (1.24, 1.41) | 1.40 (1.29, 1.52) | 0.81 (0.75, 0.88) |
| BSA 1.8 versus 2.0 among females | 1.05 (1.00, 1.10) | 1.16 (1.06, 1.26) | 0.89 (0.85, 0.93) | 0.99 (0.95, 1.02) | 0.69 (0.61, 0.77) | 1.03 (0.98, 1.06) | 1.01 (0.98, 1.04) | 0.94 (0.90, 0.97) | 1.08 (1.04, 1.12) |
| BSA 1.8 versus 2.0 among males | 1.15 (1.10, 1.20) | 1.13 (1.07, 1.20) | 1.01 (0.97, 1.05) | 1.06 (1.03, 1.09) | 0.83 (0.72, 0.95) | 1.06 (1.04, 1.11) | 1.07 (1.05, 1.10) | 1.09 (1.06, 1.12) | 0.96 (0.94, 0.99) |
| BSA 2.2 versus 2.0 among females | 1.12 (1.02, 1.22) | 0.87 (0.74, 1.02) | 1.25 (1.15, 1.35) | 1.13 (1.06, 1.20) | 1.57 (1.32, 1.89) | 1.04 (1.00, 1.17) | 1.10 (1.04, 1.17) | 1.19 (1.11, 1.27) | 0.82 (0.76, 0.89) |
| BSA 2.2 versus 2.0 among males | 1.04 (1.00, 1.09) | 0.95 (0.90, 1.01) | 1.15 (1.11, 1.18) | 1.09 (1.06, 1.11) | 1.25 (1.14, 1.37) | 1.00 (0.95, 1.01) | 1.07 (1.04, 1.09) | 1.09 (1.06, 1.12) | 0.91 (0.89, 0.93) |
| CVD with CVA | 1.22 (1.11, 1.33) | 1.72 (1.52, 1.95) | 1.12 (1.04, 1.22) | 1.27 (1.19, 1.34) | 1.22 (0.95, 1.56) | 1.12 (1.04, 1.20) | 1.26 (1.20, 1.33) | 1.26 (1.18, 1.35) | 0.75 (0.70, 0.81) |
| CVD without CVA | NA | 1.28 (1.13, 1.45) | 1.14 (1.06, 1.23) | 1.10 (1.04, 1.16) | NA | NA | 1.11 (1.05, 1.17) | 1.11 (1.05, 1.18) | 0.85 (0.78, 0.92) |
| Diabetes, insulin | 1.31 (1.20, 1.42) | 1.16 (1.03, 1.30) | 1.62 (1.52, 1.74) | 1.32 (1.25, 1.40) | 1.98 (1.59, 2.46) | NA | 1.34 (1.28, 1.41) | 1.49 (1.40, 1.58) | 0.67 (0.62, 0.72) |
| Diabetes, noninsulin | 1.12 (1.05, 1.19) | 1.16 (1.06, 1.26) | 1.28 (1.21, 1.35) | 1.11 (1.07, 1.15) | 1.30 (1.10, 1.54) | NA | 1.12 (1.08, 1.16) | 1.17 (1.12, 1.22) | 0.84 (0.81, 0.88) |
| No. diseased coronary vessels (2 versus 1 or 3 versus 2) | 1.15 (1.11, 1.19) | 1.20 (1.14, 1.26) | 1.17 (1.14, 1.21) | 1.19 (1.16, 1.22) | 1.28 (1.15, 1.42) | 1.09 (1.06, 1.11) | 1.16 (1.14, 1.18) | 1.13 (1.10, 1.16) | 0.82 (0.81, 0.84) |
| Hypertension | NA | 1.19 (1.08, 1.31) | 1.25 (1.18, 1.33) | 1.10 (1.05, 1.15) | 1.33 (1.09, 1.63) | NA | 1.12 (1.08, 1.16) | 1.08 (1.03, 1.13) | 0.92 (0.88, 0.96) |
| Immunosuppressive treatment | 1.35 (1.17, 1.54) | NA | 1.30 (1.15, 1.47) | 1.28 (1.17, 1.40) | NA | 1.27 (1.14, 1.42) | 1.26 (1.16, 1.37) | 1.22 (1.11, 1.34) | 0.75 (0.67, 0.84) |
| Left main disease | 1.12 (1.05, 1.20) | NA | NA | 1.06 (1.02, 1.11) | NA | NA | NA | NA | NA |
| Mitral insufficiency, moderate/severe | NA | NA | NA | NA | NA | NA | 1.07 (1.01, 1.12) | NA | NA |
| Tricuspid insufficiency, moderate/severe | 1.27 (1.15, 1.41) | NA | 1.25 (1.13, 1.38) | 1.15 (1.06, 1.24) | NA | NA | 1.14 (1.07, 1.22) | NA | 0.79 (0.69, 0.92) |
| Peripheral vascular disease | 1.29 (1.21, 1.37) | 1.15 (1.04, 1.27) | 1.16 (1.10, 1.23) | 1.18 (1.12, 1.24) | NA | 1.15 (1.09, 1.22) | 1.20 (1.15, 1.25) | 1.16 (1.11, 1.22) | NA |
| Mitral stenosis | 1.10 (0.99, 1.24) | NA | NA | NA | NA | NA | NA | 1.09 (1.00, 1.18) | NA |
| MI 1–21 days | 1.19 (1.10, 1.28) | NA | 1.18 (1.10, 1.26) | 1.28 (1.21, 1.35) | NA | NA | 1.22 (1.16, 1.28) | NA | NA |
| MI ≤ 21 days ^a | NA | 1.22 (1.11, 1.34) | NA | NA | NA | NA | NA | 1.16 (1.10, 1.22) | NA |
| MI < 24 hrs | 1.65 (1.42, 1.91) | NA | 1.30 (1.10, 1.54) | 1.41 (1.23, 1.62) | NA | 1.15 (1.00, 1.32) | 1.49 (1.30, 1.70) | NA | NA |
| Time trend per 6-month harvest interval | 0.98 (0.96, 0.99) | 0.98 (0.97, 1.00) | 1.01 (1.00, 1.02) | 1.01 (1.00, 1.02) | 0.96 (0.93, 0.99) | 0.99 (0.98, 1.00) | 1.00 (0.99, 1.01) | 1.01 (1.00, 1.02) | 1.00 (0.99, 1.01) |
| Race black | NA | NA | 1.15 (1.03, 1.30) | 1.31 (1.19, 1.44) | NA | 1.19 (1.06, 1.33) | 1.21 (1.11, 1.32) | 1.31 (1.19, 1.44) | 0.65 (0.58, 0.72) |
| Race Hispanic | NA | NA | 1.20 (1.03, 1.40) | 1.17 (1.03, 1.32) | NA | 1.08 (0.94, 1.24) | 1.15 (1.03, 1.28) | 1.13 (0.98, 1.30) | 0.85 (0.71, 1.02) |
| Status, urgent versus elective | 1.25 (1.17, 1.34) | NA | 1.18 (1.10, 1.26) | 1.26 (1.19, 1.33) | NA | 1.14 (1.07, 1.21) | 1.19 (1.14, 1.25) | 1.28 (1.22, 1.35) | 0.77 (0.72, 0.81) |
| Unstable angina | 1.11 (1.03, 1.21) | 0.89 (0.80, 1.00) | 1.12 (1.05, 1.20) | 1.06 (0.99, 1.13) | NA | NA | NA | NA | NA |

