Technical Notes

Pennsylvania's Guide to Coronary Artery Bypass Graft Surgery, Calendar Year 2003

The Pennsylvania Health Care Cost Containment Council
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OUTCOME MEASURES REPORTED

In-Hospital Mortality

In-hospital mortality measured the deaths that occurred during the hospital admission in which the coronary artery bypass graft (CABG) surgery was performed. Hospitals provided information to PHC4 indicating whether or not the patient died during the hospital stay.

30-Day Post-Surgical Mortality

Thirty-day post-surgical mortality measured the deaths that occurred within 30 days of the date of the CABG surgery. Unlike in-hospital mortality, it included deaths regardless of "where" the patient died. That is, it included patients who died after being discharged from the hospital. Death certificate information was obtained from the Pennsylvania Department of Health to determine whether or not a CABG patient died within 30 days of the CABG surgery. Upon the recommendation of the Council's Technical Advisory Group, "cause of death" was not considered in this analysis, unless clearly unrelated to the CABG surgery (e.g., suicide).

7-Day Readmissions

Some patients discharged from the hospital following CABG surgery were readmitted at a later date. Seven-day readmissions measured the percent of patients who were readmitted to a general acute care hospital (in Pennsylvania) within 1-7 days of being discharged from the hospitalization in which the CABG surgery was performed. Readmissions were counted when the principal diagnosis indicated a heart-related condition, infection, and/or a complication from the surgery. See Appendix B for the list of ICD-9-CM diagnosis codes included in the readmissions analyses.

30-Day Readmissions

Similar to seven-day readmissions, 30-day readmissions measured the percent of patients who were readmitted to a general acute care hospital within 1-30 days of being discharged from the hospitalization in which the CABG surgery was performed. It was calculated using the same principal diagnoses that were used for seven-day readmissions.

Post-Surgical Length of Stay

Post-surgical length of stay measured how long, on average, patients stayed in the hospital following CABG surgery.

Average Charges

Average charges are reported for hospitals only. The charges reported are charges associated with the entire hospitalization during which the CABG surgery was performed (not just the treatment associated with CABG surgery). The charges do not include professional fees (e.g., physician fees). While charges are a standard way of reporting data, they do not reflect the actual cost of treatment, nor do they reflect the payment that the hospital may have actually received.

Risk Adjustment

With the exception of average charges (which were trimmed for outliers and case-mix adjusted), each of the above measures was risk adjusted, which means that the measures take into account the patient's health condition before surgery. Some patients who undergo CABG surgery were more seriously ill than others. In order to report fair comparisons among hospitals and surgeons, PHC4 developed a complex mathematical formula to "risk-adjust" the data, meaning that hospitals and surgeons receive "extra credit" for operating on patients that were more seriously ill or at a greater risk than others. Risk-adjusting the data was important because sicker patients might be more likely to die following CABG surgery, stay in the hospital longer, or be readmitted. Through logistic or linear regression modeling, risk factors (e.g., the age of the patient and other measures that indicate the illness level of the patient) were "tested" to determine which factors predicted these particular outcomes (i.e., in-hospital mortality, 30-day post-surgical mortality, 7-day and 30-day readmissions, and post-surgical length of stay). For example, this process answered questions, such as, "Was the age of the patient important in predicting whether he/she was readmitted to the hospital"? Two important factors were the patient's "predicted probability of death" and "predicted length of stay," as calculated using *Atlas Outcomes™ (*a severity adjustment system of MediQual Systems, Inc. ®, a business of Cardinal Health). This information indicated how severely ill the patient was on admission to the hospital and how likely that was to affect the patient's length of stay. The "predicted probability of death" and the "predicted length of stay" for a patient were generated from clinical information, including lab values, in the medical record.

STUDY POPULATION

Inclusions

The CABG study population included those patients discharged from Pennsylvania hospitals in calendar year 2003 after undergoing coronary artery bypass graft (CABG) surgery, as identified by one of the following ICD-9-CM procedure codes in the medical record:

Code	Description
36.10	Aortocoronary bypass for heart revascularization, not otherwise specified
36.11	Aortocoronary bypass of one coronary artery
36.12	Aortocoronary bypass of two coronary arteries
36.13	Aortocoronary bypass of three coronary arteries
36.14	Aortocoronary bypass of four or more coronary arteries
36.15	Single internal mammary-coronary artery bypass
36.16	Double internal mammary-coronary artery bypass
36.17	Abdominal-coronary artery bypass
36.19	Other bypass anastomosis for heart revascularization

Exclusions

Cases with the following ICD-9-CM procedure codes were ***not included*** in the study population:

Procedures	ICD-9-CM Procedure Codes
Valve surgery	35.10-35.14, 35.20-35.28, or 35.99
Heart transplant	37.5, 37.51, 37.52, 37.53
Lung transplant	33.50, 33.51, 33.52
Combined heart and lung transplant	33.6
Kidney transplant	55.61, 55.69
Liver transplant	50.51, 50.59

EXCLUSIONS FOR OUTCOME ANALYSES

Standard exclusions included clinically complex cases, patients who left against medical advice, and patients less than 30 years of age. The standard exclusion criteria were applied to the in-hospital mortality analysis. Standard exclusion *and* exclusion criteria particular to the measure of interest were applied to the analyses of 30-day post-surgical mortality, 7-day and 30-day readmissions, post-surgical length-of-stay, and average hospital charges. Appendix A displays exclusion detail for each measure.

MORTALITY AND READMISSIONS ANALYSES

Risk-Adjustment Methodology

Data Preparation

After cases to be excluded from the analysis were removed, the remaining cases were randomly split into two equal-size samples—a development sample and a cross-validation sample. The number of relevant cases for each sample is shown in the following table.

Table 1. Frequencies for Development Sample, Cross-Validation Sample, and Full Data Set

	Development Sample	*Cross-Validation Sample*	*Full Data Set*
In-hospital mortality			
Number of cases	7,559	7,558	15,117
Number of in-hospital deaths	162	147	309
Mortality rate	2.1	1.9	2.0
30-day post-surgical mortality			
Number of cases	6,902	6,901	13,803
Number of deaths within 30 days	157	170	327
Mortality rate	2.3	2.5	2.4
7-day readmissions			
Number of cases	6,769	6,769	13,538
Number of readmissions within 7 days	347	368	715
Readmissions rate	5.1	5.4	5.3
30-day readmissions			
Number of cases	6,769	6,769	13,538
Number of readmissions within 30 days	937	923	1,860
Readmissions rate	13.8	13.6	13.7

Building the Risk Adjustment Models

Identify possible risk factors. The first step in building the risk adjustment models for in-hospital mortality, 30-day post-surgical mortality, 7-day and 30-day readmissions was to identify possible risk-adjustment factors, that is, those factors that potentially contributed to these events. In doing so, both clinical and demographic factors identified in the literature were considered. Also considered were those factors tested in previous cardiac-related reports released by the Council—taking into account the availability and usability of the variables in its database. These possible risk-adjustment factors are called candidate variables. Appendix C provides data for each candidate variable.

Once the candidate variables were identified, models for each measure were developed using the following processes: model selection, cross-validation, and calculation of model adequacy measures. The coefficients and odds ratios for the final models are displayed in the "Coefficients and Odds Ratios" section, following the "Building the Risk Adjustment Models" section.

Model selection identified those candidate variables that were statistically significant predictors of the relevant event (in this case in-hospital mortality, 30-day post-surgical mortality, 7-day and 30-day readmissions). These significant risk factors were identified using binary logistic regression. A backwards-stepwise logistic regression model was constructed using the cases in the development sample. All tests of significance ($p < 0.10$) were based on the likelihood ratio. Table 2 lists the variables tested and notes those that were found to be significant.

