Technical Notes

Pennsylvania's Guide to Coronary Artery Bypass Graft Surgery, Calendar Year 2004

The Pennsylvania Health Care Cost Containment Council
January 2006

Preface

This document serves as a technical supplement to *Pennsylvania's Guide to Coronary Artery Bypass Graft Surgery, Calendar Year 2004* report (January 1, 2004 to December 31, 2004). The *Technical Notes* describes the methodology of the analyses and outlines the development of the report format and presentation. This document also includes data tables containing information about the statewide results, cases excluded from analysis, and risk-adjustment models. The report presents information regarding the care received by adult patients 30 years of age or older who underwent coronary artery bypass surgery (CABG).

Measures reported for hospitals with 30 or more cases:

- *Risk-adjusted measures*
  - *In-Hospital Mortality Rating*
  - *30-Day Post-Surgical Mortality Rating*
  - *7-Day Readmissions Rating*
  - *30-Day Readmissions Rating*
  - *Post-Operative Length of Stay (in days)*
- *Average Hospital Charges*

Measures reported for surgeons with 30 or more cases:

- *Risk-adjusted measures*
  - *In-Hospital Mortality Rating*
  - *30-Day Post-Surgical Mortality Rating*
  - *7-Day Readmissions Rating*
  - *30-Day Readmissions Rating*
  - *Post-Operative Length of Stay (in days)*

The rigorous methodology described in this document was developed to account for the differences among individual patients that had the potential to influence the outcome of CABG surgery.

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DATA COLLECTION, VERIFICATION, AND PREPARATION

The Pennsylvania Health Care Cost Containment Council (PHC4) is mandated by state law to collect and disseminate health care data. The data for *Pennsylvania's Guide to Coronary Artery Bypass Graft Surgery, Calendar Year 2004* were submitted electronically on a quarterly basis to PHC4 by Pennsylvania general acute care (GAC) hospitals as directed by the data submission requirements of Act 89 of 1986 (currently Act 14 of 2003). The data included demographic information, hospital charges, and diagnosis and procedure codes using the ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification).

Facilities are required to submit data to the Council on a quarterly basis by 90 days from the last day of each quarter. Upon receipt of the data, media verification was performed to assure data were submitted in a readable format. The standard data verification process continued with extensive quality assurance and data quality checks. Error reports were then generated and returned to each facility with an opportunity to correct any problems.

Hospital and Cardiothoracic Surgeon Verification of CABG Data

Discharge records for patients undergoing CABG surgery in 2004 were subjected to additional data verification beyond the standard data verification process described above. Hospitals were requested to confirm the accuracy of the CABG discharge records, provide five additional diagnoses and three additional procedure codes as appropriate, and confirm that all cases had the correct surgeon assignment. Surgeons were requested to perform a patient level review of the submitted records and then attest to the accuracy of the data and the surgeon assignment. Hospitals and/or surgeons had the opportunity to request special exclusions for cases in which the patient's outcome was most directly associated with conditions unrelated to the CABG surgery and not accounted for through risk adjustment. In addition, because of the importance of certain risk factors, hospitals and/or surgeons had the opportunity to identify cases in which cardiogenic shock and/or acute renal failure were present at or immediately prior to CABG surgery. The outcome of each request was determined after the medical record was reviewed.

CABG Data Preparation

After the verification processes were complete, the CABG data set was reassigned using the Diagnostic Related Group (DRG) classification published by the Centers for Medicare and Medicaid Services (CMS) in the Federal Register, vol. 69, no.154, dated August 11, 2004, pages 48916-49722. The information is consistent with the fiscal 2005 Grouper version 22.0.

STUDY POPULATION

Inclusions

The CABG study population included those patients discharged from Pennsylvania general acute care hospitals in calendar year 2004 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	37.51, 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 CABG cases for the hospital that stopped performing CABG surgery during 2004, 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 details for each measure.

OUTCOME MEASURES REPORTED

In-Hospital Mortality

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

30-Day Post-Surgical Mortality

Thirty-day post-surgical mortality measured the number of 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 number 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 CABG surgery. See Appendix B for a list of diagnosis categories and related ICD-9-CM codes for which there was one or more readmissions.

30-Day Readmissions

Similar to seven-day readmissions, 30-day readmissions measured the number 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 determined using the same principal diagnosis criteria that were used for seven-day readmissions. See Appendix B for a list of diagnosis categories and related ICD-9-CM codes for which there was one or more 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 outcome measures was risk-adjusted, which means that the measures took into account the patient's health condition before surgery. Some patients who underwent 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, sex, and factors that indicate the illness level of the patient) were "tested" to determine which factors predicted patient 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 tested were the patient's "MediQual (MQ) CABG severity" and "MediQual (MQ) CABG 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 predicted how likely that was to affect mortality and length of stay. The "severity score" (also referred to as 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 (see Appendix D for a detailed explanation).

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	6,680	6,679	13,359
Number of in-hospital deaths	142	122	264
Mortality rate	2.1	1.8	2.0
30-day post-surgical mortality			
Number of cases	6,088	6,087	12,175
Number of deaths within 30 days	131	150	281
Mortality rate	2.2	2.5	2.3
7-day readmissions			
Number of cases	5,969	5,968	11,937
Number of readmissions within 7 days	306	316	622
Readmissions rate	5.1	5.3	5.2
30-day readmissions			
Number of cases	5,969	5,968	11,937
Number of readmissions within 30 days	769	807	1,576
Readmissions rate	12.9	13.5	13.2

Building the Risk-Adjustment Models

Identifying 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 the 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. The model selection step used binary logistic regression to identify 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). 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. For this

report, the candidate variables reflected the patient's condition during the hospital admission in which the CABG surgery was performed.

