```
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;
    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;
    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 isolated MV repair 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	986	986	993	993
# Operations	25694	25694	26475	26475
Mean	1.02	1.28	1.08	1.19
STD	0.19	0.22	0.40	0.42
IQR	0.055	0.066	0.092	0.10
0%	0.52	0.65	0.34	0.38

10%	0.89	1.12	0.81	0.92
20%	0.93	1.17	0.89	1.00
30%	0.95	1.20	0.92	1.03
40%	0.97	1.22	0.95	1.06
50%	0.98	1.23	0.97	1.08
60%	0.99	1.24	0.98	1.10
70%	1.00	1.25	0.99	1.11
80%	1.03	1.28	1.07	1.19
90%	1.29	1.60	1.60	1.76
100%	2.56	2.83	4.35	4.64
Midwest	286	286	273	273
Northeast	134	134	138	138
Other	0	0	7	7
South	354	354	361	361
West	212	212	214	214

*Other Region: Ontario, Canada

1b.4. Provide disparities data from the measure as specified (<u>current and over time</u>) by population group, e.g., by race/ethnicity, gender, age, insurance status, socioeconomic status, and/or disability. (<u>This is required for maintenance of endorsement.</u> 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	921	939	897	895
# Operations	15382	16266	10312	10209
Mean	1.01	1.15	1.07	1.25

STD	0.085	0.76	0.38	1.12
IQR	0.021	0.086	0.07	0.096
0%	0.64	0.38	0.54	0.38
10%	0.95	0.82	0.86	0.80
20%	0.97	0.89	0.91	0.87
30%	0.98	0.93	0.94	0.91
40%	0.99	0.95	0.96	0.94
50%	0.99	0.97	0.97	0.95
60%	1.00	0.98	0.98	0.97
70%	1.00	0.99	0.99	0.98
80%	1.00	1.00	1.00	0.99
90%	1.13	1.91	1.59	2.38
100%	1.63	9.54	4.38	14.42

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	921	939	897	895
# Operations	15382	16266	10312	10209
Mean	0.99	1.02	1.70	1.77
STD	0.08	0.61	0.57	1.46
IQR	0.021	0.076	0.11	0.14
0%	0.64	0.34	0.90	0.54
10%	0.95	0.74	1.39	1.16
20%	0.96	0.80	1.46	1.25
30%	0.97	0.83	1.51	1.31
40%	0.98	0.85	1.54	1.35
50%	0.98	0.87	1.56	1.37
60%	0.99	0.88	1.58	1.40
70%	0.99	0.89	1.59	1.41
80%	0.99	0.89	1.60	1.43
90%	1.09	1.64	2.51	3.23
100%	1.59	8.07	5.63	19.23

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	973	981	724	709
# Operations	21718	22871	3976	3604
Mean	1.06	1.19	1.00	1.04
STD	0.37	0.88	0.019	0.27
IQR	0.068	0.10	0.0052	0.044
0%	0.50	0.29	0.93	0.60
10%	0.86	0.78	0.99	0.89
20%	0.91	0.86	0.99	0.93
30%	0.94	0.91	0.99	0.96
40%	0.96	0.94	1.00	0.97
50%	0.97	0.96	1.00	0.98
60%	0.98	0.97	1.00	0.98
70%	0.99	0.99	1.00	0.99
80%	1.00	1.00	1.00	0.99
90%	1.55	2.16	1.03	1.43
100%	4.99	12.23	1.15	3.39

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	973	981	724	709
# Operations	21718	22871	3976	3604
Mean	0.91	1.01	3.11	2.59
STD	0.30	0.70	0.054	0.64
IQR	0.057	0.085	0.015	0.10
0%	0.44	0.25	2.90	1.57
10%	0.74	0.67	3.07	2.25
20%	0.79	0.74	3.08	2.34
30%	0.81	0.78	3.09	2.40
40%	0.83	0.80	3.10	2.42

50%	0.84	0.82	3.10	2.44
60%	0.85	0.83	3.10	2.46
70%	0.85	0.85	3.10	2.47
80%	0.86	0.85	3.10	2.48
90%	1.30	1.82	3.19	3.39
100%	4.02	9.48	3.54	7.80

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): 0.98 (0.63-1.51)
- Asian vs. White (including patients with race other than Black, White, Asian): 0.99 (0.48-2.04)

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 been steadily declining. The overall event rates in the last three 12-month periods were 1.24%, 1.09%, 1.03% (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	286	134	0	354	212	# Participant	273	138	7	361	214
% Participant	29.0%	13.6%	0.0%	35.9%	21.5%	% Participant	27.5%	13.9%	0.7%	36.4%	21.6%
# Operation	7146	5506	NA	8326	4716	# Operation	6771	6107	205	8274	5118
% Operation	27.8%	21.4%	NA%	32.4%	18.4%	% Operation	25.6%	23.1%	0.8%	31.3%	19.3%

*Other region: Ontario, Canada

The Society of Thoracic Surgeons 2008 Cardiac Surgery Risk Models: Part 2—Isolated Valve Surgery

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Background. Adjustment for case-mix is essential when using observational data to compare surgical techniques or providers. That is most often accomplished through the use of risk models that account for preoperative patient factors that may impact outcomes. The Society of Thoracic Surgeons (STS) uses such risk models to create risk-adjusted performance reports for participants in the STS National Adult Cardiac Surgery Database (NCD). Although risk models were initially developed for coronary artery bypass surgery, similar models have now been developed for use with heart valve surgery, particularly as the proportion of such procedures has increased. The last published STS model for isolated valve surgery was based on data from 1994 to 1997 and did not include patients undergoing mitral valve repair. STS has developed new valve surgery models using contemporary data that include both valve repair as well as replacement. Expanding upon existing valve models, the new STS models include several nonfatal complications in addition to mortality.

Methods. Using STS data from 2002 to 2006, isolated valve surgery risk models were developed for operative mortality, permanent stroke, renal failure, prolonged ventilation (> 24 hours), deep sternal wound infection, reoperation for any reason, a major morbidity or mortality composite endpoint, prolonged postoperative length of stay, and short postoperative length of stay. The study population consisted of adult patients who underwent one of three types of valve surgery: isolated aortic valve replacement (n = 67,292), isolated mitral valve replacement (n = 21,229), or isolated mitral valve repair (n = 21,238). The population was divided into a 60% development sample and a 40% validation sample. After an initial empirical investigation, the three surgery groups were combined into a single logistic regression model with numerous interactions to allow the covariate effects to differ across these groups. Variables were selected based on a combination of automated stepwise selection and expert panel review.

Results. Unadjusted operative mortality (in-hospital regardless of timing, and 30-day regardless of venue) for all isolated valve procedures was 3.4%, and unadjusted in-hospital morbidity rates ranged from 0.3% for deep sternal wound infection to 11.8% for prolonged ventilation. The number of predictors in each model ranged from 10 covariates in the sternal infection model to 24 covariates in the composite mortality plus morbidity model. Discrimination as measured by the c-index ranged from 0.639 for reoperation to 0.799 for mortality. When patients in the validation sample were grouped into 10 categories based on deciles of predicted risk, the average absolute difference between observed versus predicted events within these groups ranged from 0.06% for deep sternal wound infection to 1.06% for prolonged postoperative stay.

Conclusions. The new STS risk models for valve surgery include mitral valve repair as well as multiple endpoints other than mortality. Model coefficients are provided and an online risk calculator is publicly available from The Society of Thoracic Surgeons website.

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Models for predicting surgical outcomes on the basis of patient preoperative characteristics are valuable tools for research, quality improvement, and clinical practice. Such models are used by The Society of Thoracic Surgeons (STS) to produce risk-adjusted performance re-

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Abbreviations and Acronyms

AVR	=	aortic valve replacement
CABG	=	coronary artery bypass graft surgery
CI	=	confidence interval
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 for Thoracic Surgeons

ports for providers participating in the STS National Adult Cardiac Surgery Database (NCD). They are also used by STS surgeons and other physicians for counseling patients about the risk of surgery.

The earliest STS risk models were developed nearly 2 decades ago for isolated coronary artery bypass graft surgery (CABG). Subsequently, similar models have been developed for isolated valve replacement and combined CABG plus valve replacement. Because surgical practice and outcomes are changing rapidly, these models are updated periodically to reflect contemporary experience.

The last published STS model for isolated valve surgery was based on STS data from 1994 to 1997. The reference population included aortic and mitral valve replacements but excluded mitral valve repair, and the endpoint was operative mortality. In the decade since this model was published, many aspects of heart surgery have changed. First, as CABG volumes have decreased with the introduction of coronary stents, valve surgery as a proportion of overall heart surgery volume has increased in most practices. Between 2000 and 2006, the percentage of isolated CABG procedures decreased from 73% to 60% and the percentage of isolated valve procedures increased from 18% to 22%. Thus, in assessing provider performance, it is no longer sufficient only to consider isolated CABG surgery. Second, the frequency of mitral repair as a percentage of all isolated mitral operations in the STS NCD increased from 35% in 2000 to 53% in 2006. Third, during the same time period, the average mortality rate for isolated aortic or mitral surgery also decreased. Finally, efforts to measure and compare surgical performance have intensified and expanded. In addition to measuring operative mortality, performance reports increasingly focus on nonfatal complications as well as resource utilization and efficiency. Such outcomes have not historically been risk-adjusted for valve surgery.

The STS Quality Measurement Task Force (QMTF) has undertaken a complete revision of all STS risk models for adult cardiac surgery, and these new models were implemented in January 2008. This report, Part 2 of 3, describes the new STS models for isolated valve surgery (Part 1 describes the STS isolated CABG models, and Part 3 describes the models for CABG plus valve surgery). Authors of this report are the QMTF members who were involved in this initiative.

Two important features have been incorporated into these new models. First, the population includes mitral valve repair as well as aortic and mitral valve replacement. Second, in addition to operative mortality, the new models include six nonfatal in-hospital morbidity endpoints and two length-of-stay endpoints. In comparison with several other valve models that have recently been published [1–6], the STS models are distinguished by the large size of the development population and the broad spectrum of endpoints included.