Table 2. Development Models: Variables Evaluated as Potential Predictors for Mortality and Readmissions

Candidate Variables	Results for Mortality		Results for Readmissions	
	In-Hospital	30-Day Post-Surgical	7-Day	30-Day
Acute Myocardial Infarction (AMI)	ns	ns	ns	not tested[1]
Age	ns	ns	ns	ns
Age-Squared	✓	✓	ns	✓
Cancer	ns	not tested[2]	not tested[1]	✓
Cardiogenic Shock	✓	✓	ns	ns
Cardiomyopathy	ns	ns	ns	ns
Complicated Hypertension	ns	ns	ns	ns
Chronic Obstructive Pulmonary Disease	ns	✓	ns	ns
Diabetes	not tested[2]	not tested[2]	ns	✓
Female	ns	✓	ns	✓
Heart Failure	✓	ns	ns	✓
MQ CABG Severity[3]	✓	✓	ns	ns
MQ CABG Predicted Length of Stay[3]	not tested[2]	not tested[2]	✓	✓
Obesity	not tested[2]	not tested[2]	ns	ns
Peripheral Vascular Disease	ns	ns	ns	ns
Prior CABG and/or Valve Surgery	ns	✓	not tested[1]	not tested[1]
PTCA/Stent (same day as CABG)	ns	ns	not tested[1]	not tested[1]
Race/Ethnicity	✓	ns	ns	ns
Renal Failure/Renal Dialysis	✓	✓	ns	ns

✓ : significant predictor ($p < 0.10$)
ns : not significant
[1]This variable was not tested because it was not a good candidate variable for readmission.
[2]This variable was not tested because it was not a good candidate variable for mortality.
[3]Both CABG Severity and CABG Predicted Length of Stay were calculated using MediQual® *Atlas Outcomes™*, which takes into account the patient's risk upon admission (based on clinical data found in the medical record). See Appendix D for more information.

For this report, the candidate variables reflected the patient's condition during the hospital admission in which the CABG surgery was performed. For example, the above table shows that pre-operative cardiogenic shock during the hospital admission in which the CABG surgery was performed was a significant predictor of whether or not the patient died in the hospital or within 30 days. However, it was not a significant predictor of whether or not the patient was readmitted within 7 or 30 days.

Cross-validation. After development models were built for in-hospital mortality, 30-day post-surgical mortality, and 7-day and 30-day readmissions, the models were cross validated. In order to determine which factors remained significant when the development model was applied to the cross-validation sample, the model built in the model selection process was re-estimated using the cases in the cross-validation sample.

Table 3 presents the probability values (*p*-values) of all variables tested in the cross-validation process. Variables that were found to be not significant during the model selection process (noted with "ns" in the table) were not tested during cross-validation. Variables with a *p*-value equal to or greater than 0.10 did not cross validate, that is, for in-hospital mortality race/ethnicity did not cross validate; for 30-day post-surgical mortality female and prior CABG and/or valve surgery did not cross validate; and for 30-day readmissions age-squared and cancer did not cross validate. Variables that did not cross validate were still used as risk adjustment factors for the full dataset.

Table 3. Cross-Validation Results: p-values for Tested Variables

Candidate Variables	In-Hospital Mortality		30-Day Post-Surgical Mortality		7-Day Readmissions		30-Day Readmissions	
	Development Model	Cross-Validation Model	Development Model	Cross-Validation Model	Development Model	Cross-Validation Model	Development Model	Cross-Validation Model
Age-Squared	0.010	0.002	0.019	<0.001	ns	not tested	0.029	0.503
Cancer	ns	not tested	not tested	not tested	not tested	not tested	0.027	0.800
Cardiogenic Shock	<0.001	<0.001	<0.001	<0.001	ns	not tested	ns	not tested
Chronic Obstructive Pulmonary Disease	ns	not tested	<0.001	0.044	ns	not tested	ns	not tested
Diabetes	not tested	not tested	not tested	not tested	ns	not tested	0.029	0.067
Female	ns	not tested	0.057	0.277	ns	not tested	0.010	0.041
Heart Failure	<0.001	0.055	ns	not tested	ns	not tested	0.003	<0.001
MQ CABG Severity[1]	<0.001	<0.001	<0.001	<0.001	ns	not tested	ns	not tested
MQ CABG Predicted Length of Stay[1]	not tested	not tested	not tested	not tested	<0.001	<0.001	<0.001	<0.001
Prior CABG and/or Valve Surgery	ns	not tested	0.098	0.491	not tested	not tested	not tested	not tested
Race/Ethnicity	0.002	0.913	ns	not tested	ns	not tested	ns	not tested
Renal Failure/Renal Dialysis	<0.001	<0.001	<0.001	<0.001	ns	not tested	ns	not tested

[1] Both MQ CABG Severity and MQ CABG Predicted Length of Stay were calculated using MediQual® *Atlas Outcomes™*, which takes into account the patient's risk upon admission (based on clinical data found in the medical record). See Appendix D for more information.

Measures of model adequacy. To evaluate the model performance for both the development and cross-validation models, the estimated coefficients from the development model were applied to both samples. The *c* statistic is the measure of "goodness of fit" used to describe logistic regression models, which is a common measure for models with binary dependent variables. For binary outcomes, the *c* statistic is defined as the area under the receiver operating characteristic (ROC) curve *(Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology. 1982; 143(1): 29-36)*. The *c* statistic ranges between .5 and 1, with higher values associated with better discrimination. In some respects, the *c* statistic is similar to the R^2 commonly used in linear regression. Both *c* statistics and R^2 approach 1 for models that perfectly discriminate. However, unlike R^2, the *c* statistic is not dependent on the frequency of the outcome. The *c* statistics for each model were as follows:

Table 4. c Statistics for Developmental, Cross-Validation, and Full Dataset Models

Measure	Development Model %	Cross-Validation Model%	Full Data Set Model%
In-Hospital Mortality	81.7	80.9	82.1
30-Day Post-Surgical Mortality	78.7	77.2	78.2
7-Day Readmissions	56.6	58.6	57.6
30-Day Readmissions	60.9	60.3	60.8

Coefficients and Odds Ratios

The coefficients and the *p*-values associated with the significant risk factors are listed in the following table. The entire data set was used in creating the final coefficients (i.e., the development sample and the cross-validation sample were "recombined" and the coefficients were re-estimated). Accompanying these coefficients is the odds ratio for each risk factor or risk factor category. For a binary variable, this ratio is the change in the odds for a patient with the risk factor category compared to a patient without it. For example, for the outcome measure in-hospital mortality, it is the probability of dying in the hospital versus the probability of surviving the hospital stay. Odds ratios are not applicable for continuous variables such as age, age-squared, MQ CABG severity, and MQ CABG predicted length of stay.

Table 5. Coefficients and Odds Ratios of Predictors in the Final Models

Significant Predictors	Coefficient	*p*-value	Odds Ratio
In-hospital mortality			
Constant	-1.4955	0.197	
Age[1]	-0.0364		NA[2]
Age-Squared	0.000477	<0.001	NA[2]
Cardiogenic Shock	2.4164	<0.001	11.205
Heart Failure	0.5792	<0.001	1.785
MQ CABG Severity	0.7261	<0.001	NA[2]
Renal Failure/Renal Dialysis[3]		<0.001	
Chronic Renal Failure without Dialysis	-0.0951		0.909
Pre-op Acute Renal Failure or Renal Dialysis	1.5410		4.669
Race/Ethnicity[4]		0.015	
Hispanic	-0.2603		0.771
Black, non-Hispanic	0.6607		1.936
Other/Unknown, non-Hispanic	0.4888		1.630
30-day post-surgical mortality			
Constant	-1.3550	0.004	
Age[1]	-0.0467		NA[2]
Age-Squared	0.000550	<0.001	NA[2]
Cardiogenic Shock	2.4594	<0.001	11.697
Chronic Obstructive Pulmonary Disease	0.5696	<0.001	1.768
Female	0.2674	0.033	1.307
MQ CABG Severity	0.6123	<0.001	NA[2]
Prior CABG and/or Valve Surgery	0.1786	0.460	1.196
Renal Failure/Renal Dialysis[3]		<0.0001	
Chronic Renal Failure without Dialysis	0.6683		1.951
Pre-op Acute Renal Failure or Renal Dialysis	1.5325		4.630
7-day readmissions			
Constant	-3.6620	<0.001	
MQ CABG Predicted Length of Stay	0.0809	<0.001	NA[2]
30-day readmissions			
Constant	-1.6261	<0.001	
Age[1]	-0.0375		NA[2]
Age-Squared	0.000326	0.043	NA[2]
Cancer	0.2786	0.081	1.321
Diabetes[5]		0.002	
Diabetes without complications	0.1154		1.122
Diabetes with complications	0.3244		1.383
Female	0.1781	0.001	1.195
Heart Failure	0.3376	<0.001	1.402
MQ CABG Predicted Length of Stay	0.0638	<0.001	NA[2]

[1] Although age was not a significant predictor; it provided precise value to the age-squared variable.
[2] These factors were tested as continuous variables.
[3] "No renal failure or renal dialysis" was used as the reference to the other categories of this variable; therefore, the coefficient was equal to 0.
[4] "White, non-Hispanic" was used as the reference to the other categories of the race/ethnicity variable; therefore, the coefficient was equal to 0.
[5] "No diabetes" was used as the reference to the other categories of the diabetes variable; therefore, the coefficient was equal to 0.