Table 5. Continued

| B. Odds ratios for AVR plus CABG | | | | | | | | | |
|---|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Variable | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
| Age 60 versus 50 (no reop, elective) | 1.29 (1.20, 1.39) | 1.28 (1.19, 1.38) | 1.39 (1.32, 1.45) | 1.23 (1.20, 1.27) | 1.06 (0.92, 1.21) | 1.19 (1.15, 1.23) | 1.20 (1.16, 1.24) | 1.37 (1.32, 1.42) | 0.74 (0.72, 0.77) |
| Age 70 versus 50 (no reop, elective) | 1.67 (1.45, 1.92) | 1.64 (1.42, 1.91) | 1.92 (1.75, 2.11) | 1.52 (1.43, 1.62) | 1.11 (0.85, 1.46) | 1.41 (1.31, 1.51) | 1.44 (1.36, 1.54) | 1.86 (1.73, 2.01) | 0.55 (0.52, 0.59) |
| Age 80 versus 50 (no reop, elective) | 2.47 (2.08, 2.94) | 2.03 (1.71, 2.42) | 2.76 (2.47, 3.08) | 1.96 (1.82, 2.11) | 1.12 (0.82, 1.53) | 1.67 (1.54, 1.82) | 1.86 (1.73, 2.01) | 2.67 (2.46, 2.91) | 0.33 (0.30, 0.36) |
| CHF, not NYHA IV | 1.24 (1.14, 1.34) | 0.98 (0.88, 1.09) | 1.19 (1.11, 1.28) | 1.22 (1.16, 1.29) | NA | NA | 1.14 (1.08, 1.19) | 1.30 (1.23, 1.38) | 0.84 (0.79, 0.89) |
| CHF, NYHA IV | 1.48 (1.34, 1.64) | 1.15 (1.00, 1.32) | 1.35 (1.24, 1.48) | 1.47 (1.36, 1.59) | NA | 1.16 (1.08, 1.24) | 1.36 (1.27, 1.45) | 1.49 (1.39, 1.60) | 0.73 (0.66, 0.82) |
| Creatinine per 1 unit | 1.57 (1.49, 1.65) | 1.27 (1.18, 1.36) | 2.26 (2.13, 2.40) | 1.46 (1.41, 1.52) | NA | 1.28 (1.23, 1.34) | 1.67 (1.60, 1.74) | 1.51 (1.45, 1.58) | 0.62 (0.58, 0.67) |
| Dialysis vs no dialysis and creatinine = 1.0 | 3.20 (2.84, 3.61) | 1.42 (1.17, 1.73) | NA | 2.27 (2.06, 2.51) | NA | 1.65 (1.41, 1.92) | 2.09 (1.91, 2.30) | 2.42 (2.19, 2.67) | 0.30 (0.25, 0.37) |
| EF per 10-unit decrease | 1.10 (1.06, 1.15) | NA | 1.06 (1.03, 1.08) | 1.12 (1.10, 1.14) | NA | 1.08 (1.05, 1.10) | 1.11 (1.09, 1.13) | 1.10 (1.08, 1.13) | 0.87 (0.84, 0.89) |
| Preoperative IABP/inotropes | 1.43 (1.30, 1.58) | NA | 1.27 (1.15, 1.39) | 2.18 (2.01, 2.36) | NA | 1.16 (1.06, 1.27) | 1.76 (1.63, 1.90) | 1.41 (1.25, 1.58) | 0.56 (0.48, 0.65) |
| Shock | 1.68 (1.45, 1.94) | 1.19 (0.94, 1.50) | 1.17 (0.92, 1.50) | 1.93 (1.72, 2.16) | NA | 1.24 (1.09, 1.41) | 1.79 (1.50, 2.15) | 1.45 (1.29, 1.63) | NA |
| Female versus male (at BSA = 1.8) | 1.36 (1.26, 1.47) | 1.19 (1.07, 1.32) | 1.18 (1.10, 1.26) | 1.52 (1.44, 1.61) | 1.11 (0.88, 1.40) | 0.92 (0.87, 0.97) | 1.20 (1.15, 1.26) | 1.31 (1.24, 1.38) | 0.61 (0.57, 0.64) |
| Active infectious endocarditis | 2.04 (1.66, 2.50) | 1.83 (1.37, 2.46) | 1.52 (1.21, 1.91) | 1.96 (1.69, 2.27) | NA | 1.56 (1.28, 1.91) | 2.11 (1.83, 2.44) | 1.81 (1.41, 2.32) | 0.28 (0.20, 0.38) |
| CLD (moderate vs mild or severe vs moderate) | 1.19 (1.16, 1.23) | NA | 1.12 (1.09, 1.15) | 1.26 (1.22, 1.30) | 1.32 (1.22, 1.42) | 1.10 (1.07, 1.13) | 1.18 (1.15, 1.21) | 1.26 (1.22, 1.30) | 0.83 (0.80, 0.85) |
| Reop, 1 previous operation ^b | 2.20 (1.81, 2.67) | NA | 1.29 (1.08, 1.55) | 1.83 (1.58, 2.11) | NA | 1.39 (1.16, 1.67) | 1.50 (1.32, 1.69) | 1.55 (1.33, 1.81) | 0.67 (0.58, 0.77) |
| Reop, ≥ 2 previous operations ^b | 2.46 (1.87, 3.24) | NA | 1.47 (1.15, 1.89) | 2.19 (1.80, 2.65) | NA | 1.48 (1.15, 1.92) | 1.77 (1.51, 2.06) | 1.65 (1.34, 2.03) | 0.53 (0.43, 0.65) |
| Status emergent, no resuscitation ^b | 2.14 (1.62, 2.81) | 2.21 (1.45, 3.37) | 1.77 (1.31, 2.37) | 2.71 (2.14, 3.44) | NA | 1.41 (1.16, 1.70) | 2.17 (1.74, 2.72) | 2.72 (2.19, 3.38) | 0.33 (0.22, 0.50) |
| Status emergent, with resuscitation or salvage ^b | 4.56 (3.31, 6.29) | 2.60 (1.53, 4.43) | 1.86 (1.30, 2.65) | 2.12 (1.54, 2.92) | NA | NA | 3.34 (2.43, 4.61) | 1.76 (1.31, 2.37) | 0.18 (0.09, 0.34) |