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	not tested[1]	not tested[1]
Age	ns	ns	ns	ns
Age-Squared	ns	ns	ns	ns
Cancer	ns	ns	not tested[1]	ns
Cardiogenic Shock	✓	✓	ns	ns
Cardiomyopathy	ns	ns	ns	ns
Complicated Hypertension	ns	ns	ns	ns
Chronic Obstructive Pulmonary Disease	ns	ns	not tested[2]	✓
Diabetes	not tested[1]	not tested[1]	✓	✓
Female	ns	ns	✓	✓
Heart Failure	✓	✓	ns	✓
Logit of MQ CABG Severity[3]	✓	✓	ns	ns
MQ CABG Predicted Length of Stay[3]	not tested[1]	not tested[1]	✓	✓
Obesity	not tested[1]	not tested[1]	ns	not tested[1]
Morbid Obesity	not tested[1]	not tested[1]	not tested[1]	ns
Peripheral Vascular Disease	ns	ns	ns	ns
Prior CABG and/or Valve Surgery	ns	ns	ns	ns
PTCA/Stent (same day as CABG)	not tested[2]	ns	ns	ns
Race/Ethnicity	ns	ns	✓	✓
Chronic/Pre-op Acute Renal Failure or Renal Dialysis	ns	not tested[1]	ns	ns
Pre-op Acute Renal Failure or Renal Dialysis	not tested[1]	ns	not tested[1]	not tested[1]

✓ : significant predictor ($p < 0.10$)
ns : not significant
[1]This variable was not tested because the preliminary analysis did not suggest that the variable would be predictive of the relevant outcome.
[2]This variable was not tested in the final development model because during initial testing the sign of the coefficient was not consistent between the development and cross-validation models.
[3]Both MQ CABG severity and MQ CABG predicted length of stay were calculated using the MediQual® *Atlas Outcomes™* system, 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.

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 the variables found significant in the development model and 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 Table 2) were not tested during cross-validation. Variables with a *p*-value equal to or greater than 0.10 in the cross-validation model did not "cross validate." All significant variables in the in-hospital mortality development model did cross validate. For 30-day post-surgical mortality, heart failure did not cross validate. For 7-day readmissions, diabetes, female, and race/ethnicity did not cross validate. For 30-day readmissions chronic obstructive pulmonary

disease and diabetes did not cross validate. Variables that did not cross validate were still used as risk-adjustment factors in the full dataset.

Table 3. Cross-Validation Results: p-values for Significant Variables in the Development Model

Significant Variables in Development Model	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
Cardiogenic Shock	0.003	<0.001	0.031	0.002	NA	NA	NA	NA
Chronic Obstructive Pulmonary Disease	NA	NA	NA	NA	NA	NA	0.095	0.343
Diabetes	NA	NA	NA	NA	0.015	0.420	0.008	0.204
Female	NA	NA	NA	NA	0.030	0.500	<0.001	0.026
Heart Failure	<0.001	0.001	<0.001	0.248	NA	NA	0.008	0.049
Logit of MQ CABG Severity[1]	<0.001	<0.001	<0.001	<0.001	NA	NA	NA	NA
MQ CABG Predicted Length of Stay[1]	NA	NA	NA	NA	<0.001	<0.001	<0.001	<0.001
Race/Ethnicity	NA	NA	NA	NA	0.057	0.239	0.003	0.086

NA: Not applicable

[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 resultant *c* statistic was used to evaluate model adequacy. The *c* statistic, the measure of "goodness of fit" used to describe a logistic regression model, 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 0.5 and 1.0, with higher values associated with better discrimination, and can be expressed as a percentage ranging from 50 to 100 percent. In some respects, the *c* statistic is similar to the R^2 commonly used in linear regression. Both the *c* statistic and R^2 approach 1.0 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 the models are listed in Table 4.

Table 4. c Statistics for Development, Cross-Validation, and Full Data Set Models

Measure	Development Model %	Cross-Validation Model %	Full Data Set Model %
In-Hospital Mortality	81.2	83.6	82.4
30-Day Post-Surgical Mortality	81.2	76.9	79.1
7-Day Readmissions	61.7	57.1	59.7
30-Day Readmissions	62.6	58.4	60.7

Coefficients and Odds Ratios

The coefficients and the p-values associated with the significant risk factors are listed in Table 5. 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 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, the logit of MQ CABG severity, and MQ CABG predicted length of stay.