Calculation of Statistical Ratings

Once the significant risk factors were determined for each outcome measure (in-hospital mortality, 30-day post-surgical mortality, 7-day and 30-day readmissions), the statistical ratings were calculated. In doing so, actual rates were compared to expected rates to determine whether or not the difference was statistically significant.

Determining Actual (observed) Rates

In-hospital mortality	This rate was determined by dividing the total number of deaths that occurred in the hospital by the total number of cases.
30-day post-surgical mortality	This rate was determined by dividing the total number of deaths within 30 days of the CABG surgery date by the total number of cases.
7-day and 30-day readmissions.....	These rates were determined by dividing the total number of cases who were readmitted to a general acute care hospital (for particular principal diagnoses) within 7 or 30 days of discharge from the original hospital by the total number of cases.

Determining Expected Rates

The first step in calculating the expected rates was to estimate the probability of each of the relevant events occurring for each patient; that is: 1) the probability of in-hospital death, 2) the probability of death within 30 days, 3) the probability of being readmitted within 7 days, and 4) the probability of being readmitted within 30 days. The probability of each of these events occurring was estimated by using the statistical technique of logistic regression. In logistic regression, each category for each statistically significant clinical or demographic factor is assigned a coefficient or "weight." A factor category's weight is higher (or lower) if patients with that factor category tend to have a higher (or lower) chance of the event occurring. These weights, determined using the statewide CABG data set, were used to estimate each individual patient's probability of in-hospital death, death within 30 days, or 7-day or 30-day readmissions given the risk factors of the patient. (Note that coefficients are displayed in Table 5 in the Coefficients and Odds Ratios section.)

In general the equation to calculate a patient's probability of in-hospital death was:

(constant) + (age coefficient)(age) + (age^2 coefficient)(age^2) + (other risk factor coefficients relevant to each patient)

In general the equation to calculate a patient's probability of death within 30-days was:

(constant) + (age coefficient)(age) + (age^2 coefficient)(age^2) + (other risk factor coefficients relevant to each patient)

In general the equation to calculate a patient's probability of readmission within 7 days was:

(constant) + (MQ CABG predicted length of stay coefficient)(MQ CABG predicted length of stay)

In general the equation to calculate a patient's probability of readmission within 30 days was:

(constant) + (age coefficient)(age) + (age^2 coefficient)(age^2) + (other risk factor coefficients relevant to each patient)

The results for all patients were then summed to determine the expected number of in-hospital deaths, deaths within 30 days, and readmissions within 7 days or 30 days. This expected rate was determined by dividing the total number of expected events by the total number of cases for each measure.

The following example of the in-hospital mortality analysis illustrates the calculations used in determining the statistical ratings. The same calculations apply to 30-day post-surgical mortality and 7-day and 30-day readmissions.

Example 1: Calculations used in in-hospital mortality analysis

Total Cases: Number of hospitalizations after exclusions.

Actual Deaths: Total number of deaths (death is a discharge status equal to 20)
Percentage: Total number of deaths / Total number of cases treated

Expected Deaths: Sum of each patient's probability of death (PD)
Percentage: Total number of expected deaths / Total number of cases treated

To calculate a patient's probability of death:

Step 1: Calculate βX:

$\beta X = -1.4955$ (constant) + (-0.0364)(patient's age) + (0.000477)(patient's age)^2 + (risk factor coefficients relevant to each patient)

Step 2: Calculate the estimated probability of death (PD) using βX:

$PD = e^{\beta X} / (1 + e^{\beta X})$ where $e \approx 2.7182818285$

Test Statistic: (Actual Deaths – Expected Deaths) / Standard Deviation of Mortality

To compute Standard Deviation of Mortality:

Step 1: Compute the estimated variance of each patient's probability of death (VARPAT):

VARPAT = (PD) (1-PD)

Step 2: Calculate the Standard Deviation of Mortality

SUMVAR = sum of VARPAT across all cases

Standard Deviation of Mortality = square root of SUMVAR

p-value (two sided): Calculated using test statistic as a normal z-score

Statistical Rating: If *p*-value <0.05 and test statistic > 0, then more deaths than expected (denoted as "●")
If *p*-value <0.05 and test statistic < 0, then fewer deaths than expected (denoted as "○")
Otherwise, the number of deaths were within the expected range (denoted as "⊙")

Expected Range: Lower limit = Expected Deaths – 1.960 (Standard Deviation of Mortality)
Upper limit = Expected Deaths + 1.960 (Standard Deviation of Mortality)

POST-SURGICAL LENGTH OF STAY ANALYSIS

Risk Adjustment Methodology

Data Preparation

The first task in constructing the post-surgical length of stay model involved randomly splitting the data set into two equal-size samples (after cases to be excluded were removed). One set was used as the development sample and the other set was used as the cross-validation sample.

Table 6. Case Counts and Average Length of Stay in Days

	Development Sample	*Cross-Validation Sample*	*Full Data Set*
Number of Cases	7,315	7,314	14,629
Average Length of Stay *(arithmetic)*	6.5	6.5	6.5
Average Length of Stay *(geometric)*	5.9	5.9	5.9

Building the Risk Adjustment Model

While logistic regression was used to construct the models for in-hospital mortality, 30-day post-surgical mortality, 7-day and 30-day readmissions, a general linear modeling approach was used for post-surgical length of stay because it is a continuous variable. The model building steps were similar to those in the logistic regression models.

Model selection. The model was constructed using the development sample, after a natural log transformation was done to adjust for skewness in the distribution. All tests of significance were based on general linear model F-tests. A $p < 0.10$ model was built for more liberal identification of risk factors.

Table 7. Variables Evaluated as Potential Predictors of Post-Surgical Length of Stay

Candidate Variables	Results
Age	ns
Age-Squared	✓
Cancer	ns
Cardiogenic Shock	✓
Cardiomyopathy	ns
Complicated Hypertension	✓
Chronic Obstructive Pulmonary Disease	✓
Diabetes	ns
Female	✓
Heart Failure	✓
MQ CABG Predicted Length of Stay[1]	✓
Obesity	✓
Prior CABG and/or Valve Surgery	✓
PTCA/Stent (same day as CABG)	ns
Race/Ethnicity	✓
Renal Failure/Renal Dialysis	✓

✓ = Significant predictor
ns = not significant
[1]MQ CABG Predicted Length of Stay was calculated using MediQual® *Atlas Outcomes™* taking into account the patient's risk upon admission (based on clinical data found in the medical record). See Attachment D for more information.

Cross-validation. The steps in the model cross validation were similar to those used for in-hospital mortality, 30-day post-surgical mortality, and 7 and 30-day readmissions. The first step was to re-estimate the model, using only the variables that were significant in the development sample, to determine which factors remained significant in the cross-validation sample.

Table 8. p Values for Length of Stay Predictor Variables

Predictor Variables	Development Model	Cross-Validation Model
Age-Squared	<0.0001	<0.0001
Cardiogenic Shock	<0.0001	<0.0001
Complicated Hypertension	0.0160	<0.0001
Chronic Obstructive Pulmonary Disease	<0.0001	<0.0001
Female	0.0061	0.0006
Heart Failure	<0.0001	<0.0001
MQ CABG Predicted Length of Stay[1]	<0.0001	<0.0001
Obesity	0.0040	0.0831
Prior CABG and/or Valve Surgery	0.0770	0.0301
Race/Ethnicity	<0.0001	<0.0001
Renal Failure/Renal Dialysis	<0.0001	0.0028

Note: A *p*-value of < 0.10 was used to determine the significant risk factors for this report.
[1]MQ CABG Predicted Length of Stay was calculated using MediQual® *Atlas Outcomes™* taking into account the patient's risk upon admission (based on clinical data found in the medical record). See Attachment D for more information.

Measure of model adequacy. For the second step in the cross validation process, the estimated coefficients from the development sample were applied to both the development and the cross-validation samples. The objective was to evaluate the model's performance in both samples. R-squared was the measure considered in evaluating the model's performance.

R-squared: Coefficient of Determination (R^2) refers to the percentage of the total variability among the patients in the sample that can be explained by the estimated model involving the specified risk factors.

Table 9. R-squared Values

Development Model	Cross-Validation Model	Full Data Set Model
20.3%	18.8%	19.6%

Coefficients

Each category for each statistically significant clinical or demographic factor was assigned a weight or coefficient. These coefficients were used to compute each individual patient's expected post-surgical length of stay given the risk factors of the patient.