Table 5. Continued

| C. Odds ratios for MVR plus CABG | | | | | | | | | |
|---|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Variable | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
| Age 60 versus 50 (no reop, elective) | 1.51 (1.39, 1.64) | 1.28 (1.19, 1.38) | 1.39 (1.32, 1.45) | 1.23 (1.20, 1.27) | 1.06 (0.92, 1.21) | 1.19 (1.15, 1.23) | 1.27 (1.21, 1.32) | 1.37 (1.32, 1.42) | 0.68 (0.64, 0.72) |
| Age 70 versus 50 (no reop, elective) | 2.28 (1.94, 2.68) | 1.64 (1.42, 1.91) | 1.92 (1.75, 2.11) | 1.52 (1.43, 1.62) | 1.11 (0.85, 1.46) | 1.41 (1.31, 1.51) | 1.60 (1.47, 1.75) | 1.86 (1.73, 2.01) | 0.46 (0.41, 0.52) |
| Age 80 versus 50 (no reop, elective) | 3.95 (3.17, 4.93) | 2.03 (1.71, 2.42) | 2.76 (2.47, 3.08) | 1.96 (1.82, 2.11) | 1.12 (0.82, 1.53) | 1.67 (1.54, 1.82) | 2.18 (1.92, 2.48) | 2.67 (2.46, 2.91) | 0.25 (0.21, 0.30) |
| CHF, not NYHA IV | 0.91 (0.80, 1.03) | 0.80 (0.64, 0.99) | 0.92 (0.82, 1.03) | 1.02 (0.93, 1.11) | NA | NA | 0.94 (0.87, 1.02) | 1.03 (0.94, 1.12) | 0.84 (0.79, 0.89) |
| CHF, NYHA IV | 1.09 (0.95, 1.24) | 0.93 (0.75, 1.17) | 1.04 (0.92, 1.19) | 1.22 (1.10, 1.35) | NA | 1.16 (1.08, 1.24) | 1.13 (1.03, 1.23) | 1.17 (1.06, 1.30) | 0.73 (0.66, 0.82) |
| Creatinine per 1 unit | 1.57 (1.49, 1.65) | 1.27 (1.18, 1.36) | 1.82 (1.66, 2.01) | 1.46 (1.41, 1.52) | NA | 1.28 (1.23, 1.34) | 1.67 (1.60, 1.74) | 1.51 (1.45, 1.58) | 0.66 (0.57, 0.78) |
| Dialysis vs no dialysis and creatinine = 1.0 | 3.20 (2.84, 3.61) | 1.42 (1.17, 1.73) | NA | 2.27 (2.06, 2.51) | NA | 1.21 (0.95, 1.55) | 2.09 (1.91, 2.30) | 2.42 (2.19, 2.67) | 0.30 (0.18, 0.48) |
| EF per 10-unit decrease | 1.23 (1.16, 1.30) | NA | 1.06 (1.03, 1.08) | 1.12 (1.10, 1.14) | NA | 1.08 (1.05, 1.10) | 1.11 (1.09, 1.13) | 1.10 (1.08, 1.13) | 0.89 (0.82, 0.95) |
| Preoperative IABP/ inotropes | 1.43 (1.30, 1.58) | NA | 1.27 (1.15, 1.39) | 2.18 (2.01, 2.36) | NA | 1.16 (1.06, 1.27) | 1.76 (1.63, 1.90) | 1.29 (1.14, 1.46) | 0.51 (0.39, 0.65) |
| Shock | 1.68 (1.45, 1.94) | 1.19 (0.94, 1.50) | 1.21 (0.97, 1.50) | 1.93 (1.72, 2.16) | NA | 1.24 (1.09, 1.41) | 2.76 (2.22, 3.42) | 1.45 (1.29, 1.63) | NA |
| Female versus male (at BSA = 1.8) | 1.36 (1.26, 1.47) | 1.19 (1.07, 1.32) | 1.18 (1.10, 1.26) | 1.17 (1.08, 1.28) | 1.11 (0.88, 1.40) | 0.92 (0.87, 0.97) | 1.20 (1.15, 1.26) | 1.31 (1.24, 1.38) | 0.66 (0.59, 0.74) |
| Active infectious endocarditis | 2.04 (1.66, 2.50) | 1.83 (1.37, 2.46) | 1.52 (1.21, 1.91) | 1.96 (1.69, 2.27) | NA | 1.56 (1.28, 1.91) | 2.11 (1.83, 2.44) | 2.08 (1.62, 2.67) | 0.28 (0.20, 0.38) |
| CLD (moderate vs mild or severe vs moderate) | 1.19 (1.16, 1.23) | NA | 1.12 (1.09, 1.15) | 1.18 (1.12, 1.24) | 1.32 (1.22, 1.42) | 1.10 (1.07, 1.13) | 1.18 (1.15, 1.21) | 1.20 (1.14, 1.26) | 0.83 (0.80, 0.85) |
| Reop, 1 previous operation ^b | 2.20 (1.81, 2.67) | NA | 1.29 (1.08, 1.55) | 1.38 (1.19, 1.61) | NA | 1.15 (0.95, 1.38) | 1.50 (1.32, 1.69) | 1.30 (1.10, 1.53) | 0.81 (0.66, 0.99) |
| Reop, ≥ 2 previous operations ^b | 2.46 (1.87, 3.24) | NA | 1.47 (1.15, 1.89) | 1.66 (1.35, 2.03) | NA | 1.22 (0.95, 1.56) | 1.77 (1.51, 2.06) | 1.38 (1.12, 1.71) | 0.64 (0.50, 0.82) |
| Status emergent, no resuscitation ^b | 2.14 (1.62, 2.81) | 2.21 (1.45, 3.37) | 1.77 (1.31, 2.37) | 2.71 (2.14, 3.44) | NA | 1.41 (1.16, 1.70) | 2.17 (1.74, 2.72) | 2.72 (2.19, 3.38) | 0.26 (0.16, 0.43) |
| Status emergent, with resuscitation or salvage ^b | 4.56 (3.31, 6.29) | 2.60 (1.53, 4.43) | 1.86 (1.30, 2.65) | 2.12 (1.54, 2.92) | NA | NA | 3.34 (2.43, 4.61) | 1.76 (1.31, 2.37) | 0.14 (0.07, 0.27) |