Study Population and Endpoints

The population for this analysis consisted of operations on adult patients aged 20 to 100 years who underwent isolated single aortic or mitral valve surgery between January 1, 2002, and December 31, 2006. Only patients undergoing one of the following procedures were included: (1) isolated aortic valve replacement (AVR); (2) isolated mitral valve replacement (MVR); and (3) isolated mitral valve repair (MVRepair).

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 concomitant CABG were excluded from the current analysis, but these were included in the separate STS valve plus CABG models described in Part 3 of this series. Records with missing data on sex (n = 44) were excluded because missing sex is not allowed in the analysis dataset used for creating STS database participant feedback reports. This left a final study population of 109,759 patient operations performed at 809 STS NCD participating groups. Patients on dialysis preoperatively (n = 2,699) were not included when developing the risk model for prediction of postoperative renal failure.

Patient characteristics in the study population are presented 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

Risk models were developed for nine endpoints, identical to those in the STS CABG models. In contrast with the definition of operative mortality, which includes hospital deaths as well as deaths that occur after discharge within 30 days of surgery, the morbidity endpoints only include events that occurred before discharge. However, beginning with version 2.61, sternal infection data will be recorded for as long as 30 days postoperatively. The nine endpoints are as follows: (1) operative mortality: death during the same

Table 1. Distribution of Risk Factors in Overall Study Population Isolated Valve (2002–2006)

	Overall Valve (n = 109,759)		AVR (n = 67,292)		MVR (n = 21,229)		MVRepair (n = 21,238)	
Variable	N	%	N	%	N	%	N	%
Demographics								
Age, years								
< 55	28,147	25.6	13,227	19.66	6,601	31.09	8,319	39.17
55–64	23,258	21.2	12,987	19.30	4,833	22.77	5,438	25.61
65–74	28,145	25.6	18,299	27.19	5,294	24.94	4,552	21.43
≥75	30,209	27.5	22,779	33.85	4,501	21.20	2,929	13.79
Sex								
Male	60,752	55.4	39,209	58.27	9,055	42.65	12,488	58.80
Female	49,007	44.6	28,083	41.73	12,174	57.35	8,750	41.20
Race								
Caucasian	93,522	85.2	58,656	87.17	16,810	79.18	18,056	85.02
Black	7,630	7.0	3,555	5.28	2,383	11.23	1,692	7.97
Hispanic	3,680	3.4	2,344	3.48	889	4.19	447	2.10
Asian	1,538	1.4	719	1.07	437	2.06	382	1.80
Other	2,493	2.3	1,508	2.24	505	2.38	480	2.26
Missing	896	0.8	510	0.76	205	0.97	181	0.85
Risk factors								
Body surface area, m^2								
< 1.50	4,351	4.0	2,341	3.48	1,234	5.81	776	3.65
1.50–1.74	24,577	22.4	13,713	20.38	6,151	28.97	4,713	22.19
1.75–1.99	40,548	36.9	24,744	36.77	7,914	37.28	7,890	37.15
≥ 2.00	39,517	36.0	26,007	38.65	5,768	27.17	7,742	36.45
Missing	766	0.7	487	0.72	162	0.76	117	0.55
Body mass index, kg/m^2								
< 25	35,526	32.4	18,509	27.51	8,447	39.79	8,570	40.35
25–29	39,074	35.6	24,035	35.72	6,992	32.94	8,047	37.89
30–34	20,534	18.7	14,142	21.02	3,318	15.63	3,074	14.47
≥ 35	13,682	12.5	10,008	14.87	2,280	10.74	1,394	6.56
Missing	943	0.9	598	0.89	192	0.90	153	0.72
Diabetes mellitus								
No diabetes	88,709	80.8	52,052	77.35	17,535	82.60	19,122	90.04
Diabetes, noninsulin	14,900	13.6	11,026	16.39	2,412	11.36	1,462	6.88
Diabetes, insulin	5,788	5.3	3,974	5.91	1,216	5.73	598	2.82
Diabetes missing	138	0.1	91	0.14	34	0.16	13	0.06
Treatment missing	224	0.2	149	0.22	32	0.15	43	0.20
Hypertension								
No	41,649	37.9	22,338	33.20	8,859	41.73	10,452	49.21
Yes	67,886	61.9	44,816	66.60	12,326	58.06	10,744	50.59
Missing	224	0.2	138	0.21	44	0.21	42	0.20
Hypercholesterolemia								
No	59,003	53.8	33,156	49.27	12,857	60.56	12,990	61.16
Yes	50,328	45.9	33,865	50.33	8,286	39.03	8,177	38.50
Missing	428	0.4	271	0.40	86	0.41	71	0.33
Past or present smoker								
No	57,609	52.5	33,953	50.46	11,075	52.17	12,581	59.24
Yes	51,910	47.3	33,191	49.32	10,109	47.62	8,610	40.54
Missing	240	0.2	148	0.22	45	0.21	47	0.22
Chronic lung disease								
None	87,826	80.0	53,503	79.51	16,125	75.96	18,198	85.69
Mild	11,184	10.2	6,991	10.39	2,520	11.87	1,673	7.88
Moderate	6,346	5.8	4,022	5.98	1,494	7.04	830	3.91
Severe	3,332	3.0	2,110	3.14	853	4.02	369	1.74
Missing	1,071	1.0	666	0.99	237	1.12	168	0.79

Table 1. Continued

Variable	Overall Valve (n = 109,759)		AVR (n = 67,292)		MVR (n = 21,229)		MVRepair (n = 21,238)	
	N	%	N	%	N	%	N	%
Peripheral vascular disease								
No	101,129	92.1	61,222	90.98	19,550	92.09	20,357	95.85
Yes	8,381	7.6	5,909	8.78	1,641	7.73	831	3.91
Missing	249	0.2	161	0.24	38	0.18	50	0.24
Cerebrovascular disease								
No	96,852	88.2	58,983	87.65	18,158	85.53	19,711	92.81
Yes	12,661	11.5	8,147	12.11	3,033	14.29	1,481	6.97
Missing	246	0.2	162	0.24	38	0.18	46	0.22
CVA								
No CVA	101,631	92.6	62,518	92.91	18,833	88.71	20,280	95.49
Remote CVA (> 2 weeks)	6,926	6.3	4,203	6.25	1,912	9.01	811	3.82
Recent CVA (≤ 2 weeks)	818	0.7	325	0.48	409	1.93	84	0.40
CVA–missing timing	100	0.1	60	0.09	29	0.14	11	0.05
Missing	284	0.3	186	0.28	46	0.22	52	0.24
Endocarditis								
No endocarditis	100,998	92.0	63,257	94.00	17,926	84.44	19,815	93.30
Treated endocarditis	4,197	3.8	1,761	2.62	1,445	6.81	991	4.67
Active endocarditis	4,238	3.9	2,068	3.07	1,791	8.44	379	1.78
Endocarditis–missing type	63	0.1	30	0.04	27	0.13	6	0.03
Missing	263	0.2	176	0.26	40	0.19	47	0.22
Renal failure								
No	102,205	93.1	62,873	93.43	19,016	89.58	20,316	95.66
Yes	7,305	6.7	4,251	6.32	2,173	10.24	881	4.15
Missing	249	0.2	168	0.25	40	0.19	41	0.19
Renal function								
Creatinine < 1.00 mg/dL	42,028	38.3	25,679	38.16	7,754	36.53	8,595	40.47
Creatinine 1–1.49 mg/dL	51,939	47.3	32,058	47.64	9,372	44.15	10,509	49.48
Creatinine 1.50–1.99 mg/dL	8,081	7.4	5,078	7.55	1,875	8.83	1,128	5.31
Creatinine 2.00–2.49 mg/dL	1,946	1.8	1,192	1.77	512	2.41	242	1.14
Creatinine ≥ 2.50 mg/dL	1,294	1.2	750	1.11	390	1.84	154	0.73
Dialysis	2,699	2.5	1,464	2.18	900	4.24	335	1.58
Missing	1,772	1.6	1,071	1.59	426	2.01	275	1.29
Immunosuppressive treatment								
No	106,037	96.6	64,953	96.52	20,356	95.89	20,728	97.60
Yes	3,336	3.0	2,074	3.08	819	3.86	443	2.09
Missing	386	0.4	265	0.39	54	0.25	67	0.32
Previous CV interventions								
Previous coronary artery bypass surgery								
No	98,978	90.2	60,351	89.69	18,564	87.45	20,063	94.47
Yes	10,399	9.5	6,713	9.98	2,569	12.10	1,117	5.26
Missing	382	0.3	228	0.34	96	0.45	58	0.27
Previous valve surgery								
No	100,179	91.3	62,898	93.47	16,857	79.41	20,424	96.17
Yes	9,227	8.4	4,186	6.22	4,285	20.18	756	3.56
Missing	353	0.3	208	0.31	87	0.41	58	0.27
Previous other cardiac surgery								
No	105,686	96.3	65,084	96.72	20,034	94.37	20,568	96.85
Yes	3,662	3.3	1,975	2.93	1,077	5.07	610	2.87
Missing	411	0.4	233	0.35	118	0.56	60	0.28
Number of previous CV surgeries								
No prior CV surgery	91,196	83.1	56,629	84.15	15,239	71.78	19,328	91.01
1 prior CV surgery	15,399	14.0	9,122	13.56	4,775	22.49	1,502	7.07
2 or more prior CV surgeries	2,653	2.4	1,260	1.87	1,069	5.04	324	1.53
Missing	511	0.5	281	0.42	146	0.69	84	0.40

Table 1. Continued

	Overall Valve (n = 109,759)		AVR (n = 67,292)		MVR (n = 21,229)		MVRepair (n = 21,238)	
Variable	N	%	N	%	N	%	N	%
Prior PCI								
No PCI	101,878	92.8	62,145	92.35	19,573	92.20	20,160	94.92
PCI within 6 hours	122	0.1	58	0.09	51	0.24	13	0.06
PCI not within 6 hours	7,100	6.5	4,678	6.95	1,447	6.82	975	4.59
PCI–missing timing	133	0.1	90	0.13	28	0.13	15	0.07
