```
BEGIN

   -- Start by identifying the cases where procedures were performed that definitively put the case into the
Other category.  ProcID=null.
    if (VSTCV=1 or EndoProc=1 or OCarACDLE=1 or ResectSubA=1 or OCarCrTx=1 or OCarSVR=1 or CCancCase=1) or
(OCTumor<>1 and OCTumor is not null) or (OCPulThromDis<>1 and OCPulThromDis is not null) then
        Return null;
    else

        if (VADProc=2 and (UnplVAD=2 or UnplVAD is null)) or VADProc=3 or VADProc=4 then
            Return null;
        else

            if OCarASD=1 and (OCarASDTy=1 or OCarASDTy=2 or OCarASDTy is null) then
                Return null;
            else

                if OCarAFibSur=1 and OCarAFibAProc=2 then
                    Return null;
                else

                    if   (OpTricus is not null and OpTricus<>1) or (OpPulm is not null and OpPulm<>1) then
                        if UnplProc=1 or UnplProc=2 or UnplProc is null then
                            Return null;
                        else
                            if UnplCABG=1 or UnplAV=1 or UnplMV=1 or UnplAo=1 or UnplVAD=1 then
                                Return null;
                            end if;
                        end if;
                    end if;

                    if (UnplOth=2 or UnplOth is null) or UnplProc=2 then
                        if OpONCard=1 or OCarLVA=1 or OCarVSD=1 or OCarTrma=1 or OCarOthr=1  then
                            Return null;
                        end if;
                    end if;

                    if (OCAoProcType is not null and OCAoProcType<>1) then
                        if (UnplAo=2 or UnplAo is null) or (UnplAo=1 and UnplProc=2) then
                            Return null;
                        end if;
                    end if;
                end if;
            end if;
        end if;
    end if;
```

```
   -- Now determine whether the procedure is an isolated CAB.  ProcID=1.
    if OpCAB=1 and (UnplCABG=2 or UnplCABG is null) then
        if OpValve=2 or OpValve is null then
            if (OCarCongProc1 is null or OCarCongProc1=10 or OCarCongProc1=1291 or OCarCongProc1=1305) and
                        (OCarCongProc2 is null or OCarCongProc2=10 or OCarCongProc2=1291 or
OCarCongProc2=1305) and
                        (OCarCongProc3 is null or OCarCongProc3=10 or OCarCongProc3=1291 or
OCarCongProc3=1305) then
                Return 1;   -- Isolated CAB procedure.
            else
                Return null;
            end if;

        else
            -- OpValve can only be 1 at this point.
            if UnplProc=3 then
                If (VSAV=2 or VSAV is null) or (VSAV=1 and UnplAV=1) then
                    if (VSMV=2 or VSMV is null) or (VSMV=1 and UnplMV=1) then
                        if (OCarCongProc1 is null or OCarCongProc1=10 or OCarCongProc1=1291 or
OCarCongProc1=1305) and
                                    (OCarCongProc2 is null or OCarCongProc2=10 or OCarCongProc2=1291 or
OCarCongProc2=1305) and
                                    (OCarCongProc3 is null or OCarCongProc3=10 or OCarCongProc3=1291 or
OCarCongProc3=1305) then
                            Return 1;   -- Isolated CAB procedure.
                        else
                            Return null;
                        end if;
                    end if;
                end if;
            end if;
        end if;

   -- Procedure is not an isolated CABG, but could still be a valve or combination CAB + Valve procedure.

   -- Determine whether the procedure is an isolated AVR or AVR + CAB. ProcID=2 or 4.
    If OpValve=2 or OpValve is null then
        Return null;  -- If procedure is not an isolated CAB and no valve procedures were done, it is an
Other procedure.
    else
        if VSAV=1 and (VSAVPr=1 or VSAVPr=9) then
            if (VSMV=2 or VSMV is null) or (VSMV=1 and UnplProc=3 and UnplMV=1) then
                if (OpCAB=2 or OpCAB is null) or (OpCAB=1 and UnplProc=3 and UnplCABG=1) then
                    if (OCarCongProc1 is null or OCarCongProc1=10) and (OCarCongProc2 is null or
OCarCongProc2=10) and (OCarCongProc3 is null or OCarCongProc3=10) then
                        Return 2;   -- Isolated AVR procedure.
                    else
```

```
                        Return null;
                    end if;
                else