Table 5. Continued

| D. Odds ratios for MVRepair plus CABG | | | | | | | | | |
|---|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Variable | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
| Age 60 versus 50 (no reop, elective) | 1.46 (1.36, 1.57) | 1.28 (1.19, 1.38) | 1.39 (1.32, 1.45) | 1.23 (1.20, 1.27) | 1.06 (0.92, 1.21) | 1.19 (1.15, 1.23) | 1.28 (1.23, 1.33) | 1.37 (1.32, 1.42) | 0.66 (0.63, 0.69) |
| Age 70 versus 50 (no reop, elective) | 2.14 (1.86, 2.46) | 1.64 (1.42, 1.91) | 1.92 (1.75, 2.11) | 1.52 (1.43, 1.62) | 1.11 (0.85, 1.46) | 1.41 (1.31, 1.51) | 1.63 (1.51, 1.76) | 1.86 (1.73, 2.01) | 0.44 (0.40, 0.48) |
| Age 80 versus 50 (no reop, elective) | 3.60 (2.97, 4.33) | 2.03 (1.71, 2.42) | 2.76 (2.47, 3.08) | 1.96 (1.82, 2.11) | 1.12 (0.82, 1.53) | 1.67 (1.54, 1.82) | 2.23 (2.00, 2.49) | 2.67 (2.46, 2.91) | 0.23 (0.20, 0.27) |
| CHF, not NYHA IV | 0.96 (0.85, 1.09) | 1.05 (0.90, 1.23) | 0.99 (0.88, 1.10) | 1.10 (1.02, 1.19) | NA | NA | 1.06 (0.99, 1.14) | 1.17 (1.08, 1.26) | 0.84 (0.79, 0.89) |
| CHF, NYHA IV | 1.16 (1.02, 1.32) | 1.23 (1.04, 1.46) | 1.12 (0.99, 1.27) | 1.32 (1.21, 1.44) | NA | 1.16 (1.08, 1.24) | 1.27 (1.17, 1.37) | 1.33 (1.22, 1.45) | 0.73 (0.66, 0.82) |
| Creatinine per 1 unit | 1.57 (1.49, 1.65) | 1.27 (1.18, 1.36) | 1.87 (1.72, 2.04) | 1.46 (1.41, 1.52) | NA | 1.28 (1.23, 1.34) | 1.67 (1.60, 1.74) | 1.51 (1.45, 1.58) | 0.59 (0.53, 0.67) |
| Dialysis vs no dialysis and creatinine = 1.0 | 3.20 (2.84, 3.61) | 1.42 (1.17, 1.73) | NA | 2.27 (2.06, 2.51) | NA | 1.88 (1.52, 2.31) | 2.09 (1.91, 2.30) | 2.42 (2.19, 2.67) | 0.35 (0.24, 0.49) |
| EF per 10-unit decrease | 1.09 (1.04, 1.15) | NA | 1.06 (1.03, 1.08) | 1.12 (1.10, 1.14) | NA | 1.08 (1.05, 1.10) | 1.11 (1.09, 1.13) | 1.10 (1.08, 1.13) | 0.84 (0.81, 0.87) |
| Preoperative IABP/inotropes | 1.43 (1.30, 1.58) | NA | 1.27 (1.15, 1.39) | 2.18 (2.01, 2.36) | NA | 1.16 (1.06, 1.27) | 1.76 (1.63, 1.90) | 1.56 (1.40, 1.73) | 0.52 (0.44, 0.62) |
| Shock | 1.68 (1.45, 1.94) | 1.19 (0.94, 1.50) | 1.69 (1.41, 2.01) | 1.93 (1.72, 2.16) | NA | 1.24 (1.09, 1.41) | 2.17 (1.81, 2.60) | 1.45 (1.29, 1.63) | NA |
| Female vs male (at BSA = 1.8) | 1.36 (1.26, 1.47) | 1.19 (1.07, 1.32) | 1.18 (1.10, 1.26) | 1.25 (1.15, 1.36) | 1.11 (0.88, 1.40) | 0.92 (0.87, 0.97) | 1.20 (1.15, 1.26) | 1.31 (1.24, 1.38) | 0.60 (0.55, 0.66) |
| Active infectious Endocarditis | 2.04 (1.66, 2.50) | 1.83 (1.37, 2.46) | 1.52 (1.21, 1.91) | 1.96 (1.69, 2.27) | NA | 1.56 (1.28, 1.91) | 2.11 (1.83, 2.44) | 2.98 (1.86, 4.77) | 0.28 (0.20, 0.38) |
| CLD (moderate vs mild or severe vs moderate) | 1.19 (1.16, 1.23) | NA | 1.12 (1.09, 1.15) | 1.21 (1.16, 1.27) | 1.32 (1.22, 1.42) | 1.10 (1.07, 1.13) | 1.18 (1.15, 1.21) | 1.16 (1.10, 1.21) | 0.83 (0.80, 0.85) |
| Reop, 1 previous operation ^b | 2.20 (1.81, 2.67) | NA | 1.29 (1.08, 1.55) | 1.55 (1.32, 1.82) | NA | 1.49 (1.23, 1.82) | 1.50 (1.32, 1.69) | 1.32 (1.10, 1.58) | 0.80 (0.68, 0.95) |
| Reop, ≥ 2 previous operations ^b | 2.46 (1.87, 3.24) | NA | 1.47 (1.15, 1.89) | 1.86 (1.53, 2.26) | NA | 1.59 (1.20, 2.11) | 1.77 (1.51, 2.06) | 1.41 (1.11, 1.79) | 0.63 (0.51, 0.79) |
| Status emergent, no resuscitation ^b | 2.14 (1.62, 2.81) | 2.21 (1.45, 3.37) | 1.77 (1.31, 2.37) | 2.71 (2.14, 3.44) | NA | 1.41 (1.16, 1.70) | 2.17 (1.74, 2.72) | 2.72 (2.19, 3.38) | 0.43 (0.29, 0.66) |
| Status emergent, with resuscitation or salvage ^b | 4.56 (3.31, 6.29) | 2.60 (1.53, 4.43) | 1.86 (1.30, 2.65) | 2.12 (1.54, 2.92) | NA | NA | 3.34 (2.43, 4.61) | 1.76 (1.31, 2.37) | 0.23 (0.12, 0.44) |

^a For CVA and PLOS, MI coded ≤ 21 days; for all other endpoints, MI coded < 24 hrs or 1 to 21 days. ^b Variable interacts with age. Reported odds ratio represents effect of risk factor for patients aged 50 years old.