Missing	526	0.5	321	0.48	130	0.61	75	0.35
Preoperative cardiac status								
Acuity status								
Elective	84,052	76.6	51,734	76.88	14,293	67.33	18,025	84.87
Urgent	23,795	21.7	14,670	21.80	6,071	28.60	3,054	14.38
Emergent	1,555	1.4	685	1.02	747	3.52	123	0.58
Emergent salvage	154	0.1	70	0.10	78	0.37	6	0.03
Missing	203	0.2	133	0.20	40	0.19	30	0.14
MI								
No prior MI	99,416	90.6	60,850	90.43	18,716	88.16	19,850	93.46
MI > 21 days	7,785	7.1	4,770	7.09	1,848	8.71	1,167	5.49
MI 8–21 days	719	0.7	480	0.71	170	0.80	69	0.32
MI 1–7 days	1,247	1.1	863	1.28	315	1.48	69	0.32
MI > 6 and < 24 hours	142	0.1	61	0.09	66	0.31	15	0.07
MI ≤ 6 hours	90	0.1	42	0.06	40	0.19	8	0.04
MI–missing timing	127	0.1	79	0.12	33	0.16	15	0.07
Missing	233	0.2	147	0.22	41	0.19	45	0.21
Angina								
No	85,364	77.8	49,573	73.67	17,598	82.90	18,193	85.66
Yes	24,164	22.0	17,577	26.12	3,591	16.92	2,996	14.11
Missing	231	0.2	142	0.21	40	0.19	49	0.23
Cardiogenic shock								
No	108,163	98.5	66,646	99.04	20,460	96.38	21,057	99.15
Yes	1,329	1.2	485	0.72	725	3.42	119	0.56
Missing	267	0.2	161	0.24	44	0.21	62	0.29
Resuscitation								
No	108,958	99.3	66,832	99.32	20,992	98.88	21,134	99.51
Yes	533	0.5	297	0.44	186	0.88	50	0.24
Missing	268	0.2	163	0.24	51	0.24	54	0.25
Arrhythmia								
No arrhythmia	89,779	81.8	57,451	85.38	14,604	68.79	17,724	83.45
AFib/flutter	16,124	14.7	7,569	11.25	5,721	26.95	2,834	13.34
Heart block	1,598	1.5	1,109	1.65	315	1.48	174	0.82
Sustained VT/VF	984	0.9	486	0.72	290	1.37	208	0.98
Arrhythmia–other	688	0.6	324	0.48	175	0.82	189	0.89
Arrhythmia–missing type	312	0.3	175	0.26	74	0.35	63	0.30
Missing	274	0.2	178	0.26	50	0.24	46	0.22
Preoperative IABP								
No	107,945	98.3	66,733	99.17	20,332	95.77	20,880	98.31
Yes	1,431	1.3	342	0.51	809	3.81	280	1.32
Missing	383	0.3	217	0.32	88	0.41	78	0.37
NYHA class								
I	17,413	15.9	10,222	15.19	2,706	12.75	4,485	21.12
II	32,360	29.5	20,295	30.16	4,915	23.15	7,150	33.67
III	40,321	36.7	25,483	37.87	8,205	38.65	6,633	31.23
IV	14,324	13.1	8,104	12.04	4,256	20.05	1,964	9.25
Missing	5,341	4.9	3,188	4.74	1,147	5.40	1,006	4.74

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Table 1. Continued

	Overall Valve (n = 109,759)		AVR (n = 67,292)		MVR (n = 21,229)		MVRepair (n = 21,238)	
Variable	N	%	N	%	N	%	N	%
Congestive heart failure								
No	64,608	58.9	41,972	62.37	9,341	44.00	13,295	62.60
Yes	44,934	40.9	25,185	37.43	11,849	55.82	7,900	37.20
Missing	217	0.2	135	0.20	39	0.18	43	0.20
Number of diseased coronary vessels								
None	90,281	82.3	55,072	81.84	17,525	82.55	17,684	83.27
One	8,947	8.2	5,393	8.01	1,498	7.06	2,056	9.68
Two	3,386	3.1	2,180	3.24	735	3.46	471	2.22
Three	5,611	5.1	3,766	5.60	1,147	5.40	698	3.29
Missing	1,534	1.4	881	1.31	324	1.53	329	1.55
Left main disease ≥ 50%								
No	106,462	97.0	65,328	97.08	20,495	96.54	20,639	97.18
Yes	1,625	1.5	1,127	1.67	289	1.36	209	0.98
Missing	1,672	1.5	837	1.24	445	2.10	390	1.84
Ejection fraction, %								
< 25	2,694	2.5	1,774	2.64	341	1.61	579	2.73
25–34	5,900	5.4	3,810	5.66	1,052	4.96	1,038	4.89
35–44	10,035	9.1	6,181	9.19	2,208	10.40	1,646	7.75
45–54	20,481	18.7	12,411	18.44	4,382	20.64	3,688	17.37
≥ 55	60,890	55.5	36,584	54.37	11,308	53.27	12,998	61.20
Missing	9,759	8.9	6,532	9.71	1,938	9.13	1,289	6.07
Aortic stenosis								
No	54,457	49.6	13,309	19.78	20,303	95.64	20,845	98.15
Yes	54,681	49.8	53,722	79.83	696	3.28	263	1.24
Missing	621	0.6	261	0.39	230	1.08	130	0.61
Mitral stenosis								
No	100,609	91.7	65,186	96.87	15,383	72.46	20,040	94.36
Yes	8,155	7.4	1,401	2.08	5,676	26.74	1,078	5.08
Missing	995	0.9	705	1.05	170	0.80	120	0.57
Tricuspid stenosis								
No	108,073	98.5	66,243	98.44	20,821	98.08	21,009	98.92
Yes	331	0.3	152	0.23	120	0.57	59	0.28
Missing	1,355	1.2	897	1.33	288	1.36	170	0.80
Pulmonic stenosis								
No	107,512	98.0	65,842	97.85	20,783	97.90	20,887	98.35
Yes	141	0.1	91	0.14	29	0.14	21	0.10
Missing	2,106	1.9	1,359	2.02	417	1.96	330	1.55
Aortic insufficiency								
None	59,905	54.6	25,861	38.43	16,701	78.67	17,343	81.66
Trivial	9,191	8.4	5,916	8.79	1,661	7.82	1,614	7.60
Mild	13,282	12.1	10,014	14.88	1,798	8.47	1,470	6.92
Moderate	9,501	8.7	8,815	13.10	382	1.80	304	1.43
Severe	15,722	14.3	15,529	23.08	109	0.51	84	0.40
Missing	2,158	2.0	1,157	1.72	578	2.72	423	1.99
Mitral insufficiency								
None	43,731	39.8	40,453	60.12	2,283	10.75	995	4.68
Trivial	7,743	7.1	7,285	10.83	388	1.83	70	0.33
Mild	14,455	13.2	13,066	19.42	1,089	5.13	300	1.41
Moderate	10,224	9.3	4,438	6.60	3,246	15.29	2,540	11.96
Severe	31,813	29.0	573	0.85	14,045	66.16	17,195	80.96
Missing	1,793	1.6	1,477	2.19	178	0.84	138	0.65

Table 1. Continued

	Overall Valve (n = 109,759)		AVR (n = 67,292)		MVR (n = 21,229)		MVRepair (n = 21,238)	
Variable	N	%	N	%	N	%	N	%
Tricuspid insufficiency								
None	78,472	71.5	49,976	74.27	14,266	67.20	14,230	67.00
Trivial	8,856	8.1	5,612	8.34	1,381	6.51	1,863	8.77
Mild	13,346	12.2	7,333	10.90	2,788	13.13	3,225	15.19
Moderate	5,167	4.7	2,126	3.16	1,753	8.26	1,288	6.06
Severe	974	0.9	297	0.44	460	2.17	217	1.02
Missing	2,944	2.7	1,948	2.89	581	2.74	415	1.95
Pulmonic insufficiency								
None	97,954	89.2	60,463	89.85	18,837	88.73	18,654	87.83
Trivial	4,161	3.8	2,370	3.52	779	3.67	1,012	4.77
Mild	2,541	2.3	1,340	1.99	573	2.70	628	2.96
Moderate	441	0.4	209	0.31	144	0.68	88	0.41
Severe	76	0.1	34	0.05	30	0.14	12	0.06
Missing	4,586	4.2	2,876	4.27	866	4.08	844	3.97

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

hospitalization as surgery, regardless of timing, or within 30 days of surgery regardless of venue; (2) permanent stroke (cerebrovascular accident [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 greater than 2.0 mg/dL and double the most recent preoperative creatinine level; (4) prolonged ventilation (longer than 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 (9) short postoperative LOS (SLOS): LOS less than 6 days and patient alive at discharge.

Table 2 summarizes the endpoint frequencies in the study population.

Single Versus Multiple Models

Two issues required particularly careful consideration: whether to construct separate models for the AVR and MVR populations, and how best to further subdivide the mitral population into repair versus replacement.

Because of the large size of the STS NCD, separate

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

	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
All isolated valve (AVR, MVR, MVRepair)									
N	109,759	109,759	107,060	109,759	109,759	109,759	109,759	109,759	109,759
Events	3,706	1,751	4,673	12,892	307	9,164	20,074	9,718	41,214
%	3.4	1.6	4.3	11.8	0.3	8.4	18.3	8.9	37.6
AVR									
N	67,292	67,292	65,828	67,292	67,292	67292	67,292	67,292	67,292
Events	2,157	1,007	2,774	7,323	197	5369	11,706	5,308	26,144
%	3.2	1.5	4.1	10.9	0.3	8.0	17.4	7.9	38.9
MVR									
N	21,229	21,229	20,329	21,229	21,229	21229	21,229	21,229	21,229
Events	1,210	447	1,348	4,015	71	2450	5,675	3,244	4,727
%	5.7	2.1	6.4	18.9	0.3	11.5	26.7	15.3	22.3
MVRepair									
N	21,238	21,238	20,903	21,238	21,238	21,238	21,238	21,238	21,238
Events	339	297	551	1,554	39	1,345	2,693	1,166	10,343
%	1.6	1.4	2.6	7.3	0.2	6.3	12.7	5.5	48.7

AVR = aortic valve replacement; 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.

models for AVR, MVR, and MVRepair initially seemed both feasible and appropriate. However, because the endpoints of interest are rare events, we recognized the possibility that the number of such events would be too small to support reliable estimation of the model coefficients.