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

Predictor Variables	Coefficient	*p*-value	Odds Ratio
In-hospital mortality			
Constant	-0.4064	0.094	
Cardiogenic Shock	1.6805	<0.001	5.368
Heart Failure	0.6978	<0.001	2.009
Logit of MQ CABG Severity	1.0196	<0.001	NA[1]
30-day post-surgical mortality			
Constant	-0.4835	0.045	
Cardiogenic Shock	1.4522	<0.001	4.273
Heart Failure	0.5736	<0.001	1.775
Logit of MQ CABG Severity	0.9239	<0.001	NA[1]
7-day readmissions			
Constant	-3.8248	<0.001	
Diabetes[2]		0.023	
Diabetes without complications	0.2475		1.281
Diabetes with complications	0.1381		1.148
Female	0.1776	0.048	1.194
MQ CABG Predicted Length of Stay	0.0773	<0.001	NA[1]
Race/Ethnicity[3]		0.041	
Hispanic	0.2948		1.343
Black, non-Hispanic	0.1705		1.186
Other/unknown, non-Hispanic	0.4765		1.610
30-day readmissions			
Constant	-2.7731	<0.001	
Chronic Obstructive Pulmonary Disease	0.1297	0.071	1.139
Diabetes[2]		0.004	
Diabetes without complications	0.1919		1.212
Diabetes with complications	0.1795		1.197
Female	0.2630	<0.001	1.301
Heart Failure	0.2409	0.001	1.272
MQ CABG Predicted Length of Stay	0.0670	<0.001	NA[1]
Race/Ethnicity[3]		0.022	
Hispanic	0.00552		1.006
Black, non-Hispanic	0.3372		1.401
Other/unknown, non-Hispanic	0.2284		1.257

[1] NA: Not applicable. This factor was tested as a continuous variable.
[2] "No diabetes" was used as the reference to the other categories of the diabetes variable; therefore, the coefficient was equal to 0.
[3] "White, non-Hispanic" was used as the reference to the other categories of the race/ethnicity 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 rates were determined by dividing the total number of deaths that occurred during the hospital stay by the total number of cases included in the analysis.

30-day post-surgical mortality rates were determined by dividing the total number of deaths within 30 days of the CABG surgery date by the total number of cases included in the analysis.

7-day and 30-day readmissions were determined by dividing the total number of cases 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 included in the analysis.

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) + (cardiogenic shock coefficient)(cardiogenic shock) + (heart failure coefficient)(heart failure) + (logit of MQ CABG severity coefficient)(logit of MQ CABG severity)

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

(constant) + (cardiogenic shock coefficient)(cardiogenic shock) + (heart failure coefficient)(heart failure) + (logit of MQ CABG severity coefficient)(logit of MQ CABG severity)

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

(constant) + (diabetes coefficient)(diabetes) + (female coefficient)(female) + (other risk factor coefficients relevant to each patient)

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

(constant) + (chronic obstructive pulmonary disease coefficient)(chronic obstructive pulmonary disease) + (diabetes coefficient)(diabetes) + (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

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

To calculate a patient's probability of death:

Step 1: Calculate βX:

$$\beta X = -0.4064(\text{constant}) + (1.6805)(\text{cardiogenic shock}) + (0.6978)(\text{heart failure}) + (1.0196)(\text{logit of MQ CABG severity})$$

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

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

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	6,469	6,469	12,938
Average Length of Stay *(arithmetic)*	6.5	6.5	6.5
Average Length of Stay *(geometric)*	5.9	5.8	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. ***Development Model: Variables Evaluated as Potential Predictors of Post-Surgical Length of Stay***

Candidate Variables	Results
Acute Myocardial Infarction (AMI)	✓
Age	ns
Age-Squared	✓
Cancer	✓
Cardiogenic Shock	✓
Cardiomyopathy	ns
Complicated Hypertension	ns
Chronic Obstructive Pulmonary Disease	✓
Diabetes	ns
Female	ns
Heart Failure	✓
MQ CABG Predicted Length of Stay[1]	✓
Morbid Obesity	✓
Peripheral Vascular Disease	✓
Prior CABG and/or Valve Surgery	ns
PTCA/Stent (same day as CABG)	✓
Race/Ethnicity	✓
Chronic/Pre-operative Acute Renal Failure or 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. Cross-Validation Results: p-values for Significant Variables in the Development Model

Significant Variables in Development Model	Development Model	Cross-Validation Model
Acute Myocardial Infarction (AMI)	0.0016	0.1277
Age-Squared	<0.0001	<0.0001
Cancer	0.0588	0.0775
Cardiogenic Shock	0.0477	0.0013
Chronic Obstructive Pulmonary Disease	<0.0001	0.0026
Heart Failure	<0.0001	<0.0001
MQ CABG Predicted Length of Stay[1]	<0.0001	<0.0001
Morbid Obesity	0.0076	0.6040
Peripheral Vascular Disease	0.0428	0.0469
PTCA/Stent (same day as CABG)	0.0079	0.0002
Race/Ethnicity	<0.0001	<0.0001
Chronic/Pre-operative Renal Failure or Renal Dialysis	0.0832	0.8262

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. 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 objective was to evaluate the models' performance in both samples. The Coefficient of Determination (R^2) was the measure considered in evaluating the models' performance. R-squared 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
18.4	18.2	18.4

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 of Predictors in the Final Models***

Predictor Variables	Coefficient	*p*-value
Constant	2.068275741	
Acute Myocardial Infarction (AMI)	-0.029906684	0.0010
Age[1]	0.000486733	0.8828
Age-Squared	0.000037107	0.1484
Cancer	0.060260780	0.0084
Cardiogenic Shock	0.246435189	0.0003
Chronic Obstructive Pulmonary Disease	0.048680768	<0.0001
Heart Failure	0.202454291	<0.0001
MQ CABG Predicted Length of Stay	0.034100258	<0.0001
Morbid Obesity	0.038803161	0.0244
Peripheral Vascular Disease	0.034434221	0.0051
PTCA/Stent (same day as CABG)	0.174292405	<0.0001
Race/Ethnicity[2]		<0.0001
Hispanic	-0.011271483	
White, non-Hispanic	-0.101867291	
Black, non-Hispanic	0.064411251	
Chronic/Pre-op Acute Renal Failure or Renal Dialysis[3]		0.3726
No	-0.049038002	
Chronic Renal Failure	-0.011869101	