BSA = body surface area; CHF = congestive heart failure; CLD = chronic lung disease; Comp = composite adverse event (any); CVA = cerebrovascular accident (stroke); CVD = cerebrovascular disease; DSWI = deep sternal wound infection; EF = ejection fraction; IABP = intra-aortic balloon pump; Mort = mortality; NA = not applicable; NYHA = New York Heart Association; PLOS = prolonged length of stay; PVD = peripheral vascular disease; Reop = reoperation; RF = renal failure; SLOS = short length of stay; Vent = prolonged ventilation.

Odds Ratios

Table 5 presents the odds ratios and 95% confidence intervals (CI) derived from these models. “Not applicable” indicates that those predictors were not included in a particular risk model.

Odds ratios that do not interact with surgery type are summarized in Part A of Table 5. Several variables interact with surgery type, and the odds ratios for these variables differ for some of the endpoints depending on the specific type of surgery, as summarized in Tables 5B, C, and D (AVR plus CABG, MVR plus CABG, MVRepair plus CABG). For example, in the model for prolonged length of stay, the odds ratio for active endocarditis is 1.81 (95% CI: 1.41 to 2.32) for AVR plus CABG; 2.08 (95% CI: 1.62 to 2.67) for MVR plus CABG; and 2.98 (95% CI: 1.86 to 4.77) for MVRepair plus CABG.

Final Model Intercept and Coefficients

The algorithms for calculating predicted risk values, including the intercepts and regression coefficients, are presented in the Appendix.

Limitations

The limitations of the STS valve plus CABG models are similar to those discussed in Part 1 of this series.

Conclusion

A new STS model has been developed for valve surgery combined with CABG. This model includes specific indicator variables for each major type of valve plus CABG procedure (AVR plus CABG, MVR plus CABG, MVRepair plus CABG). Models have been developed for operative mortality, individual morbidity endpoints, a composite morbidity or mortality endpoint, and short and prolonged postoperative length of stay. Overall model performance is excellent.

References

1. Hannan EL, Kilburn H Jr, O'Donnell JF, Lukacik G, Shields EP. Adult open heart surgery in New York State. An analysis of risk factors and hospital mortality rates. *JAMA* 1990;264:2768–74.
2. Edwards FH, Clark RE, Schwartz M. Coronary artery bypass grafting: the Society of Thoracic Surgeons National Database experience. *Ann Thorac Surg* 1994;57:12–9.
3. O'Connor GT, Plume SK, Olmstead EM, et al. Multivariate prediction of in-hospital mortality associated with coronary artery bypass graft surgery. Northern New England Cardiovascular Disease Study Group. *Circulation* 1992;85:2110–8.
4. Shahian DM, Blackstone EH, Edwards FH, et al. Cardiac surgery risk models: a position article. *Ann Thorac Surg* 2004;78:1868–77.
5. Shroyer AL, Coombs LP, Peterson ED, et al. The Society of Thoracic Surgeons: 30-day operative mortality and morbidity risk models. *Ann Thorac Surg* 2003;75:1856–64.
6. Edwards FH, Peterson ED, Coombs LP, et al. Prediction of operative mortality after valve replacement surgery. *J Am Coll Cardiol* 2001;37:885–92.
7. Jamieson WR, Edwards FH, Schwartz M, Bero JW, Clark RE, Grover FL. Risk stratification for cardiac valve replacement. Na-

tional Cardiac Surgery Database. Database Committee of The Society of Thoracic Surgeons. *Ann Thorac Surg* 1999;67:943–51.

8. Hannan EL, Wu C, Bennett EV, et al. Risk index for predicting in-hospital mortality for cardiac valve surgery. *Ann Thorac Surg* 2007;83:921–9.
9. Hannan EL, Racz MJ, Jones RH, et al. Predictors of mortality for patients undergoing cardiac valve replacements in New York State. *Ann Thorac Surg* 2000;70:1212–8.
10. Nowicki ER, Birkmeyer NJ, Weintraub RW, et al. Multivariable prediction of in-hospital mortality associated with aortic and mitral valve surgery in Northern New England. *Ann Thorac Surg* 2004;77:1966–77.
11. Nowicki ER. What is the future of mortality prediction models in heart valve surgery? *Ann Thorac Surg* 2005;80:396–8.
12. Jin R, Grunkemeier GL, Starr A. Validation and refinement of mortality risk models for heart valve surgery. *Ann Thorac Surg* 2005;80:471–9.
13. Ambler G, Omar RZ, Royston P, Kinsman R, Keogh BE, Taylor KM. Generic, simple risk stratification model for heart valve surgery. *Circulation* 2005;112:224–31.
14. Nashef SA, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R. European system for cardiac operative risk evaluation (EuroSCORE). *Eur J Cardiothorac Surg* 1999;16:9–13.
15. Gardner SC, Grunwald GK, Rumsfeld JS, et al. Comparison of short-term mortality risk factors for valve replacement versus coronary artery bypass graft surgery. *Ann Thorac Surg* 2004;77:549–56.
16. Grover FL, Edwards FH. Similarity between the STS and New York State databases for valvular heart disease. *Ann Thorac Surg* 2000;70:1143–4.
17. Rankin JS, Hammill BG, Ferguson TB Jr, et al. Determinants of operative mortality in valvular heart surgery. *J Thorac Cardiovasc Surg* 2006;131:547–57.
18. Roques F, Nashef SA, Michel P. Risk factors for early mortality after valve surgery in Europe in the 1990s: lessons from the EuroSCORE pilot program. *J Heart Valve Dis* 2001;10:572–7.
19. van Gameren M, Kappetein AP, Steyerberg EW, et al. Do we need separate risk stratification models for hospital mortality after heart valve surgery? *Ann Thorac Surg* 2008;85:921–30.
20. Nagelkerke NJD. A note on a general definition of the coefficient of determination. *Biometrika* 1991;78:691–2.
21. Little RJA, Rubin DB. Statistical analysis with missing data. 2nd ed. Hoboken, NJ: Wiley-Interscience, 2002.
22. Liang KY, Zeger SL. Longitudinal data-analysis using generalized linear-models. *Biometrika* 1986;73:13–22.
23. Marcin JP, Romano PS. Size matters to a model's fit. *Crit Care Med* 2007;35:2212–3.