To assess this tradeoff, we conducted a pilot study to compare two alternative strategies for developing risk models for isolated valve surgery. The first strategy involved developing models separately for three subpopulations (AVR, MVR, and MVRepair). The second strategy involved modeling all three subpopulations together in a single model; several interaction terms were included to allow the effect of selected risk factors to differ across the subpopulations. Both strategies were pilot tested by developing risk models for two endpoints: operative mortality and permanent stroke. These pilot models were developed in a 60% development sample and tested in a separate 40% validation sample. Each model was assessed by calculating the c-index and the generalized R^2 index of Nagelkerke [7] in the validation sample for each combination of subpopulation and endpoint (3 subpopulations $\times$ 2 endpoints = 6 combinations). With the exception of AVR operative mortality, the combined model with interactions resulted in better discrimination. With the exception of MVR and MVrepair operative mortality, the combined model also captured more variation as measured by the generalized R^2 statistic.

Because the combined model strategy performed better in the majority of cases, and because a single combined model was consistent with the previous STS valve model, the combined model strategy was selected. To avoid assuming that the weighting of each risk factor was exactly constant across the three populations, we included interactions between surgery type and several key predictor variables. In principle, fitting a single model with several interactions is advantageous because it allows for pooling information across related groups without making an a priori assumption that all of the covariate effects are exactly constant across groups.

Selection of Candidate Predictor Variables

Our general approach to variable selection is discussed in Part 1 of this series describing the development of the 2008 STS isolated CABG risk models. Briefly, we initially identified potential candidate variables by reviewing four versions of the STS data collection instrument (data versions 2.35, 2.41, 2.52.1, and 2.61) as well as previously published STS and similar cardiac risk models [1–6]. A panel of cardiac surgeons and health policy experts reviewed the initial variables for face validity and to be certain that no important predictor variables available in (or mappable to) to STS NCD data version 2.61 had been excluded.

Final candidate explanatory variables and their coding are summarized in Table 3. The variables were identical to the CABG model candidate variables with the following differences: (1) percutaneous coronary intervention conducted within 6 hours or less of surgery was not a candidate variable because it was present in only 122 patients (0.1%) in the valve model population; (2) infectious endocarditis was included. This risk factor was rarely present among isolated CABG patients (0.09%), but was not uncommon (7.7%) among patients undergoing valve surgery; (3) mitral stenosis was included; this risk factor was rarely present among isolated CABG patients (0.35%) but was common (7.4%) among patients undergoing valve surgery; and (4) an indicator for surgery type (AVR, MVR, MVRepair) was included in the valve models.

Coding of Explanatory Variables

The coding of continuous and categorical variables was identical to the CABG models, except for the following differences: (1) age was modeled as a linear spline truncated from below at 50 years and with a change of slope at 75; (2) creatinine was modeled as a linear term with values less than 0.5 and greater than 5.0 mapped to those values respectively (approximately the 1st and 99th percentiles of the empirical distribution); (3) previous myocardial infarction (MI) was modeled as three categories ($<$ 24 hours, 1 to 21 days, and $>$ 21 days or no MI); the first two categories were subsequently combined after expert panel review; (4) race was modeled as three categories: black, Hispanic, Caucasian/other; and (5) chronic lung disease was modeled as linear across four categories (none, mild, moderate, severe).

In general, these differences reflect a slightly simpler coding scheme (fewer parameters) for the valve models compared with the isolated CABG models.

Repair Versus Replacement

In addition to a number of variables whose inclusion or coding were noted to be problematic during development of the 2008 STS isolated CABG models (Part 1 of this series), the approach to modeling mitral valve repair versus replacement was of some concern in the valve models. From a methodologic perspective, models used for risk-adjustment should include all patient preoperative risk factors that vary in prevalence between institutions and that substantially impact the probability of an adverse outcome. Such models should include variables that reflect the patient's baseline condition but should not include intraoperative events (eg, unexpected hemorrhage) or discretionary care processes (eg, use of a mechanical versus bioprosthetic valve). Adjusting for intraoperative events is not appropriate because these may be a reflection of the surgeon's performance. Adjusting for discretionary care processes may likewise mask differences in performance if the surgeon's choice of procedures has a substantial impact on outcomes. The same patient may receive valve repair if treated by one surgeon and replacement if treated by another. Adjusting for repair versus replacement will potentially conceal the outcomes of surgeons who achieve excellent results by repairing technically challenging valves that might otherwise be replaced if treated by a surgeon with less skill or tenacity. Importantly, there is considerable evidence to suggest the superiority of valve repair whenever feasible.

However, in addition to such discretionary factors, the decision to repair rather than replace the mitral valve is

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

Candidate Variables	Coding
Continuous variables	
Age[a]	Linear spline truncated from below at 50 and 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: body surface area < 1.4 and > 2.6 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 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
Preoperative 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	
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
Number diseased coronary vessels	3 groups: < 2, 2, 3. Modeled as linear across the categories
MI	3 groups: < 24 hr, 1–21 days, > 21 days or no MI (groups 1 and 2 were subsequently collapsed)
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+NYHA IV
Surgery type	3 groups: AVR, MVR, MVRepair
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.

also dependent upon the patient's preoperative valve disease etiology, anatomy, and pathophysiology. On average, patients amenable to valve repair have less extensive valve pathology and a relatively favorable postoperative prognosis (the mortality rate for valve repair is 1.6% compared with 5.7% for replacement). Ignoring these anatomical differences can introduce bias when comparing institutions, especially because these variables are not captured elsewhere on the STS data collection form.

A related difficulty in adjusting for repair versus re-

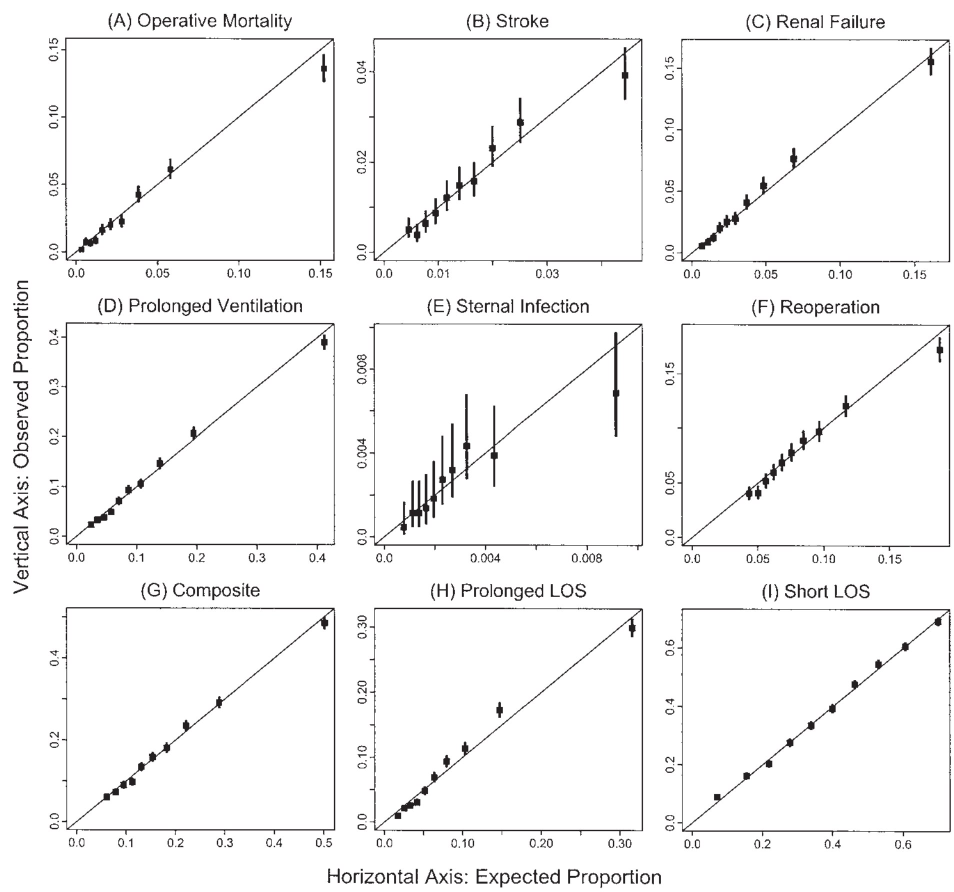

Fig 1. Plots of observed (O) versus expected (E) in validation sample

placement is that the former approach may sometimes be abandoned intraoperatively by the surgeon and converted to MVR. That may sometimes occur because of unforeseen technical problems that would prevent most surgeons from completing the repair, but in other instances, a more skilled surgeon might persist and achieve successful valve repair. Effectively separating these two scenarios is problematic from available data.

Ultimately, it was elected to include an indicator for mitral valve repair versus replacement in the valve risk models, consistent with the approach in a number of existing valve surgery models. We acknowledge that available data make it impossible to determine whether patient differences or surgical skill and judgment are the most important factors in determining between-provider variation in the proportion of valves repaired.

Recognizing the potential limitations of this modeling approach, the decision to adjust for repair versus replacement may be reassessed in future versions of the STS risk models. Beginning with data in version 2.61, the database will capture whether or not repair was attempted, and repair versus replacement may be analyzed based on an intention-to-treat principle.

Missing Data

Model variables with more than 1% missing data in the study sample were ejection fraction (8.9%), NYHA class (4.9%), tricuspid insufficiency (2.7%), aortic insufficiency (2.0%), mitral insufficiency (1.6%), left main disease (1.5%), creatinine/dialysis (1.6%), and number of diseased vessels (1.4%). The method of imputing missing data was identical to that employed in the isolated CABG models and described in Part 1 of this series. Briefly, binary risk factors were modeled as yes versus no or missing (ie, missing values were analyzed as if the endpoint did not occur). Missing data on categorical variables were imputed to the lowest risk value, typically the mode, and outcomes were typically similar for missing data and lowest risk patients. Missing data on continuous variables were imputed by grouping patients into strata and assigning the stratum-specific median value. For example, ejection fraction was imputed by grouping on sex and congestive heart failure and calculating the median ejection fraction among patients with nonmissing ejection fraction in each group.