[1] Although age was not a significant predictor; it provided precise value to the age-squared variable.
[2] "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.
[3] "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 heart failure had a "0" or "baseline" coefficient; while a patient without heart failure would be adjusted downward by 0.202454291 (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 heart failure and no heart failure would always be –0.202454291 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 103: Heart Transplant or Implant Heart Assist System
  DRG 515: Cardiac Defibrillator Implant without Cardiac Catheterization
  DRG 525: Other Heart Assist System Implant
  DRG 535: Cardiac Defibrillator Implant with Cardiac Catheterization with Acute Myocardial Infarction, Heart Failure, or Shock
  DRG 536: Cardiac Defibrillator Implant with Cardiac Catheterization without 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 at the regional level (the Council uses nine regional designations) for each of the five groups of patients. For three of the groups (DRGs 106, 108, and DRGs 103, 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 (25th percentile total charge) of all patient records from the comparative database in a particular category*

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

$IQR = Q3 - Q1$

$\text{Lower Trim Point} = Q1 - (3.0 \times IQR)$

$\text{Upper Trim Point} = Q3 + (3.0 \times IQR)$

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	$398,263	$101,440	0.0
Regions 4, 5, 6	$249,951	$92,168	2.2
Regions 7, 8, 9	$594,489	$151,414	0.6
DRG 107			
Region 1	$286,609	$72,043	1.2
Region 2	$267,127	$104,508	1.7
Region 3	$113,768	$59,297	2.3
Region 4	$193,858	$64,716	1.7
Region 5	$168,307	$63,253	2.5
Region 6	$175,312	$58,214	0.9
Region 7	$217,929	$75,968	2.2
Region 8	$558,627	$126,118	1.0
Region 9	$681,573	$165,561	1.6
DRG 108			
Regions 1, 2, 3	$461,795	$106,922	0.0
Regions 4, 5, 6	$183,512	$56,603	0.0
Regions 7, 8, 9	$369,934	$97,860	8.7
DRG 109			
Region 1	$283,549	$61,442	0.7
Region 2	$178,356	$72,081	1.7
Region 3	$82,565	$44,783	3.2
Region 4	$103,606	$45,115	2.5
Region 5	$123,344	$48,289	2.7
Region 6	$117,499	$43,512	0.7
Region 7	$188,201	$62,063	0.8
Region 8	$378,318	$86,899	0.7
Region 9	$573,080	$140,727	0.6
DRGs 103, 515, 525, 535, 536			
Region 1, 2, 3	$696,444	$269,442	2.2
Region 4, 5, 6	$374,881	$163,628	6.5
Region 7, 8, 9	$874,979	$309,211	7.5

*Charges of less than $10,000 were considered invalid. Therefore, with the exception of DRG 109 in Region 3, there were no lower trim points. The lower trim point for DRG 109 in Region 3 was $10,171.

Case-Mix Adjustment of Average Charges

Using case-mix adjustment, a composite average charge was developed for each of the five groups of patients in the hospital region. 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 in the hospital region.

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 Charges	Relative Weight
DRG 106		
Regions 1, 2, 3	$122,467	1.45810231
Regions 4, 5, 6	$99,657	1.39070204
Regions 7, 8, 9	$186,629	1.85459202
DRG 107		
Region 1	$81,414	0.96932060
Region 2	$108,112	1.15143494
Region 3	$61,684	1.06886124
Region 4	$70,651	0.98592716
Region 5	$69,758	1.13646298
Region 6	$62,181	1.07677720
Region 7	$82,582	0.82064492
Region 8	$156,324	1.08311648
Region 9	$199,396	1.06563184
DRG 108		
Regions 1, 2, 3	$115,974	1.38079710
Regions 4, 5, 6	$66,837	0.93270972
Regions 7, 8, 9	$118,543	1.17800413
DRG 109		
Region 1	$73,745	0.87801391
Region 2	$71,713	0.76377469
Region 3	$46,837	0.81159565
Region 4	$47,554	0.66361072
Region 5	$51,683	0.84200114
Region 6	$45,305	0.78453723
Region 7	$69,676	0.69239515
Region 8	$107,239	0.74302518
Region 9	$164,974	0.88166802
DRGs 103, 515, 525, 535, 536		
Region 1, 2, 3	$261,587	3.11446882
Region 4, 5, 6	$159,624	2.22754854
Region 7, 8, 9	$306,693	3.04771036

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	*14,382*	*100.00*	*2.3*
Exclusions:			
❖ Hospital no longer performs CABG (2004)	31	0.2	0.0
❖ Clinically complex cases*	984	6.8	7.0
❖ Patients who left against medical advice	7	<0.1	0.0
❖ Patients < 30 years of age	1	<0.1	0.0
Total exclusions	*1,023*	*7.1*	*6.7*
Total cases remaining in analysis	*13,359*	*92.9*	2.0

*Clinically complex cases are: those *not* in DRG 103, 106, 107, 108, 109, 515, 525, 535, 536, or 541, 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	*13,359*	*100.00*	–
Exclusions:			
❖ Cases with invalid/inconsistent data[1]	44	0.3	–
❖ Out-of-state residents[2]	1,140	8.5	–
Total exclusions	1,184	8.9	–
Total cases remaining in analysis	*12,175*	*91.1*	*2.3*