                    -- OpCAB can only be 1 at this point.
                    If (UnplProc=3 and (UnplCABG=2 or UnplCABG is null)) or (UnplProc=1 or UnplProc=2 or
UnplProc is null) then
                        if (OCarCongProc1 is null or OCarCongProc1=10 or OCarCongProc1=1291 or
OCarCongProc1=1305) and
                                (OCarCongProc2 is null or OCarCongProc2=10 or OCarCongProc2=1291 or
OCarCongProc2=1305) and
                                (OCarCongProc3 is null or OCarCongProc3=10 or OCarCongProc3=1291 or
OCarCongProc3=1305) then
                            Return 4;   -- AVR + CAB procedure.
                        else
                            Return null;
                        end if;
                    end if;
                end if;
            end if;
        end if;

    -- Determine whether the procedure is an isolated MVR or MVR + CAB.  ProcID=3 or 5.
    if VSMV=1 and (VSMVPr=2) then
        if (VSAV=2 or VSAV is null) or (VSAV=1 and UnplProc=3 and UnplAV=1) then
            if (OpCAB=2 or OpCAB is null) or (OpCAB=1 and UnplProc=3 and UnplCABG=1) then
                if (OCarCongProc1 is null or OCarCongProc1=10) and (OCarCongProc2 is null or
OCarCongProc2=10) and (OCarCongProc3 is null or OCarCongProc3=10) then
                    Return 3;   -- Isolated MVR procedure.
                else
                    Return null;
                end if;
            else
                -- OpCAB can only be 1 at this point.
                If (UnplProc=3 and (UnplCABG=2 or UnplCABG is null)) or (UnplProc=1 or UnplProc=2 or
UnplProc is null) then
                    if (OCarCongProc1 is null or OCarCongProc1=10 or OCarCongProc1=1291 or
OCarCongProc1=1305) and
                            (OCarCongProc2 is null or OCarCongProc2=10 or OCarCongProc2=1291 or
OCarCongProc2=1305) and
                            (OCarCongProc3 is null or OCarCongProc3=10 or OCarCongProc3=1291 or
OCarCongProc3=1305) then
                        Return 5;   -- MVR + CAB procedure.
                    else
                        Return null;
                    end if;
                end if;
            end if;
```

```
        end if;
    end if;

    -- Determine whether the procedure is an AVR + MVR.   ProcID=6.
    if VSAV=1 and (VSAVPr=1 or VSAVPr=9) and VSMV=1 and VSMVPr=2 then
        if (OpCAB=2 or OpCAB is null) or (OpCAB=1 and UnplProc=3 and UnplCABG=1) then
            if (OCarCongProc1 is null or OCarCongProc1=10) and (OCarCongProc2 is null or OCarCongProc2=10)
and (OCarCongProc3 is null or OCarCongProc3=10) then
                Return 6;   -- AVR + MVR procedure.
            else
                Return null;
            end if;
        end if;
    end if;

    -- Determine whether the procedure is an MV Repair or MV Repair + CAB.  ProcID=7 or 8.
    if VSMV=1 and VSMVPr=1 then
        if (VSAV=2 or VSAV is null) or (VSAV=1 and UnplProc=3 and UnplAV=1) then
            if (OpCAB=2 or OpCAB is null) or (OpCAB=1 and UnplProc=3 and UnplCABG=1) then
                if (OCarCongProc1 is null or OCarCongProc1=10) and (OCarCongProc2 is null or
OCarCongProc2=10) and (OCarCongProc3 is null or OCarCongProc3=10) then
                    Return 7;   -- MV Repair procedure.
                else
                    Return null;
                end if;

            else
                -- OpCAB can only be 1 at this point.
                if (UnplProc=3 and (UnplCABG=2 or UnplCABG is null)) or (UnplProc=1 or UnplProc=2 or
UnplProc is null) then
                    if (OCarCongProc1 is null or OCarCongProc1=10 or OCarCongProc1=1291 or
OCarCongProc1=1305) and
                                (OCarCongProc2 is null or OCarCongProc2=10 or OCarCongProc2=1291 or
OCarCongProc2=1305) and
                                (OCarCongProc3 is null or OCarCongProc3=10 or OCarCongProc3=1291 or
OCarCongProc3=1305) then
                        Return 8;   -- MV Repair + CAB procedure.
                    else
                        Return null;
                    end if;
                end if;
            end if;
        end if;
    end if;

    -- If ProcID still has not been determined, then it is an Other procedure.  ProcID = null.
    return null;
```

```
   EXCEPTION
     WHEN NO_DATA_FOUND THEN
       NULL;
     WHEN OTHERS THEN
       Null;
       RAISE;
END getProcID;
/
```