Although multiple imputation is generally preferable to single imputation [8], single imputation was chosen for this analysis mainly because of practical considerations. Furthermore, because of the small fraction of missing data, the impact of single versus multiple imputation was considered to be inconsequential. Subsequent sensitivity analyses confirmed that the choice between single versus multiple imputation had little impact on the final regression coefficients, risk estimates, and confidence intervals. A summary of these sensitivity analyses, including coef-

Table 4. Discrimination of Models in Development and Validation Samples

	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
Overall									
Development sample	0.805	0.694	0.782	0.770	0.704	0.643	0.721	0.770	0.738
Validation sample	0.799	0.691	0.762	0.762	0.659	0.639	0.718	0.773	0.734
AVR									
Development sample	0.779	0.679	0.766	0.748	0.710	0.630	0.698	0.752	0.713
Validation sample	0.759	0.689	0.749	0.736	0.637	0.619	0.694	0.759	0.713
MVR									
Development sample	0.794	0.679	0.767	0.772	0.591	0.642	0.735	0.748	0.726
Validation sample	0.802	0.702	0.748	0.772	0.656	0.634	0.738	0.729	0.710
MVRepair									
Development sample	0.855	0.736	0.813	0.765	0.774	0.616	0.703	0.777	0.733
Validation sample	0.844	0.672	0.788	0.773	0.714	0.646	0.712	0.800	0.725

AVR = aortic valve replacement; 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.

ficients 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 final candidate variables except for interaction terms. Age, sex, body surface area, and month of surgery were forced into each model. Other variables were selected in a stepwise fashion using a significance criterion of 0.05 for entry and removal. This criterion was less stringent than that employed in development of the CABG models, because the sample size in the former was so much larger than that which was used for the valve models. The stepwise procedure was performed separately for each endpoint. The results were then reviewed by an expert panel of surgeons, and the following changes were made based on their feedback: (1) "MI less than 24 hours" and "MI 1 to 21 days" were collapsed into a single category; (2) preoperative atrial fibrillation was forced into the model for stroke (CVA); and (3) an indicator variable for dialysis was forced into any model that included creatinine level.

Interaction Terms

In addition to including main effects, we tested the interaction between surgery group (AVR, MVR, MVRepair) and each of the following variables: age, diabetes mellitus, dialysis, creatinine, reoperation, endocarditis, emergent status, chronic lung disease, congestive heart failure, ejection fraction, sex, shock, intra-aortic balloon pump/inotropes, mitral insufficiency, aortic insufficiency, mitral stenosis, and aortic stenosis. These interaction terms allowed the effect of these selected risk factors to differ across the surgery populations.

Four additional sets of interactions were also included in the models: (1) sex by body surface area (BSA); (2) sex by BSA^2; (3) age by reoperation; and (4) age by emergent status. These interaction terms were preselected and were not tested as part of the backward selection algorithm. Additional technical details are provided in the Appendix. For reasons described in Part 1 of this series (isolated CABG risk models), an extensive automated search for additional interaction terms was not conducted.

Adjustment for Time Trends

Surgery date was included in each model to adjust for changes in the frequency of adverse outcomes over the 5-year study period. Although surgery date is not itself a variable of interest, we adjusted for it to reduce potential confounding by time trends when estimating regression coefficients for the variables that are of primary interest (ie, patient preoperative risk factors). An example is provided in Part 1 of this series.

Surgery date was categorized into 6-month intervals (corresponding to the biannual STS data harvests) and modeled as a linear trend across the ordinal categories. Because it is a nuisance variable, surgery date is not included in the final risk prediction algorithm. Thus, a patient's predicted risk does not depend on the patient's surgery date. As described in the Appendix, the published intercept parameter has been adjusted to incorporate the time trend. The adjusted intercept reflects the baseline risk for a reference period of July to December 2006.

Results

Assessment of Model Fit and Discrimination

Because of the relatively large size of our sample, the Hosmer-Lemeshow test is uninformative and would invariably result in a significant p value [9]. As an alternative, model fit was assessed graphically by plotting observed versus predicted rates of each endpoint across deciles of predicted risk in the development and validation samples. This was done in the overall population and in subgroups based on surgery type (AVR, MVR, MVRepair); age (< 60, 60 to 79, ≥ 80 years); sex (male, female); diabetes mellitus (yes/no); status (elective, nonelective); and ejection fraction

Table 5. Odds Ratios (95% Confidence Intervals) for the Final Selected 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 (1.10, 1.31)	1.06 (0.93, 1.20)	NA	1.18 (1.11, 1.25)	NA	1.11 (1.04, 1.18)	1.12 (1.07, 1.18)	1.17 (1.10, 1.24)	0.74 (0.70, 0.78)
BSA 1.6 versus 2.0 among females	1.19 (1.09, 1.30)	1.18 (1.03, 1.35)	0.95 (0.87, 1.04)	1.15 (1.08, 1.22)	0.42 (0.27, 0.68)	1.26 (1.18, 1.34)	1.17 (1.12, 1.23)	1.11 (1.04, 1.17)	0.99 (0.95, 1.04)
BSA 1.6 versus 2.0 among males	1.75 (1.48, 2.07)	1.17 (0.92, 1.47)	1.33 (1.12, 1.58)	1.56 (1.41, 1.74)	0.94 (0.49, 1.84)	1.34 (1.21, 1.49)	1.44 (1.33, 1.57)	1.39 (1.25, 1.56)	0.73 (0.68, 0.79)
BSA 1.8 versus 2.0 among females	0.99 (0.95, 1.04)	1.08 (0.99, 1.17)	0.90 (0.86, 0.94)	1.00 (0.97, 1.03)	0.65 (0.54, 0.77)	1.07 (1.03, 1.11)	1.02 (0.99, 1.04)	0.99 (0.96, 1.02)	1.05 (1.03, 1.08)
BSA 1.8 versus 2.0 among males	1.21 (1.14, 1.29)	1.07 (0.98, 1.16)	1.07 (1.00, 1.14)	1.14 (1.10, 1.19)	0.90 (0.70, 1.14)	1.12 (1.08, 1.16)	1.12 (1.09, 1.16)	1.10 (1.06, 1.15)	0.92 (0.89, 0.94)
BSA 2.2 versus 2.0 among females	1.21 (1.11, 1.33)	0.94 (0.80, 1.10)	1.30 (1.21, 1.41)	1.15 (1.09, 1.21)	1.57 (1.26, 1.96)	1.02 (0.95, 1.09)	1.12 (1.07, 1.16)	1.14 (1.08, 1.21)	0.85 (0.81, 0.88)
BSA 2.2 versus 2.0 among males	0.98 (0.93, 1.03)	0.95 (0.88, 1.03)	1.09 (1.05, 1.14)	1.05 (1.02, 1.08)	1.32 (1.17, 1.48)	0.95 (0.93, 0.98)	1.02 (0.99, 1.04)	1.03 (1.00, 1.07)	0.94 (0.93, 0.96)
Creatinine per 1 unit	1.55 (1.46, 1.64)	1.34 (1.22, 1.47)	2.04 (1.93, 2.16)	1.58 (1.51, 1.65)	NA	1.27 (1.20, 1.33)	1.64 (1.57, 1.71)	1.58 (1.51, 1.65)	0.64 (0.61, 0.68)
CVD with CVA	NA	1.81 (1.56, 2.10)	1.22 (1.09, 1.37)	1.28 (1.18, 1.38)	NA	1.14 (1.05, 1.24)	1.20 (1.12, 1.28)	1.40 (1.29, 1.52)	0.77 (0.72, 0.83)
CVD without CVA	NA	1.32 (1.11, 1.57)	1.23 (1.10, 1.37)	1.14 (1.05, 1.23)	NA	1.06 (0.96, 1.17)	1.08 (1.01, 1.15)	NA	0.80 (0.73, 0.88)
No. diseased coronary vessels (2 versus 1 or 3 versus 2)	NA	1.10 (1.01, 1.20)	NA	1.07 (1.02, 1.11)	NA	NA	1.04 (1.00, 1.08)	1.03 (0.98, 1.08)	0.90 (0.86, 0.94)