[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	*13,359*	*100.00*	–	–
Exclusions:				
❖ Patients who died during hospitalization where CABG was performed	264	2.0	–	–
❖ Cases with invalid/inconsistent data[1]	53	0.4		–
❖ Out-of-state residents[2]	1,105	8.3	–	–
Total exclusions	*1,422*	*10.6*	–	–
Total cases remaining in analysis	*11,937*	*89.4*	*5.2*	*13.2*

[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	*13,359*	*100.00*	*7.1*
Exclusions:			
❖ Patients who died during hospitalization where CABG was performed	264	2.0	13.0
❖ Patients with post-surgical LOS > 30 days	143	1.1	50.6
❖ Patients with post-surgical LOS < 2 days	14	0.1	1.0
Total exclusions	*421*	*3.2*	25.4
Total cases remaining in analysis	*12,938*	*96.8*	*6.5*

Exclusions from hospital "Average Charges" Analysis

	Statewide Data		
	Case #	***Case %***	***Avg. Charges***
Total cases prior to average charges exclusions	*13,359*	*100.00*	–
Exclusions:			
❖ Patients with invalid or missing charges[1]	8	0.1	–
❖ Tracheostomy cases (DRG 541)	208	1.6	$552,307
❖ Charge outliers[2]	191	1.4	$399,562
Total exclusions	*407*	*3.0*	–
Total cases remaining in analysis	*12,952*	*97.0*	*$99,483*

[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 that indicated a heart-related condition, infection, and/or a complication from the CABG surgery. The following table includes only those diagnosis categories with at least one readmission. Data for readmissions was organized into the following categories: cardiac diagnoses, neurologic diagnoses, respiratory diagnoses, and other diagnoses including infections and complications of surgery.

		7-Day		***30-Day***	
		N = 622 (5.2%)		*N = 1,576 (13.2%)*	
Diagnosis	***ICD-9-CM Code***	#	%	#	%
CARDIAC DIAGNOSES					
Cardiac dysrhythmias post cardiac surgery		**58**	**9.3**	**110**	**7.0**
Conduction disorders (i.e., av block)	426.x	1	0.2	3	0.2
Paroxysmal tachycardias	427.0, 427.1	3	0.5	6	0.4
Atrial fibrillation/flutter	427.31, 427.32	38	6.1	76	4.8
Cardiac arrest	427.5	1	0.2	2	0.1
Premature beats	427.69	0	–	1	0.1
Other rhythm disorders (i.e., ectopic, nodal)	427.81, 427.89	15	2.4	22	1.4
Heart failure/Hypertensive heart disease		**114**	**18.3**	**275**	**17.4**
Rheumatic heart failure	398.91	2	0.3	3	0.2
Malignant hypertensive heart disease with heart failure	402.01	0	–	1	0.1
Unspecified hypertensive heart disease with heart failure	402.91	1	0.2	3	0.2
Unspecified hypertensive renal disease with renal failure	403.91	0	–	5	0.3
Unspecified hypertensive heart and renal disease with heart failure and renal failure	404.93	0	–	1	0.1
Congestive heart failure	428.x, 428.xx	88	14.1	206	13.1
Functional disturbances following cardiac surgery (post cardiotomy syndrome)	429.4	22	3.5	55	3.5
Cardiogenic shock	785.51	1	0.2	1	0.1
Coronary atherosclerosis/myocardial ischemia/infarction		**33**	**5.3**	**103**	**6.5**
Acute myocardial infarction (AMI)	410.x1	14	2.3	44	2.8
Postmyocardial infarction syndrome	411.0	6	1.0	13	0.8
Acute ischemic heart disease	411.89	0	–	1	0.1
Angina pectoris	413.x	1	0.2	1	0.1
Coronary atherosclerosis	414.0x	12	1.9	41	2.6
Other forms of chronic ischemic heart disease	414.8	0	–	2	0.1
Other AMI sequelae	429.79	0	–	1	0.1
Hypertension/Hypotension/Syncope/Dizziness	401.x, 458.x, 458.xx, 780.2, 780.4, 796.3	**13**	**2.1**	**53**	**3.4**
Artery and vein disease/Embolism/Thrombosis		**13**	**2.1**	**62**	**3.9**
Atherosclerosis of artery and vein graft	440.x, 440.xx	1	0.2	10	0.6
Abdominal and thoracic aortic aneurysm or dissection	441.x, 441.xx	2	0.3	13	0.8
Arterial embolism and thrombosis	444.x, 444.xx	1	0.2	6	0.4
Artheroembolism of lower extremity	445.02	0	–	2	0.1
Phlebitis and thrombophlebitis of deep vessels, lower extremity	451.9	2	0.3	2	0.1
Venous embolism and thrombosis of deep vessels of proximal lower extremity	453.41	1	0.2	3	0.2
Venous embolism and thrombosis of deep vessels of other specified vein	453.8	5	0.8	19	1.2
Peripheral vascular complications	997.2	0	–	5	0.3
Vascular complications-vessel, not elsewhere classified	997.79	1	0.2	2	0.1