1b.2. Provide performance scores on the measure as specified (current and over time) at the specified level of analysis. (This is required for maintenance of endorsement. 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 sub-criterion on improvement (4b1) under Usability and Use.

The measure was calculated using STS data for patients undergoing AVR + CABG in two consecutive time periods, July 2011 – June 2014 and July 2014 – June 2017.

The summary statistic provided is the Participant's Estimated Odds Ratio (OR) based on a hierarchical logistic regression analysis. The OR measures the impact that a participant's performance level has on a patient's probability of experiencing an adverse outcome. An OR greater than 1.0 implies that the participant increases a patient's risk of experiencing the outcome, relative to an average STS participant. An OR less than 1.0 implies that the participant decreases a patient's risk of experiencing the outcome, relative to an "average" STS participant. A high OR is undesirable and we define the percentiles with increasing OR. For example, 10% of STS participants have an OR greater than the value indicated by the "90th percentile" below.

Also provided is the distribution of the risk adjusted event rate. The risk adjusted rate is an estimate of the participant's event rate if, hypothetically, the case-mix of the patients treated by the participants is the same as the overall STS case-mix. It is calculated by the OR of the participant, other patient level parameter estimates from the hierarchical logistic model, and the overall STS event rate, by:

STS event rate * (Participant's Expected Event Rate) / (Participant's Expected Event Rate Assuming Its Performance = STS Average Performance)

In the above equation, "Participant's Expected Event Rate" is calculated with the participant's actual OR, and "Participant's Expected Event Rate Assuming Its Performance = STS Average Performance" is calculated by assuming the participant's OR = 1 (i.e. no difference in performance from the STS average).

Distribution of participant-specific risk adjusted odds ratio and event rates in July 2011 - June 2014 and July 2014 - June 2017

Distribution	July 2011 - June 2014 Odds ratio	July 2011 - June 2014 Risk adjusted Rate, %	July 2014 - June 2017 Odds ratio	July 2014 - June 2017 Risk adjusted Rate, %
# Participant	1083	1083	1086	1086
# Operations	54859	54859	52245	52245
Mean	1.04	4.19	1.05	3.86
STD	0.25	0.92	0.28	0.91
IQR	0.28	1.07	0.26	0.88

0%	0.39	1.68	0.44	1.73
10%	0.79	3.24	0.78	2.96
20%	0.86	3.49	0.86	3.24
30%	0.91	3.71	0.91	3.41
40%	0.95	3.85	0.95	3.55
50%	0.98	3.98	0.98	3.66
60%	1.05	4.21	1.04	3.86
70%	1.12	4.51	1.11	4.08
80%	1.21	4.81	1.20	4.42
90%	1.37	5.42	1.38	4.97
100%	2.25	8.51	3.72	11.63
Midwest	311	311	305	305
Northeast	138	138	142	142
Other*	0	0	9	9
South	408	408	408	408
West	226	226	222	222

*Other region: Ontario, Canada

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 maintenance of endorsement. Describe the data source including number of measured entities; number of patients; dates of data; if a sample, characteristics of the entities included.) For measures that show high levels of performance, i.e., "topped out", disparities data may demonstrate an opportunity for improvement/gap in care for certain sub-populations. This information also will be used to address the sub-criterion on improvement (4b1) under Usability and Use.

Even though the measure is used to measure participant-level results, we understand it is of interest to see whether disparity exists between race and sex groups. We provide below the participant level distribution of the measure by race, ethnicity and sex.

Distribution of participant-specific risk adjusted odds ratio in July 2011 - June 2014 and July 2014 - June 2017, by sex

Distribution	Male July 11 - June 14	Male July 14 - June 17	Female July 11 - June 14	Female July 14 - June 17
# Participant	1075	1080	1055	1029
# Operations	39020	39150	15839	13095

Mean	1.03	1.03	1.03	1.02
STD	0.19	0.22	0.23	0.17
IQR	0.20	0.23	0.23	0.17
0%	0.40	0.46	0.56	0.63
10%	0.84	0.82	0.82	0.87
20%	0.90	0.87	0.88	0.91
30%	0.93	0.92	0.92	0.94
40%	0.96	0.95	0.95	0.96
50%	0.98	0.98	0.97	0.98
60%	1.02	1.02	0.99	0.99
70%	1.08	1.10	1.10	1.05
80%	1.15	1.18	1.19	1.14
90%	1.26	1.32	1.29	1.20
100%	2.10	2.47	2.69	2.77

Distribution of participant-specific risk adjusted event rates (%) in July 2011 - June 2014 and July 2014 - June 2017, by sex