EF per 10-unit decrease	1.09 (1.05, 1.14)	NA	1.04 (1.00, 1.09)	1.12 (1.09, 1.15)	1.26 (1.12, 1.41)	1.08 (1.04, 1.11)	1.10 (1.07, 1.12)	1.12 (1.08, 1.15)	0.87 (0.85, 0.90)
Hypertension	1.12 (1.03, 1.22)	1.19 (1.07, 1.33)	1.35 (1.25, 1.45)	1.11 (1.06, 1.17)	NA	NA	1.11 (1.07, 1.15)	NA	0.94 (0.91, 0.97)
Immunosuppressive treatment	1.42 (1.21, 1.67)	NA	1.39 (1.19, 1.62)	NA	NA	NA	1.16 (1.06, 1.27)	1.31 (1.17, 1.47)	NA
Left main disease	1.19 (0.98, 1.46)	NA	1.19 (0.98, 1.44)	NA	2.17 (1.13, 4.16)	NA	NA	NA	NA
Active infectious endocarditis	1.95 (1.68, 2.27)	1.87 (1.52, 2.29)	2.17 (1.88, 2.50)	2.15 (1.95, 2.36)	NA	1.55 (1.39, 1.73)	1.97 (1.80, 2.15)	2.79 (2.51, 3.09)	0.34 (0.30, 0.38)
Mitral insufficiency, moderate/severe	NA	1.26 (1.14, 1.39)	NA	NA	NA	NA	NA	NA	NA
Tricuspid insufficiency, moderate/severe	NA	NA	1.14 (1.01, 1.29)	1.14 (1.04, 1.25)	NA	1.09 (1.00, 1.20)	1.21 (1.12, 1.30)	1.17 (1.05, 1.31)	0.82 (0.73, 0.92)
Peripheral vascular disease	1.25 (1.12, 1.38)	1.29 (1.11, 1.49)	NA	NA	NA	1.22 (1.12, 1.32)	1.14 (1.07, 1.21)	1.17 (1.09, 1.25)	0.83 (0.78, 0.88)
Aortic stenosis		NA	NA	0.90 (0.83, 0.97)	NA	0.90 (0.84, 0.96)	0.93 (0.87, 0.98)	0.86 (0.80, 0.92)	1.07 (1.02, 1.13)
Mitral stenosis	1.24 (1.08, 1.41)	NA	NA	NA	NA	NA	NA	NA	NA
MI ≤ 21 days	1.14 (0.98, 1.34)	NA	NA	1.37 (1.22, 1.55)	NA	1.04 (0.91, 1.18)	1.28 (1.16, 1.41)	1.21 (1.06, 1.37)	0.81 (0.72, 0.91)
Time trend, per 6-month harvest interval	0.98 (0.97, 0.99)	0.98 (0.96, 1.00)	1.01 (0.99, 1.02)	1.02 (1.01, 1.03)	0.97 (0.93, 1.01)	1.00 (0.99, 1.01)	1.01 (1.00, 1.02)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
Race black	NA	1.33 (1.13, 1.57)	1.51 (1.34, 1.69)	1.42 (1.27, 1.58)	NA	1.27 (1.15, 1.40)	1.37 (1.27, 1.49)	1.45 (1.31, 1.60)	0.64 (0.59, 0.70)
Race Hispanic	NA	0.87 (0.64, 1.19)	1.16 (0.97, 1.38)	1.07 (0.94, 1.22)	NA	1.14 (1.00, 1.30)	1.09 (0.98, 1.22)	1.16 (0.98, 1.38)	0.82 (0.72, 0.93)
Status urgent	1.29 (1.19, 1.40)	NA	1.21 (1.11, 1.33)	1.29 (1.20, 1.39)	NA	1.17 (1.10, 1.25)	1.22 (1.15, 1.29)	1.42 (1.33, 1.51)	0.70 (0.66, 0.74)
Unstable angina	1.21 (1.04, 1.41)	NA	NA	NA	NA	NA	NA	NA	NA

Table 5. Continued

B. Odds ratios for aortic valve replacement

Variable	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
Age 60 versus 50	1.43 (1.34, 1.52)	1.48 (1.38, 1.59)	1.38 (1.30, 1.47)	1.31 (1.26, 1.36)	1.52 (1.31, 1.76)	1.16 (1.12, 1.21)	1.23 (1.19, 1.26)	1.31 (1.25, 1.37)	0.75 (0.73, 0.77)
Age 70 versus 50	2.04 (1.79, 2.32)	2.19 (1.90, 2.52)	1.90 (1.68, 2.16)	1.71 (1.59, 1.84)	2.31 (1.72, 3.10)	1.35 (1.25, 1.46)	1.50 (1.42, 1.59)	1.71 (1.55, 1.87)	0.57 (0.54, 0.60)
Age 80 versus 50	3.34 (2.84, 3.93)	3.21 (2.70, 3.81)	2.88 (2.46, 3.37)	2.31 (2.12, 2.52)	2.73 (1.95, 3.80)	1.59 (1.44, 1.76)	1.97 (1.82, 2.12)	2.50 (2.24, 2.79)	0.34 (0.32, 0.36)
CHF, not NYHA IV	1.29 (1.18, 1.42)	NA	1.24 (1.14, 1.34)	1.33 (1.24, 1.43)	NA	NA	1.20 (1.13, 1.27)	1.25 (1.17, 1.34)	0.86 (0.81, 0.91)
CHF, NYHA IV	1.83 (1.62, 2.07)	NA	1.61 (1.44, 1.81)	1.92 (1.77, 2.08)	NA	1.25 (1.17, 1.35)	1.62 (1.51, 1.73)	1.54 (1.40, 1.68)	0.72 (0.65, 0.79)
Diabetes, insulin	1.62 (1.43, 1.83)	NA	1.91 (1.70, 2.14)	1.42 (1.31, 1.55)	1.56 (1.05, 2.31)	1.20 (1.10, 1.31)	1.39 (1.29, 1.50)	1.68 (1.55, 1.83)	0.64 (0.59, 0.69)
Diabetes, noninsulin	1.27 (1.15, 1.39)	NA	1.45 (1.34, 1.57)	1.12 (1.04, 1.20)	NA	NA	1.12 (1.06, 1.18)	1.22 (1.15, 1.30)	0.85 (0.81, 0.88)
Dialysis versus no dialysis and creatinine = 1.0	2.85 (2.35, 3.45)	1.65 (1.34, 2.03)	NA	3.07 (2.74, 3.43)	NA	1.79 (1.60, 2.01)	2.42 (2.21, 2.66)	2.94 (2.64, 3.27)	0.29 (0.24, 0.34)
Preoperative IABP/ inotropes	1.47 (1.26, 1.71)	NA	1.34 (1.15, 1.57)	1.78 (1.55, 2.05)	1.69 (1.08, 2.65)	1.14 (1.02, 1.29)	1.75 (1.59, 1.94)	1.46 (1.30, 1.63)	0.56 (0.48, 0.66)
Shock	1.62 (1.29, 2.03)	1.65 (1.21, 2.25)	NA	2.09 (1.77, 2.47)	NA	1.32 (1.11, 1.58)	2.11 (1.80, 2.49)	1.74 (1.37, 2.21)	NA
Female versus male (at BSA = 1.8)	1.23 (1.10, 1.36)	1.25 (1.09, 1.43)	0.97 (0.88, 1.07)	1.29 (1.21, 1.38)	0.98 (0.72, 1.33)	0.86 (0.81, 0.93)	1.03 (0.98, 1.08)	1.25 (1.16, 1.35)	0.69 (0.66, 0.73)
CLD (moderate versus mild, or severe versus moderate)	1.27 (1.21, 1.33)	NA	1.18 (1.13, 1.23)	1.26 (1.22, 1.30)	1.27 (1.13, 1.42)	1.09 (1.06, 1.12)	1.17 (1.14, 1.20)	1.29 (1.24, 1.34)	0.81 (0.79, 0.83)
Reoperation, 1 previous operation[a]	2.11 (1.78, 2.49)	2.09 (1.64, 2.65)	1.55 (1.31, 1.84)	1.83 (1.64, 2.05)	NA	1.31 (1.16, 1.49)	1.55 (1.42, 1.70)	1.42 (1.27, 1.59)	0.67 (0.62, 0.72)
Reoperation, ≥ 2 previous operations[a]	2.48 (1.99, 3.08)	2.36 (1.76, 3.16)	1.66 (1.33, 2.07)	2.49 (2.14, 2.90)	NA	1.41 (1.19, 1.67)	1.96 (1.73, 2.22)	1.76 (1.52, 2.03)	0.50 (0.43, 0.58)
Status emergent, no resuscitation[a]	3.77 (2.75, 5.16)	2.78 (1.85, 4.17)	3.10 (2.21, 4.35)	4.54 (3.54, 5.83)	NA	1.63 (1.31, 2.03)	3.23 (2.66, 3.93)	2.45 (2.02, 2.97)	0.33 (0.25, 0.42)
Status emergent, with resuscitation or salvage[a]	7.94 (5.40, 11.66)	2.11 (1.06, 4.19)	3.47 (2.19, 5.51)	3.50 (2.41, 5.08)	NA	NA	3.38 (2.36, 4.84)	NA	0.32 (0.19, 0.54)

Table 5. Continued

C. Odds ratios for mitral valve replacement

Variable	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
Age 60 versus 50	1.65 (1.53, 1.78)	1.48 (1.38, 1.59)	1.35 (1.26, 1.44)	1.31 (1.26, 1.36)	1.52 (1.31, 1.76)	1.25 (1.19, 1.31)	1.33 (1.29, 1.39)	1.26 (1.21, 1.33)	0.71 (0.68, 0.74)
Age 70 versus 50	2.71 (2.33, 3.17)	2.19 (1.90, 2.52)	1.81 (1.60, 2.06)	1.71 (1.59, 1.84)	2.31 (1.72, 3.10)	1.56 (1.42, 1.71)	1.78 (1.65, 1.92)	1.60 (1.45, 1.76)	0.50 (0.46, 0.55)
Age 80 versus 50	5.14 (4.15, 6.37)	3.21 (2.70, 3.81)	2.67 (2.23, 3.20)	2.31 (2.12, 2.52)	2.73 (1.95, 3.80)	1.97 (1.72, 2.26)	2.54 (2.27, 2.84)	2.27 (2.00, 2.58)	0.28 (0.25, 0.32)
CHF, not NYHA IV	1.29 (1.18, 1.42)	NA	1.24 (1.14, 1.34)	1.19 (1.07, 1.32)	NA	NA	1.11 (1.01, 1.21)	1.25 (1.17, 1.34)	0.96 (0.87, 1.06)
CHF, NYHA IV	1.83 (1.62, 2.07)	NA	1.61 (1.44, 1.81)	1.72 (1.55, 1.91)	NA	1.25 (1.17, 1.35)	1.49 (1.36, 1.64)	1.54 (1.40, 1.68)	0.80 (0.71, 0.91)
Diabetes, insulin	1.62 (1.43, 1.83)	NA	1.91 (1.70, 2.14)	1.66 (1.47, 1.86)	1.56 (1.05, 2.31)	1.20 (1.10, 1.31)	1.67 (1.52, 1.83)	1.68 (1.55, 1.83)	0.64 (0.59, 0.69)
Diabetes, noninsulin	1.27 (1.15, 1.39)	NA	1.45 (1.34, 1.57)	1.30 (1.16, 1.45)	NA	NA	1.34 (1.22, 1.47)	1.22 (1.15, 1.30)	0.85 (0.81, 0.88)
Dialysis versus no dialysis and creatinine = 1.0	4.59 (3.65, 5.77)	1.65 (1.34, 2.03)	NA	3.07 (2.74, 3.43)	NA	1.79 (1.60, 2.01)	2.42 (2.21, 2.66)	2.94 (2.64, 3.27)	0.23 (0.16, 0.33)
Preoperative IABP/ inotropes	1.47 (1.26, 1.71)	NA	1.34 (1.15, 1.57)	2.21 (1.90, 2.56)	1.69 (1.08, 2.65)	1.14 (1.02, 1.29)	1.75 (1.59, 1.94)	1.46 (1.30, 1.63)	0.63 (0.51, 0.77)
Shock	1.62 (1.29, 2.03)	1.65 (1.21, 2.25)	NA	2.09 (1.77, 2.47)	NA	1.32 (1.11, 1.58)	2.11 (1.80, 2.49)	1.05 (0.85, 1.31)	NA
Female versus male (at BSA=1.8)	1.11 (0.97, 1.27)	1.25 (1.09, 1.43)	0.97 (0.88, 1.07)	1.06 (0.98, 1.16)	0.98 (0.72, 1.33)	0.79 (0.72, 0.87)	1.03 (0.98, 1.08)	1.09 (0.99, 1.19)	0.69 (0.66, 0.73)
CLD (moderate versus mild, or severe versus moderate)	1.08 (1.01, 1.16)	NA	1.18 (1.13, 1.23)	1.26 (1.22, 1.30)	1.27 (1.13, 1.42)	1.09 (1.06, 1.12)	1.17 (1.14, 1.20)	1.16 (1.11, 1.22)	0.81 (0.79, 0.83)
Reoperation, 1 previous operation[a]	2.11 (1.78, 2.49)	2.09 (1.64, 2.65)	1.55 (1.31, 1.84)	1.50 (1.34, 1.67)	NA	1.31 (1.16, 1.49)	1.55 (1.42, 1.70)	1.42 (1.27, 1.59)	0.67 (0.62, 0.72)