Appendix B: Readmissions Data *continued*

Diagnosis	*ICD-9-CM Code*	*7-Day*		*30-Day*	
		#	%	#	%
Other forms of heart disease		**8**	**1.3**	**21**	**1.3**
Acute pericarditis	420.xx	2	0.3	4	0.3
Acute and subacute bacterial endocarditis	421.0	0	–	1	0.1
Other diseases of pericardium (hemopericardium, restrictive)	423.x	6	1.0	16	1.0
NEUROLOGIC DIAGNOSES					
Stroke/Transient cerebral ischemia		**18**	**2.9**	**58**	**3.7**
Intracerebral hemorrhage	431	0	–	2	0.1
Occlusion and stenosis of precerebral arteries with and without infarction	433.xx	0	–	9	0.6
Occlusion of cerebral arteries with and without infarction	434.xx	8	1.3	24	1.5
Transient cerebral ischemia	435.x	4	0.6	13	0.8
Acute, but ill-defined cerebrovascular disease (CVA)	436	1	0.2	5	0.3
Iatrogenic cerebrovascular infarction or hemorrhage	997.02	4	0.6	4	0.3
Anoxic brain damage	348.1	1	0.2	1	0.1
RESPIRATORY DIAGNOSES					
Pleurisy		**27**	**4.3**	**65**	**4.1**
Pleural effusion/atelectasis	511.9, 518.0	23	3.7	57	3.6
Hemothorax/hemopneumothorax	511.8	1	0.2	3	0.2
Pneumothorax	512.x	3	0.5	5	0.3
Pulmonary edema/insufficiency		**8**	**1.3**	**15**	**1.0**
Pulmonary insufficiency post trauma or surgery	518.5	2	0.3	3	0.2
Acute respiratory failure	518.81	5	0.8	11	0.7
Acute and chronic respiratory failure	518.84	1	0.2	1	0.1
Respiratory and other chest symptoms		**28**	**4.5**	**91**	**5.8**
Tietze's disease (i.e. costochondritis)	733.6	0	–	3	0.2
Respiratory and other chest symptoms (e.g., shortness of breath, chest pain)	786.x, 786.xx	28	4.5	88	5.6
Pulmonary embolism/Infarction	415.xx	**31**	**5.0**	**63**	**4.0**
Aspiration pneumonia	507.0, 997.3	**30**	**4.8**	**67**	**4.3**
OTHER DIAGNOSES					
Infections		**130**	**20.9**	**375**	**23.8**
Intestinal infection due to clostridium difficile	008.45	6	1.0	16	1.0
Septicemia	038.xx	13	2.1	28	1.8
Pneumonia	482.x, 482.xx, 486	30	4.8	54	3.4
Empyema	510.9	1	0.2	1	0.1
Urinary tract infection	599.0	1	0.2	10	0.6
Cellulitis	682.3, 682.6	5	0.8	15	1.0
Acute osteomyelitis, NEC	730.08	1	0.2	1	0.1
Fever	780.6	2	0.3	6	0.4
Septic shock	785.52	0	–	1	0.1
Bacteremia	790.7	2	0.3	2	0.1
Infection and inflammatory reaction due to heart device	996.61	2	0.3	5	0.3
Infected post-surgical seroma	998.51	0	–	3	0.2
Infection and inflammatory reaction due to vascular device	996.62	2	0.3	3	0.2

Appendix B: Readmissions Data *continued*

Diagnosis	*ICD-9-CM Code*	*7-Day*		*30-Day*	
		#	%	#	%
Infections *continued*					
Other post-surgical infection	998.59	64	10.3	225	14.3
Non-healing surgical wound	998.83	1	0.2	4	0.3
Infection complication of medical care, not elsewhere classified	999.3	0	–	1	0.1
Device, Implant, or Graft Complications		**5**	**0.8**	**6**	**0.4**
Mechanical complication of cardiac device, implant, graft	996.0x	2	0.3	2	0.1
Other complication of cardiac device, implant, graft	996.72	3	0.5	4	0.3
GI hemorrhage/complications		**26**	**4.2**	**52**	**3.3**
Esophageal hemorrhage	530.21	1	0.2	2	0.1
Chronic/unspecified gastric ulcer	531.40	2	0.3	3	0.2
Acute duodenal ulcer	532.00	1	0.2	1	0.1
Chronic duodenal ulcer with hemorrhage and/or perforation, and obstruction	532.40, 532.61	5	0.8	14	0.9
Chronic peptic ulcer with hemorrhage	533.40	1	0.2	2	0.1
Other specified gastritis with hemorrhage	535.41	2	0.3	3	0.2
Vascular insufficiency of intestine (bowel infarction, ischemic colitis)	557.0, 557.9	1	0.2	3	0.2
Intestinal obstruction/paralytic ileus	560.1, 560.9	4	0.6	6	0.4
Hemorrhage of rectum and anus	569.3	0	–	1	0.1
Blood in stool	578.1	1	0.2	3	0.2
Hemorrhage of gastrointestinal tract, unspecified	578.9	5	0.8	11	0.7
Digestive system complications due to procedure	997.4	3	0.5	3	0.2
Genitourinary complications		**12**	**1.9**	**28**	**1.8**
Acute renal failure	584.x	10	1.6	25	1.6
Hematuria	599.7	2	0.3	3	0.2
Anemia/Thrombocytopenia/Anticoagulation disorders		**1**	**0.2**	**12**	**0.8**
Iron deficiency anemias	280.x	0	–	3	0.2
Other and unspecified anemias (i.e., post hemorrhagic anemia)	285.xx	0	–	5	0.3
Other and unspecified coagulation defect	286.9	0	–	1	0.1
Pupura and other hemorrhagic conditions	287.x	1	0.2	1	0.1
Hemorrhage, unspecified	459.0	0	–	1	0.1
Abnormal coagulation profile	790.92	0	–	1	0.1
Fluid and electrolyte imbalance	276.x	**8**	**1.3**	**23**	**1.5**
Other surgical complications		**59**	**9.5**	**97**	**6.2**
Cardiac complications resulting from procedure	997.1	39	6.3	60	3.8
Hemorrhage or hematoma complicating a procedure	998.1x	4	0.6	9	0.6
Dehiscence or rupture of operation wound	998.3x	15	2.4	23	1.5
Other procedure complications, not elsewhere classified	998.89	1	0.2	5	0.3

