**Hospital-level 30-day All-Cause Mortality Following
Coronary Artery Bypass Graft Surgery**

Updated Measure Methodology Report

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1. INTRODUCTION

1.1 Background

CMS has contracted with Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation (YNHHSC/CORE) to develop two administrative-based, risk-adjusted Coronary Artery Bypass Graft (CABG) outcomes measures suitable for public reporting that reflect the quality of care for hospitalized patients undergoing CABG in the United States: 1) Hospital-level 30-day, All-Cause, Risk-Standardized Mortality Rate (RSMR) Following Coronary Artery Bypass Graft (CABG) Surgery, and 2) Hospital-level 30-day, All-Cause, Unplanned, Risk-Standardized Readmission Rate (RSRR) Following Coronary Artery Bypass Graft (CABG) Surgery. <u>The goal of the measures is to improve the quality of care delivered to patients undergoing CABG procedures</u>. They are complementary measures that assess different domains of quality. The mortality measure will both document short-term survival and inform quality improvement efforts targeted toward maximizing survival in the post-operative period. As readmission following CABG is likely a signal of both perioperative complications and suboptimal transitional care, the readmission measure offers the additional benefit of assisting hospitals in minimizing medical and surgical complications during surgery and the postoperative period and improving the care provided in the transition to outpatient settings. The premise is that improved quality of care, including coordination and communication among providers and with patients and their caregivers, can favorably influence performance on these measures.

In this technical report we provide detailed information on the development of the administrative-based CABG mortality measure. Briefly, we developed the measure as an all-cause mortality measure designed to capture deaths within 30 days of an isolated CABG procedure (i.e., CABG surgeries not accompanied with a valve or other major cardiac/thoracic procedure). The CABG mortality measure complies with accepted standards for outcomes measure development, including appropriate risk adjustment and transparency of specifications. The model was developed in 2009 Medicare Fee-for-Service (FFS) data and validated using data from 2008 and 2010 data. Although we developed the measure using Medicare data, the measure was also tested in and adapted for all-payer datasets.

1.2 Importance of CABG Mortality

CABG is a priority area for outcomes measure development because it is a common procedure associated with considerable morbidity, mortality, and health care spending. In 2007, there were 114,028 hospitalizations for CABG surgery and 137,721 hospitalizations for combined surgeries for CABG and valve procedures ("CABG plus valve" surgeries) among Medicare FFS patients in the U.S.[1]

CABG surgeries are costly procedures that account for the majority of major cardiac surgeries performed nationally. In fiscal year 2009, isolated CABG surgeries accounted for almost half (47.6%) of all cardiac surgery hospital admissions in Massachusetts.[2] In

2008, the average Medicare payment[1] was $30,546 for CABG without valve and $47,669 for CABG plus valve surgeries.[3]

Mortality rates following CABG surgery are not insignificant and vary across hospitals. For example, in January 2009 – September 2011 Medicare FFS data, the median hospital-level risk-standardized mortality rate after CABG was 3.1% and ranged from 1.5% to 9.3%. Even within a single state[4], the observed in-hospital/30-day all-cause, hospital-level mortality rate was 1.81% and ranged from 0.0% to 5.6% among patients who were discharged after CABG surgery (without any other major heart surgery earlier in the hospital stay) in New York in 2008. The risk-adjusted mortality rate ranged from 0.0% to 8.2%.[4]

Variation in these rates suggests that there is room for improvement. An all-cause mortality measure for patients who undergo CABG surgery will provide hospitals with an incentive to reduce mortality through improved coordination of perioperative care and discharge planning. This is further supported by the success of registry-based mortality measures in reducing CABG mortality rates. For example, California reports that CABG mortality in that state has steadily declined from 2.9% in 2003, the first year of mandatory reporting of their state registry measure, to 2.2% in 2008.[5]

1.3   CABG Mortality as a Measure of Quality

Outcome measures can focus attention on a broad set of healthcare activities that affect patients' well-being. Moreover, improving patient outcomes is the ultimate goal of quality improvement, so outcomes are a direct measure of success in quality improvement. Two statutes direct the Department of Health and Human Services to develop outcomes measures. The Deficit Reduction Act (DRA) of 2005 mandated that the Secretary of Health and Human Services publicly report quality measures that include measures of hospital outcomes and efficiency under the Hospital Inpatient Quality Reporting (IQR) Program (formerly the Reporting Hospital Quality Data for Annual Payment Update Program). In addition, the Affordable Care Act of 2010 promotes the further development and use of outcomes measures.

The goal of outcomes measurement is to evaluate patient outcomes after accounting for patients' conditions at the time of hospital admission (hospital case-mix). This mortality measure was developed to identify hospitals that perform better or worse than would be expected based on their patient case-mix, and therefore to promote hospital quality improvement and better inform consumers about quality of care.

1.4   Approach to Measure Development

We developed this measure in accordance with national guidelines for publicly reported outcomes measures, and in consultation with clinical and measurement experts, key stakeholders, and the public. The proposed measure is consistent with the technical approach to outcomes measurement set forth in National Quality Forum (NQF) guidance for outcomes measures,[6] CMS's Measure Management System (MMS) guidance, and the guidance articulated in the American Heart Association scientific statement, "Standards for Statistical Models Used for Public Reporting of Health Outcomes."[7] Throughout measure

development, we obtained expert and stakeholder input via two mechanisms: first, through regular discussions with an advisory working group, and second, through meetings with a national Technical Expert Panel (TEP). In addition, we worked closely with the Society of Thoracic Surgeons (STS) to ensure this measure was harmonized with a registry-based CABG readmission measure under development by STS.

The working group was comprised of two cardiothoracic surgeons in addition to the development team. The working group meetings addressed key issues surrounding measure development, including detailed discussions regarding the appropriate cohort for inclusion in the measure. The working group provided a forum for focused expert review and discussion of technical issues during measure development prior to consideration by the broader TEP.

In addition to the working group, and in alignment with the CMS's MMS, we convened a TEP of diverse perspectives and backgrounds, including clinicians, consumers, hospitals, purchasers, and experts in quality improvement.

To recruit the TEP we posted a call for TEP nominations on the CMS Web site, which included a brief description of the measures being developed, the measure development process, and information on expected TEP member involvement. We also identified potential TEP members and relevant organizations and notified them of the call. All nominations (comprised of a signed nomination/disclosure/agreement form, a statement of interest, and a CV) were compiled, reviewed with the Society for Thoracic Surgeons (STS), and confirmed by CMS in order to conduct a joint TEP for the measures. The final TEP consisted of 15 members, although one member recused himself after being appointed to the NQF Consensus Standards Approval Committee.

We convened three TEP conference calls during the course of measure development. In contrast to the working group meetings, the TEP meetings followed a more structured format. We presented key methods decisions, relevant data and analysis, and our proposed approach. Presentations were followed by open discussions of issues with TEP members.

We publicly posted the preliminary measure specifications and a summary of the TEP discussions and made a widely distributed call for public comments. We collected comments through the CMS MMS Web site (https://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/MMS/CallforPublicComment.html) and took the comments into consideration during the final stages of measure development. In addition, we summarized the public comments for CMS and posted the verbatim comments and a summary of public comments on the publicly accessible CMS MMS Web site.

Finally, using New York Cardiac Surgery Reporting System (CSRS) Registry data we performed a clinical data validation study of the administrative risk adjustment model and hospital performance assessment, detailed in Appendix D.

2. METHODS

2.1 Overview

We developed a hospital-level mortality measure for patients aged 65 years and over admitted for a qualifying isolated CABG procedure to non-Federal acute care hospitals in the U.S. (including U.S. Virgin Islands, Puerto Rico, Guam, Northern Mariana Islands, and American Samoa).

To develop the measure, we used Medicare administrative datasets that contain hospitalization data for FFS Medicare beneficiaries hospitalized in calendar year 2009 for a qualifying CABG procedure. The datasets also include administrative data on each patient for the 12 months prior to the index admission and the 30 days following it. An index admission is the hospitalization considered for the outcome. We subsequently updated some results in this report using CABG admissions from January 1, 2009 – September 30, 2011.

The measure calculates hospital-level risk-standardized mortality rates (RSMRs) using a hierarchical logistic regression model to account for the clustering of patients within hospitals while risk-adjusting for differences in patient case-mix. We risk-adjusted for patients' comorbid conditions, as identified in both inpatient and outpatient claims for the 12 months prior to the index hospitalization, as well as those present at admission. The model does not risk-adjust for diagnoses that may have been a complication of the index admission.

The measure was validated using Medicare FFS data from 2008 and 2010. The measure was also tested in an all-payer dataset and shown to be applicable to all-payer data for patients 18 years and older.

2.2 Data Sources

Part A inpatient data (to identify the cohort and comorbidities for risk adjustment)- contains final action claims data submitted by inpatient hospital providers for Medicare FFS beneficiaries for reimbursement of facility costs. Information in this file includes diagnoses (The International Classification of Diseases, 9th Revision, Clinical Modification or ICD-9 diagnosis codes), procedures (ICD-9 procedure codes), dates of service, hospital provider, and beneficiary demographic information.

Part A outpatient data (to identify comorbidities for risk adjustment) - contains final action claims submitted by inpatient hospital providers for Medicare FFS claims paid for the facility component of surgical or diagnostic procedures, emergency room care, and other non-inpatient services performed in a hospital outpatient department or ambulatory surgical/diagnostic center.

Part B data (to identify comorbidities for risk adjustment) - contains final action claims for physician services (regardless of setting) and other outpatient care, services, and supplies for Medicare FFS beneficiaries. For purposes of this project, Part B services included only face-to-face encounters between a care provider and patient. We, thus, do

not include services such as laboratory tests, medical supplies, or other ambulatory services.

Medicare Enrollment Database (EDB) (to determine the outcome) - contains Medicare beneficiary demographic, benefit/coverage, and vital status information.

New York Cardiac Surgery Reporting System (CSRS) Registry data (to validate risk adjustment model) – a large CABG registry that has been used to collect and publicly reported outcomes since 1992.

California Patient Discharge Data (to test the measure in all-payer data) – contains linked administrative data for approximately three million adult discharges from more than 450 non-federal acute care hospitals (2006 data), including readmission and mortality outcomes (via linking with California vital statistics records).

2.3   Outcome Definition

The outcome for this measure is 30-day all-cause mortality. We define this as death from any cause within 30 days of the CABG procedure date.

2.3.1   30-Day Timeframe

We use a standard period of assessment so that the outcome for each patient is measured consistently. Without a standard period, variation in length of stay would have an undue influence on mortality rates, and institutions would have an incentive to adopt strategies to shift deaths out of the hospital without improving quality.

We chose 30-day mortality because it is an outcome that can be strongly influenced by hospital care and the early transition to the outpatient setting. Clinical experts concur that a 30-day timeframe is clinically sensible for measuring outcomes following CABG surgery.

Monitoring survival over shorter periods of time following CABG than 30 days may be inadequate to capture all relevant outcomes and may provide insufficient power to capture meaningful hospital performance variation. Extending the assessment period beyond 30 days may capture events more heavily impacted by factors unrelated to the care the patient received. Furthermore, this outcome period is consistent with other NQF-endorsed CMS mortality measures, including Hospital 30-day Risk-standardized Mortality Rates following Percutaneous Coronary Intervention (PCI) for patient without ST segment elevation myocardial infarction (STEMI) and without cardiogenic shock, Hospital 30-day Risk-standardized Mortality Rates following Percutaneous Coronary Intervention (PCI) for patient with ST segment elevation myocardial infarction (STEMI) or cardiogenic shock, and the Risk-adjusted Operative Mortality for CABG measure developed by STS.

This CABG mortality measure differs from the NQF-endorsed publicly reported acute myocardial infarction (AMI), heart failure and pneumonia mortality measures by dating the 30-day mortality timeframe from the procedure date rather than from the admission date. We chose to use the procedure date as the admission date is likely an inadequate surrogate for date of CABG surgery. Data from 2009 Medicare FFS patients demonstrates that 25% of CABG procedures occurred more than 3 days after the

admission date. Therefore, dating the measurement period from admission would potentially underestimate the period of risk for a substantial number of hospitals.

2.3.2 All-Cause Mortality

We measure all-cause mortality rather than CABG-specific mortality for several reasons. First, limiting the measure to CABG-related mortalities may limit the focus of efforts to improve care to a narrow set of approaches as opposed to encouraging broader initiatives aimed at improving the overall in-hospital care. Second, cause of death may be unreliably recorded and it is often not possible to exclude quality issues and accountability based on the documented cause of mortality. Finally, from a patient perspective death due to any cause is the outcome that matters.

2.4 Cohort Definition

The cohort includes patients aged 65 years and older who received a qualifying CABG procedure at an acute care facility. Patients are eligible for inclusion if they had a qualifying isolated CABG procedure and continuous enrollment in Medicare FFS one year prior to the first day of the index hospital stay and through 30 days post-procedure. The cohort is defined using the ICD-9 Clinical Modification (ICD-9-CM) procedure codes identified in Medicare Part A inpatient claims data. Table 1 below provides the final CABG measure cohort codes.

Table 1. Qualifying CABG Measure Cohort Codes

ICD-9 Code	Description
36.1x	Aortocoronary bypass for heart revascularization, not otherwise specified
36.11	(Aorto) coronary bypass of one coronary artery
36.12	(Aorto) coronary bypass of two coronary arteries
36.13	(Aorto) coronary bypass of three coronary arteries
36.14	(Aorto) coronary 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

2.4.1 Isolated CABG Cohort Definition

In order to include a clinically-coherent set of patients in the measure, we sought input from clinical experts regarding the inclusion of other concomitant cardiac and non-cardiac procedures, such as valve replacement and carotid endarterectomy. Clinical outcome rates following such procedures are higher than those following "isolated" CABG procedures[8], performed without concomitant high-risk cardiac and non-cardiac procedures. All of those measures developed by the STS, including the NQF-endorsed STS Risk-Adjusted Operative Mortality for CABG measure,[9] consider isolated CABG patients separate from those undergoing CABG plus valve procedures. Limiting the measure cohort to "isolated" CABG patients is consistent with published reports of CABG outcomes[8] and the NQF-endorsed STS Risk-Adjusted Operative Mortality for CABG measure[9]. In addition, our clinical experts, consultants and TEP members agreed that an isolated CABG cohort is a clinically coherent cohort for quality measurement.

We defined isolated CABG patients as those undergoing CABG procedures without concomitant valve or other major cardiac, vascular or thoracic procedures (Table 2). We also considered excluding a number of cardiac procedures that we ultimately decided to include in the measure cohort if they occurred concomitantly with CABG procedures. These procedures did not represent that same increased risk of mortality as those listed in Table 3 and were more discretionary in nature. While we do not anticipate that hospitals might perform or code for additional procedures in order to avoid measurement, we did not want to provide any incentive or opportunity for such behaviors.

The administrative CABG mortality measure isolated CABG cohort is as harmonized with that of the STS registry-based CABG Operative Mortality measure cohort as the limitations of the two data sources allow. The only clinical difference is that this measure includes only epicardial MAZE procedures while the STS measure cohort excludes all MAZE procedures. This is because the version of the STS data collection form at the time of this measure development did not differentiate between open and epicardial MAZE procedures, limiting their current ability to include epicardial MAZE procedures. Appendix A provides the ICD-9 codes and CMS's Hierarchical Condition Categories ([HCCs], see Section 2.9 for additional information on HCCs) excluded from the isolated CABG cohort.

Table 2. Concurrent procedure groups that exclude patients from isolated CABG cohort

Procedure groups **excluded from "isolated CABG"**[2]:	Rationale
• Valve procedures • Atrial and/or ventricular septal defects • Congenital anomalies • Other open cardiac procedures • Heart transplants • Aorta or other non-cardiac arterial bypass procedures • Head, neck, intracranial vascular procedures	• Represent higher risk population of patients • Aligned with STS measures (to the extent possible given data limitations)

Table 3. Concurrent procedure groups considered, but rejected as criteria for excluding patients (CABG patients with these procedures are retained in the measure.)

Procedure groups considered for exclusion but ultimately **included in isolated CABG**:	Rationale
• Computer Assisted Surgery • Placement of circulatory assist devices (includes Ventricular assist devices [VADs], excludes implantation of cardiomyostimulation system, often planned) • Lead removal/revision/replacement • Pacemaker implantation • Implantable Cardioverter Defibrillator (ICD) implantation • Transmyocardial revascularization (TMR) procedures • Miscellaneous (e.g., other revascularization, cardiac massage, epicardial "MAZE" procedures intended to eliminate atrial fibrillation)	• Do not represent higher patient risk categories • Rare procedures that are discretionary and, as such, may provide additional hospital performance information • Aligned with STS measures (to the extent possible given data limitations)

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[2] Refer to full list of codes in Appendix A.

2.5   Inclusion/Exclusion Criteria

Admissions eligible for inclusion in the measure are those for patients aged 65 years or older admitted to non-federal acute care hospitals for isolated CABG procedures (i.e., CABG surgeries that occur concomitantly with excluded procedures and procedure groups such as aortic valve replacement) AND continuously enrolled in Medicare FFS one year prior to the first day of the index hospitalization. Medicare patients younger than age 65 usually qualify for the program due to severe disability. They are not included in the measure because they are considered to be too clinically distinct from Medicare patients aged 65 and over. The flow chart depicting eligible admissions is presented in Figure 2 in the Results Section. An index admission is any eligible admission to a non-federal acute care hospital assessed in the measure for the outcome (died within 30 days of the date of the CABG procedure). Eligible index admissions are identified using the ICD-9 codes listed in Table 1.

We excluded the following admissions from the measure:

- Patients with inconsistent or unknown vital status or other unreliable data.

  Rationale: We exclude these because the outcome cannot be adequately measured in these patients.

- Patients who leave hospital against medical advice (AMA).

  Rationale: We exclude hospital stays for patients who are discharged AMA because providers did not have the opportunity to deliver full care and prepare the patient for discharge.

- Subsequent qualifying CABG procedures during the measurement period.

  Rationale: CABG procedures are expected to last for several years without the need for revision or repeat revascularization. A repeat CABG procedure during the measurement period very likely represents a complication of the original CABG procedure and is a clinically more complex and higher risk surgery. We therefore select the first CABG admission for inclusion in the measure and exclude subsequent CABG admissions from the cohort.

2.6   Transferred Patients and Attribution of Mortality Outcome

In measure development, the goal was to attribute the mortality outcome to the hospital performing the first ("index") CABG. However, patients may have more than one admission during an acute episode of care for CABG surgery. For example, a patient may be admitted to hospital A, where a qualifying CABG procedure is performed, and then transferred to hospital B. The initial admission to hospital A and the admission to hospital B are considered one acute episode of care, made up of two inpatient admissions. We identified transferred patients as those who are admitted to an acute care hospital on the same day or following day of discharge from an eligible admission. Below we summarize the most common transfer scenarios arising in the CABG measure

development cohort and the attribution of the mortality outcome in each scenario. The following decisions are based upon the fact that transfer following a CABG procedure almost always reflects one or more serious complication(s) (and/or its sequelae) arising at the index hospital.