Distribution	Male July 11 - June 14	Male July 14 - June 17	Female July 11 - June 14	Female July 14 - June 17
# Participant	1075	1080	1055	1029
# Operations	39020	39150	15839	13095
Mean	3.71	3.46	5.20	4.81
STD	0.64	0.68	1.04	0.69
IQR	0.67	0.73	1.09	0.72
0%	1.60	1.62	2.94	3.12
10%	3.07	2.80	4.19	4.18
20%	3.27	2.96	4.51	4.37
30%	3.38	3.12	4.68	4.48
40%	3.48	3.22	4.82	4.56
50%	3.57	3.31	4.93	4.63
60%	3.69	3.42	5.02	4.69
70%	3.91	3.69	5.51	4.94
80%	4.13	3.93	5.94	5.34
90%	4.48	4.33	6.43	5.62
100%	7.19	7.89	12.27	11.19

Distribution of participant-specific risk adjusted odds ratio in July 2011 - June 2014 and July 2014 - June 2017, by age

Distribution	Age < 75, July 11 - June 14	Age < 75, July 14- June 17	Age ≥ 75, July 11 - June 14	Age ≥ 75, July 14 - June 17
# Participant	1071	1080	1066	1052
# Operations	28096	29925	26763	22320
Mean	1.05	1.01	1.03	1.03
STD	0.28	0.12	0.21	0.21
IQR	0.28	0.14	0.21	0.23
0%	0.37	0.63	0.53	0.51
10%	0.80	0.90	0.84	0.82
20%	0.86	0.93	0.89	0.88
30%	0.90	0.95	0.93	0.93
40%	0.94	0.97	0.96	0.95
50%	0.97	0.98	0.98	0.98
60%	1.00	1.00	1.01	1.01
70%	1.11	1.05	1.08	1.09
80%	1.21	1.10	1.16	1.17
90%	1.42	1.16	1.29	1.27
100%	3.30	1.82	2.08	2.67

Distribution of participant-specific risk adjusted event rates (%) in July 2011 - June 2014 and July 2014 - June 2017, by age

Distribution	Age < 75, July 11 - June 14	Age < 75, July 14- June 17	Age ≥ 75, July 11 - June 14	Age ≥ 75, July 14 - June 17
# Participant	1071	1080	1066	1052
# Operations	28096	29925	26763	22320
Mean	3.36	3.00	5.01	4.82
STD	0.81	0.33	0.92	0.89
IQR	0.83	0.38	0.96	0.98
0%	1.30	1.92	2.73	2.49
10%	2.63	2.69	4.15	3.95
20%	2.82	2.78	4.38	4.19
30%	2.94	2.84	4.56	4.37

40%	3.04	2.89	4.69	4.50
50%	3.13	2.93	4.80	4.62
60%	3.22	2.96	4.95	4.73
70%	3.54	3.11	5.26	5.09
80%	3.86	3.25	5.59	5.41
90%	4.43	3.41	6.12	5.86
100%	8.37	5.10	9.75	11.25

At the operation level, we were able to estimate the risk adjusted odds ratios between race groups. The odds ratios were estimated from a model with race and other covariates from the 2008 validated Valve risk models.

Risk Adjusted OR:

- Black vs. White (including patients with race other than Black, White, Asian): 1.00 (0.85-1.16)
- Asian vs. White (including patients with race other than Black, White, Asian): 1.05 (0.82-1.34)

4b1. Refer to data provided in 1b but do not repeat here. Discuss any progress on improvement (trends in performance results, number and percentage of people receiving high-quality healthcare; Geographic area and number and percentage of accountable entities and patients included.)

Looking at the overall temporal trend, the operative mortality rate has decreased slightly. The overall event rates in the last three 12-month periods were 3.99%, 3.53%, 3.63% (July 2014-June 2015, July 2015-June 2016, July 2016-June 2017, respectively).

Number of participants and operations by geographic regions, in July 2011 to June 2014 and in July 2014 to June 2017

July 2011 to June 2014						July 2014 to June 2017					
	Midwest	Northeast	Other region	South	West		Midwest	Northeast	Other region	South	West
# Participant	311	138	0	408	226	# Participant	305	142	9	408	222
% Participant	28.7%	12.7%	0.0%	37.7%	20.9%	% Participant	28.1%	13.1%	0.8%	37.6%	20.4%
# Operation	14153	11708	NA	18840	10158	# Operation	13166	11107	449	18023	9500
% Operation	25.8%	21.3%	NA%	34.3%	18.5%	% Operation	25.2%	21.3%	0.9%	34.5%	18.2%

*Other region: Ontario, Canada

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

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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 (MVRepair) 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

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.