Table 10. Coefficients for Post-Surgical Length of Stay Final Model

Significant Predictors	Coefficient	*p*-value
Constant	2.443176891	
Age[1]	-0.000781923	
Age-Squared	0.000054363	<0.001
Cardiogenic Shock	0.437585111	<0.001
Complicated Hypertension	0.099337866	<0.001
Chronic Obstructive Pulmonary Disease	0.064634923	<0.001
Female	0.032100639	<0.001
Heart Failure	0.176768966	<0.001
MQ Predicted Length of Stay	0.02802447	<0.001
Obesity[2]		0.0019
None	-0.053718855	
Unspecified Obesity	-0.067818881	
Prior CABG and/or Valve Surgery	0.042931628	0.0045
Race/Ethnicity[3]		<0.001
Hispanic	-0.034866933	
White, non-Hispanic	-0.097864705	
Black, non-Hispanic	0.078257930	
Renal Failure/Renal Dialysis[4]		<0.001
None	-0.189121912	
Chronic Renal Failure without Dialysis	-0.143587986	

[1] Although age was not a significant predictor; it provided precise value to the age-squared variable.
[2] "Morbid obesity" was used as the reference to the other categories of the obesity variable; therefore, the coefficient was equal to 0.
[3] "Other/Unknown, non-Hispanic" was used as the reference to the other categories of the race/ethnicity variable; therefore, the coefficient was equal to 0.
[4] "Pre-op acute renal failure or renal dialysis" was used as the reference to the other categories of this variable; therefore, the coefficient was equal to 0.

Calculation of Risk-Adjusted Post-Surgical Length of Stay

Once the significant risk factors were determined, the actual post-surgical length of stay and the expected post-surgical length of stay were used to calculate the risk-adjusted post-surgical length of stay.

Actual Length of Stay

The actual post-surgical length of stay was derived by subtracting the CABG procedure date from the discharge date. The average post-surgical length of stay is reported as a geometric mean not an arithmetic mean.

Because a natural log transformation of each length of stay value was done to adjust for skewness in the distribution, it was necessary to convert the logarithm values back to days when reporting or displaying post-surgical length of stay. This process results in geometric means, not arithmetic means. Unlike an arithmetic mean that is derived by summing individual values and dividing by the number of observations, a geometric mean is calculated by multiplying the individual values and taking the n^{th} root of the product. Geometric means are averages and are the natural result when using the log transformation. Using hospitals as an example, a hospital's expected average was determined by averaging the expected post-surgical lengths of stay for each CABG patient. The expected average was then compared to the actual average (both are geometric averages) to determine whether the actual is

significantly higher or lower than expected. Post-surgical length of stay outcomes for hospitals and surgeons were evaluated in the same way.

Expected Length of Stay

Each category for each statistically significant clinical or demographic factor was assigned a weight or coefficient. Coefficients are listed in Table 10. These coefficients were summed to compute each individual patient's expected length of stay, given the risk factors of the patient. The coefficient for a category represented the estimated difference in mean (log) length of stay for this category versus the base category of that factor. Thus, the coefficient for the base category of a factor was always "0" (zero). When dealing with categorical variables in the length of stay model there was no particular importance to the order of these categories. The constant term in the model represents the predicted value for all categorical factors at the base level. The coefficients for the other levels within a factor represent adjustments to that "baseline." No adjustment was required at the base level for any factor, because it was already accounted for in the constant. For example, a patient with morbid obesity had a "0" or "baseline" coefficient; while a patient without obesity would be adjusted downward by 0.053718855 (see Table 10). The order was not important because each ordering scheme would result in different coefficients, but the estimated difference between any pairs of levels would be the same (i.e., the difference between morbid obesity and no obesity would always be – 0.053718855 independent of what the specific coefficients were for each). For quantitative factors (e.g., age, age-squared and MQ CABG severity), there is always an adjustment since the "baseline" is 0.

Risk-Adjusted Post-Surgical Length of Stay

Length of stay is reported in average days instead of a statistical rating. Unlike other measures (such as mortality where a lower number of deaths is obviously better than a higher number), it is not known whether shorter lengths of stay are "better" than longer lengths of stay or vice versa. Reporting the average length of stay in days, therefore, presents information that can be used to examine differences in lengths of stay without taking a position on what is "best."

An example of the complete calculation follows:

Example 2: Calculations Used for Post-Surgical Length of Stay Analysis

Total Cases: Number of cases *after exclusions*

Actual Mean LOS: Geometric mean of the length of stay across all cases

Calculate geometric mean length of stay (GMLOS):

Step 1: Calculate the natural log (**ln**) of GMLOS:

$$\mathbf{ln}(\text{GMLOS}) = (1/n)(\mathbf{ln}\text{LOS}_{\text{case 1}} + \mathbf{ln}\text{LOS}_{\text{case 2}} + \ldots + \mathbf{ln}\text{LOS}_{\text{case n}})$$

Step 2: Convert **ln**(GMLOS) to GMLOS (i.e., convert to days):

$$\text{GMLOS} = e^{\mathbf{ln}(\text{GMLOS})} \quad \text{where } e \approx 2.7182818285$$

Expected Mean LOS: Geometric mean of the *expected* length of stay for all cases

Calculate geometric mean of the *expected* length of stay (GM*E*LOS):

Step 1: Calculate each patient's *E***ln**LOS:

*E***ln**LOS = (constant) + (risk factor category coefficients relevant to each patient)

Step 2: Calculate the **ln**GM*E*LOS:

$$\mathbf{ln}(\text{GM}E\text{LOS}) = (1/n)(E\mathbf{ln}\text{LOS}_{\text{case 1}} + E\mathbf{ln}\text{LOS}_{\text{case 2}} + \ldots + \mathbf{ln}\text{LOS}_{\text{case n}})$$

Step 3: Convert the **ln**(GM*E*LOS) to GM*E*LOS (i.e., convert to days):

$$\text{GM}E\text{LOS} = e^{\mathbf{ln}(\text{GM}E\text{LOS})} \quad \text{where } e \approx 2.7182818285$$

Note: The following calculation can be used in determining a *patient's* expected length of stay; it is not necessary, however, in determining a hospital's geometric mean of the expected length of stay.

Calculate a patient's *expected* length of stay (*E*LOS):

Convert the *E***ln**LOS to *E*LOS (i.e., convert to days):

$$E\text{LOS} = e^{(E\mathbf{ln}\text{LOS})} \quad \text{where } e \approx 2.7182818285$$

Risk-Adjusted Length of Stay: Average length of stay / expected average length of stay x state average length of stay (5.9 days)

ln = natural logarithm (base e)

HOSPITAL AVERAGE CHARGES ANALYSIS

Average charges were trimmed and case-mix adjusted. They are reported for hospitals only.

Construction of Reference Database

For average charges the full dataset, after exclusions, was analyzed using five distinct DRG groups. It is important to note that the study population was not identified by DRG; however, all patients were included in one of the five groups listed below:

- Group 1 DRG 106: Coronary Bypass with PTCA
- Group 2 DRG 107: Coronary Bypass with Cardiac Catheterization
- Group 3 DRG 108: Other Cardiothoracic Procedures
- Group 4 DRG 109: Coronary Bypass without Cardiac Catheterization
- Group 5 DRG 515: Cardiac Defibrillator Implant without Cardiac Catheterization
  DRG 525: Heart Assist System Implant
  DRG 535: Cardiac Defibrillator Implant without Cardiac Catheterization with Acute Myocardial Infarction, Heart Failure, or Shock
  DRG 536: Cardiac Defibrillator Implant without Cardiac Catheterization with Acute Myocardial Infarction, Heart Failure, or Shock

Trim Methodology

Trimming methodology was used to remove outlier charge values from the study population. Identification of outliers was imperative for the elimination of extreme values that may have had a significant and unrepresentative impact on the mean (average).

The trimming (deleting) of individual records from the analysis was performed after all other exclusions were satisfied. If the charge on a particular record was less than the lower trim point or in excess of the upper trim point, that record was removed from the charge analysis.

For this analysis, upper and lower trim points were calculated using the "+/- 3.0 interquartile range" method. This non-parametric methodology was used because, historically, the distribution for charge data does not follow a "normal, bell-shaped" pattern.

Since charges varied dramatically among regions, upper and lower trim points were calculated for each of the five groups of patients at the regional level (the Council uses nine regional designations). For three of the groups (DRGs 106,108, and DRGs 515, 525, 535, 536), these nine regions were regrouped into larger areas because of the small numbers of cases in several regions.