CABG Transfer Scenarios:

Transfer Scenario 1 (below) indicates that a patient undergoes a CABG procedure at Hospital A and then is transferred to hospital B (but does not receive additional CABG procedures). The measure attributes the mortality outcome to Hospital A, which performed the index CABG procedure, and starts the 30-day window from the day the CABG is performed at Hospital A. This scenario is included in the measure because excluding it might miss important quality of care information. Clinical experts in both the CORE and STS working groups uniformly supported that transfer following CABG is likely an indication of complications and thus impacts mortality risk. In addition, excluding this scenario might provide hospitals with an incentive to transfer sicker patients to other hospitals in order to avoid measurement.

(Data: 2010 CABG index file)			% of all CABG hospitalizations	% of all CABG transfers	*Proposed* CABG Inclusion/Exclusion	*Proposed* CABG Attribution
❖ Scenario 1:	Hospital A CABG → Transfer → Hospital B No CABG	N = 881	0.63%	5.67%	Include	Hospital A

Transfer Scenario 2 (below) indicates that a patient is admitted to Hospital A (but does not receive a CABG procedure at hospital A) and is transferred to hospital B to receive a CABG procedure. The measure attributes the mortality outcome to Hospital B, which performed the index CABG procedure, and starts the 30-day window from the day the CABG is performed at Hospital B. This is a common scenario arising in the CABG measure development cohort and attributing the outcome to the second hospital is consistent with other procedure-based measures.[10,11]

(Data: 2010 CABG index file)			% of all CABG hospitalizations	% of all CABG transfers	*Proposed* CABG Inclusion/Exclusion	*Proposed* CABG Attribution
❖ Scenario 2:	Hospital A No CABG → Transfer → Hospital B CABG	N = 14,652	10.44%	94.30%	Include	Hospital B

Transfer Scenario 3 (below) indicates that a patient undergoes a CABG procedure at Hospital A and then is transferred to hospital B, to receive a second CABG procedure. The measure attributes the mortality outcome to Hospital A, which performed the index CABG procedure, and starts the 30-day window from the day the CABG is performed at Hospital A. Similar to Scenario 1, this rare scenario is included in the measure as excluding it might miss important quality of care information. Clinical experts in both the CORE and STS working groups unanimously agreed that transfer following CABG is likely an indication of complications and thus impacts mortality risk. In addition, excluding this scenario might provide hospitals with an incentive to transfer sicker patients to other hospitals in order to avoid measurement.

(Data: 2010 CABG index file)				% of all CABG hospitalizations	% of all CABG transfers	*Proposed* CABG Inclusion/Exclusion	*Proposed* CABG Attribution
❖ **Scenario 3:**	Hospital A CABG	Transfer →	Hospital B CABG	N = 4	0.00%	0.03%	Include	Hospital A

2.7 Model Development and Validation Samples

To create the model development and validation samples, we applied the inclusion and exclusion criteria to all 2008-2010 admissions. We used CABG admissions in 2009 that met the inclusion and exclusion criteria to create the model development sample and used the remaining admissions (in 2008 and 2010) as our model validation sample. Our approach to validation is outlined in Section 2.12 Measure Testing below. We subsequently updated selected results in this report using CABG admissions in January 1, 2009 – September 30, 2011. Measure results using the 33-month sample are reported in Section 3.1 below.

2.8 Approach to Risk Adjustment

The goal of risk adjustment is to account for patient demographic and clinical characteristics in order to illuminate differences in quality of care. The model adjusts for case-mix differences based on the clinical status of the patient at the time of admission. Conditions that may represent adverse outcomes due to care received during the index admission are not considered for inclusion in the risk-adjusted model. Although they may increase the risk of mortality, including them as covariates in a risk-adjusted model could attenuate the measure's ability to characterize the quality of care delivered by hospitals. Appendix B lists the conditions not adjusted for if they only appear in the index admission and not in the 12 months prior to admission. This methodology is consistent with NQF guidelines (http://www.qualityforum.org/docs/measure_evaluation_criteria.aspx).

The model does not adjust for socioeconomic status (SES), race, or ethnicity. Variation in quality associated with these characteristics may be indicative of disparities[12] in the quality of the care provided to vulnerable populations, and risk adjusting for these factors would obscure these disparities. The model does not adjust for hospital characteristics either (e.g., teaching status) since this would hold different types of hospitals to different

quality standards, and because such characteristics may exist on a causal pathway to the outcome, rather than act as confounders.

2.9   Candidate and Final Risk-Adjustment Variables

Our goal was to develop a parsimonious model that included clinically relevant variables associated with mortality. The candidate variables for the model were derived from: the index admission, with comorbidities identified from the index admission secondary diagnoses (excluding potential complications), 12-month pre-index inpatient Part A data, outpatient hospital data, and Part B physician data.

For administrative model development, we started with 189 Condition Categories (CCs) which are part of CMS's Hierarchical Condition Categories (HCC). The HCC system groups the ICD-9-CM codes into larger groups that are used in models to predict medical care utilization, mortality or other related measures. CCs are clinically relevant diagnostic groups of the more than 15,000 ICD-9 codes.[13] We used the ICD-9 to CC assignment map, which is maintained by CMS.

To select candidate variables, a team of clinicians reviewed all 189 CCs and excluded those that were not relevant to the Medicare population or that were not clinically relevant to the mortality outcome (e.g., attention deficit disorder, female infertility, Appendix C). Clinically relevant CCs were selected as candidate variables and some of those CCs were then combined into clinically coherent CC groupings. Other candidate variables included age, gender, and cardiogenic shock (Table 4). Gender was included in risk adjustment due to the fact that women have smaller vessels and thus represent more technically challenging CABG procedures compared to men.[14]

Table 4. Candidate Model Variables for Risk Adjustment

Category	Variable	CC
Demographics	Age	
	Gender	
Comorbidities	Cardiogenic Shock	ICD-9 code 785.51
	History of Infection	CC 1, 3-6
	Septicemia/Shock	CC 2
	Cancer (Metastatic Cancer and Acute Leukemia; Lung, Upper Digestive Tract, and Other Severe Cancers; Lymphatic, Head and Neck, Brain and Other Major Cancers; Breast, Prostate, Colorectal and Other Cancers and Tumors; Other Respiratory and Heart Neoplasms; Other Digestive and Urinary Neoplasms)	CC 7-12
	Other Neoplasms	CC 13
	Benign Neoplasms of Skin, Breast, Eye	CC 14
	Diabetes and DM Complications	CC 15-20, 119-120
	Protein-Calorie Malnutrition	CC 21
	Disorders of Fluid/Electrolyte/Acid-Base	CC 22-23
	Obesity/Disorders of Thyroid, Cholesterol, Lipids	CC 24
	Liver and Biliary Disease	CC 25-30

Category	Variable	CC
	Intestinal Obstruction/Perforation	CC 31
	Pancreatic Disease	CC 32
	Inflammatory Bowel Disease	CC 33
	Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders	CC 34
	Other Gastrointestinal Disorders	CC 36
	Bone/Joint/Muscle Infections/Necrosis	CC 37
	Rheumatoid Arthritis and Inflammatory Connective Tissue Disease	CC 38
	Disorders of the Vertebrae and Spinal Discs	CC 39
	Osteoarthritis of Hip or Knee	CC 40
	Osteoporosis and Other Bone/Cartilage Disorders	CC 41
	Other Musculoskeletal and Connective Tissue Disorders	CC 43
	Severe Hematological Disorders	CC 44
	Disorders of Immunity	CC 45
	Coagulation Defects and Other Specified Hematological Disorders	CC 46
	Iron Deficiency and Other/Unspecified Anemia and Blood Disease	CC 47
	Delirium and Encephalopathy	CC 48
	Dementia or Other Specified Brain Disorders	CC 49-50
	Drug/Alcohol Abuse/Dependence/Psychosis (Drug/Alcohol Induced Dependence/Psychosis; Drug/Alcohol Dependence; Drug/Alcohol Abuse, without Dependence)	CC 51-53
	Major Psychiatric Disorders	CC 54-56
	Depression	CC 58
	Anxiety Disorders	CC 59
	Other Psychiatric Disorders	CC 60
	Hemiplegia, Paraplegia, Paralysis, Functional Disability	CC 67-69, 100-102, 177-178
	Polyneuropathy	CC 71
	Parkinson's and Huntington's Diseases	CC 73
	Seizure Disorders and Convulsions	CC 74
	Mononeuropathy, Other Neurological Conditions/Injuries	CC 76
	Respiratory Arrest/Cardio-Respiratory Failure and Shock	CC 78-79
	Congestive Heart Failure	CC 80
	Acute Myocardial Infarction	CC 81
	Unstable Angina and Other Acute Ischemic Heart Disease	CC 82
	Angina Pectoris/Old Myocardial Infarction	CC 83
	Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease	CC 84
	Heart Infection/Inflammation, Except Rheumatic; Valvular and Rheumatic Heart Disease	CC 85-86

Category	Variable	CC
	Congenital Cardiac/Circulatory Defect (Major Congenital Cardiac/Circulatory Defect; Other Congenital) Heart/Circulatory Disease	CC 87-88
	Hypertensive Heart and Renal Disease or Encephalopathy	CC 89
	Hypertensive Heart Disease	CC 90
	Hypertension	CC 91
	Arrhythmias	CC 92-93
	Other and Unspecified Heart Disease	CC 94
	Stroke	CC 95-96
	Cerebrovascular Disease	CC 97-99, 103
	Vascular Disease and Complications or Circulatory Disease	CC 104-106
	Chronic Obstructive Pulmonary Disease	CC 108
	Fibrosis of Lung and Other Chronic Lung Disorder	CC 109
	Asthma	CC 110
	Pneumonia	CC 111-113
	Pleural Effusion/Pneumothorax	CC 114
	Other Lung Disorders	CC 115
	Retinal Detachment/Retinal Disorders (Retinal Detachment; Retinal Disorders, Except Detachment and Vascular Retinopathies)	CC 118, 121
	Glaucoma	CC 122
	Other Eye Disorders	CC 124
	Significant Ear, Nose, and Throat Disorders	CC 125
	Hearing Loss	CC 126
	Other Ear, Nose, Throat, and Mouth Disorders	CC 127
	End-stage Renal Disease or Dialysis	CC 130
	Renal Failure	CC 131
	Nephritis	CC132
	Urinary Obstruction and Retention	CC 133
	Incontinence	CC 134
	Urinary Tract Infection	CC 135
	Other Urinary Tract Disorders	CC 136
	Pelvic Inflammatory Disease	CC 138
	Other Female Genital Disorders	CC 139
	Male Genital Disorders	CC 140
	Decubitus Ulcer or Chronic Skin Ulcer	CC 148-149
	Cellulitis, Local Skin Infection	CC 152
	Other Dermatological Disorders	CC 153
	Trauma	CC 154-156, 158-161
	Vertebral Fractures	CC 157
	Other Injuries	CC 162
	Poisoning and Allergic Reactions	CC 163
	Major Complications of Medical Care and Trauma	CC 164

Category	Variable	CC
	Other Complications of Medical Care	CC 165
	Major Symptoms, Abnormalities	CC 166
	Minor Symptoms, Signs, Findings	CC 167

To inform final variable selection, a modified approach to stepwise logistic regression was performed. The development sample was used to create 1,000 "bootstrap" samples. For each sample, we ran a logistic stepwise regression that included the candidate variables. The results (not shown in this report) were summarized to show the percentage of times that each of the candidate variables was significantly associated with mortality (p<0.001) in each of the 1,000 repeated samples (e.g., 90 percent would mean that the candidate variable was selected as significant at p<0.001 in 90 percent of the estimations). We also assessed the direction and magnitude of the regression coefficients.

The clinical team reviewed these results and decided to retain risk adjustment variables above a 70% cutoff, because they demonstrated a relatively strong and stable association with risk for death and were clinically relevant. Additionally, specific variables with particular clinical relevance to the risk of death were forced into the model (regardless of percent selection) to ensure appropriate risk adjustment for CABG. These included:

Clinical variables associated with CABG:
- History of Prior CABG or Valve Surgery (ICD-9 procedure codes: V42.2, V43.3, V45.81, 414.02, 414.03, 414.04, 414.05, 414.06, 414.07, 996.02, 996.03, 39.61)[15]

Markers for end of life/frailty:
- Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)
- Dementia and Senility (CC 49 and CC 50, respectively)
- Metastatic Cancer and Acute Leukemia (CC 7)
- Protein-calorie Malnutrition (CC 21)
- Hemiplegia, Paraplegia, Paralysis, Functional disability (CC 67-69, 100-102, 177-178)
- Stroke (CC 95-96)

Diagnoses with potential asymmetry among hospitals that would impact the validity of the model:
- Lung, Upper Digestive Tract, and Other Severe Cancers (CC 8)
- Lymphatic, Head and Neck, Brain, and Other Major Cancers; Breast, Prostate, Colorectal and Other Cancers and Tumors; Other Respiratory and heart Neoplasms (CC 9-11)
- Other Digestive and Urinary Neoplasms (CC 12)

Final model variables are listed in Table 5.

Table 5. Final Model Variables

Category	Variable	CC
Demographics	Age	
	Gender	
Comorbidities	History of Prior CABG or Valve Surgery	ICD-9 diagnosis codes: V42.2, V43.3, V45.81, 414.02, 414.03, 414.04, 414.05, 414.06, 414.07, 996.02, 996.03 ICD-9 procedure codes: 39.61
	Cardiogenic Shock	ICD-9 code 785.51
	Cancer	CC 7-12
	Protein-calorie Malnutrition	CC 21
	Obesity/Disorders of Thyroid, Cholesterol, Lipids	CC 24
	Liver and Biliary Disease	CC 25-30
	Other Gastrointestinal Disorders	CC 36
	Dementia or Other Specified Brain Disorders	CC 49-50
	Hemiplegia, Paraplegia, Paralysis, Functional Disability	CC 67-69, 100-102, 177-178
	Congestive Heart Failure	CC 80
	Acute Myocardial Infarction	CC 81
	Unstable Angina and Other Acute Ischemic Heart Disease	CC 82
	Angina Pectoris/Old Myocardial Infarction	CC 83
	Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease	CC 84
	Hypertension	CC 91
	Stroke	CC 95-96
	Vascular Disease and Complications or Circulatory Disease	CC 104-106
	Chronic Obstructive Pulmonary Disease	CC 108
	Pneumonia	CC 111-113
	End-stage Renal Disease or Dialysis	CC 130
	Renal Failure	CC 131
	Decubitus Ulcer or Chronic Skin Ulcer	CC 148-149

2.10   Statistical Approach to Model Development

The measure calculates mortality rates using a hierarchical logistic regression model to account for the clustering of patients within hospitals while risk-adjusting for differences in patient case-mix. We modeled the log-odds of mortality within 30 days of procedure date from an index CABG admission as a function of patient demographic and clinical characteristics, and a random hospital-specific intercept. This strategy accounts for within-hospital correlation of the observed outcomes and models the assumption that underlying differences in quality among the health care groups being evaluated lead to systematic differences in outcomes.

We then calculate hospital-specific risk-standardized mortality rates. These rates are obtained as the ratio of predicted to expected deaths, multiplied by the national unadjusted rate. The "predicted" number of deaths (the numerator) is calculated using the coefficients estimated by regressing the risk factors and the hospital-specific intercept on the risk of mortality. The estimated hospital-specific intercept is added to the sum of the estimated regression coefficients multiplied by the patient characteristics. The results are then transformed and summed over all patients attributed to a hospital to get a predicted value. The "expected" number of deaths (the denominator) is obtained in the same manner, but a common intercept using all hospitals in our sample is added in place of the hospital-specific intercept. The results are then transformed and summed over all patients in the hospital to get an expected value. To assess hospital performance for each reporting period, we re-estimate the model coefficients using the years of data in that period.

More specifically, we estimate two types of regression models using the administrative data (Figure 1). First, we fit a logistic regression model linking the outcome to the risk factors.[16] Let Y_{ij} denote the outcome (equal to 1 if patient is readmitted within 30-days, zero otherwise) for the jth patient discharged from the ith hospital; $\mathbf{Z}_{ij}$ denotes a set of risk factors based on the administrative data. Let I denote the total number of hospitals and n_i the number of index admissions to hospital i. We assume the outcome is related linearly to the covariates via a known linked function, h, where

> Logistic Regression Model $\quad h(Y_{ij}) = \alpha + \beta \mathbf{Z}_{ij}$ $\qquad\qquad$ (1)

and $\mathbf{Z}_{ij} = (Z_{1ij}, Z_{2ij}, \ldots, Z_{pij})$ is a set of p patient-specific covariates. In our case, $h =$ the logit link.

To account for the natural clustering of observations within hospitals, we estimate a hierarchical logistic regression model that links the risk factors to the same outcomes and a hospital-specific random effect,

> Hierarchical logistic regression model $\quad h(Y_{ij}) = \alpha_i + \beta \mathbf{Z}_{ij}$ $\qquad$ (2)
> $\qquad\qquad\qquad\qquad\qquad\qquad\quad \alpha_i = \mu + \omega_i; \quad \omega_i \sim N(0, \tau^2)$ $\quad$ (3)

where α_i represents the hospital-specific intercept, $\mathbf{Z}_{ij}$ is defined as above, μ the adjusted average outcome over all hospitals in the sample, and τ^2 the between-hospital variance component.[17] This model separates within-hospital variation from between-hospital variation. Both hierarchical logistic regression models and logistic regression

models are estimated using the SAS software system (GLIMMIX and LOGISTIC procedures respectfully).

We first fit the logistic regression model described in Equation (1) using the logit link. Having identified the covariates that remained, we next fit the hierarchical logistic regression model described in Equations (2) and (3), again using the logit link function; e.g.,

$$\text{Logit } (P(Y_{ij} = 1)) = \alpha_i + \beta \, \mathbf{Z}_{ij}$$
$$\alpha_i = \mu + \omega_i, \quad \omega_i \sim N(0, \tau^2)$$

where $\mathbf{Z}_{ij}$ consisted of the covariates retained in the logistic regression model. As before, $Y_{ij} = 1$ if patient j treated at hospital i had the event; 0 otherwise.

2.11   Hospital Performance Reporting

For each hospital, bootstrapping simulations were used to compute a 95% interval estimate of the RSMR to characterize the level of uncertainty around the specific point estimate. The point estimate and interval estimate can be used to characterize and compare a hospital's performance (e.g., higher than expected, as expected, or lower than expected) to an average hospital with a similar case-mix.