Appendix

Regression Coefficients and Variable Definitions for STS 2008 Valve Plus CABG Models

For each endpoint, the formula for calculating a patient's predicted risk of the endpoint has the form:

$$\text{Predicted Risk} = \frac{e^{(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n)}}{1 + e^{(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_n x_n)}}$$

where x_1, x_2, \dots, x_n denote patient preoperative risk factors (eg, quantitative variables such as age, and comorbidities coded as 1=present, 0=absent); and $\beta_0, \beta_1, \dots, \beta_n$ denote regression coefficients (numerical constants). Regression coefficients for each endpoint are presented in Appendix Table 1. The variables x_1, x_2, \dots, x_n are the same for each endpoint and are defined in Appendix Table 2. The regression coefficient for the time trend is not presented. Instead, the intercept has been adjusted to incorporate the time trend. This adjusted intercept reflects the baseline risk for a reference period of July–December 2006.

Appendix Table 1. Regression Coefficients

| Variable | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
|-----------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Intercept | −5.24391 | −5.14546 | −5.32535 | −3.63438 | −6.50043 | −3.16980 | −2.99714 | −4.15892 | 1.18582 |
| Preoperative AFib | 0.18430 | 0.04634 | 0.16567 | 0.12059 | 0.00000 | 0.14910 | 0.13766 | 0.19656 | −0.34095 |
| Age function 1 | 0.02560 | 0.02487 | 0.03268 | 0.02106 | 0.00545 | 0.01715 | 0.01838 | 0.03115 | −0.02970 |
| Age function 3 | 0.02758 | −0.00709 | 0.00671 | 0.00791 | −0.00985 | −0.00021 | 0.01425 | 0.00985 | −0.04542 |
| Age by reop function | −0.00861 | 0.00458 | 0.00077 | −0.00673 | 0.00314 | −0.00399 | −0.00202 | −0.00678 | 0.00656 |
| Age by status function | −0.00507 | −0.01979 | −0.00178 | −0.00750 | 0.01627 | −0.00029 | 0.00229 | −0.02247 | 0.00692 |
| Age by MVR function | 0.01564 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00527 | 0.00000 | −0.00866 |
| Age by MVRepair function | 0.01240 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00599 | 0.00000 | −0.01159 |
| BSA function 1 | −1.14176 | −0.81169 | −0.41848 | −0.66843 | 0.86401 | −0.51266 | −0.70411 | −0.84204 | 0.51295 |
| BSA function 2 | 2.25471 | 0.94689 | 1.84088 | 1.80467 | 0.42453 | 0.70024 | 1.70623 | 2.10402 | −1.66758 |
| CHF but not NYHA IV | 0.21206 | −0.01726 | 0.17460 | 0.20063 | 0.00000 | 0.00000 | 0.12880 | 0.26291 | −0.17652 |
| CHF and NYHA IV | 0.39457 | 0.14109 | 0.30146 | 0.38383 | 0.00000 | 0.14499 | 0.30567 | 0.39791 | −0.31077 |
| CHF by MVR function | −0.31077 | −0.20917 | −0.25767 | −0.18455 | 0.00000 | 0.00000 | −0.18635 | −0.23729 | 0.00000 |
| CHF by MVRepair function | −0.24791 | 0.06897 | −0.18667 | −0.10484 | 0.00000 | 0.00000 | −0.06920 | −0.10954 | 0.00000 |
| CLD function | 0.17713 | 0.00000 | 0.11379 | 0.23345 | 0.27571 | 0.09280 | 0.16523 | 0.22999 | −0.19234 |
| CLD by MVR function | 0.00000 | 0.00000 | 0.00000 | −0.06780 | 0.00000 | 0.00000 | 0.00000 | −0.04591 | 0.00000 |
| CLD by MVRepair function | 0.00000 | 0.00000 | 0.00000 | −0.04014 | 0.00000 | 0.00000 | 0.00000 | −0.08501 | 0.00000 |
| Creatinine function 1 | 0.44794 | 0.23545 | 0.81612 | 0.38147 | 0.00000 | 0.24620 | 0.51256 | 0.41472 | −0.47658 |
| Creatinine by MVR function | 0.00000 | 0.00000 | −0.21574 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.06652 |
| Creatinine by MVRepair function | 0.00000 | 0.00000 | −0.18787 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | −0.04407 |
| CVD without prior CVA | 0.00000 | 0.24847 | 0.13299 | 0.09769 | 0.00000 | 0.00000 | 0.10255 | 0.10601 | −0.16643 |
| CVD and prior CVA | 0.19754 | 0.54344 | 0.11571 | 0.23581 | 0.19686 | 0.10974 | 0.23332 | 0.23319 | −0.28560 |
| Diabetes, noninsulin | 0.11060 | 0.14576 | 0.24490 | 0.10365 | 0.26281 | 0.00000 | 0.11462 | 0.15846 | −0.17020 |
| Diabetes, insulin | 0.26870 | 0.14582 | 0.48504 | 0.27893 | 0.68330 | 0.00000 | 0.29508 | 0.39583 | −0.40448 |
| Dialysis | 1.61151 | 0.58833 | 0.00000 | 1.20290 | 0.61527 | 0.74332 | 1.25181 | 1.29747 | −1.67728 |
| Dialysis by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | −0.30339 | 0.00000 | 0.00000 | 0.04745 |
| Dialysis by MVRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.13058 | 0.00000 | 0.00000 | 0.09778 |
| Ejection fraction function | 0.00989 | 0.00000 | 0.00534 | 0.01113 | 0.00000 | 0.00703 | 0.01061 | 0.00995 | −0.01440 |
| EF by MVR function | 0.01056 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00228 |
| EF by MVRepair function | −0.00117 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | −0.00309 |
| Endocarditis, active | 0.71327 | 0.60657 | 0.41797 | 0.67172 | 0.00000 | 0.44757 | 0.74858 | 0.59333 | −1.27854 |
| Endocarditis by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.13795 | 0.00000 |
| Endocarditis by MVRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.49934 | 0.00000 |
| Female | 0.30852 | 0.17170 | 0.16668 | 0.41874 | 0.10654 | −0.08221 | 0.18594 | 0.26947 | −0.50044 |
| Female by MVR function | 0.00000 | 0.00000 | 0.00000 | −0.25972 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.08895 |
| Female by MVRepair function | 0.00000 | 0.00000 | 0.00000 | −0.19373 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | −0.00229 |
| Female by BSA function 1 | 0.51233 | 0.07575 | 0.76032 | 0.48032 | 0.80594 | 0.16701 | 0.41581 | 0.91055 | −0.59086 |
| Female by BSA function 2 | −0.27980 | −0.88628 | −0.57622 | −0.49740 | 0.58767 | 0.52524 | −0.40427 | −0.78096 | 0.15748 |
| Hypertension | 0.00000 | 0.17080 | 0.22638 | 0.09581 | 0.28851 | 0.00000 | 0.11445 | 0.07602 | −0.08668 |