Trim points were determined as follows:

Q1 = *the first quartile (25^{th} percentile total charge) of all patient records from the comparative database in a particular category*

Q3 = *the third quartile (75^{th} percentile total charge) of all patient records from the comparative database in a particular category*

IQR = *Q3 – Q1*

Lower Trim Point = *Q1 – (3.0 x IQR)*

Upper Trim Point = *Q3 + (3.0 x IQR)*

See Table 11 for upper trim points, median charge, and the percent of outliers for each DRG group for each region.

Table 11. Trim Points for Average Charges

	Upper Trim Point*	Median	Outlier %
DRG 106			
Regions 1, 2, 3	$360,304	$92,781	1.6
Regions 4, 5, 6	$246,557	$85,299	1.4
Regions 7, 8, 9	$807,964	$153,632	2.4
DRG 107			
Region 1	$251,291	$66,133	1.0
Region 2	$297,625	$90,887	0.4
Region 3	$108,600	$55,025	1.8
Region 4	$149,455	$53,228	2.1
Region 5	$168,526	$58,856	1.6
Region 6	$168,348	$55,708	1.1
Region 7	$184,261	$62,466	1.6
Region 8	$483,292	$118,428	0.9
Region 9	$745,912	$163,344	0.9
DRG 108			
Regions 1, 2, 3	$317,768	$88,870	1.0
Regions 4, 5, 6	$216,782	$57,731	2.2
Regions 7, 8, 9	$1,078,750	$80,241	0.0
DRG 109			
Region 1	$246,959	$59,950	0.6
Region 2	$193,628	$46,703	1.7
Region 3	$90,798	$43,262	2.7
Region 4	$95,897	$39,573	2.9
Region 5	$97,903	$41,682	3.1
Region 6	$117,298	$42,220	1.1
Region 7	$133,567	$50,016	3.2
Region 8	$336,925	$83,498	1.0
Region 9	$544,751	$114,919	2.7
DRGs 515, 525, 535, 536			
Region 1, 2, 3	$558,704	$230,691	2.3
Region 4, 5, 6	$603,180	$173,173	0.0
Region 7, 8, 9	$1,167,838	$269,857	0.9

*Charges of less than $10,000 were considered invalid so no lower trim point is displayed.

Case-Mix Adjustment of Average Charges

Using case-mix adjustment, a composite average charge was developed for each of the five groups of patients. The charges associated with each group were adjusted according to the number of patients and the relative cost associated with treating patients in each of the five groups.

First, regional relative weights for each of the five groups were determined. After all exclusions were satisfied and outlier trimming was performed, the relative weight for each of the five groups within each of the nine regions (or the three larger areas) was calculated using the formula:

$$\text{Relative Weight} = \frac{\text{Average Charge for Each Group (either Group 1, 2, 3, 4, or 5)}}{\text{Average Charge for Groups 1, 2, 3, 4, and 5 (combined)}}$$

Next, each hospital's case-mix index was calculated.

$$\text{A Hospital's Case-Mix Index} = \frac{\Sigma(n_i \times RW_i)}{\Sigma n_i}$$

where, for a hospital located in a particular region:

- n_i = the number of cases (corresponding to each of the five groups)
- RW_i = the regional relative weights (corresponding to each of the five groups)
- Σn_i = total number of cases for the hospital (for all of the five groups)

Finally, for each hospital the trimmed and case-mix adjusted average charge was calculated.

$$\text{Trimmed and Adjusted Charge} = \frac{\text{Average Charge for the Five Groups (combined)}}{\text{Case-Mix Index}}$$

See Table 12 for average charges and relative weights associated with each DRG group for each region.

Table 12. Average Total Charges (by DRG and Region) and Associated Relative Weights

	Average Charge	Relative Weight
DRG 106		
Regions 1, 2, 3	$110,569	1.44297840
Regions 4, 5, 6	$91,670	1.39050998
Regions 7, 8, 9	$191,476	2.02308580
DRG 107		
Region 1	$74,775	0.97585522
Region 2	$94,561	1.18290656
Region 3	$57,337	1.05279330
Region 4	$58,512	0.88755001
Region 5	$65,852	1.17985476
Region 6	$59,065	1.06622701
Region 7	$68,806	0.72699181
Region 8	$142,016	1.08694173
Region 9	$204,408	1.10475685
DRG 108		
Regions 1, 2, 3	$96,438	1.25857095
Regions 4, 5, 6	$68,816	1.04384601
Regions 7, 8, 9	$188,505	1.99169513
DRG 109		
Region 1	$68,324	0.89166154
Region 2	$57,839	0.72353779
Region 3	$45,816	0.84125851
Region 4	$42,865	0.65021054
Region 5	$42,980	0.77006592
Region 6	$43,473	0.78476223
Region 7	$54,693	0.57787771
Region 8	$100,039	0.76566487
Region 9	$147,634	0.79791159
DRGs 515, 525, 535, 536		
Region 1, 2, 3	$233,091	3.04196163
Region 4, 5, 6	$200,868	3.04690564
Region 7, 8, 9	$319,479	3.37553521

APPENDIX A: EXCLUSION DATA

Specific cases were excluded from the analysis. Standard exclusions were identified for the in-hospital mortality analysis first. Additional cases were then excluded from the analyses for the other measures in this report (30-day post-surgical mortality, 7-day readmissions, 30-day readmissions, post-surgical length of stay, and average hospital charges).

Exclusions from "In-Hospital Mortality" Analysis

	Statewide Data		
	Case #	***Case %***	***Mortality %***
Total cases prior to in-hospital mortality exclusions	*16,032*	*100.0*	*2.4*
Exclusions:			
❖ Clinically complex cases*	903	5.6	9.0
❖ Patients who left against medical advice	8	<0.1	0.0
❖ Patients < 30 years of age	4	<0.1	0.0
Total exclusions	*915*	*5.7*	*8.9*
Total cases remaining in analysis	*15,117*	*94.3*	2.0

*Clinically complex cases are: those *not* in DRG 106, 107, 108, 109, 483, 515, 525, 535, or 536; cases excluded during individual case review; and cases undergoing certain procedures during the same admission as defined by one of the following procedures:

Procedure	***ICD-9-CM Codes***
• *lung volume reduction (performed at the same time as CABG)*	*32.22*
• *operations on structures adjacent to heart valves*	*35.31-35.35, 35.39*
• *creation of septal defect in heart*	*35.42*
• *repair of atrial and ventricular septa*	*35.50-35.54, 35.60-35.63, 35.70-35.73*
• *total repair of certain congenital cardiac anomalies*	*35.81-35.84*
• *other operations on valves and septa of heart*	*35.91-35.95, 35.98*
• *repair of aneurysm of coronary vessel*	*36.91*
• *other operations on vessels of heart*	*36.99*
• *excision of aneurysm of heart or other lesion of heart*	*37.32, 37.33*
• *carotid endarterectomy*	*38.12*
• *resection of abdominal aorta, thoracic vessel, abdominal arteries*	*38.44-38.46*
• *clipping of aneurysm/other aneurysm repair*	*39.51, 39.52*
• *diagnosis of constrictive pericarditis & undergoing pericardiectomy*	*Principal diagnosis of 423.2 in combination with 37.31*

Appendix A: Exclusion Data *continued*

Exclusions from "30-Day Mortality" Analysis

	Statewide Data		
	Case #	***Case %***	***30-Day Post-Surgical Mortality %***
Total cases prior to 30-day mortality exclusions	*15,117*	*100.0*	–
Exclusions:			
❖ Cases with invalid/inconsistent data[1]	41	0.3	–
❖ Out-of-state residents[2]	1,273	8.4	–
Total exclusions	*1,314*	*8.7*	–
Total cases remaining in analysis	*13,803*	*91.3*	*2.4*

[1]Cases with invalid/inconsistent data (i.e., social security number, date of birth, or sex) could not be linked to death certificate information.
[2]Out-of-state residents were excluded because such patients could undergo CABG surgery in a Pennsylvania hospital, return to their home state and die there. Therefore, no death certificate data would be available for these patients.