Using the set of risk factors in the logistic regression model, we fit the hierarchical logistic regression model defined by Equations (2) - (3) and estimate the parameters, $\hat{\mu}$, $\{\hat{\alpha}_i, \hat{\alpha}_2, ..., \hat{\alpha}_I\}$, $\hat{\beta}$, and $\hat{\tau}^2$. We calculate a standardized outcome, s_i, for each hospital by computing the ratio of the number of predicted deaths to the number of expected deaths, multiplied by the unadjusted overall mortality rate, $\bar{y}$. Specifically, we calculate

$$\text{Predicted} \qquad \hat{y}_{ij}(Z) = h^{-1}(\hat{\alpha}_i + \hat{\beta} \, \mathbf{Z}_{ij}) \qquad\qquad (4)$$

$$\text{Expected} \qquad \hat{e}_{ij}(Z) = h^{-1}(\hat{\mu} + \hat{\beta} \, \mathbf{Z}_{ij}) \qquad\qquad (5)$$

$$\hat{s}_i(Z) = \frac{\sum_{j=1}^{n_i} \hat{y}_{ij}(Z)}{\sum_{j=1}^{n_i} \hat{e}_{ij}(Z)} \times \bar{y} \qquad\qquad (6)$$

If the number of "predicted" deaths is higher (or lower) than the "expected" number of deaths, then that hospital's $\hat{s}_i$ will be higher (or lower) than the unadjusted average. For each hospital, we compute an interval estimate of s_i to characterize the level of uncertainty around the point estimate using bootstrapping simulations. The point estimate and interval estimate can be used to characterize and compare hospital performance (e.g., higher than expected, as expected, or lower than expected).

i.   Creating Interval Estimates

Because the statistic described in Equation (6) is a complex function of parameter estimates, we use re-sampling and simulation techniques to derive an

interval estimate. In particular, we use bootstrapping procedures to compute confidence intervals. Because the theoretical-based standard errors are not easily derived, and to avoid making unnecessary assumptions, we use the bootstrap to empirically construct the sampling distribution for each hospital-specific RSMR.

ii.　Algorithm

Let I denote the total number of hospitals in the sample. We repeat steps 1 – 4 below for b = 1,2,…B times:

1. Sample I hospitals with replacement.

2. Fit the hierarchical logistic regression model using all patients within each sampled hospital. We use as starting values the parameter estimates obtained by fitting the model to all hospitals. If some hospitals are selected more than once in a bootstrapped sample, we treat them as distinct so that we have I random effects to estimate the variance components. At the conclusion of Step 2, we have:

    a. $\hat{\beta}^{(b)}$ (the estimated regression coefficients of the risk factors).
    b. The parameters governing the random effects, hospital adjusted outcomes, distribution, $\hat{\mu}^{(b)}$ and $\hat{\tau}^{2(b)}$.
    c. The set of hospital-specific intercepts and corresponding variances, $\{\hat{\alpha}_i^{(b)}, \widehat{var}(\alpha_i^{(b)}); i = 1,2,…,I\}$.

3. We generate a hospital random effect by sampling from the distribution of the hospital-specific distribution obtained in Step 2c. We approximate the distribution for each random effect by a normal distribution. Thus, we draw $\alpha_i^{(b*)} \sim N(\hat{\alpha}_i^{(b)}, \widehat{var}(\hat{\alpha}_i^{(b)}))$ for the unique set of hospitals sampled in Step 1.

4. Within each unique hospital i sampled in Step 1, and for each case j in that hospital, we calculate $\hat{y}_{ij}^{(b)}$, $\hat{e}_{ij}^{(b)}$, and $\hat{s}_i(Z)^{(b)}$ where $\hat{\beta}^{(b)}$ and $\hat{\mu}^{(b)}$ are obtained from Step 2 and $\hat{\alpha}_i^{(b*)}$ is obtained from Step 3.

    Ninety-five percent interval estimates (or alternative interval estimates) for the hospital-standardized outcome can be computed by identifying the 2.5[th] and 97.5[th] percentiles of randomly half of the B estimates (or the percentiles corresponding to the alternative desired intervals).[18]

Figure 1. Analysis Steps

Step 1:
Compute Bivariate and Univariate
summaries
Z & Y

Step 2:
Logistic Regression Model
$h(Y_{ij}) = \alpha^A + \beta^A Z_{ij}$
Obtain residuals, etc.

Step 3:
Hierarchical Logistic Regression Model
$h(Y_{ij}) = \alpha_i^A + \beta^A Z_{ij}$
$\alpha_i^{(A)} \sim N(\mu_A, \tau_A^2)$

Step 4:

Hospital-Specific Predicted
Outcomes
$\hat{y}_i^A(\mathbf{Z}) = \dfrac{1}{n_i} \sum_{j=1}^{n_i} h^{-1}(\hat{\alpha}_i^A + \hat{\beta}^A \mathbf{Z}_{ij})$

Hospital-Specific Expected
Outcomes
$\hat{e}_i^A(\mathbf{Z}) = \dfrac{1}{n_i} \sum_{j=1}^{n_i} h^{-1}(\hat{\mu}_A + \hat{\beta}^A \mathbf{Z}_{ij})$

Hospital-Specific Risk-
Standardized Outcomes
$$\hat{r}_i^A(Z) = \frac{\hat{y}_i^A(Z)}{\hat{e}_i^A(Z)}$$
$$\hat{s}_i^A\ Z\ = \frac{\hat{y}_i^A\ Z}{\hat{e}_i^A\ Z} \times \overline{y}$$

2.12   Measure Testing

2.12.1 Reliability of Data Elements

For measure development, we only use data elements in claims that have both face validity and reliability. We do not use fields that are inconsistently coded across providers. We also only use fields that are consequential for payment and which are audited. We identify these variables through empiric analyses and our understanding of CMS auditing and billing policies and do not use variables which do not meet these standards. For example, "discharge disposition" is a variable in Medicare claims data that is not consistently coded across hospitals. Thus, we construct an indicator variable as a surrogate for "discharge disposition" to identify patients that are transferred using variables in the claims data with greater reliability, including admit and discharge dates.

In addition, CMS has in place several hospital auditing programs used to assess overall claims code accuracy, ensure appropriate billing, and recoup overpayments. CMS routinely conducts data analysis to identify potential problem areas and detect fraud, and audits important data fields used in our measures, including diagnosis and procedure codes, and other elements that are consequential to payment.

2.12.2 Reliability of Model

To test the reliability of the model, we assessed model performance and the effect of the risk-adjustment variables on the outcome across the years of data. We computed several summary statistics for assessing model performance which included:[19] over-fitting indices,[3] predictive ability, area under the (ROC) curve, distribution of residuals, and model chi-square.[4]

2.12.3 Measure Results Reliability

The reliability of a measurement is the degree to which repeated measurements of the same entity agree with each other. For measures of hospital performance, the measured entity is the hospital, and reliability is the extent to which repeated

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[3] Over-fitting (γ_0, γ_1) provides evidence of over-fitting and requires several steps to calculate. Let *b* denote the *estimated vector* of regression coefficients. *Predicted Probabilities* ($_{\hat{p}}$) = 1/(1+exp{-Xb}), and $Z = Xb$ (e.g., the linear predictor that is a scalar value for everyone). A new logistic regression model that includes only an intercept and a slope by regressing the logits on Z is fitted in the validation sample; e.g., Logit(P(Y=1|Z)) = γ_0 + γ_1Z. Estimated values of γ_0 far from 0 and estimated values of γ_1 far from 1 provide evidence of over-fitting.

[4] Chi-Square – A test of statistical significance usually employed for categorical data to determine whether there is a good fit between the observed data and expected values; i.e., whether the differences between observed and expected values are attributable to true differences in characteristics or instead the result of chance variation. The formula for computing the chi-square is as follows:

$$\sum \frac{(O-E)^2}{E}$$

where O = observed value
E = expected value, and
degrees of freedom (df) = (rows-1)(columns-1)

measurements of the same hospital give similar results. Accordingly, our approach to assessing measure reliability is to consider the extent to which assessments of a hospital using different but randomly selected subsets of patients produce similar measures of hospital performance. That is, we take a "test-retest" approach in which hospital performance is measured once using a random subset of patients, then measured again using a second random subset exclusive of the first, and the agreement of the two resulting performance measures is compared across hospitals.[20]

For test-retest reliability of the measure in Medicare FFS patients aged 65 years and older, we combined index admissions from successive measurement periods into one dataset, randomly sampled half of patients within each hospital, calculated the measure for each hospital, and repeated the calculation using the second half. Thus, each hospital is measured twice, but each measurement is made using an entirely distinct set of patients. To the extent that the calculated measures of these two subsets agree, we have evidence that the measure is assessing an attribute of the hospital, not of the patients.

As a metric of agreement we calculated the intra-class correlation coefficient[21] and assessed the values according to conventional standards.[22] Specifically, we used a combined 2008-2010 sample, randomly split it into two approximately equal, mutually exclusive subsets of patients, and calculated the RSMR for each hospital for each sample. The agreement of the two RSMRs was quantified for hospitals in each sample using the intra-class correlation (ICC) as defined by ICC (2,1) by Shrout and Fleiss.[21]

Using two non-overlapping random samples provides an honest estimate of the measure's reliability, compared with using two random but potentially overlapping samples which would exaggerate the agreement. Moreover, because our final measure is derived using hierarchical logistic regression, and a known property of hierarchical logistic regression models is that smaller volume hospitals contribute less 'signal', a split sample using a single three-year measurement period will introduce extra noise, potentially underestimating the actual test-retest reliability that would be achieved if the measure were reported using a full three years of data.

2.12.4 Validity

To assess face validity, we surveyed the Technical Expert Panel and asked each member to rate the following statement using a six-point scale (1=Strongly Disagree, 2=Moderately Disagree, 3=Somewhat Disagree, 4=Somewhat Agree, 5=Moderately Agree, and 6=Strongly Agree): "The mortality rates obtained from the mortality measure as specified will provide an accurate reflection of quality."

In addition, in collaboration with STS, we performed a validation study of the companion administrative claims-based CABG readmission measure using the national STS Adult Cardiac Surgery Database. The validation study evaluated both the administrative definition of isolated CABG (cohort validation) as well as the readmission risk-adjustment model. The readmission cohort validation

showed high correlation between the claims-based and registry-based definitions of isolated CABG. Details are provided in Section 3.2.3.1 and the methodology report for the companion claims-based CABG readmission measure.

Finally, using New York Cardiac Surgery Reporting System (CSRS) Registry data, we performed a clinical data validation study of the administrative risk adjustment model and hospital performance assessment, detailed in Appendix D.

2.12.5 Testing of Measure in All-Payer Data

Using 2006 California Patient Discharge Data, we created a measure cohort with up to one year of hospital admission claims history and 30-days follow-up data. We then created the patient cohort using the CABG mortality measure inclusion and exclusion criteria for the isolated CABG cohort (with the exceptions of including all patients 18+ and dropping the hospice exclusion), and compared the FFS 65+, non-FFS 65+, all 65+, and all-payer 18-64 year-old patient subgroups with respect to the distribution of risk factors and the crude outcome rate. We fit the model in all patients 18+ and (a) examined overall model performance in terms of the C-statistic; (b) compared performance (C-statistic, predictive ability) across patient subgroups (FFS 65+, non-FFS 65+, all 65+, and all-payer 18-64); and (c) compared the distribution of Pearson residuals (model fit) across the patient subgroups. To help determine whether the measure could be applied to a population of patients aged 18+ (i.e., including younger patients aged 18-64), we examined the interaction terms between age (18-64 vs. 65+) and each of the other risk factors in 2006 California Patient Discharge Data. Specifically, we fit the model in all patients 18+ with and without interaction terms and (a) conducted a reclassification analysis to compare risk prediction at the patient level; (b) compared the C-statistic; and (c) compared hospital-level risk-standardized rates (scatterplot, ICC) to assess whether the model with interactions is different from the current model in profiling hospital rates. Details of all-payer data testing are provided in Appendix E.

3. RESULTS

3.1   Model Results

3.1.1   January 2009-September 2011 Sample

The 33-month sample included 155,392 admissions from 1,197 hospitals. Results tables are presented at the end of Section 4. The flow chart depicting eligible admissions and exclusions is presented in Figure 2.

Table 6 conveys the risk factor frequencies, parameter estimates, standard errors, odds ratios (ORs), and 95% confidence intervals for the model risk factors in the development sample.

Figure 2. Selection of January 2009-September 2011 Sample

Medicare FFS patients ≥65 years of age with continuous enrollment for 12 months prior to the date of admission and enrolled in Part A during the index admission for a qualifying isolated CABG procedure (January 2009 – September 2011)
N = 155,477

Patients with inconsistent or unknown vital status or other unreliable data* [N= 7; 0.00%]

Patients who leave against medical advice (AMA)* [N= 42; 0.03%]

Randomly select one hospitalization per patient per year
N = 155,428

Hospitalizations Not Selected [N= 36; 0.02%]

Final Index Cohort
N = 155,392 (99.9%)

*Categories are not mutually exclusive.

3.1.2 Hierarchical Logistic Regression Model

Table 7 conveys the adjusted odds ratios for the 2009 development sample (60,474 admissions at 1,160 hospitals) calculated via the hierarchical logistic regression model. The odds ratios are nearly identical to those calculated using the logistic regression model (Table 6). The results are similar using the January 1, 2009 – September 30, 2011 sample.

3.1.3 Unadjusted and Adjusted Mortality Rates

The unadjusted mean hospital mortality rate is 3.7% and ranges from 0-100% with a median of 2.9% (25th and 75th percentiles are 1.5% and 4.8%, respectively). Figure 3 displays the hospital risk-standardized rates for the January 2009 – September 2011 sample, calculated via the hierarchical logistic regression model. The adjusted rates have a mean of 3.3%, and range from 1.5-9.3%. The median risk-standardized rate is 3.1% (25th and 75th percentiles are 2.7% and 3.7%, respectively).

In the hierarchical model, each hospital has its own intercept (random intercept model), which is used to measure the differences in mortality between hospitals while adjusting for case-mix (patient risk factors).

Figure 3. Distribution of Hospital-Level Risk-Standardized Mortality Rates (January 2009-September 2011 Sample; n=155,392 Admissions from 1,197 Hospitals)
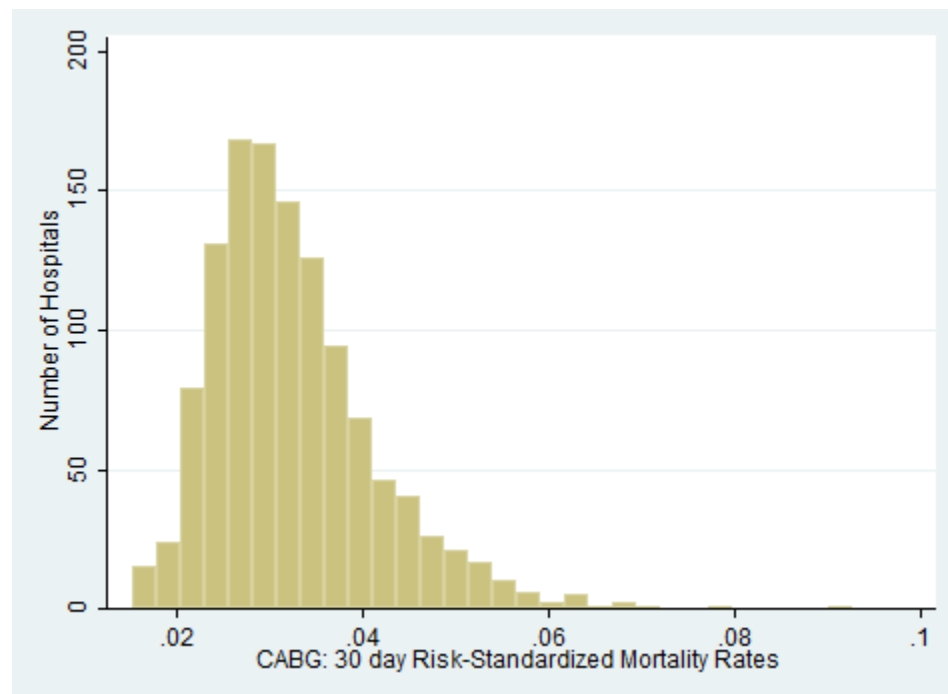
3.2   Measure Testing

   3.2.1   Reliability of Data Elements

         We used data from 2008, 2009, and 2010 to assess the data elements over time:
         64,811 admissions from 1,163 hospitals in 2008; 60,474 admissions from 1,160
         hospitals in 2009; and 50,006 admissions from 1,170 hospitals in 2010. Table 8
         conveys the model risk factor frequencies in these samples. Although the
         number of isolated CABG procedures appears to be declining over time, the risk
         factor frequencies changed very little across the three-year period from 2008 to
         2010. The percentage of patients diagnosed with Obesity/Disorders of Thyroid,
         Cholesterol, Lipids (CC 24) increased from 83.5% in 2008 to 85.4% in 2010. The
         percentage of patients with renal failure (CC 131) increased from 12.1% in 2008
         to 14.4% in 2010. There were no other notable changes.

         Table 9 shows the adjusted ORs for the logistic regression (patient-level) model
         variables and mortality in the 2008, 2009, and 2010 data samples. There are no
         notable differences in the ORs across the samples. The consistency in the rates
         of the risk-adjustment variables and in their relationship to the outcome across
         the one-year samples (development in 2009 and validation in 2008 and 2010)
         and the three years of combined data all demonstrate the reliability of the
         measure data elements used in risk adjustment.

   3.2.2   Reliability of Model and Measure Results

         To test the reliability of the model, we assessed model performance (Table 10)
         and the effect of the risk-adjustment variables on the outcome across the years
         of data (Table 9). Model performance is similar across years with strong model
         discrimination and fit. Predictive ability is also similar in the 2008, 2009 and 2010
         samples. The C-statistic (area under the receiver operator curve) is nearly
         identical for development and validation samples (0.75 when applied to the 2009
         development sample, 0.74 for the model in 2008 data and 0.75 for the model in
         2010 data) (Table 10). No notable differences were observed in risk factor ORs
         across the years of data.

         In terms of measure results reliability, there were 181,291 admissions in the
         combined three-year sample, with 90,583 in randomly selected group A and
         90,708 in randomly selected group B, each mutually exclusive of the other. The
         intra-class correlation (ICC) between the two RSMRs for each hospital was 0.32,
         which according to the conventional interpretation is "Fair."[22] The intra-class
         correlation coefficient is based on a split sample of three years of data, resulting
         in a volume of patients in each sample equivalent to only 1.5 years of data,
         whereas, if publicly reported, the measure is likely to be reported with a full three
         years of data. Based on our experiences with similar measures using split
         samples from 4 years (and resulting sample volumes equivalent to two years),
         the intra-class correlation coefficient would be higher and likely in the "Moderate"
         range.