Appendix Table 1. Continued

| Variable | Mort | CVA | RF | Vent | DSWI | Reop | Comp | PLOS | SLOS |
|---------------------------------------|----------|----------|---------|----------|---------|----------|----------|----------|----------|
| IABP or inotropes | 0.36025 | 0.00000 | 0.23674 | 0.77918 | 0.00000 | 0.15075 | 0.56477 | 0.34008 | −0.58536 |
| IABP by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | −0.08732 | −0.09462 |
| IABP by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.10281 | −0.06743 |
| Immunosuppressive treatment | 0.29654 | 0.00000 | 0.26400 | 0.24814 | 0.00000 | 0.24041 | 0.23332 | 0.19750 | −0.28819 |
| Insufficiency, mitral | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.06414 | 0.00000 | 0.00000 |
| Insufficiency, tricuspid | 0.24006 | 0.00000 | 0.22040 | 0.13606 | 0.00000 | 0.00000 | 0.13318 | 0.00000 | −0.23141 |
| Left main disease | 0.11450 | 0.00000 | 0.00000 | 0.06181 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |
| MI 1–21 days | 0.17038 | 0.00000 | 0.16476 | 0.24560 | 0.00000 | 0.00000 | 0.19751 | 0.00000 | 0.00000 |
| MI ≤ 21 days | 0.00000 | 0.19671 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.14599 | 0.00000 |
| MI < 24 hours | 0.49918 | 0.00000 | 0.26240 | 0.34321 | 0.00000 | 0.13716 | 0.39731 | 0.00000 | 0.00000 |
| MVR | 0.14888 | 0.32659 | 0.90926 | 0.76504 | 0.28437 | 0.41642 | 0.41322 | 0.73530 | −0.82339 |
| MVRRepair | −0.07374 | 0.06933 | 0.51275 | 0.28204 | 0.19499 | 0.07390 | −0.03949 | 0.30384 | −0.03552 |
| No. diseased coronary vessel function | 0.13746 | 0.18243 | 0.15791 | 0.17277 | 0.24582 | 0.08187 | 0.14767 | 0.12474 | −0.19250 |
| Peripheral vascular disease | 0.25173 | 0.13776 | 0.14995 | 0.16591 | 0.00000 | 0.14312 | 0.18062 | 0.14863 | 0.00000 |
| Race black | 0.00000 | 0.00000 | 0.14301 | 0.26900 | 0.00000 | 0.17364 | 0.19182 | 0.26856 | −0.43385 |
| Race Hispanic | 0.00000 | 0.00000 | 0.18384 | 0.15363 | 0.00000 | 0.08065 | 0.13561 | 0.12286 | −0.15901 |
| Reop, 1 previous operation | 0.78624 | 0.00000 | 0.25782 | 0.60179 | 0.00000 | 0.33209 | 0.40293 | 0.43757 | −0.39723 |
| Reop, ≥ 2 previous operations | 0.90015 | 0.00000 | 0.38499 | 0.78263 | 0.00000 | 0.39502 | 0.56875 | 0.50334 | −0.63237 |
| Reop by MVR function | 0.00000 | 0.00000 | 0.00000 | −0.27846 | 0.00000 | −0.19608 | 0.00000 | −0.17836 | 0.18262 |
| Reop by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | −0.16306 | 0.00000 | 0.06985 | 0.00000 | −0.16007 | 0.17613 |
| Shock | 0.51917 | 0.17321 | 0.15810 | 0.65653 | 0.00000 | 0.21271 | 0.58409 | 0.36987 | 0.00000 |
| Shock by MVR function | 0.00000 | 0.00000 | 0.02883 | 0.00000 | 0.00000 | 0.00000 | 0.43045 | 0.00000 | 0.00000 |
| Shock by MVRRepair function | 0.00000 | 0.00000 | 0.36429 | 0.00000 | 0.00000 | 0.00000 | 0.19084 | 0.00000 | 0.00000 |
| Status urgent | 0.22591 | 0.00000 | 0.16451 | 0.22905 | 0.00000 | 0.12800 | 0.17511 | 0.24758 | −0.26626 |
| Status emergent | 0.75852 | 0.79460 | 0.56854 | 0.99818 | 0.00000 | 0.34063 | 0.77631 | 1.00162 | −1.09633 |
| Status salvage | 1.51811 | 0.95665 | 0.61798 | 0.75178 | 0.00000 | 0.00000 | 1.20732 | 0.56482 | −1.72252 |
| Status by MVR function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | −0.25083 |
| Status by MVRRepair function | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.25943 |
| Stenosis, mitral | 0.09879 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.08469 | 0.00000 |
| Unstable angina | 0.10722 | −0.11292 | 0.11597 | 0.05762 | 0.00000 | 0.00000 | 0.00000 | 0.00000 | 0.00000 |

Afib = atrial fibrillation; BSA = body surface area; CHF = congestive heart failure; CLD = chronic lung disease; Comp = composite adverse event (any); CVA = cerebrovascular accident (stroke); CVD = cerebrovascular disease; DSWI = deep sternal wound infection; EF = ejection fraction; IABP = intra-aortic balloon pump; MI = myocardial infarction; Mort = mortality; MVR = mitral valve replacement; MVRRepair = mitral valve repair; NYHA = New York Heart Association; PLOS = prolonged length of stay; PVD = peripheral vascular disease; Reop = reoperation; RF = renal failure; SLOS = short length of stay; Vent = prolonged ventilation.

Appendix Table 2. Definition of Variables Appearing in STS 2008 Valve Plus CABG Models