Reoperation, ≥ 2 previous operations[a]	2.48 (1.99, 3.08)	2.36 (1.76, 3.16)	1.66 (1.33, 2.07)	2.03 (1.76, 2.35)	NA	1.41 (1.19, 1.67)	1.96 (1.73, 2.22)	1.76 (1.52, 2.03)	0.50 (0.43, 0.58)
Status emergent, no resuscitation[a]	2.74 (1.99, 3.78)	2.78 (1.85, 4.17)	2.20 (1.59, 3.05)	3.19 (2.41, 4.23)	NA	1.63 (1.31, 2.03)	3.23 (2.66, 3.93)	2.45 (2.02, 2.97)	0.33 (0.25, 0.42)
Status emergent, with resuscitation or salvage[a]	5.78 (3.77, 8.85)	2.11 (1.06, 4.19)	2.46 (1.56, 3.88)	2.46 (1.66, 3.65)	NA	NA	3.38 (2.36, 4.84)	NA	0.32 (0.19, 0.54)

Table 5. Continued

D. Odds ratios for mitral valve repair

Variable	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
Age 60 versus 50	1.80 (1.62, 2.00)	1.48 (1.38, 1.59)	1.55 (1.41, 1.71)	1.31 (1.26, 1.36)	1.52 (1.31, 1.76)	1.20 (1.13, 1.27)	1.31 (1.26, 1.37)	1.50 (1.41, 1.60)	0.62 (0.60, 0.65)
Age 70 versus 50	3.24 (2.63, 4.00)	2.19 (1.90, 2.52)	2.42 (2.00, 2.92)	1.71 (1.59, 1.84)	2.31 (1.72, 3.10)	1.44 (1.29, 1.62)	1.73 (1.58, 1.89)	2.25 (1.98, 2.55)	0.39 (0.36, 0.42)
Age 80 versus 50	6.72 (5.00, 9.04)	3.21 (2.70, 3.81)	4.11 (3.14, 5.38)	2.31 (2.12, 2.52)	2.73 (1.95, 3.80)	1.75 (1.48, 2.07)	2.42 (2.12, 2.76)	3.78 (3.17, 4.51)	0.19 (0.17, 0.22)
CHF, not NYHA IV	1.29 (1.18, 1.42)	NA	1.24 (1.14, 1.34)	1.16 (0.99, 1.35)	NA	NA	1.11 (0.99, 1.24)	1.25 (1.17, 1.34)	0.92 (0.80, 1.05)
CHF, NYHA IV	1.83 (1.62, 2.07)	NA	1.61 (1.44, 1.81)	1.67 (1.43, 1.95)	NA	1.25 (1.17, 1.35)	1.50 (1.33, 1.68)	1.54 (1.40, 1.68)	0.76 (0.65, 0.90)
Diabetes, insulin	1.62 (1.43, 1.83)	NA	1.91 (1.70, 2.14)	1.68 (1.42, 1.97)	1.56 (1.05, 2.31)	1.20 (1.10, 1.31)	1.57 (1.36, 1.81)	1.68 (1.55, 1.83)	0.64 (0.59, 0.69)
Diabetes, noninsulin	1.27 (1.15, 1.39)	NA	1.45 (1.34, 1.57)	1.31 (1.11, 1.55)	NA	NA	1.26 (1.10, 1.45)	1.22 (1.15, 1.30)	0.85 (0.81, 0.88)
Dialysis versus no dialysis and creatinine = 1.0	6.24 (4.19, 9.30)	1.65 (1.34, 2.03)	NA	3.07 (2.74, 3.43)	NA	1.79 (1.60, 2.01)	2.42 (2.21, 2.66)	2.94 (2.64, 3.27)	0.26 (0.19, 0.37)
Preoperative IABP/ inotropes	1.47 (1.26, 1.71)	NA	1.34 (1.15, 1.57)	2.90 (2.28, 3.70)	1.69 (1.08, 2.65)	1.14 (1.02, 1.29)	1.75 (1.59, 1.94)	1.46 (1.30, 1.63)	0.49 (0.38, 0.64)
Shock	1.62 (1.29, 2.03)	1.65 (1.21, 2.25)	NA	2.09 (1.77, 2.47)	NA	1.32 (1.11, 1.58)	2.11 (1.80, 2.49)	2.50 (1.51, 4.12)	NA
Female versus male (at BSA = 1.8)	0.97 (0.77, 1.21)	1.25 (1.09, 1.43)	0.97 (0.88, 1.07)	1.23 (1.10, 1.38)	0.98 (0.72, 1.33)	0.90 (0.80, 1.02)	1.03 (0.98, 1.08)	1.28 (1.12, 1.47)	0.69 (0.66, 0.73)
CLD (moderate versus mild, or severe versus moderate)	1.23 (1.09, 1.39)	NA	1.18 (1.13, 1.23)	1.26 (1.22, 1.30)	1.27 (1.13, 1.42)	1.09 (1.06, 1.12)	1.17 (1.14, 1.20)	1.26 (1.15, 1.40)	0.81 (0.79, 0.83)
Reoperation, 1 previous operation[a]	2.11 (1.78, 2.49)	2.09 (1.64, 2.65)	1.55 (1.31, 1.84)	2.06 (1.73, 2.45)	NA	1.31 (1.16, 1.49)	1.55 (1.42, 1.70)	1.42 (1.27, 1.59)	0.67 (0.62, 0.72)
Reoperation ≥ 2 previous operations[a]	2.48 (1.99, 3.08)	2.36 (1.76, 3.16)	1.66 (1.33, 2.07)	2.80 (2.32, 3.37)	NA	1.41 (1.19, 1.67)	1.96 (1.73, 2.22)	1.76 (1.52, 2.03)	0.50 (0.43, 0.58)
Status emergent, no resuscitation[a]	8.73 (4.84, 15.74)	2.78 (1.85, 4.17)	3.03 (1.69, 5.43)	6.12 (3.96, 9.46)	NA	1.63 (1.31, 2.03)	3.23 (2.66, 3.93)	2.45 (2.02, 2.97)	0.33 (0.25, 0.42)
Status emergent, with resuscitation or salvage[a]	18.39 (9.68, 34.96)	2.11 (1.06, 4.19)	3.39 (1.76, 6.54)	4.72 (2.71, 8.23)	NA	NA	3.38 (2.36, 4.84)	NA	0.32 (0.19, 0.54)

[a] 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; MI = myocardial infarction; Mort = mortality; NA = not applicable; NYHA = New York Heart Association; PLOS = prolonged length of stay; Reop = reoperation; RF = renal failure; SLOS = short length of stay; Vent = prolonged ventilation.

(≤ 40, > 40). Calibration plots (observed versus expected) based on the overall validation sample are presented in Figure 1. The average absolute difference between observed versus predicted event rates within deciles of predicted risk ranged from 0.06% for deep sternal wound infection to 1.06% for prolonged postoperative stay. Analogous figures were produced for specific valve procedures and numerous subgroups, and these are available at www.sts.org/riskmodels.

Model fit appeared to be adequate for each endpoint with the possible exception of deep sternal wound infection, which revealed some overfitting within certain subgroups. A modest degree of overfitting was expected for this endpoint given the relatively small number of infections and large number of candidate predictors.

Discrimination was assessed by the c-statistic, also known as the area under the receiver operating characteristic (ROC) curve. Table 4 presents the discrimination of each model in the development and validation samples for all patients combined and for subgroups consisting of AVR, MVR, and MVRepair. In the validation sample, c-statistics for the operative mortality model were 0.799 (overall), 0.759 (AVR), 0.802 (MVR), and 0.844 (MVRepair). C-statistics in the validation sample for other endpoints ranged from 0.619 for reoperation in the AVR subgroup to 0.800 for prolonged length of stay in the MVRepair subgroup.

Final Models

After validating the models 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 regressions were estimated using generalized estimating equations with empirical (sandwich) standard error estimates to account for clustering of patients within institutions [10]. An independence working correlation matrix was used to apply the generalized estimating equations methodology. 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.

Odds Ratios

Odds ratios and 95% confidence intervals (CI) for the final selected models are presented in Table 5. "Not applicable" indicates that the specific predictor was not included in a particular risk model. Because several variables interact with surgery type, the odds ratios for these variables differ depending on the type of surgery (AVR, MVR, MVRepair). For example, in the operative mortality model, the odds ratio for emergent status is 3.77 (95% CI: 2.75, 5.16) for AVR, 2.74 (95% CI: 1.99, 3.78) for MVR, and 8.73 (95% CI: 4.84, 15.74) for MVRepair. Odds ratios that do not interact with surgery type are summarized in Table 5, Part A. Odds ratios that differ by surgery type for at least one endpoint are presented in Table 5, Parts B, C, and D.

Final Model Intercept and Coefficients

The final risk prediction algorithms, including all coefficients and intercepts, are presented in the Appendix.

Limitations

The limitations for these valve models are similar to those for the CABG models and are thoroughly discussed in Part 1 of this series (2008 STS CABG risk models).

Conclusion

The STS Quality Measurement Task Force has developed and tested nine new risk-adjustment models for isolated valve surgery using the STS NCD. This report includes a detailed exposition of the model development process, including not only statistical issues but also the many clinical and pragmatic judgments that were required. An online risk calculator is also available through a link from the STS website.

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Appendix

Regression Coefficients and Variable Definitions for STS 2008 Valve 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 to December 2006.