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, and 996.02, 996.03, 996.61, or 996.72 in the principal diagnosis position
PTCA/Stent (same day as CABG) 36.01, 36.02, 36.05, 36.06, 36.07, 36.09
Renal Dialysis 39.95, 54.98 and procedure date was prior to or the same day as CABG surgery
Renal Failure – Chronic 585
Renal Failure – Pre-operative acute renal failure 584.5 – 584.9 and medical record review to determine that diagnosis was prior to CABG surgery

Appendix C: Candidate Variables *continued*

Mortality—Candidate Variable Frequency

Variable	In-Hospital Mortality		30-Day Mortality	
	#	%	#	%
Acute Myocardial Infarction (AMI)				
No	10,174	1.5	9,270	1.8
Yes (initial episode as principal diagnosis)	3,185	3.4	2,905	3.8
Age & Age-Squared *(tested as continuous variables)*				
30-39 years	98	0.0	93	0.0
40-49 years	812	0.4	744	0.9
50-59 years	2,810	0.6	2,546	1.0
60-69 years	4,012	1.6	3,617	1.7
70-79 years	4,343	2.6	3,988	2.9
80-89 years	1,270	5.3	1,174	6.0
90-99 years	14	7.1	13	7.7
Average age:	*66.1 (females 68.7, males 65.1)*		*66.2 (females 68.8, males 65.1)*	
Cancer				
No	13,053	1.9	11,897	2.3
Yes	306	3.9	278	3.6
Cardiogenic Shock				
No	13,297	1.9	12,119	2.2
Yes (prior to surgery–using clinical information in medical record)	62	29.0	56	26.8
Cardiomyopathy				
No	12,960	1.9	11,812	2.3
Yes	399	4.0	363	3.0
Complicated Hypertension				
No	12,735	1.7	11,603	2.1
Yes	624	7.7	572	7.2
Chronic Obstructive Pulmonary Disease				
No	11,013	1.8	10,028	2.1
Yes	2,346	3.0	2,147	3.3
Female				
No	9,541	1.6	8,665	1.9
Yes	3,818	2.9	3,510	3.4
Heart Failure				
No	11,098	1.3	10,177	1.6
Yes	2,261	5.5	1,998	5.9
MQ CABG Severity *(tested as logit of probability of death- a continuous variable)*				
0.000 – 0.001	0	-	0	-
0.002 – 0.011	5,475	0.3	4,973	0.5
0.012 – 0.057	6,943	2.1	6,341	2.5
0.058 – 0.499	940	10.4	861	11.0
0.500 – 1.000	1	0.0	0	-
Peripheral Vascular Disease				
No	12,227	1.9	11,135	2.2
Yes	1,132	2.7	1,040	3.5
Prior CABG and/or Valve Surgery				
No	12,759	1.8	11,633	2.2
Yes	600	5.2	542	5.2
PTCA/Stent (same day as CABG)				
No	13,238	1.9	12,067	2.2
Yes	121	10.7	108	12.0
Race/Ethnicity				
Hispanic	236	0.8	226	0.4
White, non-Hispanic	11,949	1.9	10,950	2.3
Black, non-Hispanic	515	3.5	473	3.4
Other/unknown, non-Hispanic	659	2.7	526	3.0
Chronic/Pre-operative Acute Renal Failure or Dialysis				
No	13,192	1.9	NA	NA
Yes	167	9.0	NA	NA
Pre-operative Acute Renal Failure or Dialysis				
No	NA	NA	12,064	2.2
Yes	NA	NA	111	12.6