Exclusions from "7-Day Readmissions" and "30-Day Readmissions" Analyses

	Statewide Data			
	Case #	***Case %***	***7-day Readmit %***	***30-day Readmit %***
Total cases prior to readmissions exclusions	*15,117*	*100.0*	–	–
Exclusions:			–	–
❖ Patients who died during hospitalization where CABG was performed	309	2.0	–	–
❖ Cases with invalid/inconsistent data[1]	51	0.3	–	–
❖ Out-of-state residents[2]	1,219	8.1	–	–
Total exclusions	*1,579*	*10.4*	–	–
Total cases remaining in analysis	*13,538*	*89.6*	*5.3*	*13.7*

[1]Cases with invalid/inconsistent data (i.e., social security number, date of birth, sex, admit date, discharge date) could not be linked to subsequent hospital admissions.
[2]Out-of-state residents were excluded because such patients could undergo CABG surgery in a Pennsylvania hospital, return to their home state and be readmitted there. Therefore, no readmission information would be available for these patients.

Appendix A: Exclusion Data *continued*

Exclusions from post-surgical "Length of Stay" (LOS) Analysis

	Statewide Data		
	Case #	***Case %***	***Avg. Post-Surgical LOS (days)***
Total cases prior to length of stay exclusions	*15,117*	*100.0*	*7.2*
Exclusions:			
❖ Patients who died during hospitalization where CABG was performed	309	2.0	13.3
❖ Patients with post-surgical LOS > 30 days	171	1.1	50.9
❖ Patients with post-surgical LOS same day or one day	8	0.1	0.6
Total exclusions	*488*	*3.2*	*26.2*
Total cases remaining in analysis	*14,629*	*96.8*	*6.5*

Exclusions from hospital "Average Charges" Analysis

	Statewide Data		
	Case #	***Case %***	***Avg. Charges***
Total cases prior to average charges exclusions	*15,117*	*100.0*	*$102,604*
Exclusions:			
❖ Patients with invalid or missing charges[1]	7	<0.1	–
❖ Tracheostomy cases (DRG 483)	241	1.6	$524,591
❖ Charge outliers[2]	200	1.3	$357,685
Total exclusions	*448*	*3.0*	–
Total cases remaining in analysis	*14,669*	*97.0*	*$92,242*

[1]Invalid/missing charges included cases with negative charges or charges that were less than $10,000.
[2]Charge outliers were determined using the "± 3.0 interquartile range" method–after accounting for differences in charges by DRG groupings and by region.

APPENDIX B: READMISSIONS DATA

A readmission was counted only if the patient was readmitted with a principal diagnosis of one of the ICD-9-CM codes listed below. Data for readmissions was organized into the following categories: cardiac diagnoses, neurologic diagnoses, respiratory diagnoses, and other diagnoses including infections and complications of surgery.

Diagnosis	*ICD-9-CM Code*	*7-Day* N = 715 (5.3%)		*30-Day* N = 1,860 (13.7%)	
		#	%	#	%
CARDIAC DIAGNOSES					
Cardiac dysrhythmias post cardiac surgery		**58**	**8.1**	**134**	**7.2**
Conduction disorders (i.e., av block)	426.xx	1	0.1	2	0.1
Paroxysmal tachycardias	427.0, 427.1, 427.2	5	0.7	16	0.9
Atrial fibrillation/flutter	427.31, 427.32	37	5.2	86	4.6
Premature beats	427.69	1	0.1	2	0.1
Other rhythm disorders (i.e., ectopic, nodal)	427.81, 427.89, 427.9	12	1.7	26	1.4
Cardiac arrest	427.5	2	0.3	2	0.1
Heart failure/Hypertensive heart disease		**143**	**20.0**	**339**	**18.2**
Rheumatic heart failure	398.91	0	–	1	0.1
Malignant hypertensive heart disease without heart failure	402.00	0	–	1	0.1
Unspecified hypertensive heart disease with heart failure	402.91	2	0.3	5	0.3
Malignant hypertensive renal disease with renal failure	403.01	0	–	1	0.1
Unspecified hypertensive renal disease with renal failure	403.91	0	–	5	0.3
Malignant hypertensive heart and renal disease with heart failure	404.03	0	–	1	0.1
Unspecified hypertensive heart and renal disease with heart failure and renal failure	404.93	1	0.1	2	0.1
Malignant secondary hypertension, renovascular	405.01	0	–	1	0.1
Congestive heart failure	428.xx	111	15.5	256	13.8
Functional disturbances following cardiac surgery (post cardiotomy syndrome)	429.4	29	4.1	66	3.5
Coronary atherosclerosis/myocardial ischemia/infarction		**38**	**5.3**	**124**	**6.7**
Acute myocardial infarction (AMI)	410.x1	20	2.8	62	3.3
Postmyocardial infarction syndrome	411.0	6	0.8	20	1.1
Intermediate coronary syndrome (unstable angina)	411.1	1	0.1	2	0.1
Angina pectoris	413.x	0	–	1	0.1
Coronary atherosclerosis	414.0x	10	1.4	37	2.0
Other forms of chronic ischemic heart disease	414.8	1	0.1	2	0.1
Hypertension/Hypotension/Syncope/Dizziness	401.x, 458.x, 780.2, 780.4, 796.3	**34**	**4.8**	**79**	**4.2**
Artery and vein disease/Embolism/Thrombosis		**15**	**2.1**	**58**	**3.1**
Atherosclerosis of artery, extremity, aorta, renal artery	440.x, 440.xx	2	0.3	14	0.8
Arterial embolism and thrombosis	444.xx	1	0.1	2	0.1
Artheroembolism of lower extremity	445.02	0	–	1	0.1
Phlebitis and thrombophlebitis	451.x	1	0.1	3	0.2
Other venous embolism and thrombosis of other specified veins	453.8	5	0.7	24	1.3
Peripheral vascular complications	997.2	5	0.7	12	0.6
Vascular complications-vessel, not elsewhere classified	997.79	0	–	1	0.1
Vascular complications med care, not elsewhere classified	999.2	1	0.1	1	0.1

Appendix B: Readmissions Data *continued*

Diagnosis	*ICD-9-CM Code*	*7-Day*		*30-Day*	
		#	%	#	%
Other forms of heart disease		**7**	**1.0**	**21**	**1.1**
Acute pericarditis	420.xx	4	0.6	7	0.4
Other diseases of pericardium (hemopericardium, restrictive)	423.x	2	0.3	12	0.6
Mitral valve disorder	424.0	1	0.1	1	0.1
Endocarditis, valve unspecified, unspecified cause	424.90	0	–	1	0.1
NEUROLOGIC DIAGNOSES					
Stroke/Transient cerebral ischemia		**23**	**3.2**	**55**	**3.0**
Intracerebral hemorrhage	431	0	–	2	0.1
Unspecified intracranial hemorrhage	432.9	0	–	1	0.1
Occlusion and stenosis of precerebral arteries	433.xx	4	0.6	11	0.6
Occlusion of cerebral artery	434.xx	11	1.5	24	1.3
Transient cerebral ischemia	435.x	4	0.6	8	0.4
Acute, but ill-defined cerebrovascular disease (CVA)	436	1	0.1	2	0.1
Other alteration of consciousness	780.09	0	–	2	0.1
Iatrogenic cerebrovascular infarction or hemorrhage	997.02	3	0.4	5	0.3
Encephalopathy, not elsewhere classified	348.3	**1**	**0.1**	**1**	**0.1**
RESPIRATORY DIAGNOSES					
Pleurisy		**51**	**7.1**	**122**	**6.6**
Pleurisy	511.0	0	–	1	0.1
Pleural effusion/atelectasis	511.9, 518.0	38	5.3	98	5.3
Hemothorax/hemopneumothorax	511.8	11	1.5	18	1.0
Pneumothorax	512.x	2	0.3	5	0.3
Pulmonary edema/insufficiency		**7**	**1.0**	**15**	**0.8**
Acute pulmonary edema	518.4	0	–	2	0.1
Pulmonary insufficiency post trauma or surgery	518.5	0	–	1	0.1
Acute respiratory failure	518.81	7	1.0	12	0.6
Respiratory and other chest symptoms		**49**	**6.9**	**122**	**6.6**
Tietze's disease (i.e. costochondritis)	733.6	1	0.1	3	0.2
Respiratory and other chest symptoms (e.g., shortness of breath, chest pain)	786.x, 786.xx	41	5.7	110	5.9
Pulmonary congestion and hypostasis	514	1	0.1	1	0.1
Mediastinitis	519.2	3	0.4	3	0.2
Trachea/bronchus disease not elsewhere classified (ulcer in trachea)	519.1	1	0.1	2	0.1
Tracheostomy complications	519.09	2	0.3	3	0.2
Pulmonary embolism/Infarction	415.xx	**34**	**4.8**	**66**	**3.5**
Aspiration pneumonia	507.0, 997.3	**35**	**4.9**	**69**	**3.7**
OTHER DIAGNOSES					
Infections		**120**	**16.8**	**424**	**22.8**
Intestinal infection due to clostridium difficile	008.45	2	0.3	12	0.6
Septicemia	038.xx	10	1.4	30	1.6
Bacteremia	790.7	0	–	2	0.1
Pneumonia	482.xx, 485, 486	29	4.1	73	3.9
Empyema	510.0, 510.9	0	–	2	0.1
Urinary tract infection	599.0	4	0.6	15	0.8