3.2.3 Validity

Using New York Cardiac Surgery Reporting System (CSRS) Registry data we performed a clinical data validation study of the administrative risk adjustment model and hospital performance assessment, detailed in Appendix D. In a matched cohort of registry patients, the administrative claims-based model for risk adjustment of 30-day all-cause mortality following isolated CABG surgery performed similarly to a clinical-based risk model, with nearly identical discrimination, but with two discordant hospital performance categorizations. The C-statistics for the two models were similar: 0.74 for the claims-model and 0.75 for the clinical-model. When shock (for which comorbidity vs. complication status is difficult to confirm) was removed from the models, the respective C-statistics fell to 0.70 and 0.73. The distributions in hospital RSMRs for the claims-based and clinical-based models are similar, although the claims-based model shows a narrower range of outcome rates. Overall agreement between hospital performance categorization between the claims-based and clinical-based models was 94.3% (33 of 35 hospitals had concordant performance categorization) and the correlation was 0.90 (weighted Spearman correlation). The registry model identified two "worse performing" outlier hospitals, while the claims model identified none; neither model identified any "better performing" outliers in the matched sample.

In addition, 14 TEP members provided the following responses: Strongly Disagreed (1), Moderately Disagreed (1), Somewhat Disagreed (1), Somewhat Agreed (1), Moderately Agreed (8), and Strongly Agreed (2). Hence, 79% of TEP members agreed (71% moderately or strongly agreed) that the measure will provide an accurate reflection of quality.

3.2.3.1 Validation of the administrative isolated CABG cohort

There were no changes to the CABG mortality measure cohort detailed in this report based upon the results of cohort validation of the companion readmission measure. The readmission cohort validation showed high correlation between the claims-based and registry-based definitions of isolated CABG and the level of agreement for the companion readmission measure was higher than prior studies comparing administrative definitions of isolated CABG to registry data.[28]

Specifically, the validation of the administrative claims isolated CABG cohort definition using the companion CABG readmission measure and the national STS Adult Cardiac Surgery database demonstrated an overall agreement rate of 96.5% (200,475 of 207,656 matched patients were designated as isolated or non-isolated CABG patients by both measure cohort definitions). Among the 4,720 patients identified as isolated CABG by the claims measure but not by the registry measure, 37% were due to expected causes (i.e., the fact that the registry

measure excludes all MAZE procedures while the claims measure excludes only open MAZE procedures). The remaining 2,976 patients identified as isolated CABG by the claims measure but not by the registry measure and the 2,461 patients identified as isolated CABG patients by the registry measure but not by the claims measure were due to inconsistencies that could not clearly be attributed to inaccuracies in the claims-based definition of the isolated CABG cohort. For example, among a proportion of patients, the patient had a code for an aortic valve replacement but the registry data did not show that this procedure was performed. Alternatively, the registry data indicated an aortic valve procedure was performed but there was no corresponding claims code for this procedure. Such inconsistencies could be due to coding errors in the claims data, abstraction errors in the registry data, or may be due to inconsistencies in the probabilistic matching process used to create a matched set of patients for the validation. An additional reason that patients might be identified as isolated CABG patients by the registry measure but not by the claims measure is that the CABG procedure occurred on a separate day within the index admission than the valve or other procedure that excluded the patient from the claims-based isolated CABG cohort. Two of 286 such discrepant aortic valve procedures could be attributed to procedures occurring on different days during the index admission. Among the discrepant patients, the non-CABG-related ICD-9 procedure codes represented only nonspecific ancillary procedures to CABG surgery, such as code 39.61 "Extracorporeal circulation auxiliary to open heart surgery" and could not be used to further increase the precision of the administrative claims-based isolated CABG cohort definition. Further details of the cohort validation are provided in the methodology report for the companion claims-based CABG readmission measure.

3.2.4   Testing of Measure in All-Payer Data

Using all-payer data, the C-statistic for the CABG mortality model in FFS 65 years or over year old patients was 0.84 and in 18-64 year old all-payer patients was 0.79. When the model was applied to all patients aged 18 years and older the overall discrimination was good (C-statistic=0.84). In addition, there was good discrimination and predictive ability in both those aged 18-64 and those aged 65 years or over. Moreover, the distribution of Pearson residuals was comparable across the patient subgroups. When comparing the model with and without interaction terms: (a) the reclassification analysis using models with and without age-risk factor interaction terms demonstrated 97%-99% overall agreement in patient risk categorization across age (18-64 versus 65 years or over) and insurance (all payer versus FFS) subgroups; (b) the C-statistic was nearly identical (0.85 and 0.84 in models with and without interaction terms, respectively); and (c) hospital-level risk-standardized rates were highly correlated (ICC=0.998). Thus, the inclusion of interactions did not substantively affect either patient-level model performance or hospital-level results. Based on the results of the all-payer testing (detailed in Appendix E), we conclude that the CABG mortality measure performs well when applied to all-payer data (all patients aged

18 years or over). Although there are two statistically significant age-by-risk-factor interaction terms (Older and COPD and Older and Dementia or Senility), the inclusion of the interactions did not substantively affect either patient-level model performance or hospital-level results. Therefore, the measure can be applied to all-payer data for patients 18 years and older. For simplicity and pending further study, the only change currently recommended to the measure specifications to allow application to an all-payer, 18 years or over population is transformation of the Age variable from "Age – 65" to a fully continuous age variable.

4. MAIN FINDINGS / SUMMARY

The proposed mortality measure has the potential to significantly improve the quality of care delivered to both Medicare FFS patients 65 years and older and patients 18 years and older in all-payer data for patients undergoing CABG surgery. The cohort for inclusion in the measure is appropriately defined, consisting of patients undergoing isolated CABG procedures and excluding those procedures that may be asymmetrically performed across hospitals and constitute greatly increased risk of mortality. We excluded covariates that are not appropriate for inclusion in a quality measure, including physician- and hospital-level variables (e.g., procedural volume). The hierarchical modeling accounts for the clustering of patients within hospitals and differences in sample size across hospitals, thereby allowing for valid comparisons across hospitals. We found variability in the RSMRs across hospitals and these differences remained, even after adjustment for case-mix. RSMRs can be used for targeted quality improvement efforts by hospitals to decrease rates for death. The risk-standardized model meets recognized standards for outcomes measurement and was developed with extensive input from clinicians and experts in measure development. The model is reliable and valid and can be applied to an all-payer dataset and/or patients younger than 65 years of age. In summary, we present a claims-based mortality outcome measure for patients undergoing CABG surgery that is suitable for public reporting.

Table 6. Adjusted OR* for Model Risk Factors and Mortality in Development Samples (Logistic Regression Model)**

Variable	2009 Development Sample (n=60,474 admissions at 1,160 hospitals)				
	Frequency (%)	Estimate	SE	OR	95% CI
Demographics					
Age-65 (Continuous)	-	0.06	0.00	1.06	(1.05-1.07)
Male	68.1	-0.33	0.05	0.72	(0.65-0.80)
Comorbidities					
Cardiogenic Shock (ICD-9 Code 785.51)	3.8	1.29	0.07	3.65	(3.18-4.19)
History of Prior CABG or Valve Surgery	5.6	0.62	0.09	1.86	(1.57-2.22)
Pneumonia (CC 111-113)	12.8	0.48	0.06	1.62	(1.44-1.82)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	84.2	-0.41	0.06	0.66	(0.59-0.74)
Protein-Calorie Malnutrition (CC21)	3.2	0.55	0.09	1.73	(1.46-2.06)
Renal Failure (CC131)	13.6	0.34	0.06	1.41	(1.24-1.60)
COPD (CC108)	23.8	0.28	0.05	1.32	(1.19-1.47)
End-Stage Renal Disease Or Dialysis (CC 130)	1.3	0.73	0.13	2.08	(1.60-2.71)
Liver and Biliary Disease (CC 25-30)	5.2	0.43	0.09	1.54	(1.29-1.83)
Congestive Heart Failure (CC 80)	20.1	0.26	0.06	1.30	(1.16-1.45)
Other Gastrointestinal Disorders (CC 36)	44.1	-0.27	0.05	0.76	(0.69-0.84)
Unstable Angina And Other Acute Ischemic Heart Disease (CC82)	43.3	-0.24	0.05	0.79	(0.71-0.87)
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC84)	80.9	-0.30	0.06	0.74	(0.66-0.83)
Hypertension (CC 91)	85.3	-0.27	0.06	0.77	(0.68-0.87)
Acute Myocardial Infarction (CC 81)	16.2	0.24	0.06	1.27	(1.13-1.43)
Angina Pectoris/Old Myocardial Infarction (CC83)	39.1	-0.23	0.05	0.80	(0.72-0.89)
Vascular Disease and Complications or Circulatory Disease (CC 104-106)	33.3	0.16	0.05	1.17	(1.06-1.29)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	3.1	0.15	0.11	1.16	(0.93-1.44)
Cancer (CC 7-12)	19.4	0.06	0.06	1.06	(0.94-1.19)
Stroke (CC 95-96)	4.8	0.08	0.11	1.08	(0.88-1.33)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	2.8	0.02	0.13	1.02	(0.79-1.33)
Dementia or Other Specified Brain Disorders (CC 49-50)	5.0	-0.02	0.10	0.98	(0.80-1.19)

SE = Standard Error; OR = Odds Ratio; CI = Confidence Interval
* Each variable in the model is adjusted for the effects of the others.
** The results are similar when using the January 1, 2009 – September 30, 2011 sample.

Table 7. Adjusted OR* for Model Risk Factors and Mortality in Development Sample (Hierarchical Logistic Regression Model)**

Variable	Frequency (%)	2009 Development Sample (60,474 admissions at 1,160 hospitals)			
		Estimate	SE	OR	95% CI
Demographics					
Age-65 (Continuous)		0.06	0.00	1.06	(1.05-1.07)
Male	68.1	-0.33	0.05	0.72	(0.65-0.78)
Comorbidities					
Cardiogenic Shock (ICD-9 Code 785.51)	3.8	1.32	0.07	3.74	(3.29-4.26)
History of Prior CABG or Valve Surgery	5.6	0.63	0.08	1.88	(1.60-2.20)
Pneumonia (CC 111-113)	12.8	0.48	0.05	1.62	(1.46-1.80)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	84.2	-0.40	0.05	0.67	(0.61-0.75)
Protein-Calorie Malnutrition (CC21)	3.2	0.55	0.08	1.73	(1.47-2.03)
Renal Failure (CC131)	13.6	0.35	0.06	1.42	(1.27-1.60)
COPD (CC108)	23.8	0.28	0.05	1.32	(1.20-1.45)
End-Stage Renal Disease Or Dialysis (CC 130)	1.3	0.74	0.12	2.10	(1.65-2.67)
Liver and Biliary Disease (CC 25-30)	5.2	0.43	0.08	1.54	(1.31-1.81)
Congestive Heart Failure (CC 80)	20.1	0.28	0.05	1.32	(1.19-1.47)
Other Gastrointestinal Disorders (CC 36)	44.1	-0.28	0.05	0.76	(0.69-0.83)
Unstable Angina And Other Acute Ischemic Heart Disease (CC82)	43.3	-0.23	0.05	0.79	(0.72-0.87)
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC84)	80.9	-0.30	0.05	0.74	(0.66-0.82)
Hypertension (CC 91)	85.3	-0.27	0.06	0.77	(0.68-0.86)
Acute Myocardial Infarction (CC 81)	16.2	0.25	0.05	1.28	(1.15-1.43)
Angina Pectoris/Old Myocardial Infarction (CC83)	39.1	-0.23	0.05	0.79	(0.72-0.87)
Vascular Disease and Complications or Circulatory Disease (CC 104-106)	33.3	0.16	0.05	1.18	(1.07-1.29)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	3.1	0.15	0.10	1.17	(0.95-1.42)
Cancer (CC 7-12)	19.4	0.06	0.06	1.07	(0.96-1.19)
Stroke (CC 95-96)	4.8	0.07	0.10	1.07	(0.89-1.30)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	2.8	0.03	0.12	1.03	(0.81-1.31)
Dementia or Other Specified Brain Disorders (CC 49-50)	5.0	-0.04	0.09	0.96	(0.80-1.15)

SE = Standard Error; OR = Odds Ratio; CI = Confidence Interval

* Each variable in the model is adjusted for the effects of the others.

** The results are similar when using the January 1, 2009 – September 30, 2011 sample.

Table 8. Risk Factor Frequency (%) in Data Samples*

Description	2008 n= 64,811	2009 n= 60,474	2010 n=56,006
Demographics			
Age-65 (Continuous)		-	
Male	67.7	68.1	69.3
Comorbidities			
Cardiogenic Shock (ICD-9 Code 785.51)	3.5	3.8	4.6
History of Prior CABG or Valve Surgery	5.6	5.6	5.3
Pneumonia (CC 111-113)	12.8	12.8	12.5
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	83.5	84.2	85.4
Protein-Calorie Malnutrition (CC21)	2.7	3.2	3.3
Renal Failure (CC131)	12.1	13.6	14.4
COPD (CC108)	24.1	23.8	24.0
End-Stage Renal Disease Or Dialysis (CC 130)	1.2	1.3	1.5
Liver and Biliary Disease (CC 25-30)	4.9	5.2	5.5
Congestive Heart Failure (CC 80)	19.7	20.1	19.7
Other Gastrointestinal Disorders (CC 36)	44.5	44.1	44.7
Unstable Angina And Other Acute Ischemic Heart Disease (CC82)	44.2	43.3	42.8
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC84)	81.0	80.9	81.8
Hypertension (CC 91)	85.4	85.3	85.6
Acute Myocardial Infarction (CC 81)	16.9	16.2	16.4
Angina Pectoris/Old Myocardial Infarction (CC83)	40.1	39.1	39.0
Vascular Disease and Complications or Circulatory Disease (CC 104-106)	33.0	33.3	33.6
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	3.1	3.1	3.3
Cancer (CC 7-12)	19.9	19.4	19.2
Stroke (CC 95-96)	5.0	4.8	4.8
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	2.9	2.8	2.9
Dementia or Other Specified Brain Disorders (CC 49-50)	4.9	5.0	5.0

*The results are similar when using the January 1, 2009 – September 30, 2011 sample.

Table 9. Temporal Trend in Adjusted OR* for Model Risk Factors and Mortality in Development and Validation Samples (Logistic Regression Model)**

Description	2008 n= 64,811		2009 n= 60,474		2010 n=56,006	
	OR	95% CI	OR	95% CI	OR	95% CI
Demographics						
Age-65 (Continuous)	1.07	(1.06-1.07)	1.06	(1.05-1.07)	1.07	(1.06-1.07)
Male	0.77	(0.70-0.84)	0.72	(0.65-0.80)	0.71	(0.64-0.79)
Comorbidities						
Cardiogenic Shock (ICD-9 Code 785.51)	3.42	(2.98-3.93)	3.65	(3.18-4.19)	3.56	(3.11-4.08)
History of Prior CABG or Valve Surgery	1.58	(1.33-1.88)	1.86	(1.57-2.22)	1.72	(1.42-2.08)
Pneumonia (CC 111-113)	1.39	(1.25-1.56)	1.62	(1.44-1.82)	1.38	(1.21-1.56)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	0.64	(0.57-0.71)	0.66	(0.59-0.74)	0.59	(0.52-0.66)
Protein-Calorie Malnutrition (CC21)	1.92	(1.61-2.28)	1.73	(1.46-2.06)	1.57	(1.30-1.89)
Renal Failure (CC131)	1.40	(1.24-1.58)	1.41	(1.24-1.60)	1.36	(1.20-1.56)
COPD (CC108)	1.25	(1.13-1.38)	1.32	(1.19-1.47)	1.39	(1.25-1.55)
End-Stage Renal Disease Or Dialysis (CC 130)	1.66	(1.26-2.18)	2.08	(1.60-2.71)	2.19	(1.69-2.83)
Liver and Biliary Disease (CC 25-30)	1.25	(1.04-1.50)	1.54	(1.29-1.83)	1.23	(1.02-1.49)
Congestive Heart Failure (CC 80)	1.47	(1.32-1.64)	1.30	(1.16-1.45)	1.16	(1.03-1.31)
Other Gastrointestinal Disorders (CC 36)	0.85	(0.78-0.94)	0.76	(0.69-0.84)	0.82	(0.74-0.91)
Unstable Angina And Other Acute Ischemic Heart Disease (CC82)	0.80	(0.73-0.88)	0.79	(0.71-0.87)	0.83	(0.75-0.92)
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC84)	0.72	(0.65-0.81)	0.74	(0.66-0.83)	0.82	(0.72-0.93)
Hypertension (CC 91)	0.85	(0.75-0.96)	0.77	(0.68-0.87)	0.72	(0.63-0.81)
Acute Myocardial Infarction (CC 81)	1.38	(1.24-1.54)	1.27	(1.13-1.43)	1.32	(1.17-1.48)
Angina Pectoris/Old Myocardial Infarction (CC83)	0.74	(0.67-0.82)	0.80	(0.72-0.89)	0.76	(0.68-0.84)
Vascular Disease and Complications or Circulatory Disease (CC 104-106)	1.17	(1.06-1.29)	1.17	(1.06-1.29)	1.21	(1.09-1.35)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	1.31	(1.07-1.60)	1.16	(0.93-1.44)	1.20	(0.96-1.49)
Cancer (CC 7-12)	0.91	(0.81-1.02)	1.06	(0.94-1.19)	0.94	(0.83-1.07)
Stroke (CC 95-96)	1.25	(1.04-1.50)	1.08	(0.88-1.33)	1.16	(0.95-1.42)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	0.92	(0.72-1.18)	1.02	(0.79-1.33)	1.27	(1.00-1.63)
Dementia or Other Specified Brain Disorders (CC 49-50)	1.15	(0.97-1.38)	0.98	(0.80-1.19)	1.29	(1.07-1.55)

OR = Odds Ratio; CI = Confidence Interval
* Each variable in the model is adjusted for the effects of the others.
** The results are similar when using the January 1, 2009 – September 30, 2011 sample.

Table 10. Mortality Model Performance for Development and Validation Samples (Logistic Regression Model)*

Indices	Development Sample	Validation Sample	
Year	2009	2008	2010
Number of Admissions	60,474	64,811	56,006
Number of Hospitals	1,160	1,163	1,170
Mean Risk-Standardized Mortality Rate % (SD)	3.2 (0.9)	3.3 (0.8)	3.2 (1.1)
Calibration (γ_0, γ_1)[5]	(0, 1)	(0.01, 0.99)	(-0.10, 0.97)
Discrimination -Predictive Ability (lowest decile %, highest decile %)	(0.7-11.1)	(0.6-11.8)	(0.5-10.6)
Discrimination – Area Under Receiver Operator Curve (C statistic) [6]	0.75	0.74	0.75
Residuals Lack of Fit (Pearson Residual Fall %)			
<-2	0.0	0.0	0.0
[-2, 0)	96.84	96.74	96.86
[0, 2)	0.14	0.12	0.14
[2+	3.02	3.14	3.00
Model Wald χ^2 [Number of Covariates] (p-value)	1559 [24] (<0.0001)	1651 [24] (<0.0001)	1462 [24] (<0.0001)
Between-Hospital Variance (τ) (Standard Error)	0.24 (0.03)	0.22 (0.03)	0.31 (0.04)

*The results are similar when using the January 1, 2009 – September 30, 2011 sample.