Appendix Table 1. Regression Coefficients

Variable	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
Intercept	−5.78680	−5.83957	−5.52789	−3.96796	−7.11095	−3.08816	−3.06527	−4.30676	1.25115
Atrial fibrillation	0.18074	0.05524	0.00000	0.16527	0.00000	0.10305	0.11403	0.15530	−0.30247
Age function 1	0.03557	0.03909	0.03219	0.02683	0.04180	0.01512	0.02041	0.02670	−0.02834
Age function 3	0.02804	−0.00132	0.01809	0.00629	−0.05024	0.00218	0.01282	0.02315	−0.04637
Age by reoperation function	−0.01308	−0.02043	−0.00551	−0.00840	−0.00939	−0.00697	−0.00684	−0.00485	0.00927
Age by status function	−0.02495	−0.02987	−0.00721	−0.01377	0.00277	0.00102	−0.00677	−0.00379	−0.00795
Age by MVR function	0.01436	0.00000	−0.00245	0.00000	0.00000	0.00715	0.00848	−0.00324	−0.00603
Age by MVRepair function	0.02326	0.00000	0.01190	0.00000	0.00000	0.00315	0.00685	0.01378	−0.01883
BSA function 1	−1.40168	−0.38619	−0.71012	−1.11750	0.14188	−0.73553	−0.91858	−0.82801	0.77317
BSA function 2	2.16782	0.23148	1.92875	2.29127	2.04603	0.83644	1.65638	1.65423	−1.76728
CHF but not NYHA IV	0.25590	0.00000	0.21233	0.28353	0.00000	0.00000	0.17974	0.22508	−0.15108
CHF and NYHA IV	0.60544	0.00000	0.47812	0.65056	0.00000	0.22686	0.48025	0.42957	−0.33521
CHF by MVR function	0.00000	0.00000	0.00000	−0.11007	0.00000	0.00000	−0.07864	0.00000	0.11503
CHF by MVRepair function	0.00000	0.00000	0.00000	−0.13792	0.00000	0.00000	−0.07731	0.00000	0.06468
CLD function	0.23846	0.00000	0.16629	0.22816	0.23817	0.08406	0.16044	0.25263	−0.21022
CLD by MVR function	−0.15906	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	−0.10092	0.00000
CLD by MVRepair function	−0.03243	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	−0.01795	0.00000
Creatinine function 1	0.43909	0.29230	0.71439	0.45646	0.00000	0.23562	0.49230	0.45631	−0.44178
CVD without prior CVA	0.00000	0.27837	0.20531	0.12726	0.00000	0.05830	0.07684	0.00000	−0.22223
CVD and prior CVA	0.00000	0.59220	0.20018	0.24512	0.00000	0.13200	0.18343	0.33480	−0.25595
Diabetes, noninsulin	0.23563	0.00000	0.37172	0.11040	0.00000	0.00000	0.11355	0.19843	−0.16630
Diabetes, insulin	0.48368	0.00000	0.64648	0.35367	0.44389	0.18293	0.33165	0.51913	−0.45093
Diabetes by MVR function	0.00000	0.00000	0.00000	0.15051	0.00000	0.00000	0.17990	0.00000	0.00000
Diabetes by MVRepair function	0.00000	0.00000	0.00000	0.16260	0.00000	0.00000	0.11734	0.00000	0.00000
Dialysis	1.48666	0.79199	0.00000	1.57690	1.19109	0.81972	1.37741	1.53351	−1.69019
Dialysis by MVR function	0.47550	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	−0.20998
Dialysis by MVRepair function	0.78385	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	−0.07964
Ejection fraction function	0.00904	0.00000	0.00407	0.01107	0.02308	0.00734	0.00925	0.01111	−0.01348
Endocarditis, active	0.66737	0.62434	0.77276	0.76318	0.00000	0.43876	0.67810	1.02521	−1.08299
Female	0.20372	0.21925	−0.03031	0.25668	−0.02355	−0.14567	0.03066	0.22437	−0.36400
Female by MVR function	−0.10089	0.00000	0.00000	−0.19465	0.00000	−0.08773	0.00000	−0.14211	0.00000
Female by MVRepair function	−0.23812	0.00000	0.00000	−0.04564	0.00000	0.04424	0.00000	0.02470	0.00000
Female by BSA function 1	0.96491	−0.02257	0.83074	0.77598	2.00214	0.16707	0.52716	0.57195	−0.75434
Female by BSA function 2	0.18084	−0.07419	0.08397	−0.58460	−1.87036	0.25158	−0.09063	−0.12289	0.35123
Hypertension	0.11372	0.17789	0.29770	0.10799	0.00000	0.00000	0.10361	0.00000	−0.06504
IABP or inotropes	0.38682	0.00000	0.29606	0.57608	0.52474	0.13432	0.56046	0.37621	−0.57115
IABP by MVR function	0.00000	0.00000	0.00000	0.21517	0.00000	0.00000	0.00000	0.00000	0.10760
IABP by MVRepair function	0.00000	0.00000	0.00000	0.48870	0.00000	0.00000	0.00000	0.00000	−0.13850

Appendix Table 1. Continued

Variable	Mort	CVA	RF	Vent	DSWI	Reop	Comp	PLOS	SLOS
Immunosuppressive treatment	0.35022	0.00000	0.32828	0.00000	0.00000	0.00000	0.14887	0.27152	0.00000
Insufficiency mitral	0.00000	0.23253	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Insufficiency tricuspid	0.00000	0.00000	0.13159	0.12973	0.00000	0.08969	0.18929	0.15846	−0.20027
Left main disease	0.17593	0.00000	0.17280	0.00000	0.77557	0.00000	0.00000	0.00000	0.00000
MI ≤ 21 days	0.13276	0.00000	0.00000	0.31706	0.00000	0.03495	0.24687	0.18812	−0.20961
MVR	0.10284	0.00000	0.40455	0.44639	0.00000	0.12852	0.13795	0.58004	−0.61402
MVRepair	−0.65440	0.00000	−0.23666	−0.19726	0.00000	−0.22398	−0.23002	−0.37618	0.25710
No. diseased vessel function	0.00000	0.09556	0.00000	0.06299	0.00000	0.00000	0.03700	0.03312	−0.10126
Peripheral vascular disease	0.21980	0.25236	0.00000	0.00000	0.00000	0.19758	0.13174	0.15342	−0.18903
Race black	0.00000	0.28378	0.40941	0.34795	0.00000	0.23856	0.31567	0.37161	−0.44177
Race Hispanic	0.00000	−0.13774	0.14968	0.06720	0.00000	0.12816	0.08581	0.15128	−0.20068
Reop, 1 previous operation	0.74484	0.73489	0.43804	0.60704	0.00000	0.27365	0.44052	0.35252	−0.40042
Reop, ≥ 2 previous operations	0.90625	0.85841	0.50595	0.91229	0.00000	0.34233	0.67201	0.56294	−0.69765
Reop by MVR function	0.00000	0.00000	0.00000	−0.20333	0.00000	0.00000	0.00000	0.00000	0.00000
Reop by MVRepair function	0.00000	0.00000	0.00000	0.11559	0.00000	0.00000	0.00000	0.00000	0.00000
Shock	0.47961	0.50213	0.00000	0.73670	0.00000	0.28068	0.74786	0.55376	0.00000
Shock by MVR function	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	−0.50071	0.00000
Shock by MVRepair function	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.36096	0.00000
Status urgent	0.25552	0.00000	0.19344	0.25714	0.00000	0.15548	0.19858	0.35184	−0.36106
Status emergent	1.32597	1.02109	1.13199	1.51294	0.00000	0.49075	1.17360	0.89480	−1.12373
Status salvage	2.07144	0.74530	1.24544	1.25342	0.00000	0.00000	1.21823	0.00000	−1.13785
Status by MVR function	−0.31729	0.00000	−0.34380	−0.35206	0.00000	0.00000	0.00000	0.00000	0.00000
Status by MVRepair function	0.84051	0.00000	−0.02373	0.29927	0.00000	0.00000	0.00000	0.00000	0.00000
Stenosis aortic	0.00000	0.00000	0.00000	−0.10782	0.00000	−0.10852	−0.07479	−0.15434	0.06873
Stenosis mitral	0.21309	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Unstable angina	0.18950	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

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; MVR = mitral valve replacement; MVRepair = mitral valve repair; NYHA = New York Heart Association; PLOS = prolonged length of stay; Reop = reoperation; RF = renal failure; SLOS = short length of stay; Vent = prolonged ventilation.

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

Variable	Definition
Intercept	= 1 for all patients
Atrial fibrillation	= 1 if patient has history of preop atrial fibrillation, = 0 otherwise
Age function 1	= max (age – 50, 0)
Age function 3	= max (age – 75, 0)
Age by reoperation 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	= $(\text{BSA function 1})^2$
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
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
Diabetes by MVR function	= 1 if patient has diabetes and operation is MVR, = 0 otherwise
Diabetes by MVRepair function	= 1 if patient has diabetes and operation is MVRepair, = 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)
Endocarditis, active	= 1 if patient has active endocarditis, = 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/inotropes and operation is MVR, = 0 otherwise
IABP by MVRepair function	= 1 if patient requires preop IABP/inotropes and operation is MVRepair, = 0 otherwise
Immunosuppressive treatment	= 1 if patient 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 $\leq$ 21 days	= 1 if patient has history of MI within 21 days of 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 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 prior operation	= 1 if patient has had exactly 1 previous CV surgery, = 0 otherwise
Reop, $\geq$ 2 prior 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

Appendix Table 2. Continued

Variable	Definition
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 aortic	= 1 if patient has aortic stenosis, = 0 otherwise
Stenosis mitral	= 1 if patient has mitral stenosis, = 0 otherwise
Unstable angina	= 1 if patient has unstable angina, no MI within 7 days of surgery, = 0 otherwise

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

BSA = body surface area; CHF = congestive heart failure; CLD = chronic lung disease; CVA = cerebrovascular accident, or 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; PCI = percutaneous coronary intervention; PLOS = prolonged length of stay; Preop = preoperative; Reop = reoperation; Comp = composite adverse event (any); RF = renal failure; SLOS = short length of stay; STS = The Society of Thoracic Surgeons; Vent = prolonged ventilation.