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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 (MVRepair) 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 MVRepair 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 MVRepair 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, MVRepair 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

	Overall Valve + CABG (n = 101,661)		AVR + CABG (n = 66,074)		MVR + CABG (n = 13,663)		MVRepair + CABG (n = 21,924)	
Variable	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)		MVRepair + 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 (≤ 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 ≥ 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
≥ 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)		MVRepair + 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)		MVRepair + 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 ≥ 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
≥ 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)		MVRepair + 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; MVRepair = 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, MVRepair) 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, MVRepair + 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
MVRepair + 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); 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 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. *Note: BSA < 1.4 and > 2.6 were mapped to those values, respectively.*
Creatinine	Linear (only for patients not on dialysis). *Note: Creatinine < 0.5 and > 5.0 mapped to those values, respectively.*
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, MVRepair + 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. *Note: groups 1 and 2 were subsequently collapsed for some models.*
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; MVRepair = 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, MVRepair plus CABG); age ($<$ 60, 60 to 79, $\geq$ 80 years); sex (male, female); diabetes mellitus (yes/no); status (elective, nonelective); and ejection fraction ($\leq$ 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-

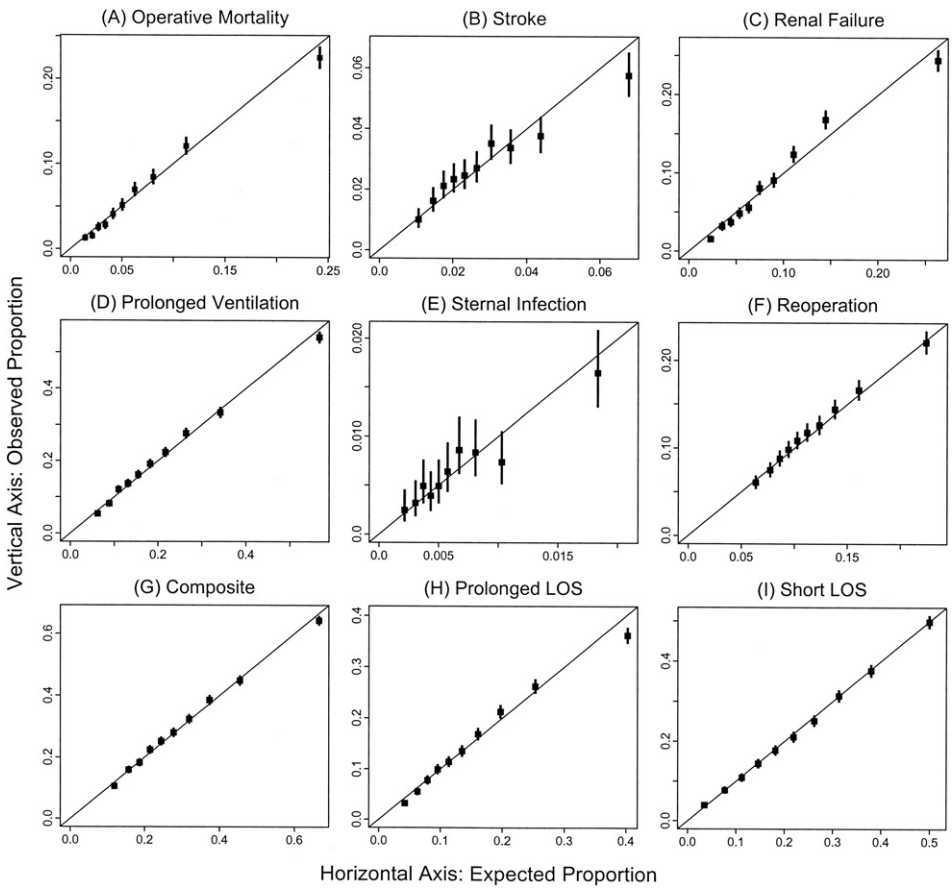

Fig 1. Plots of observed (O) versus expected (E) in validation sample

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 $\leq$ 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.

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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:

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

where $x_1, x_2, \ldots, x_n$ denote patient preoperative risk factors (eg, quantitative variables such as age, and comorbidities coded as 1=present, 0=absent); and $\beta_0, \beta_1, \ldots, \beta_n$ denote regression coefficients (numerical constants). Regression coefficients for each endpoint are presented in Appendix Table 1. The variables $x_1, x_2, \ldots, x_n$ 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 MVRepair 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
MVRepair	−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 MVRepair 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 MVRepair 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 MVRepair 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; MVRepair = 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 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 rescuscitation), = 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

[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; MVRepair = 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.