[5] Over-Fitting Indices (γ_0, γ_1) provide evidence of over-fitting and require several steps to calculate. Let *b* denote the *estimated vector* of regression coefficients. *Predicted Probabilities* ($\hat{p}$) = 1/(1+exp{-Xb}), and *Z* = *Xb* (e.g., the linear predictor that is a scalar value for everyone). A new logistic regression model that includes only an intercept and a slope by regressing the logits on Z is fitted in the validation sample; e.g., Logit(P(Y=1|Z)) = γ_0 + γ_1Z. Estimated values of γ_0 far from 0 and estimated values of γ_1 far from 1 provide evidence of over-fitting.
[6] Calculated using logistic regression model

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6. APPENDIX

Appendix A: Definition of Isolated CABG Procedures in Administrative Claims Data

CABG Cohort Definition:
- All 36.1x codes that do not occur concomitantly with the exclusion codes in Table 11.
- Excluded cohort codes should be for index hospitalization or, for transfer scenarios, the first hospital performing CABG.

Table 11. CABG Cohort Exclusion Codes

EXCLUDE from CABG cohort if 36.1x occurs with any of the following:	Description	N	Category
0.61	Percutaneous angioplasty or atherectomy of precerebral (extracranial) vessel(s)	105	Head, neck, intracranial vascular procedure
0.62	Percutaneous angioplasty or atherectomy of intracranial vessel(s)	11	Head, neck, intracranial vascular procedure
0.63	Percutaneous insertion of carotid artery stent(s)	102	Head, neck, intracranial vascular procedure
0.64	Percutaneous insertion of other precerebral (extracranial) artery stent(s)	6	Head, neck, intracranial vascular procedure
0.65	Percutaneous insertion of intracranial vascular stent(s)	2	Head, neck, intracranial vascular procedure
32.4x	Lobectomy with segmental resection of adjacent lobes of lung, excludes that with radical dissection [excision] of thoracic structures	23	Lobectomy
33.5x	Lung transplant	20	Lung Transplant
33.6	Combined heart-lung transplantation	0	Lung Transplant
35.00	Closed heart valvotomy, unspecified valve	0	Valve procedures
35.01	Closed heart valvotomy, aortic valve	1	Valve procedures
35.02	Closed heart valvotomy, mitral valve	3	Valve procedures
35.03	Closed heart valvotomy, pulmonary valve	0	Valve procedures
35.04	Closed heart valvotomy, tricuspid valve	0	Valve procedures
35.10	Open heart valvuloplasty without replacement, unspecified valve	2	Valve procedures
35.11	Open heart valvuloplasty of aortic valve without replacement	232	Valve procedures
35.12	Open heart valvuloplasty of mitral valve without replacement	3,636	Valve procedures
35.13	Open heart valvuloplasty of pulmonary valve without replacement	9	Valve procedures
35.14	Open heart valvuloplasty of tricuspid valve without replacement	621	Valve procedures
35.20	Replacement of unspecified heart valve	2	Valve procedures
35.21	Replacement of aortic valve with tissue graft	15,503	Valve procedures

EXCLUDE from CABG cohort if 36.1x occurs with any of the following:	Description	N	Category
35.22	Other replacement of aortic valve	6,554	Valve procedures
35.23	Replacement of mitral valve with tissue graft	2614	Valve procedures
35.24	Other replacement of mitral valve	1,680	Valve procedures
35.25	Replacement of pulmonary valve with tissue graft	9	Valve procedures
35.26	Other replacement of pulmonary valve	4	Valve procedures
35.27	Replacement of tricuspid valve with tissue graft	47	Valve procedures
35.28	Other replacement of tricuspid valve	53	Valve procedures
35.31	Operations on papillary muscle	10	Valve procedures
35.32	Operations on chordae tendineae	75	Valve procedures
35.33	Annuloplasty	3,189	Valve procedures
35.34	Infundibulectomy	0	Valve procedures
35.35	Operations on trabeculae carneae cordis	1	Valve procedures
35.39	Operations on other structures adjacent to valves of heart	53	Valve procedures
35.41	Enlargement of existing atrial septal defect	2	Atrial Septal Defect
35.42	Creation of septal defect in heart	1	Atrial Septal Defect
35.50	Repair of unspecified septal defect of heart with prosthesis	0	Atrial Septal Defect
35.51	Repair of atrial septal defect with prosthesis, open technique	36	Atrial Septal Defect
35.52	Repair of atrial septal defect with prosthesis, closed technique	32	Atrial Septal Defect
35.53	Repair of ventricular septal defect with prosthesis, open technique	33	Ventricular Septal Defect
35.54	Repair of endocardial cushion defect with prosthesis	2	Ventricular Septal Defect
35.55	Repair of ventricular septal defect with prosthesis, closed technique	0	Ventricular Septal Defect
35.60	Repair of unspecified septal defect of heart with tissue graft	1	Ventricular Septal Defect
35.61	Repair of atrial septal defect with tissue graft	62	Atrial Septal Defect
35.62	Repair of ventricular septal defect with tissue graft	41	Ventricular Septal Defect
35.63	Repair of endocardial cushion defect with tissue graft	5	Ventricular Septal Defect
35.70	Other and unspecified repair of unspecified septal defect of heart	41	Ventricular Septal Defect
35.71	Other and unspecified repair of atrial septal defect	1,101	Atrial Septal Defect
35.72	Other and unspecified repair of ventricular septal defect	60	Ventricular Septal Defect
35.73	Other and unspecified repair of endocardial cushion defect	6	Ventricular Septal Defect
35.81	Total repair of tetralogy of Fallot	1	Correction of congenital anomalies
35.82	Total repair of total anomalous	4	Correction of congenital anomalies

EXCLUDE from CABG cohort if 36.1x occurs with any of the following:	Description	N	Category
	pulmonary venous connection		
35.83	Total repair of truncus arteriosus	0	Correction of congenital anomalies
35.84	Total correction of transposition of great vessels, not elsewhere classified	1	Correction of congenital anomalies
35.91	Interatrial transposition of venous return	3	Correction of congenital anomalies
35.92	Creation of conduit between right ventricle and pulmonary artery	0	Correction of congenital anomalies
35.93	Creation of conduit between left ventricle and aorta	7	Correction of congenital anomalies
35.94	Creation of conduit between atrium and pulmonary artery	0	Correction of congenital anomalies
35.95	Revision of corrective procedure on heart	14	Correction of congenital anomalies
35.96	Percutaneous valvuloplasty	7	Valve procedures
35.98	Other operations on septa of heart	2	Ventricular Septal Defect
35.99	Other operations on valves of heart	23	Other valve procedures
37.31	Pericardiectomy	255	Repair/restoration of pericardium
37.32	Excision of aneurysm of heart	430	Other open cardiac procedures
37.33	Excision or destruction of other lesion or tissue of heart,open approach	4,784	Other open cardiac procedures
37.35	Partial ventriculectomy	6	Other open cardiac procedures
37.51	Heart transplantation	1	Heart transplant
37.52	Implantation of total internal biventricular heart replacement system	0	Heart replacement procedures
37.53	Replacement or repair of thoracic unit of (total) replacement heart system	0	Heart replacement procedures
37.54	Replacement or repair of other implantable component of (total) replacement heart system	0	Heart replacement procedures
37.55	Removal of internal biventricular heart replacement system	1	Heart replacement procedures
37.63	Repair of heart assist system	12	Circulatory assist devices (includes VAD)
37.67	Implantation of cardiomyostimulation system	0	Circulatory assist devices (includes VAD)
38.12	Endarterectomy, other vessels of head and neck	2,033	Head, neck, intracranial vascular procedure
38.11	Head and Neck Endarterectomy	3	Head, neck, intracranial vascular procedure
38.14	Endarterectomy of Aorta	372	Aorta or other non-cardiac arterial bypass procedures
38.15	Thoracic Endarterectomy	12	Aorta or other non-cardiac arterial bypass procedures
38.16	Endarterectomy: Excision of tunica intima of artery to relieve arterial walls thickened by plaque or chronic inflammation. Location includes abdominal arteries excluding abdominal aorta: Celiac, Gastric, Hepatic, Iliac, Mesenteric, Renal, Splenic, Umbi	12	Aorta or other non-cardiac arterial bypass procedures
38.17	Endarterectomy - abdominal veins: Iliac, Portal, Renal, Splenic, Vena cava.	0	Aorta or other non-cardiac arterial bypass procedures

EXCLUDE from CABG cohort if 36.1x occurs with any of the following:	Description	N	Category
38.34	Resection of vessel with replacement: Angiectomy, excision of aneurysm (arteriovenous), blood vessel (lesion) with anastomosis (4=aorta, abdominal)	0	Aorta or other non-cardiac arterial bypass procedures
38.42	Resection of vessel with replacement: Angiectomy, excision of aneurysm with replacement (2= other vessels of head and neck; carotid, jugular)	4	Head, neck, intracranial vascular procedure
38.44	Resection of vessel with replacement, aorta, abdominal	203	Aorta or other non-cardiac arterial bypass procedures
38.45	Resection of vessel with replacement, thoracic vessels	1,612	Aorta or other non-cardiac arterial bypass procedures
39.21	Caval-pulmonary artery anastomosis	2	Aorta or other non-cardiac arterial bypass procedures
39.22	Aorta-subclavian-carotid bypass	75	Aorta or other non-cardiac arterial bypass procedures
39.23	Other intrathoracic vascular shunt or bypass	4	Aorta or other non-cardiac arterial bypass procedures
39.24	Aorta-renal bypass	2	Aorta or other non-cardiac arterial bypass procedures
39.25	Aorta-iliac-femoral bypass	13	Aorta or other non-cardiac arterial bypass procedures
39.26	Other intra-abdominal vascular shunt or bypass	5	Aorta or other non-cardiac arterial bypass procedures
39.28	Extracranial-intracranial (EC-IC) vascular bypass	0	Head, neck, intracranial vascular procedure
39.29	Other (peripheral) vascular shunt or bypass	151	Aorta or other non-cardiac arterial bypass procedures
39.71	Endovascular implantation of graft in abdominal aorta	69	Aorta or other non-cardiac arterial bypass procedures
39.72	Endovascular embolization or occlusion of head and neck vessels	4	Head, neck, intracranial vascular procedure
39.73	Endovascular implantation of graft in thoracic aorta	82	Aorta or other non-cardiac arterial bypass procedures
39.74	Endovascular removal of obstruction from head and neck vessel(s)	22	Head, neck, intracranial vascular procedure
39.75	Endovascular embolization or occlusion of vessel(s) of head or neck using bare coils	0	Head, neck, intracranial vascular procedure
39.76	Endovascular embolization or occlusion of vessel(s) of head or neck using bioactive coils	0	Head, neck, intracranial vascular procedure
39.79	Other endovascular procedures on other vessels	62	Aorta or other non-cardiac arterial bypass procedures
85.22	Resection of quadrant of breast	0	Mastectomy
85.23	Subtotal Mastectomy, which excludes quadrant resection (85.22)	0	Mastectomy
85.4x	Mastectomy - includes simple/extended simple, unilateral/bilateral, radical/extended radical	1	Mastectomy

Table 12. ICD-9 Procedure Codes Explicitly Considered for Exclusion but Ultimately Included in CABG Cohort

Category	ICD-9 code	Description	N
Computer Assisted Surgery	0.31	Computer assisted surgery with CT/CTA	1
Computer Assisted Surgery	0.32	Computer assisted surgery with MR/MRA	0
Computer Assisted Surgery	0.33	Computer assisted surgery with fluoroscopy	4
Computer Assisted Surgery	0.34	Imageless computer assisted surgery	2
Computer Assisted Surgery	0.34	Imageless computer assisted surgery	2
Computer Assisted Surgery	0.35	Computer assisted surgery with multiple datasets	0
-	0.36	(No longer exists)	1
Computer Assisted Surgery	0.39	Other computer assisted surgery	3
Computer Assisted Surgery	17.41	Open robotic assisted procedure	295
Computer Assisted Surgery	17.42	Laparoscopic robotic assisted procedure	12
Computer Assisted Surgery	17.43	Percutaneous robotic assisted procedure	6
Computer Assisted Surgery	17.44	Endoscopic robotic assisted procedure	85
Computer Assisted Surgery	17.45	Thoracoscopic robotic assisted procedure	145
Computer Assisted Surgery	17.49	Other and unspecified robotic assisted procedure	55
Circulatory assist devices (includes VAD)	37.60	Implantation or insertion of biventricular external heart assist system	17
Circulatory assist devices (includes VAD)	37.61	Implant of pulsation balloon	13,039
Circulatory assist devices (includes VAD)	37.62	Insertion of temporary non-implantable extracorporeal circulatory assist device	42
Circulatory assist devices (includes VAD)	37.64	Removal of external heart assist system(s) or device(s)	270
Circulatory assist devices (includes VAD)	37.65	Implant of single ventricular (extracorporeal) external heart assist system	47
Circulatory assist devices (includes VAD)	37.66	Insertion of implantable heart assist system	41
Circulatory assist devices (includes VAD)	37.68	Insertion of percutaneous external heart assist device	72
Lead removal/revision/replacement	37.75	Revision of lead [electrode]	116
Lead removal/revision/replacement	37.76	Replacement of transvenous atrial and/or ventricular lead(s) [electrode]	85
Lead removal/revision/replacement	37.77	Removal of lead(s) [electrode] without replacement	50
Pacemaker implantation	37.72	Initial insertion of transvenous leads [electrodes] into atrium and ventricle	1,827
Pacemaker implantation	37.73	Initial insertion of transvenous lead [electrode] into atrium	10
Pacemaker implantation	37.74	Insertion or replacement of epicardial lead [electrode] into epicardium	514
Pacemaker implantation	37.78	Insertion of temporary transvenous pacemaker system	456
Pacemaker implantation	37.79	Revision or relocation of cardiac device pocket	34
Pacemaker implantation	37.80	Insertion of permanent pacemaker, initial or replacement, type of device not specified	18
Pacemaker implantation	37.81	Initial insertion of single-chamber device, not specified as rate responsive	45
Pacemaker implantation	37.82	Initial insertion of single-chamber device, rate responsive	36
Pacemaker implantation	37.83	Initial insertion of dual-chamber device	1,618
Pacemaker implantation	37.85	Replacement of any type pacemaker device with single-chamber device, not specified as rate responsive	8
Pacemaker implantation	37.86	Replacement of any type of pacemaker device with single-chamber device, rate responsive	6

Category	ICD-9 code	Description	N
Pacemaker implantation	37.87	Replacement of any type pacemaker device with dual-chamber device	101
Pacemaker implantation	37.89	Revision or removal of pacemaker device	33
Pacemaker implantation	37.90	Insertion of left atrial appendage device	11
ICD implantation	37.94	Implantation or replacement of automatic cardioverter/defibrillator, total system [AICD]	827
ICD implantation	37.95	Implantation of automatic cardioverter/defibrillator lead(s) only	12
ICD implantation	37.96	Implantation of automatic cardioverter/defibrillator pulse generator only	1
ICD implantation	37.97	Replacement of automatic cardioverter/defibrillator lead(s) only	6
ICD implantation	37.98	Replacement of automatic cardioverter/defibrillator pulse generator only	12
Transmyocardial revascularization	36.31	Open chest transmyocardial revascularization	938
Transmyocardial revascularization	36.32	Other transmyocardial revascularization	68
Transmyocardial revascularization	36.33	Endoscopic transmyocardial revascularization	5
Transmyocardial revascularization	36.34	Percutaneous transmyocardial revascularization	1
Miscellaneous	36.39	Other heart revascularization	8
Miscellaneous	36.91	Repair of aneurysm of coronary vessel	97
Miscellaneous	36.99	Other operations on vessels of heart (Exploration, Incision, Ligation of coronary artery, Repair of arteriovenous fistula)	544
Miscellaneous	37.34	Excision or destruction of other lesion or tissue of heart, other approach	574
Atrial appendage	37.36	Excision or destruction of left atrial appendage	3,626
Miscellaneous	37.37	Excision or destruction of other lesion or tissue of heart, thoracoscopic approach	0
Miscellaneous	37.91	Open chest cardiac massage	421
Miscellaneous	37.92	Injection of therapeutic substance into heart	6
Miscellaneous	37.93	Injection of therapeutic substance into pericardium	2
Miscellaneous	37.99	Other (Atrioplasty NEC; Ligation , atrium, heart; Ligation , auricle, heart; Operation , cardiac NEC; Operation , heart NEC; Operation , pericardium NEC; Repair , cardioverter/defibrillator (automatic) pocket, (skin) (subcutaneous))	564
Miscellaneous	39.27	Arteriovenostomy for renal dialysis	78

Appendix B: Condition Categories That May Represent Adverse Outcomes of Care Received During Index Admission

CC	Description
2	Septicemia/Shock
6	Other Infectious Diseases
17	Diabetes with Acute Complications
23	Disorders of Fluid/Electrolyte/Acid-Base
28	Acute Liver Failure/Disease
31	Intestinal Obstruction/Perforation
34	Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders
46	Coagulation Defects and Other Specified Hematological Disorders
47	Iron Deficiency and Other/ Unspecified Anemias and Blood Disease
48	Delirium and Encephalopathy
51	Drug/Alcohol Psychosis
75	Coma, Brain Compression/Anoxic Damage
77	Respirator Dependence/Tracheostomy Status
78	Respiratory Arrest
79	Cardio-respiratory failure and shock
80	Congestive heart failure
85	Heart Infection/Inflammation, Except Rheumatic
86	Valvular and Rheumatic Heart Disease
92	Specified Heart Arrhythmias
93	Other Heart Rhythm and Conduction Disorders
95	Cerebral Hemorrhage
96	Ischemic or Unspecified Stroke
97	Precerebral Arterial Occlusion and Transient Cerebral Ischemia
100	Hemiplegia/Hemiparesis
101	Cerebral Palsy and Other Paralytic Syndromes
102	Speech, Language, Cognitive, Perceptual
104	Vascular Disease with Complications
105	Vascular Disease
106	Other Circulatory Disease
111	Aspiration and Specified Bacterial Pneumonias
112	Pneumococcal Pneumonia, Emphysema, Lung Abscess
114	Pleural Effusion/Pneumothorax
130	Dialysis Status
131	Renal failure
133	Urinary Obstruction and Retention
135	Urinary Tract Infection
148	Decubitus Ulcer of Skin
152	Cellulitis, Local Skin Infection
154	Severe Head Injury
155	Major Head Injury
156	Concussion or Unspecified Head Injury
158	Hip Fracture/Dislocation

CC	Description
159	Major Fracture, Except of Skull, Vertebrae, or Hip
160	Internal Injuries
163	Poisonings and Allergic Reactions
164	Major Complications of Medical Care and Trauma
165	Other Complications of Medical Care
166	Major Symptoms, Abnormalities
177	Amputation Status, Lower Limb/Amputation
178	Amputation Status, Upper Limb