NA: not applicable

Appendix C: Candidate Variables *continued*

Readmissions—Candidate Variable Frequency

Variable	7 & 30 Day Readmissions	7-Day Readmissions	30-Day Readmissions
	#	%	%
Age & Age-Squared *(tested as continuous variables)*			
30-39 years	93	9.7	16.1
40-49 years	741	3.4	11.6
50-59 years	2,529	4.5	11.4
60-69 years	3.558	5.1	12.6
70-79 years	3,890	5.4	14.0
80-89 years	1,114	7.0	17.1
90-99 years	12	0.0	16.7
Average age: 66.1 (females 68.6, males 65.0)			
Cancer			
No	11,667	5.2	13.2
Yes	270	4.8	13.7
Cardiogenic Shock			
No	11,898	5.2	13.2
Yes (prior to surgery–using clinical information in medical record)	39	10.3	20.5
Cardiomyopathy			
No	11,589	5.1	13.0
Yes	348	7.5	18.7
Complicated Hypertension			
No	11,407	5.1	12.8
Yes	530	8.1	20.9
Chronic Obstructive Pulmonary Disease			
No	9,854	4.9	12.6
Yes	2,083	6.6	16.1
Diabetes			
No	7,573	4.6	11.9
Diabetes without complication	3,547	6.1	14.9
Diabetes with complication	817	6.7	17.5
Female			
No	8,530	4.8	11.9
Yes	3,407	6.3	16.6
Heart Failure			
No	10,051	4.7	12.1
Yes	1,886	8.1	19.0
MQ CABG Severity *(tested as logit of probability of death- a continuous variable)*			
0.000 – 0.001	0	-	-
0.002 – 0.011	4,957	4.4	10.5
0.012 – 0.057	6,209	5.4	14.3
0.058 – 0.499	771	9.2	21.9
0.500 – 1.000	0	-	-
MQ CABG Predicted Length of Stay *(tested as a continuous variable)*			
<5.533 days	273	2.9	7.7
5.533 – 6.464 days	1,597	3.7	7.5
6.465 – 11.996 days	8,254	5.1	13.2
11.997 – 17.474 days	1,567	7.1	18.4
> 17.474 days	246	8.5	22.8
Obesity			
No	10,285	5.1	NA
Unspecified obesity	1,162	5.8	NA
Morbid obesity	490	5.7	NA
Morbid Obesity			
No	11,447	NA	13.0
Yes	490	NA	18.2
Peripheral Vascular Disease			
No	10,925	5.1	13.0
Yes	1,012	6.7	15.7
Prior CABG and/or Valve Surgery			
No	11,421	5.2	13.1
Yes	516	6.4	15.9
PTCA/Stent (same day as CABG)			
No	11,841	5.2	13.1
Yes	96	8.3	20.8
Race/Ethnicity			
Hispanic	225	6.7	12.9
White, non-Hispanic	10,739	5.0	12.9
Black, non-Hispanic	460	6.5	18.9
Other/unknown, non-Hispanic	513	7.8	15.6
Chronic/Pre-operative Acute Renal Failure or Dialysis			
No	11,797	5.2	13.1
Yes	140	8.6	22.9

NA: not applicable

Appendix C: Candidate Variables *continued*

Post-Surgical Length of Stay—Candidate Variable Frequency

Variable	Length of Stay	
	#	*Days*
Acute Myocardial Infarction (AMI)		
No	9,927	6.3
Yes (initial episode as principal diagnosis)	3,011	7.1
Age & Age-Squared *(tested as continuous variables)*		
30-39 years	96	5.2
40-49 years	799	5.4
50-59 years	2,768	5.8
60-69 years	3,917	6.2
70-79 years	4,168	7.1
80-89 years	1,177	7.9
90-99 years	13	7.9
Average age: 66.0 (females 68.6, males 65.0)		
Cancer		
No	12,650	6.5
Yes	288	7.4
Cardiogenic Shock		
No	12,906	6.5
Yes (prior to surgery–using clinical information in the medical record)	32	10.0
Cardiomyopathy		
No	12,568	6.5
Yes	370	7.8
Complicated Hypertension		
No	12,382	6.4
Yes	556	8.7
Chronic Obstructive Pulmonary Disease		
No	10,704	6.3
Yes	2,234	7.5
Diabetes		
No	8,190	6.4
Diabetes without complication	3,864	6.5
Diabetes with complication	884	7.5
Female		
No	9,284	6.3
Yes	3,654	7.0
Heart Failure		
No	10,884	6.1
Yes	2,054	8.8
MQ CABG Predicted Length of Stay *(tested as a continuous variable)*		
<5.533 days	299	4.6
5.533 – 6.464 days	1,772	5.1
6.465 – 11.996 days	8,952	6.4
11.997 – 17.474 days	1,664	8.6
> 17.474 days	251	9.5
Morbid Obesity		
No	12,415	6.5
Yes	523	6.9
Peripheral Vascular Disease		
No	11,849	6.5
Yes	1,089	6.7
Prior CABG and/or Valve Surgery		
No	12,375	6.5
Yes	563	6.9
PTCA/Stent (same day as CABG)		
No	12,833	6.5
Yes	105	7.8
Race/Ethnicity		
Hispanic	229	7.0
White, non-Hispanic	11,591	6.4
Black, non-Hispanic	487	7.9
Other/unknown, non-Hispanic	631	7.0
Chronic/Pre-operative Acute Renal Failure or Dialysis		
No	12,789	6.5
Chronic renal failure	41	8.9
Pre-op acute renal failure or renal dialysis	108	9.2

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 a maximum time period of the first two days of the hospital stay (time of admission and/or procedure may shorten the number of hours available for collection of KCFs). This system represents a summarization of patient risk/severity that includes the patient's predicted probability of death and predicted length of stay. The predicted probability of death is derived from a logistic regression model and has a value from 0.000 to 1.000. The predicted length of stay 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 test results, EKG findings, 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 the CABG population, MediQual (MQ), in consultation with their Clinical Advisory Panel, designed mortality and length of stay models focusing specifically on the CABG patients. These models have many similarities to other disease group models used to calculate Admission Severity Groups (ASGs) in the *Atlas Outcomes*™ system, though some differences were introduced to account for the unique characteristics of this population.

The results of these models were predicted probabilities of in-hospital mortality, represented by the MQ CABG severity score, and predicted length of stay, represented by the MQ CABG predicted length of stay score, for each of the reported patients receiving CABG in 2004. Note that if a hospital did not submit KCFs for a particular patient, the MQ CABG severity score and the MQ predicted length of stay score could not be assigned. If a discharge record was missing the MQ scores, PHC4 imputed the values using the average scores for the hospital. PHC4 used the MQ CABG severity and MQ predicted length of stay scores, along with other patient risk factors, to risk-adjust the hospital- and physician-specific outcomes in the 2004 CABG Report.