Appendix B: Readmissions Data *continued*

Diagnosis	*ICD-9-CM Code*	*7-Day*		*30-Day*	
		#	%	#	%
Infections *continued*					
Cellulitis	682.6, 682.7	2	0.3	16	0.9
Fever	780.6	2	0.3	4	0.2
Infection and inflammatory reaction due to heart device	996.61	0	–	4	0.2
Infected post-surgical seroma	998.51	1	0.1	3	0.2
Infection and inflammatory reaction due to vascular device	996.62	0	–	4	0.2
Non-healing surgical wound	998.83	0	–	7	0.4
Other post-surgical infection	998.59	70	9.8	252	13.5
Device, Implant, or Graft Complications		**3**	**0.4**	**10**	**0.5**
Mechanical complication of cardiac device, implant, graft	996.0x	0	–	3	0.2
Other complication of cardiac device, implant, graft	996.72	3	0.4	7	0.4
GI hemorrhage/complications		**29**	**4.1**	**55**	**3.0**
Esophageal hemorrhage	530.2, 530.21	0	–	1	0.1
Acute gastric ulcer	531.00	2	0.3	2	0.1
Chronic/unspecified gastric ulcer	531.40	2	0.3	3	0.2
Acute duodenal ulcer	532.00	1	0.1	2	0.1
Chronic/unspecified duodenal ulcer	532.40	7	1.0	16	0.9
Other specified gastritis with hemorrhage	535.40 535.41	1	0.1	4	0.2
Duodenitis with hemorrhage	535.61	1	0.1	1	0.1
Vascular insufficiency of intestine (bowel infarction, ischemic colitis)	557.0, 557.9	3	0.4	7	0.4
Intestinal obstruction without hernia	560.1, 560.39, 560.89, 560.9	1	0.1	4	0.2
Other suppurative peritonitis	567.2	1	0.1	1	0.1
Hemorrhage of rectum and anus	569.3	1	0.1	2	0.1
Blood in stool	578.1	3	0.4	4	0.2
Hemorrhage of gastrointestinal tract, unspecified	578.9	5	0.7	6	0.3
Digestive system complications due to procedure	997.4	1	0.1	2	0.1
Genitourinary complications		**7**	**1.0**	**21**	**1.1**
Acute renal failure	584.x	6	0.8	19	1.0
Hematuria	599.7	1	0.1	1	0.1
Urinary complications due to procedure	997.5	0	–	1	0.1
Anemia/Thrombocytopenia/Anticoagulation disorders		**5**	**0.7**	**18**	**1.0**
Iron deficiency anemias	280.x	0	–	2	0.1
Other and unspecified anemias (i.e., post hemorrhagic anemia)	285.xx	3	0.4	8	0.4
Hemorrhagic disorder due to circulating anticoagulants	286.5	1	0.1	1	0.1
Acquired coagulation factor deficiency	286.7	1	0.1	1	0.1
Other and unspecified coagulation defects	286.9	0	–	2	0.1
Secondary hypercoagulable state	289.82	0	–	1	0.1
Abnormal coagulation profile	790.92	0	–	3	0.2
Fluid and electrolyte imbalance	276.x	**15**	**2.1**	**38**	**2.0**
Other surgical complications		**41**	**5.7**	**89**	**4.8**
Cardiac complications resulting from procedure	997.1	27	3.8	52	2.8
Hemorrhage or hematoma complicating a procedure	998.1x	3	0.4	11	0.6
Dehiscence or rupture of operation wound	998.3x	8	1.1	23	1.2
Other procedure complications, not elsewhere classified	998.89	3	0.4	3	0.2

APPENDIX C: CANDIDATE VARIABLES

ICD-9-CM Codes Used to Define Mortality, Readmissions, and Length of Stay Variables

Variable
ICD-9-CM Codes

Acute Myocardial Infarction (AMI)
410.x1

Cancer
140.0 - 208.9, 230.0 - 239.9

Cardiomyopathy
425.3, 425.4, 425.8, 425.9

Complicated Hypertension
402.x1, 403.x1, 404.x1, 404.x2, 404.x3, 405.xx

Chronic Obstructive Pulmonary Disease
491.20, 491.21, 492.0, 492.8, 496, 506.4, 518.2

Diabetes
Without complication – 250.0x
With complication – 250.1x - 250.9x

Heart Failure
398.91, 428.0 - 428.9
For those cases having one of the above heart failure codes and a hypertension with congestive heart failure code (402.x1, 404.x1, 404.x3) in the same record, only the hypertension code was used.

Obesity
Unspecified obesity – 278.00
Morbid obesity – 278.01

Peripheral Vascular Disease
443.0, 443.1, 443.81, 443.89, 443.9

Prior CABG and/or Valve Surgery
V42.2, V43.3, V45.81, 414.02 - 414.05, 996.02, 996.03

PTCA/Stent (same day as CABG)
36.01, 36.02, 36.05, 36.06, 36.07, 36.09

Renal Failure/Renal Dialysis
Chronic renal failure without dialysis – Chronic renal failure – 585
Pre-operative acute renal failure or renal dialysis
Acute renal failure – 584.5 – 584.9 *and before surgery, using clinical information in medical record;* renal dialysis – 39.95, 54.98

Appendix C: Candidate Variables *continued*

Mortality—Candidate Variable Frequency

Variable	In-Hospital Mortality		30-Day Mortality	
	#	%	#	%
Acute Myocardial Infarction (AMI)				
No	11,485	1.5	10,489	1.9
Yes (initial episode as principal diagnosis)	3,632	3.6	3,314	3.8
Age & Age-Squared (tested as continuous variables)				
30-39 years	111	0.0	99	0.0
40-49 years	933	1.0	841	1.2
50-59 years	3,139	0.9	2,869	1.0
60-69 years	4,493	1.4	4,069	1.7
70-79 years	4,903	2.4	4,502	2.9
80-89 years	1,525	6.0	1,411	6.2
90-99 years	13	7.7	12	8.3
	Average age: 66.2 (males 65.2; females 68.9)		*66.3 (males 65.2; females 69.0)*	
Cancer				
No	14,770	2.0	13,493	2.4
Yes	347	2.0	310	1.6
Cardiogenic Shock				
No	15,026	1.9	13,720	2.2
Yes (prior to surgery–using clinical information in medical record)	91	34.1	83	33.7
Cardiomyopathy				
No	14,703	2.0	13,438	2.3
Yes	414	3.1	365	4.4
Complicated Hypertension				
No	14,477	1.8	13,209	2.2
Yes	640	6.6	594	6.6
Chronic Obstructive Pulmonary Disease				
No	12,541	1.8	11,446	2.0
Yes	2,576	3.1	2,357	4.1
Diabetes				
No	9,688	2.1	8,823	2.4
Diabetes without complication	4,488	1.8	4,105	2.3
Diabetes with complication	941	1.9	875	2.4
Female				
No	10,767	1.6	9,791	1.9
Yes	4,350	3.1	4,012	3.6
Heart Failure				
No	12,495	1.3	11,467	1.7
Yes	2,622	5.4	2,336	5.7
MQ CABG Severity *(tested as probability of death – a continuous variable)*				
0.000 – 0.001	0	–	0	–
0.002 – 0.011	5,323	0.4	4,852	0.7%
0.012 – 0.057	8,482	1.8	7,752	2.2%
0.058 – 0.499	1,309	10.0	1,196	10.1%
0.500 – 1.000	3	66.7	3	0.0
Obesity				
No	13,188	2.2	12,042	2.5
Unspecified obesity	1,345	1.0	1,224	1.2
Morbid obesity	584	1.7	537	2.2
Peripheral Vascular Disease				
No	13,880	2.0	12,668	2.3
Yes	1,237	2.7	1,135	3.1
Prior CABG and/or Valve Surgery				
No	14,388	2.0	13,148	2.3
Yes	729	3.4	655	3.5
PTCA/Stent (same day as CABG)				
No	14,995	2.0	13,688	2.3
Yes	122	8.2	115	7.0
Race/Ethnicity				
Hispanic	237	1.3	227	1.8
White, non-Hispanic	13,626	1.9	12,501	2.2
Black, non-Hispanic	570	4.6	528	4.9
Other/unknown, non-Hispanic	684	2.9	547	2.9
Renal Failure/Renal Dialysis				
No	14,772	1.8	13,477	2.1
Chronic renal failure without dialysis	79	5.1	77	9.1
Pre-op acute renal failure or renal dialysis	266	16.9	249	16.1