Appendix C: Condition Categories Not Considered for Risk Adjustment

CC	Description	Rationale
66	Attention Deficit Disorder	Pediatric ; Low frequency
123	Cataracts	Marker of clinical practice, not clinically relevant
129	End Stage Renal Disease	Not included in CMS-HCC Model
137	Female Infertility	Irrelevant to Medicare FFS Population
141	Ectopic Pregnancy	Irrelevant to Medicare FFS Population
142	Miscarriage/Abortion	Irrelevant to Medicare FFS Population
143	Completed Pregnancy with Major Complications	Irrelevant to Medicare FFS Population
144	Completed Pregnancy with Complications	Irrelevant to Medicare FFS Population
145	Completed Pregnancy without Complication	Irrelevant to Medicare FFS Population
146	Uncompleted Pregnancy with Complications	Irrelevant to Medicare FFS Population
147	Uncompleted Pregnancy with No or Minor Complications	Irrelevant to Medicare FFS Population
168	Extremely Low Birthweight Neonates	Fetal Effects; Irrelevant to Medicare FFS Population
169	Very Low Birthweight Neonates	Fetal Effects; Irrelevant to Medicare FFS Population
170	Serious Perinatal Problems Affecting Newborn	Fetal Effects; Irrelevant to Medicare FFS Population
171	Other Perinatal Problems Affecting Newborn	Fetal Effects; Irrelevant to Medicare FFS Population
172	Normal, Single Birth	Fetal Effects; Irrelevant to Medicare FFS Population
173	Major Organ Transplant	Not included in CMS-HCC Model
176	Artificial Openings for Feeding or Elimination	CC too heterogeneous; Mix of disparate codes
179	Post-Surgical States/Aftercare/Elective	CC too heterogeneous; Mix of disparate codes
180	Radiation Therapy	CC too heterogeneous; Mix of disparate codes
181	Chemotherapy	CC too heterogeneous; Mix of disparate codes
182	Rehabilitation	CC too heterogeneous; Mix of disparate codes
183	Screening/Observation/Special Exams	CC too heterogeneous; Mix of disparate codes
184	History of Disease	CC too heterogeneous; Mix of disparate codes
185	Oxygen	Not included in CMS-HCC Model; Durable Medical Equipment (DME)
186	CPAP/IPPB/Nebulizers	Not included in CMS-HCC Model; DME
187	Patient Lifts, Power Operated Vehicles, Beds	Not included in CMS-HCC Model; DME
188	Wheelchairs, Commodes	Not included in CMS-HCC Model; DME
189	Walkers	Not included in CMS-HCC Model; DME

Appendix D: Clinical Registry Data Validation of CABG Readmission Measure

Hospital-level 30-day Mortality Following Coronary Artery Bypass Graft Surgery

Measure Validation Report

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Validation of Administrative Claims-Based 30-Day All-Cause CABG Mortality Measure Using New York Cardiac Surgery Reporting System (CSRS) Registry Data

The Centers for Medicare and Medicaid Services (CMS) contracted with Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation (CORE) to develop an administrative claims-based Hospital 30-day All-Cause Risk-Standardized Coronary Artery Bypass Graft (CABG) Mortality Measure. This measure was developed concurrently with a Hospital 30-Day All-Cause Risk-Standardized CABG Readmission Measure. The goal of the measures is to evaluate the quality of care as well as inform performance improvement efforts for patients undergoing CABG procedures.

In this report, we present the methodology and findings of a validation study of the risk-standardized mortality measure. In order to validate the risk model used in this measure, CORE contracted with Dr. Edward Hannan, Distinguished Professor Emeritus, SUNY-Albany School of Public Health, to validate the claims-based mortality measure using clinical data from the New York State Cardiac Surgery Reporting System (CSRS) from the New York Department of Health.

Overview:

To validate the administrative risk-adjustment model, we calculated hospital-level, risk-standardized mortality rates (RSMRs) using the claims-based CABG mortality measure risk model and a risk model created using clinical registry data in a common cohort of isolated CABG patients (2008-2010) and compared the results. We measured the correlation between the two sets of results at the hospital level. In addition, we used a bootstrapping approach similar to that used for public reporting of the acute myocardial infarction (AMI), heart failure and pneumonia mortality measures to categorize hospital performance as better, worse or no different than the average hospital observed mortality rate.[1] We then performed a reclassification analysis to determine how many hospitals might be reclassified to a different performance category if assessed by the administrative model as compared to the registry model. In order to isolate differences due to the method of risk adjustment, both measures were calculated in the same cohort of patients, used the same outcome definition (30-day all-cause mortality defined by administrative claims data) and a consistent approach to risk-adjustment modeling (the hierarchical logistic regression model approach used in CMS's publicly reported claims-based outcome measures).

Methods:

Defining matched validation cohort

Source of Data: We used the New York State CSRS, which represents a large CABG registry that has been used to collect and publicly report outcomes since 1992.

Study Population: We limited the analysis population to patients undergoing isolated CABG. This is consistent with published reports of CABG outcomes and the NQF-endorsed Society of Thoracic Surgeons (STS) Risk-Adjusted Operative Mortality for CABG measure. In addition, our clinical experts, consultants and technical expert panel members agreed that an isolated CABG cohort is a clinically coherent cohort for quality measurement. From all

patients included in New York's CSRS during 2008-2011, 7,905 non-isolated CABG patients were excluded from the CSRS sample. CSRS records were classified as "isolated CABG" according to the CSRS registry definition if the field "coronary artery bypass grafting" was "yes" and all of the following fields were "no": valve surgery (field #1290), aortic valve operation (field #1630), mitral valve operation (field #1640), tricuspid valve operation (field #1650), pulmonic valve operation (field #1660), other non-cardiac procedure (field #1320), left ventricular aneurysm repair (field #2360), ventricular septal defect repair (field #2370), atrial septal defect repair (field #2380), Batista (field #2390), surgical ventricular restoration (field #2400), congenital defect repair (field #2410), cardiac trauma (field #2430), cardiac transplant (field #2440), atrial fibrillation correction surgery (field # 2470), aortic aneurysm operation (field #2510), and field "other" (field #2560) from section "other cardiac procedures." Records not meeting the above criteria were classified as "not isolated CABG" according to the registry definition.

We then created a cohort of Medicare fee-for-service (FFS) patients meeting the cohort eligibility criteria for the administrative claims-based isolated CABG mortality measure (detailed in the measure methodology report[2]) but limited to those with an index admission in New York state. The claims-based measure cohort similarly excludes patients with non-isolated CABG procedures, as well as other exclusions required for risk adjustment (i.e., 12-months of Medicare enrollment prior to index admission) and measure validity (e.g., selecting only one CABG procedure per measurement period and excluding patients who left against medical advice). We did not evaluate the accuracy of the claims-based cohort definition of isolated CABG, as this has already been tested during validation of the CABG readmission measure and found to have strong performance characteristics (sensitivity, specificity, positive and negative predictive values between 92% and 97%), compared to national registry data.[3]

Linkage of New York's CSRS and CMS Records: We then matched the CSRS registry sample to the Medicare FFS claims-based sample. Because we did not have unique identifiers due to statutory restrictions protecting the New York CSRS data, the linkage was performed using combinations of indirect identifiers (i.e., age, sex, admission date, procedure date, and discharge date). Eligible New York CSRS and Medicare FFS records were considered to link if they agreed exactly on all 5 matching variables (Figure 1).

Outcome definition

Definition of 30-Day Mortality: The mortality measure assesses death from any cause within 30 days of a hospitalization, regardless of whether the patient dies while still in the hospital or after discharge. The outcome was determined using the Medicare Enrollment Database, which contains Medicare beneficiary demographic, benefit/coverage, and vital status information. Using this endpoint definition, the observed 30-day all-cause mortality rate in the matched sample was 154 deaths per 8,228 patients or 1.9 %.

Risk model development and determination of hospital performance categories

Development of Clinical-based Risk Model: The clinical risk model was derived by evaluating approximately 40 clinical covariates in the CSRS and assessing the bivariate relationship with each of the binary and categorical risk factors and 30-day mortality using Chi-Square testing. Continuous risk factors (age and body surface area) were plotted against the logit of the mortality measure to determine the strongest functional form of relationship. Categorical, linear, and linear spline functions were considered as alternatives. All risk factors with probability values less than 0.10 were then used in a logistic regression model with 30-day mortality as the binary dependent variable.

Logistic regression coefficients and their odds ratios with 95% confidence intervals and probability values were calculated.

Development of Administrative Claims-based Risk Model: The risk model used for this comparison was consistent with existing CMS publicly reported outcome measures and is detailed in the measure methodology report for the claims-based 30-day all-cause isolated CABG mortality measure.[2] Risk variable coefficients were re-estimated using the matched sample.

Definition of Performance Categories: A bootstrapping algorithm was used to construct a 95% interval estimate for each RSMR. We categorized hospitals into three performance groups -- "Better," "No different" and "Worse" than average -- according to the methodology used for the current publicly reported CMS mortality and readmission measures.[1,4] We classified a hospital as performing "Better" than average if the 95% interval estimate for that hospital was entirely below the overall observed mortality rate for all hospitals in the matched sample (carried out to three decimal places), "Worse" if the estimate for that hospital was entirely above the overall observed mortality rate, and "No different" if the estimate included the overall observed mortality rate. This approach differs slightly from that used for the currently publicly reported CMS mortality measures[1], where the observed national outcome rate is rounded to one decimal place, but allows greater granularity of assessment for this validation study, where the underlying mortality rate for CABG surgery is considerably lower than the outcome rates for the currently reported measures. Similar to both the CMS publicly reported mortality measures and the consensus of a technical expert panel convened during development of the claims-based CABG readmission and mortality measures, we excluded hospitals with fewer than 25 eligible cases within the three-year measurement period from reporting of the reclassification analysis. Such low volume hospitals likely have less reliable estimates and are excluded from public reporting of performance, although these hospitals were included in calculation of the performance categories for the validation.

Comparison of CSRS clinical-based model and Medicare FFS claims-based model

For each of the two risk models, RSMRs and 95% interval estimates were calculated using a hierarchical logistic regression model with hospital-specific random intercept parameters. Agreement between claims-based and clinical-based RSMRs was assessed by Spearman Rank Correlation and depicted graphically as a scatterplot. Regression analysis was used to model the relationship between RSMRs obtained using the registry model and those produced using the claims-based model, as we are evaluating how well the claims-based model predicts the results of the clinical-based model (the gold standard), and we assessed fit diagnostics for the claims-based model. For each individual hospital, the difference between the claims-based and clinical-based RSMR was quantified by the absolute difference (= |claims-based RSMR - clinical-based RSMR|). Agreement between claims-based and clinical-based performance categories was assessed in a 3 x 3 table using the clinical-based results as the reference standard. A calibration analysis examining observed and predicted standardized mortality rates (SMR) across deciles of patient risk was performed for the clinical- and claims-based models.

Comparison of matched validation and national Medicare FFS isolated CABG cohorts

In order to understand how representative the CSRS population is of the national Medicare FFS population assessed by the claims-based CABG mortality measure, we compared the observed outcome (30-day all-cause) mortality and the prevalence and odds ratios of the claims-based risk model covariates in both samples.

Results:

Defining matched validation cohort

Based on the methodology described above, we identified 8,228 CABG admissions at 36 hospitals that constituted the matched cohort for the validation (Figure 1). The match rate was 80.1% (8,228/10,268), which is consistent with prior projects matching Medicare FFS administrative claims data to registry data when using probabilistic matching.[5]

Figure 1. Derivation of Matched Sample
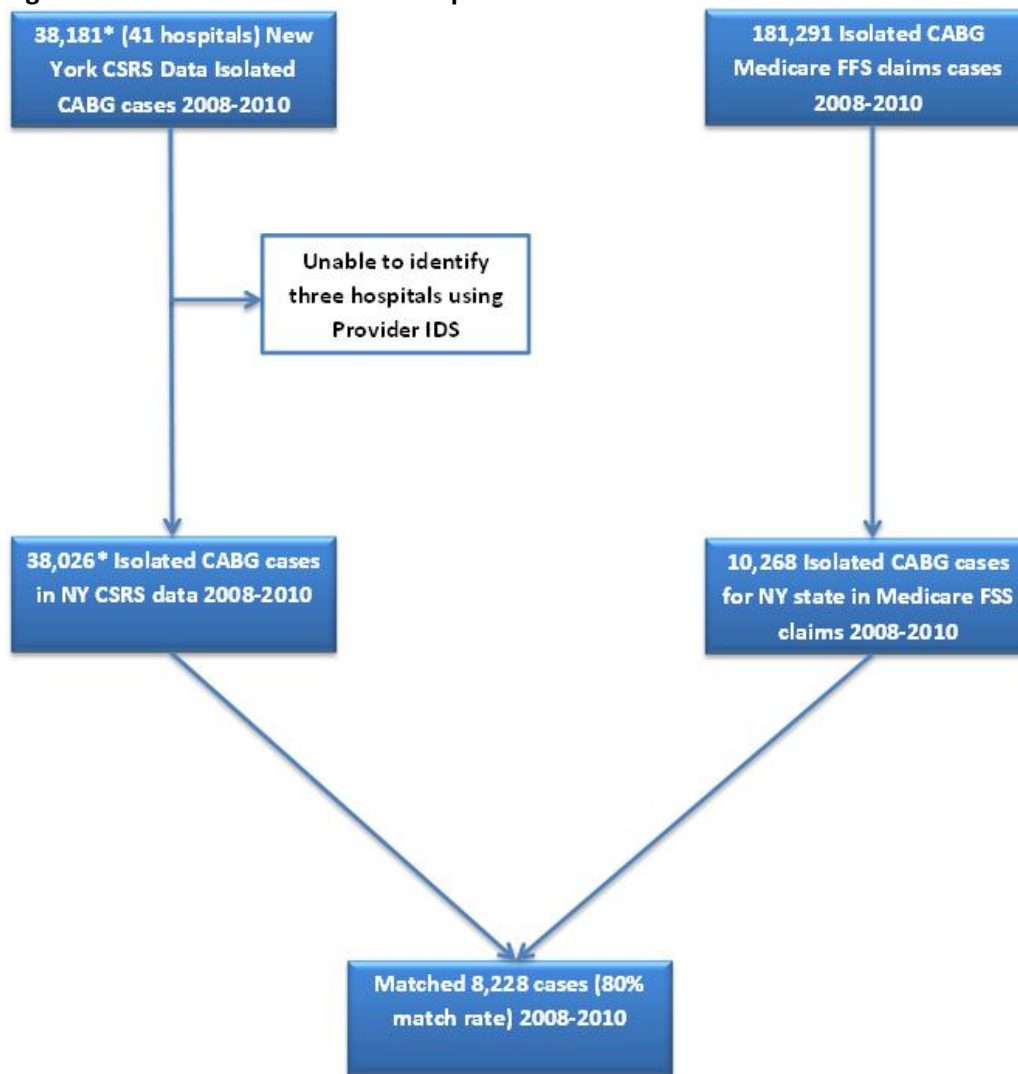
*The CSRS sample of 38,181 isolated CABG cases was not limited to 65 and older Medicare FFS patients; this step occurred during the final matching process.

Comparison of CSRS clinical-based model and Medicare FFS claims-based model

Table 1 and Figure 2 present the distribution of claims-based and clinical-based hospital-level RSMRs in the matched population. The median RSMR was similar with the claims-based and clinical-based models; however, the interquartile range and range were larger for the clinical-based model. The C-statistic for the clinical-based model was 0.75 while that for the claims-based model was 0.74. Figure 3 presents a scatterplot of the hospital-level RSMRs produced by both measures in the matched cohort of patients, where each dot represents a single hospital. The correlation between RSMRs for the two models was 0.90 using weighted Spearman correlation and 0.94 with an unweighted Spearman correlation. When we fit a regression line to the scatterplot data, the slope of the regression line was 1.81 (Figure 4). Full results for the analyses examining the correlation of the models are provided in the Appendix. When shock was removed from both models, the C-statistic decreased to 0.73 for the registry model and 0.70 for the claims model.

Table 1. Distribution of Clinical-based Model RSMRs and Claims-based Model RSMRs, %

Model	Minimum	25th Percentile	Median	75th Percentile	Maximum
Claims-based	1.41	1.65	1.84	2.12	3.04
Clinical-based	1.09	1.49	1.75	2.33	4.05

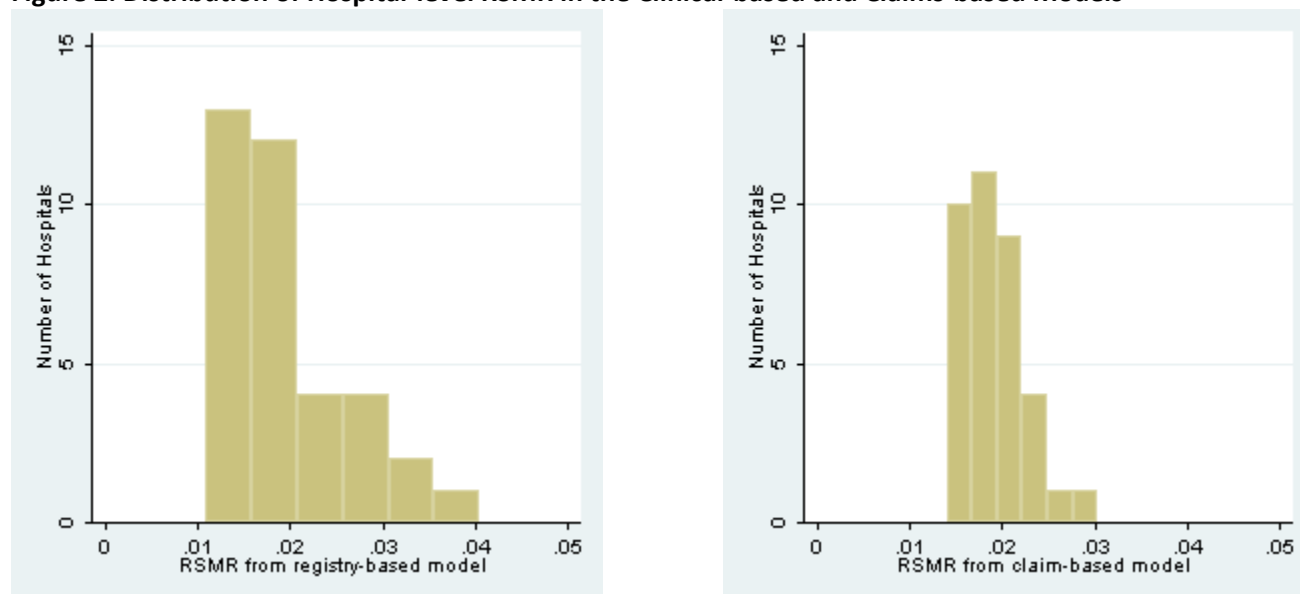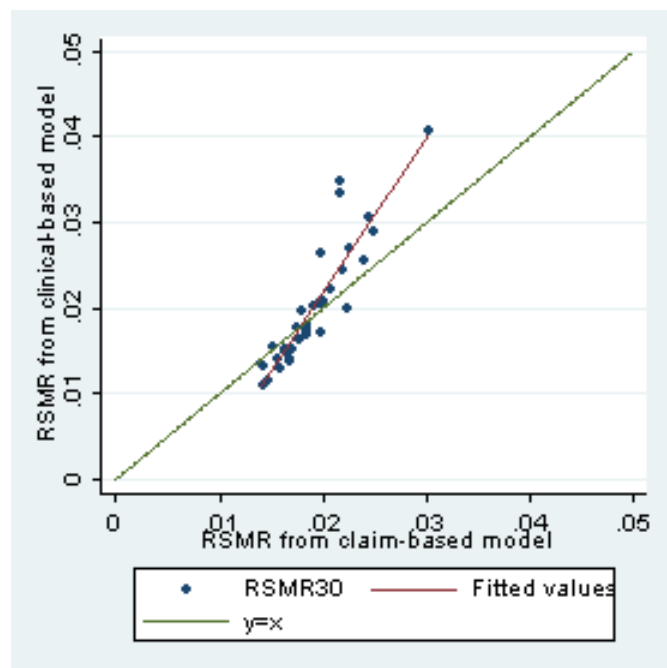**Figure 2. Distribution of Hospital-level RSMR in the Clinical-based and Claims-based Models**

Figure 3. Comparison of Clinical-based and Claims-based Model RSMRs

Six of 36 (16.7%) hospitals had claims-based and clinical-based RSMRs that differed by more than 0.4 of a percentage point while a majority of hospital estimates for RSMR differed by less than 0.2 of a percentage point (Table 2).