| Variable | Definition |
|---------------------------------------|--|
| Intercept | = 1 for all patients |
| Preoperative AFib | = 1 if patient has history of preoperative atrial fibrillation, = 0 otherwise |
| Age function 1 | = max (age – 50, 0) |
| Age function 3 | = max (age – 75, 0) |
| Age by reop function | = Age function 1 if surgery is a reoperation, = 0 otherwise |
| Age by status function | = Age function 1 if status is emergent or salvage, = 0 otherwise |
| Age by MVR function | = Age function 1 if operation is MVR, = 0 otherwise |
| Age by MVRepair function | = Age function 1 if operation is MVRepair, = 0 otherwise |
| BSA function 1 | = max (1.4, min [2.6, BSA]) – 1.8 |
| BSA function 2 | = (BSA function 1) ² |
| CHF but not NYHA IV | = 1 if patient has CHF and is not NYHA class IV, = 0 otherwise |
| CHF and NYHA IV | = 1 if patient has CHF and is NYHA class IV, = 0 otherwise |
| CHF by MVR function | = 1 if patient has CHF and operation is MVR, = 0 otherwise |
| CHF by MVRepair function | = 1 if patient has CHF and operation is MVRepair, = 0 otherwise |
| CLD function | = 0 if no CLD, = 1 if mild CLD, = 2 if moderate CLD, = 3 if severe CLD |
| CLD by MVR function | = CLD function if operation is MVR, = 0 otherwise |
| CLD by MVRepair function | = CLD function if operation is MVRepair, = 0 otherwise |
| Creatinine function 1 | = max (0.5, min [creatinine, 5.0]) if patient is not on dialysis, = 0 otherwise |
| Creatinine by MVR function | = Creatinine function 1 if valve operation is MVR, = 0 otherwise |
| Creatinine by MVRepair function | = Creatinine function 1 if valve operation is MVRepair, = 0 otherwise |
| CVD without prior CVA | = 1 if patient has history of CVD and no prior CVA, = 0 otherwise |
| CVD and prior CVA | = 1 if patient has history of CVD and a prior CVA, = 0 otherwise |
| Diabetes, noninsulin | = 1 if patient has diabetes not treated with insulin, = 0 otherwise |
| Diabetes, insulin | = 1 if patient has diabetes treated with insulin, = 0 otherwise |
| Dialysis | = 1 if patient requires dialysis preoperatively, = 0 otherwise |
| Dialysis by MVR function | = 1 if patient has history of dialysis and operation is MVR, = 0 otherwise |
| Dialysis by MVRepair function | = 1 if patient has history of dialysis and operation is MVRepair, = 0 otherwise |
| Ejection fraction function | = max (50 – ejection fraction, 0) |
| EF by MVR function | = Ejection fraction function if valve operation is MVR, = 0 otherwise |
| EF by MVRepair function | = Ejection fraction function if valve operation is MVRepair, = 0 otherwise |
| Endocarditis, active | = 1 if patient has active endocarditis, = 0 otherwise |
| Endocarditis by MVR function | = 1 if patient has active endocarditis and valve operation is MVR, = 0 otherwise |
| Endocarditis by MVRepair function | = 1 if patient has active endocarditis and valve operation is MVRepair, = 0 otherwise |
| Female | = 1 if patient is female, = 0 otherwise |
| Female by MVR function | = 1 if female and operation is MVR, = 0 otherwise |
| Female by MVRepair function | = 1 if female and operation is MVRepair, = 0 otherwise |
| Female by BSA function 1 | = BSA function 1 if female, = 0 otherwise |
| Female by BSA function 2 | = BSA function 2 if female, = 0 otherwise |
| Hypertension | = 1 if patient has hypertension, = 0 otherwise |
| IABP or inotropes | = 1 if patient requires IABP or inotropes preoperatively, = 0 otherwise |
| IABP by MVR function | = 1 if patient requires preop IABP or inotropes and operation is MVR, = 0 otherwise |
| IABP by MVRepair function | = 1 if patient requires preop IABP or inotropes and operation is MVRepair, = 0 otherwise |
| Immunosuppressive treatment | = 1 if patient has received immunosuppressive therapy within 30 days, = 0 otherwise |
| Insufficiency, mitral | = 1 if patient has at least moderate mitral insufficiency, = 0 otherwise |
| Insufficiency, tricuspid | = 1 if patient has at least moderate tricuspid insufficiency, = 0 otherwise |
| Left main disease | = 1 if patient has left main disease, = 0 otherwise |
| MI 1–21 days | = 1 if history of MI 1 to 21 days prior to surgery, = 0 otherwise |
| MI ≤ 21 days ^a | = 1 if patient has history of MI within 21 days prior to surgery, = 0 otherwise (for CVA and PLOS; coded as < 24 hours and 1–21 days for others) |
| MI < 24 hours | = 1 if history of MI < 24 hours prior to surgery, = 0 otherwise |
| MVR | = 1 if valve operation is mitral valve replacement, = 0 otherwise |
| MVRepair | = 1 if valve operation is mitral valve repair, = 0 otherwise |
| No. diseased coronary vessel function | = 2 if triple-vessel disease, = 1 if double-vessel disease, = 0 otherwise |

Appendix Table 2. Continued

| Variable | Definition |
|------------------------------------|--|
| Peripheral vascular disease | = 1 if patient has peripheral vascular disease, = 0 otherwise |
| Race black | = 1 if patient is black, = 0 otherwise |
| Race Hispanic | = 1 if patient is nonblack Hispanic, = 0 otherwise |
| Reop, 1 previous operation | = 1 if patient has had exactly 1 previous CV surgery, = 0 otherwise |
| Reop, ≥ 2 previous operations | = 1 if patient has had 2 or more previous CV surgeries, = 0 otherwise |
| Reop by MVR function | = 1 if surgery is a reoperation and operation is MVR, = 0 otherwise |
| Reop by MVRRepair function | = 1 if surgery is a reoperation and operation is MVRRepair, = 0 otherwise |
| Shock | = 1 if patient was in shock at time of procedure, = 0 otherwise |
| Shock by MVR function | = 1 if shock and operation is MVR, = 0 otherwise |
| Shock by MVRRepair function | = 1 if shock and operation is MVRRepair, = 0 otherwise |
| Status urgent | = 1 if status is urgent, = 0 otherwise |
| Status emergent | = 1 if status is emergent (but not resuscitation), = 0 otherwise |
| Status salvage | = 1 if status is salvage (or emergent plus resuscitation), = 0 otherwise |
| Status by MVR function | = 1 if status is emergent or salvage and operation is MVR, = 0 otherwise |
| Status by MVRRepair function | = 1 if status is emergent or salvage and operation is MVRRepair, = 0 otherwise |
| Stenosis, mitral | = 1 if patient has mitral stenosis, = 0 otherwise |
| Unstable angina | = 1 if patient has unstable angina and no MI within 7 days of surgery, = 0 otherwise |

^a MI coded ≤ 21 days for CVA and PLOS endpoints; for all other endpoints, coded as < 24 hours and 1 to 21 days.

Note: See www.sts.org for exact definitions of terms used above.

BSA = body surface area; CABG = coronary artery bypass graft surgery; CHF = congestive heart failure; CLD = chronic lung disease; Comp = composite adverse event (any); CVA = cerebrovascular accident (stroke); CVD = cerebrovascular disease; DSWI = deep sternal wound infection; EF = ejection fraction; IABP = intra-aortic balloon pump; MI = myocardial infarction; Mort = mortality; MVR = mitral valve replacement; MVRRepair = mitral valve repair; NYHA = New York Heart Association; PLOS = prolonged length of stay; PVD = peripheral vascular disease; Reop = reoperation; RF = renal failure; SLOS = short length of stay; STS = The Society of Thoracic Surgeons; Vent = prolonged ventilation.