Appendix C: Candidate Variables *continued*

Readmissions—Candidate Variable Frequency

Variable	7 & 30 Day Readmissions	7-Day Readmissions	30-Day Readmissions
	#	%	%
Acute Myocardial Infarction (AMI)			
No	10,334	5.1	13.6
Yes (initial episode as principal diagnosis)	3,204	5.7	14.1
Age & Age-Squared *(tested as continuous variables)*			
30-39 years	99	3.0	8.1
40-49 years	833	4.7	12.0
50-59 years	2,846	4.9	11.9
60-69 years	4,012	5.0	12.6
70-79 years	4,399	5.6	14.8
80-89 years	1,338	6.4	18.8
90-99 years	11	9.1	18.2
Average age: 66.2 (males 65.1; females 68.9)			
Cancer			
No	13,232	5.3	13.6
Yes	306	5.2	17.6
Cardiogenic Shock			
No	13,483	5.3	13.7
Yes (prior to surgery–using clinical information in medical record)	55	10.9	21.8
Cardiomyopathy			
No	13,183	5.2	13.6
Yes	355	7.0	19.4
Complicated Hypertension			
No	12,981	5.2	13.4
Yes	557	8.1	22.6
Chronic Obstructive Pulmonary Disease			
No	11,253	5.0	13.2
Yes	2,285	6.7	16.2
Diabetes			
No	8,645	5.0	12.6
Diabetes without complication	4,032	5.3	14.6
Diabetes with complication	861	7.4	21.3
Female			
No	9,644	5.0	12.5
Yes	3,894	6.0	16.7
Heart Failure			
No	11,320	4.9	12.3
Yes	2,218	7.4	20.9
MO CABG Severity *(tested as probability of death – a continuous variable)*			
0.000 – 0.001	0	–	–
0.002 – 0.011	4,833	4.1	10.2
0.012 – 0.057	7,619	5.6	14.6
0.058 – 0.499	1,085	8.2	23.4
0.500 – 1.000	1	0.0	0.0
MO Predicted Length of Stay *(tested as a continuous variable)*			
<2.358 days	312	5.1	12.5
2.358 – 4.139 days	1,883	5.0	11.8
4.140 – 8.124 days	9,260	4.8	12.7
8.125 – 11.436 days	1,800	7.9	19.9
> 11.437 days	283	7.1	22.3
Obesity			
No	11,798	5.2	13.6
Unspecified obesity	1,212	5.4	13.4
Morbid obesity	528	7.6	18.8
Peripheral Vascular Disease			
No	12,433	5.2	13.4
Yes	1,105	6.0	17.5
Prior CABG and/or Valve Surgery			
No	12,902	5.3	13.7
Yes	636	5.2	14.5
PTCA/Stent (same day as CABG)			
No	13,432	5.2	13.7
Yes	106	9.4	13.2
Race/Ethnicity			
Hispanic	225	4.4	10.2
White, non-Hispanic	12,278	5.2	13.6
Black, non-Hispanic	503	7.4	17.7
Other/unknown, non-Hispanic	532	5.8	14.7
Renal Failure/Renal Dialysis			
No	13,256	5.2	13.6
Chronic renal failure without dialysis	73	12.3	19.2
Pre-op acute renal failure or renal dialysis	209	8.1	23.0

Appendix C: Candidate Variables *continued*

Post-Surgical Length of Stay—Candidate Variable Frequency

Variable	Length of Stay	
	#	*Days*
Acute Myocardial Infarction (AMI)		
No	11,200	6.3
Yes (initial episode as principal diagnosis)	3,429	7.1
Age & Age-Squared *(tested as continuous variables)*		
30-39 years	111	5.0
40-49 years	919	5.4
50-59 years	3,083	5.7
60-69 years	4,382	6.3
70-79 years	4,712	7.1
80-89 years	1,410	7.9
90-99 years	12	9.5
Average age:	*66.1 (males 65.0; females 68.7)*	
Cancer		
No	14,291	6.5
Yes	338	6.8
Cardiogenic Shock		
No	14,577	6.5
Yes (prior to surgery–using clinical information in the medical record)	52	12.9
Cardiomyopathy		
No	14,239	6.5
Yes	390	8.1
Complicated Hypertension		
No	14,059	6.4
Yes	570	9.7
Chronic Obstructive Pulmonary Disease		
No	12,183	6.3
Yes	2,446	7.6
Diabetes		
No	9,370	6.4
Diabetes without complication	4,355	6.5
Diabetes with complication	904	7.7
Female		
No	10,470	6.3
Yes	4,159	7.1
Heart Failure		
No	12,242	6.1
Yes	2,387	8.7
MQ Predicted Length of Stay *(tested as a continuous variable)*		
<2.358 days	337	5.6
2.358 – 4.139 days	2,016	5.9
4.140 – 8.124 days	10,063	6.3
8.125 – 11.436 days	1,922	7.9
> 11.437 days	291	9.9
Obesity		
No	12,737	6.5
Unspecified obesity	1,325	6.2
Morbid obesity	567	6.9
Peripheral Vascular Disease		
No	13,441	6.5
Yes	1,188	6.9
Prior CABG and/or Valve Surgery		
No	13,937	6.5
Yes	692	7.1
PTCA/Stent (same day as CABG)		
No	14,519	6.5
Yes	110	8.0
Race/Ethnicity		
Hispanic	231	6.9
White, non-Hispanic	13,215	6.4
Black, non-Hispanic	531	8.2
Other/unknown, non-Hispanic	652	7.2
Renal Failure/Renal Dialysis		
No	14,364	6.4
Chronic renal failure without dialysis	72	9.4
Pre-op acute renal failure or renal dialysis	193	11.1

APPENDIX D: *ATLAS OUTCOMES*™ APPROACH FOR RISK ADJUSTMENT

Hospitals are required to use the MediQual® *Atlas Outcomes™* System to abstract patient severity information, which is an objective severity of illness grouping, and risk-adjustment system that classifies each patient's risk on admission using data known as Key Clinical Findings (KCFs). It represents a summarization of patient risk based on clinical data found in the medical record. The information used covers the first two days of the hospital stay. This system represents a summarization of patient risk/severity that includes the patient's predicted probability of death (MQPredDeath) and predicted length of stay (MQPredLOS). The MQPredDeath is derived from a logistic regression model and has a value from 0.000 to 1.000. The MQPredLOS is derived from a linear regression model and has no bounds.

The *Atlas Outcomes*™ system is based on the examination of numerous Key Clinical Findings (KCFs) such as lab tests, EKG readings, vital signs, the patient's medical history, imaging results, pathology, age, sex, and operative/endoscopy findings. Hospital personnel abstract these KCFs during specified time frames in the hospitalization. Some pre-admission data are also captured (e.g., cardiac catheterization findings), as are some history findings. The KCF results are entered into algorithms that calculate the overall predicted probability of death or the predicted length of stay.

For this project, MediQual, in consultation with their Clinical Advisory Panel, designed mortality and length of stay models focusing specifically on the CABG population. These models have many similarities to other disease group models used to calculate Admission Severity Groups (ASGs) in the Atlas system, though some differences were introduced to account for the unique characteristics of this population.

Like other MediQual clinical models, the CABG models use Key Clinical Findings (KCFs), history findings, and information from the Uniform Hospital Discharge Data Set to predict probabilities of in-hospital mortality and length of stay. Normally, KCFs would be included in the predictions if they were collected on the first or second day; but for these models, KCFs collected on the second day for patients receiving CABG on the first day were not included. Furthermore, new variables were defined from other Atlas data specifically for use in these models, as suggested and defined by their Clinical Advisory Panel.

The results of these models were predicted probabilities of in-hospital mortality and length of stay for each of the reported patients receiving CABG in 2003. PHC4 used the probabilities of in-hospital mortality and length of stay, along with other patient risk factors, to risk-adjust the hospital- and physician-specific outcomes printed in the 2003 CABG Report.