Table 2. Number of Hospitals and Absolute Difference in Clinical-based and Claims-based Model RSMRs

Absolute Difference in RSMRs	≤0.1%	>0.1 to 0.2%	>0.2 to 0.3%	>0.3 to 0.4%	>0.4%
Number of Hospitals	7	14	5	4	6
Percent of Hospitals	19.4	38.9	13.9	11.1	16.7
Number of Hospitals that Changed Performance Category (see Table 3) (e.g., Worse by registry model and No Different by claims model)	0	0	0	0	2

Table 3 provides a reclassification analysis examining the frequency of hospitals determined to be "Better," "No different," and "Worse" than average using the claims-based model compared to the clinical-based model. Neither the clinical- nor claims-based models identified any "Better than average" hospitals in the matched sample. One hospital was excluded from Table 3 based on the volume threshold and among the remaining 35 hospitals, 33 hospitals were classified as "No different than average" by both models, while 2 hospitals were classified as "Worse than average" in the clinical-based model and "No different than average" in the claims-based model. Table 4 and Table 5 further examine the ability of the claims-based measure to identify Better and Worse performing hospitals, respectively, using the clinic-based model as the gold standard. If the definition of performance categories currently used for public reporting of the AMI, heart failure and pneumonia mortality measures was applied to this sample, only one discordant worse performing outlier would be identified by the registry model (and identified as no different by the claims model). However, since observed CABG mortality rate in the matched sample is less than 2%, it is reasonable to use more decimal places in comparing mortality rates.

Table 3. Reclassification Analysis of Hospitals Based on Claims-based and Clinical-based RSMRs

		Clinical-based CABG Mortality Measure			
		Better than average	No different than average	Worse than average	Total
Claims-Based CABG Mortality Measure	Better than average	0	0	0	**0**
	No different than average	0	33	2	**35**
	Worse than average	0	0	0	**0**
	Total	**0**	**33**	**2**	**35***

* One hospital had fewer than 25 cases within the three-year measurement period and was excluded from reporting

Table 4. Accuracy of Claims-based Measure in Identifying "Better" Performing Hospitals

		Clinical-based CABG Mortality Measure		
		Better than average	No different or Worse than average	Total
Claims-Based CABG Mortality Measure	**Better than average**	0	0	**0**
	No different or Worse than average	0	35	**35**
	Total	**0**	**35**	**35***

* One hospital had fewer than 25 cases within the three-year measurement period and was excluded from reporting

Table 5. Accuracy of Claims-based Measure in Identifying "Worse" Performing Hospitals

		Clinical-based CABG Mortality Measure		
		Worse than average	No different or Better than average	Total
Claims-Based CABG Mortality Measure	**Worse than average**	0	0	**0**
	No different or Better than average	2	33	**35**
	Total	**2**	**33**	**35***

* One hospital had fewer than 25 cases within the three-year measurement period and was excluded from reporting

We also graphically present the RSMRs and 95% interval estimates for each of the 36 hospitals in the validation using the registry and claims model in Figure 4. The hospitals are ordered by case volume within the three-year measurement period (2008-2010), with lowest volume hospitals located on the left-hand side of the graph. The first hospital (#1) had only 14 cases in the three-year period and thus is excluded from Table 3, Table 4, and Table 5. The RSMR point estimates are indicated by diamonds with the interval estimates indicated by vertical lines. The top of the grey shaded area represents the observed outcome rate in the matched sample. Therefore, any interval estimate line that is either fully above (two) or fully below (none) the top of the grey shaded area is identified as significantly different than the observed rate and is considered a performance outlier. The two worse performing outliers identified by the registry model are noted by red diamonds. In all pair-wise comparisons, the two models produced similar RSMRs with overlapping 95% interval estimates.

The results of the calibration analysis in which observed and predicted SMR are plotted across deciles of patient risk for both models are displayed in Figure 5 and Figure 6, respectively, and demonstrate similar calibration for the claims-based and clinical-based models.

Figure 4. RSMRs and 95% Interval Estimates for All Hospitals in the Match Sample, Relative to the Observed Mortality Rate

36 hospitals in the Matched Validation Sample, ranked from lowest (left) to highest (right) case volume from 2008-2010
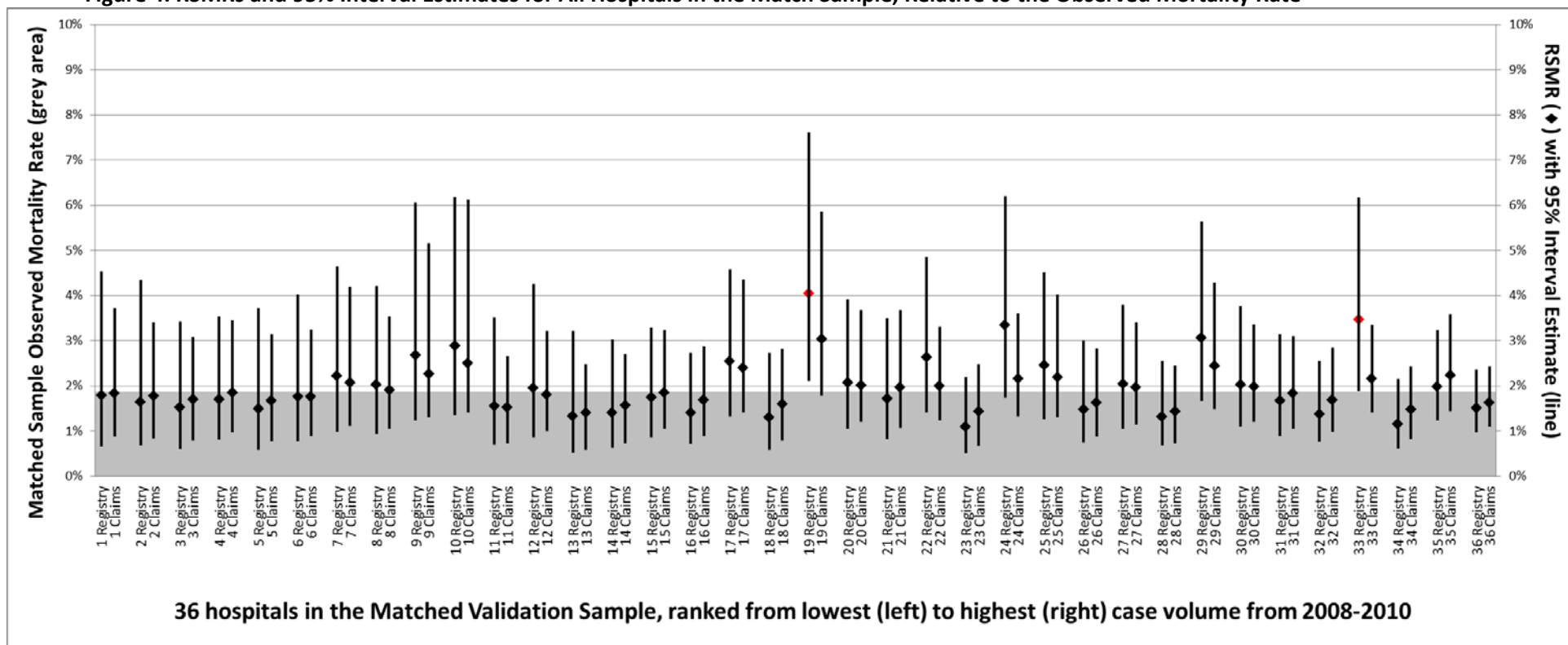
Figure 5. Plot of Predicted and Observed Standardized Mortality Rates Across Deciles of Patient Risk in the Claims-based model.
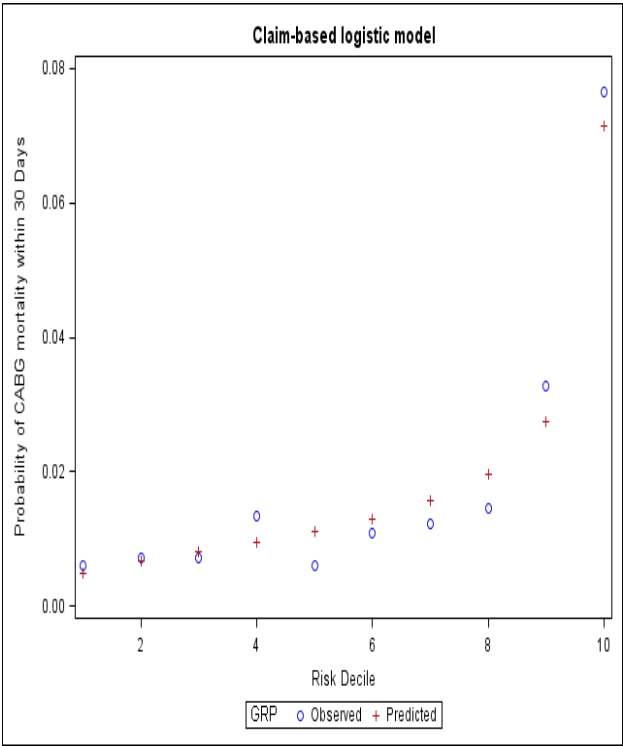
Figure 6. Plot of Predicted and Observed Standardized Mortality Rates Across Deciles of Patient Risk in the Clinical-based model.
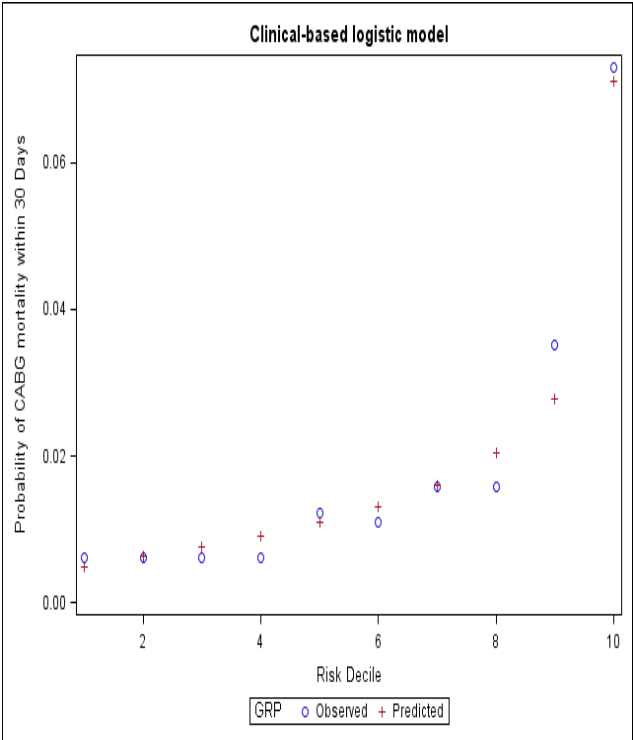
Comparison of Matched Validation and National Medicare FFS Isolated CABG Cohorts

To examine how the New York matched cohort compared to national Medicare FFS, we examined the outcome rate and prevalence of the constituent risk factors in the 30-day CABG mortality model as well as the OR (95% CI, Table 6) in both the matched sample and the national measure cohort. The median (IQR) 30-day all-cause observed mortality rate following isolated CABG surgery was lower in the matched cohort [1.78 (1.15-2.36)], as compared to national Medicare FFS data [2.84 (2.00-4.05)]. Although several risk variables had statistically different frequencies between the match sample and the national claims-based measure cohort, and there were a few risk variables with different effects in the two samples (e.g., an odds ratio <1.0 in the matched sample versus and odds ratio >1.0 in the national measure cohort), the odds ratios within the matched sample had confidence intervals that uniformly included 1.0.

Table 6.Outcome Rate and Claims-based Model Covariate Prevalence and Odds Ratios for Matched Cohort and National Medicare FFS Isolated CABG Cohort.

Outcome	Matched Validation Cohort (n=8,228)		National Medicare FFS Isolated CABG Cohort(n=181,291)		
30-Day Mortality following CABG, median (IQR) %	1.78 (1.15-2.36)		2.84 (2.00-4.05)		
Characteristic/Factor	**Frequency (%)**	**OR (95% CI)**	**Frequency (%)**	**OR (95% CI)**	**p-value***
Demographics					
Age-65 (Continuous)		1.03 (1.01-1.06)		1.07 (1.06-1.07)	<.0001
Male	5,576 (67.8)	0.72 (0.52-1.00)	123,879 (68.3)	0.73 (0.69-0.77)	0.2831
Comorbidities					
Cardiogenic Shock (ICD-9 Code 785.51)	366 (4.5)	5.39 (3.58-8.10)	7,158 (4.0)	3.66 (3.39-3.95)	0.0231
History of Prior CABG or Valve Surgery	215 (2.6)	0.46 (0.11-1.82)	10,046 (5.5)	1.74 (1.58-1.91)	<.0001
Pneumonia (CC 111-113)	1,030 (12.5)	1.31 (0.87-1.97)	22,982 (12.7)	1.45 (1.36-1.54)	0.6722
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	7,135 (86.7)	0.53 (0.36-0.80)	152,853 (84.3)	0.64 (0.60-0.68)	<.0001
Protein-Calorie Malnutrition (CC21)	208 (2.5)	2.19 (1.20-4.03)	5,566 (3.1)	1.74 (1.58-1.92)	0.0051
Renal Failure (CC131)	1,189 (14.5)	1.08 (0.70-1.66)	24,107 (13.3)	1.40 (1.30-1.50)	0.0026
COPD (CC108)	1,982 (24.1)	1.44 (1.02-2.04)	43,397 (23.9)	1.30 (1.23-1.38)	0.754
End-Stage Renal Disease Or Dialysis (CC 130)	126 (1.5)	1.18 (0.45-3.13)	2,415 (1.3)	1.98 (1.71-2.28)	0.1243
Liver and Biliary Disease (CC 25-30)	492 (6.0)	1.52 (0.88-2.62)	9,396 (5.2)	1.35 (1.22-1.49)	0.0015
Congestive Heart Failure (CC 80)	1,930 (23.5)	1.67 (1.16-2.40)	35,959 (19.8)	1.33 (1.25-1.41)	<.0001
Other Gastrointestinal Disorders (CC 36)	3,711 (45.1)	0.87 (0.62-1.21)	80,482 (44.4)	0.81 (0.77-0.85)	0.206
Unstable Angina And Other Acute Ischemic Heart Disease (CC82)	3,786 (46.0)	0.72 (0.52-1.00)	78,761 (43.4)	0.81 (0.76-0.85)	<.0001
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC84)	4,615 (56.1)	0.89 (0.64-1.22)	147,223 (81.2)	0.76 (0.72-0.81)	<.0001
Hypertension (CC 91)	7,138 (86.8)	0.75 (0.49-1.15)	154,897 (85.4)	0.78 (0.73-0.83)	0.001
Acute Myocardial Infarction (CC 81)	1,571 (19.1)	1.07 (0.72-1.58)	29,932 (16.5)	1.35 (1.27-1.44)	<.0001
Angina Pectoris/Old Myocardial Infarction (CC83)	3,465 (42.1)	0.97 (0.70-1.35)	71,463 (39.4)	0.76 (0.72-0.81)	<.0001

Characteristic/Factor	Frequency (%)	OR (95% CI)	Frequency (%)	OR (95% CI)	p-value*
Vascular or Circulatory Disease (CC 104-106)	3,165 (38.5)	1.44 (1.02-2.02)	60,330 (33.3)	1.19 (1.13-1.26)	<.0001
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	402 (4.9)	0.76 (0.38-1.51)	5,729 (3.2)	1.25 (1.11-1.40)	<.0001
Cancer (CC 7-12)	1,930 (23.5)	0.87 (0.58-1.30)	35,382 (19.5)	0.98 (0.91-1.04)	<.0001
Stroke (CC 95-96)	447 (5.4)	0.92 (0.46-1.85)	8.878 (4.9)	1.18 (1.06-1.31)	0.028
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	222 (2.7)	1.66 (0.77-3.56)	5,188 (2.9)	1.06 (0.92-1.21)	0.3835
Dementia or Senility (CC 49-50)	473 (5.8)	1.03 (0.56-1.91)	9,008 (5.0)	1.12 (1.01-1.24)	0.0015

*p value for comparison of the prevalence in matched sample compared to national data.

Discussion

CMS contracted with the Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation (CORE) to develop the administrative claims-based, risk-standardized CABG 30-day, all-cause mortality measure to evaluate and improve the quality of care for hospitalized patients undergoing CABG in the United States. In a matched cohort of registry patients from New York, the administrative claims-based model for risk adjustment of 30-day, all-cause mortality following isolated CABG surgery performed similarly to a clinical-based risk model, with nearly identical discrimination, but with two discordant hospitals. Key findings from this validation are provided below:

- The distributions in hospital RSMRs for the claims-based and clinical-based models are similar, although the claims-based model shows a narrower range of outcome rates.

- The C-statistics for the two models were similar: 0.74 for the claims-based model and 0.75 for the clinical-based model. When shock (for which comorbidity vs. complication status is difficult to confirm) was removed from the models, the respective C-statistics decreased to 0.70 and 0.73.

- Overall agreement between hospital performance categorization between the claims-based and clinical-based models was 94.3% (33 of 35 hospitals had concordant performance categorization) and the correlation was 0.90 (weighted Spearman correlation).

- Six of 36 hospitals (16.7%) had greater than 0.4% absolute difference in RSMR calculated by the claims-based versus clinical-based models.

- The clinical-based model identified two worse performing outlier hospitals, while the claims-based model identified none; neither model identified any better performing outliers in the matched sample.

- 2 hospitals were assigned discordant performance categories by the two models; the clinical-based model identified two hospitals with significantly higher mortality, and neither was identified as having significantly higher mortality by the claims model.

Although every attempt was made to eliminate potential sources of discordance between the two models in order to isolate the performance of the claims-based risk model, the study required linking Medicare FFS patients in the registry and Medicare FFS patients in administrative claims data using indirect identifiers. However, the match rate was 80%, with all patients matching on all five identifiers. As we used identical modeling approaches, including the hierarchical technique used in currently publicly reported CMS outcome measures, and an identical sample of patients, the remaining source of discordance is likely attributable to differences between the claims and clinical risk models.

Claims-based risk variables are limited by the administrative data used to assess them and although the claims-based model does not adjust for potential complications of care, such as sepsis, that are only coded during the index admission and not during the prior 12 months, this approach may not accurately distinguish between conditions that are present on admission and those that are truly complications of care. For this measure, our working group, collaborators at the Society of Thoracic Surgery and technical expert panel recommended that shock (defined as ICD-9-CM code 785.51) be considered in the risk model as the clinical experts considered it to be more likely a presenting condition than a complication of care for CABG. Removing this variable from the risk model decreased the C-statistic of the claims model from 0.74 to 0.70, while similarly removing shock from the clinical risk model decreased the registry model C-statistic from 0.75 to 0.73. As the claims-based model performance demonstrated a greater decrease when shock was removed than the clinical-based model, the claims-based model shock variable may overestimate the influence of shock and this may occur due to inclusion of post-operative complications in the definition. Consideration of using Present On Admission codes to more accurately define risk variables that truly reflect the status of the patient upon presentation may offer more specificity and improve claims-based model performance and should be considered as such data are more widely available.

Despite these limitations, both models produced similar discrimination when shock was included, but different discrimination when shock was removed from both models. The claims-based model consistently produced a narrower range of RSMR estimates compared to the registry model and thus is unlikely to erroneously identify outlier hospitals. For public reporting, such a bias is preferable to misclassifying hospitals as poor performers when they are, in fact, not.

However, the claims-based model may also fail to identify true outlier hospitals, and the extent to which this is the case should be examined carefully using a national sample of data. In general, the claims-based model produced RSMR point estimates closer to the average observed mortality rate in the matched sample than the clinical-based model – that is, generally lower RSMR estimates compared with the registry model among hospitals with higher estimated RSMRs, and generally higher RSMR estimates among those hospitals with lower RSMRs (although not all lower RSMRs produced by the clinical model were over-estimated by the claims model). Combined with the fact that the registry model identified two worse performing outliers while the claims model identified no outliers, the results support the benefits of

further examining the number of performance outlier hospitals identified by the claims model in a national sample.

If the definition of performance categories currently used for public reporting of the AMI, heart failure and pneumonia mortality measures was applied to this sample, only one discordant worse performing outlier would be identified by the clinical-based model (and identified as no different by the claims-based model). The reason a different definition (two decimal places rather than one when reporting percentages) was used for CABG surgery is that its underlying mortality rate is considerably lower than for the currently reported measures. Determination of the threshold used to identify performance outliers (e.g., the number of decimal places to use) as well as what degree of performance variation is required for incorporating an outcome measure into public reporting programs, such as the Inpatient Quality Reporting Program, should be a consensus decision between CMS and stakeholders.

There are limitations to this analysis. First, this validation analysis was limited to patients undergoing isolated CABG surgery in a single state. New York has a long history of public reporting of CABG outcomes and participation in quality improvement activities and may not be representative of the national population of patients undergoing these procedures. This is supported by a lower observed mortality rate, few outlier hospitals identified in the performance category assessment, and a narrower (and lower) range of RSMRs in the matched sample (IQR: 1.7 to 2.2%) than that seen in the national measure cohort (IQR: 2.6 to 3.6%).[2] However, the match rate for patients was over 80% and we compared the matched sample to the national measure cohort, finding a slightly lower observed mortality rate, but similar risk factor frequencies and coefficients. In addition, New York's extensive experience with performance assessment allowed validation of the claims model against a clinical risk model developed by one of the nation's most well-established CABG quality reporting programs.

Second, the matched sample contained only 8,228 isolated CABG procedures across 36 New York hospitals and two outlier hospitals were identified by the registry model and none by the claims-based model. Given this, consideration should be given to ensuring the claims-based mortality measure has sufficient discriminatory power to identify performance outliers in the national dataset. This could be accomplished by bootstrap analyses similar to those performed on national data to ascertain the number of outlier hospitals for public reporting (i.e., "Better," "No different" and "Worse" than average performance categories). However, the discrimination of the registry and claims models was similar, with nearly identical C-statistics and similar calibration, and the IQR of RSMRs using the claims measure in national data was 1.4 to 4.4% with a full range of 1.5 to 7.9%.

Conclusion

With input from experts and stakeholders, restricted to patients undergoing isolated CABG, and applying hierarchical modeling to account for the clustering of patients within hospitals and differences in sample size across hospitals, we developed an administrative claims model for 30-day all-cause mortality following CABG. Thorough evaluation adherent to nationally accepted standards for outcome measure development[6] indicate that the model has similar discrimination and calibration to a New York state-derived clinical risk model, although the relative discrimination was lower when a risk variable (shock),

whose pre-operative status was unknown, was removed from the claims-based model. Although both the mortality rate and range of performance in the matched sample was less than that of US hospitals overall, the frequency and effect of risk variables was similar in the matched sample and national data.

The models produce similar estimates of hospital performance. However, the claims-based model generally produces lower RSMR estimates compared with the clinical-based model among hospitals with higher estimated RSMRs, and higher RSMR estimates among those hospitals with lower RSMRs. Assuming that the clinical-based model is the gold standard (and does not over-estimate poor performing hospitals' RSMRs), our findings suggest that the claims-based model may underestimate poor performing hospitals' RSMRs and may be less likely to identify poor performance outliers compared with the clinical-based model. Similarly, the claims-based model may be less likely to identify hospitals with significantly better than average performance, although this validation study cannot assess this as the clinical-based model did not identify high performing outlier hospitals. Analyses that demonstrate the claims-based model's ability to identify outliers in national data and therefore to adequately capture performance variation, are recommended to determine the measure's utility as a valid metric of US CABG care quality.

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Testing Hospital-level Coronary Artery Bypass Graft (CABG) Surgery
30-day Mortality & Readmission Measures in California All-payer Data

Submitted By Yale New Haven Health Services Corporation/Center for Outcomes Research & Evaluation (YNHHSC/CORE)

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Introduction

Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation (YNHHSC/CORE) is developing hospital 30-day risk-standardized mortality and readmission measures for patients hospitalized for coronary artery bypass graft surgery (CABG) for the Centers for Medicare & Medicaid Services (CMS). We are developing the measures using Medicare fee-for-service (FFS) claims data for beneficiaries aged 65 years and older, given that Medicare is the only current national claims dataset. However, ideally we would like to specify the measure for use in Medicare and all-payer populations so that it can be applied to the expanding number of available all-payer datasets. Consequently, we tested the measure in an all-payer patient population of adults aged 18 years and older. In this report, we detail our approach to addressing this question and present the findings.

The mortality and readmission measures employ administrative claims data, and are calculated using hierarchical logistic regression models to account for the clustering of observations within hospitals and differences in the number of admissions across hospitals. For risk adjustment, patient comorbidities are identified through claims data from each index hospitalization, and from inpatient and outpatient Medicare claims during the 12 months prior to the index hospitalization. The measure development process in the Medicare FFS population is available in the detailed methodology report for each measure.

The results of our all-payer testing support expanding the CABG mortality and readmission measures' patient populations to include both non-FFS Medicare patients aged 65+ years and all-payer patients aged 18-64 years. Based on the results presented below, we conclude that CMS' risk-standardized mortality and readmission rates (RSMRs and RSRRs) for CABG perform well when applied to all-payer data (all patients aged 18+ years). For each measure, model testing demonstrated both strong patient-level model performance and consistent hospital-level results. Although there were few significant age-risk factor interaction terms (Older and COPD, and Older and Dementia or Senility for mortality; and Older and Pneumonia for readmission), they do not appear to affect the model results. For simplicity and pending further study, the only change currently recommended to either measure's specifications to allow application to an all-payer, 18+ year population is transformation of the Age variable from "Age – 65" to a fully continuous age variable.

Methods

Data Source: For our analyses, we used 2006 all-payer data from California. California is a diverse state, and, with more than 37 million residents, California represents 12% of the U.S. population. We used the California Patient Discharge Data (PDD), a large, linked database of patient hospital admissions. In 2006, there were approximately 3 million adult discharges from more than 450 non-federal acute care hospitals. Records are linked by a unique patient identification number, allowing us to determine patient history from previous hospitalizations and to evaluate rates of both mortality and readmission (via linking with California vital statistics records).

Using all-payer data from California as well as CMS Medicare FFS data for California hospitals, we performed analyses to determine whether the CABG measures can be applied to all adult patients, including FFS Medicare patients aged 65+, non-FFS Medicare patients aged 65+, and patients aged 18-64 years at the time of admission. The CABG models developed in Medicare FFS 65+ patients use inpatient and outpatient data for risk adjustment (consistent with CMS' publicly reported mortality and readmission measures for acute myocardial infarction [AMI], heart failure [HF], and pneumonia[1-6]).

To determine whether the measures can be used in all-payer data, the following questions must be addressed:

Question 1: Given that outpatient claims are not available in the all-payer dataset, how do the current CMS models perform when using only inpatient claims data (i.e., hospital claims for admitted patients)? That is, does the exclusion of outpatient claims data adversely affect measure performance and results at the patient level and the hospital level?

Question 2: When applied to all patients 18+, do the models perform well both at the patient level and at the hospital level? That is, at the patient level, do the models, when derived in the full 18+ population, have good discrimination, predictive ability, and model fit across patient subgroups? In addition, when new patients are added, do potential differences in the effects of risk factors across patient subgroups affect risk prediction at the patient level and risk profiling at the hospital level?

Question 1 analyses: Can risk-adjustment data be limited to inpatient claims?

In testing other administrative claims measures developed in Medicare FFS data − including mortality and readmission measures for AMI, HF, pneumonia, and chronic obstructive pulmonary disease (COPD) − we have validated both the accuracy of the PDD in capturing Medicare claims and the use of only inpatient data for risk adjustment.[7-8] We also found that, although the prevalence of most risk factors is lower when using only inpatient claims data, the magnitude of effect for most risk factors was similar when comparing the models that use all patient history data with those that use only inpatient claims data. Over 95% of patients were in a similar risk category (defined as being in the same or adjacent category) regardless of the risk-adjustment dataset used, and the integrated discrimination improvement values were relatively low (ranging from -0.001 for COPD readmission, to 0.007 for pneumonia mortality). For all measures, the C statistic was also qualitatively similar between the two approaches. (The greatest difference in C statistic between inpatient only versus all patient history data risk-adjustment models was 0.012, for AMI mortality.) Moreover, when comparing the models using full history data with the models using only inpatient claims data, hospital-level risk-standardized rates were highly correlated (intraclass correlation coefficients ranged from 0.95 for AMI readmission to 0.99 for HF mortality). Based on this reassuring data across measures, we did not repeat these analyses for the CABG mortality and readmission measures, but rather assumed that inpatient claims data would provide adequate risk-adjustment information for application of the measures in all-payer data.

Question 2 analyses: Can the models be used in all-payer patient population of adults 18 years and older?

To address the question of how well the models perform when applied to all patients 18+, we used the PDD Data. Specifically, using 2006 data, we created measure cohorts with up to one year of hospital inpatient claims history and 30-day follow-up data. For both measures, we:

A.   Created the patient cohort using the respective measure inclusion and exclusion criteria (with the exception of including all patients 18+), and compared the FFS 65+, non-FFS 65+, and 18-64 year-old patient subgroups with respect to the distribution of risk factors and the crude outcome rate.

B.   Fit the model in all patients 18+ and: (i) examined overall model performance in terms of the C statistic, (ii) compared performance (C statistic and predictive ability) across the patient subgroups (FFS 65+, non-FFS 65+, all 65+, and all-payer 18-64), and (iii) compared the distribution of Pearson residuals (model fit) across the patient subgroups.

C.   Fit the model separately in each patient subgroup and compared odds ratios (ORs) associated with the risk factors to assess differences in magnitude or direction of ORs among the subgroups.

To determine whether the relationship between each risk factor and the outcome differed for those aged 65+ vs. 18-64 in ways that would affect measure results, we:

D.   Fit the model in all patients 18+ and tested interaction terms between age (65+ vs. 18-64) and each of the other risk factors.

E.   Fit the model in all patients 18+ with interaction terms and compared performance (C statistic and predictive ability) across the patient subgroups.

F.   Fit the model in all patients 18+ with and without interaction terms and (i) conducted a reclassification analysis to compare risk prediction at the patient level; (ii) compared the C statistic; and (iii) compared hospital-level risk-standardized rates using a scatterplot and the intra-class correlation coefficient (ICC) to assess whether the model with interactions is statistically different from the current model in profiling hospital rates.

All patient-level models were estimated using a logistic regression model; next, hospital-level RSMR and RSRR analyses were conducted using a hierarchical logistic regression model approach.

Results

Can the models be used in all-payer patient population of adults 18 years and older?

A.   The CABG mortality and readmission cohorts are presented in Figure 2 of the mortality and readmission methodology reports. As the results in Table 1a-Table

1b (for the mortality and readmission measures, respectively) demonstrate, there are some differences in the risk factor profiles and crude outcome rate among patient subgroups. In general, the prevalence of risk factors was similar in FFS 65+ and non-FFS 65+ patients. When comparing risk factor prevalence estimates between those 65+ and younger patients aged 18-64, frequencies were generally either lower in the younger cohort or similar between the groups. For some risk factors, including Liver and Biliary Disease (CC 25-30) in the mortality model and Diabetes Mellitus (DM) and DM Complications (CC 15-20, 119, 120) in the readmission model, prevalence estimates were in fact higher in younger than in older patients (Table 1a-Table 1b). As expected, the crude mortality and readmission rates were lower in the younger cohorts (Table 1a and Table 1b).

B. Nevertheless, when the current models were applied to all patients 18+, overall discrimination was good (C statistic=0.84 for CABG mortality and 0.66 for CABG readmission) (Table 2a-Table 2b). There was also good discrimination and predictive ability in all subgroups of patients (Table 3a-Table 3b). Moreover, for both measures, the distribution of Pearson residuals was comparable across the patient subgroups (Table 4a-Table 4b).

C. For both measures, ORs were generally similar for FFS 65+ and non-FFS 65+ patients. For some risk factors, such as COPD in the mortality model, there were differences in magnitude of effect between younger and older patients (Table 5a-Table 5b).

D. For mortality, there were significant age-by-risk-factor interaction terms for two variables (Older and COPD, and Older and Dementia or Senility); COPD was protective in younger age groups. Only one interaction term was significant for readmission (Older and Pneumonia) (Table 6a-Table 6b).

E. Inclusion of the interaction terms, however, did not substantively change the level of discrimination and predictive ability across the patient subgroups (Table 7a-Table 7b).

F. In addition, when comparing patient risk classifications for each measure with and without interaction terms, the reclassification analysis for both measures demonstrated good patient-level risk prediction: for both measures and all patient subgroups, nearly 100% of patients were in a similar risk category (defined as being in the same or adjacent category) regardless of risk-adjustment strategy (Table 8a-Table 8b). Moreover, the C statistic was nearly identical for the models with and without interaction terms (0.85 vs. 0.86, respectively, for CABG mortality, and 0.66 vs. 0.66 for CABG readmission) (Table 9a-Table 9b). Finally, when comparing each measure with and without interaction terms, the hospital-level risk-standardized rates estimated by the two versions of each model were highly correlated (ICC is 0.998 for CABG mortality and 0.998 for CABG readmission) (Figure 1a and Figure 1b).

Conclusions

Based on the results presented above, we conclude that CMS's administrative claims-based CABG mortality and readmission measures perform well when applied to all-payer data (all patients aged 18+ years). Although there were a few significant age-risk factor interaction terms (Older and COPD, and Older and Dementia or Senility for mortality; and Older and Pneumonia for readmission), they do not appear to affect the model results, as the inclusion of the interactions did not substantively affect either patient-level model performance or hospital-level results. For simplicity and pending further study, the only change currently recommended to the measure specifications to allow application to an all-payer, 18+ year population is transformation of the Age variable from "Age-65" to a fully continuous age variable. We have demonstrated that the models can be applied to all patients aged 18+ years and that they perform well when only inpatient admission claims data are used to determine patient history. Thus, based on these results, we will specify the measure to include the 18+ population and to allow for the use of inpatient claims only for risk adjustment when complete claims history (i.e., outpatient data) is unavailable.

The California PDD have some limitations. Data on previous admissions and 30-day readmissions are available only from California hospitals; however, it is unlikely that a high proportion of patients sought hospital inpatient care outside the state given that relatively few California residents live in cities bordering other U.S. states. Likewise, linked data on 30-day mortality outside the hospital are available only for deaths within California. Moreover, although in similar measures we confirmed measure performance without the use of outpatient data for risk adjustment in the FFS Medicare 65+ population, we did not assess this for the CABG measures. However, had the testing been possible, it is unlikely to have altered the conclusions, as all other testing demonstrated comparability between FFS Medicare and non-FFS Medicare patients aged 65+ years.

In summary, CMS's CABG measures – hospital 30-day all-cause RSMR and RSRR for CABG – perform well when used in all-payer data (all patients aged 18+ years). For each measure, model testing demonstrated both strong patient-level model performance and consistent hospital-level results.

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Table 1a. Raw Outcome Rates and Prevalence of Risk Factors in CABG <u>Mortality</u> Model for All Patients Aged 18+ Years, FFS 65+ Patients, Non-FFS 65+ Patients, and All Patients 18-64 Years of Age

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Description	All 18+ (Total)	FFS 65+	Non-FFS 65+	Age 18-64 Years
	N (%)	N (%)	N (%)	N (%)
Raw Mortality Rate, %	1.8	2.6	2.4	1.0
Demographics				
Mean Age (SD)	66.0 (10.6)	74.0 (6.1)	73.2 (5.8)	56.1 (6.2)
Male	11,146 (74.9)	3,294 (70.5)	2,723 (71.9)	5,129 (79.8)
Comorbidities				
Cardiogenic Shock (ICD-9 Code 785.51)	477 (3.2)	161 (3.5)	123 (3.3)	193 (3.0)
History of Prior CABG or Valve Surgery	282 (1.9)	99 (2.1)	79 (2.1)	104 (1.6)
Pneumonia (CC 111-113)	1,264 (8.5)	480(10.3)	357(9.4)	427 (6.6)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	11,897 (79.9)	3,615 (77.4)	3,056 (80.7)	5,226 (81.3)
Protein-Calorie Malnutrition (CC 21)	240 (1.6)	111 (2.4)	66 (1.7)	63 (1.0)
Renal Failure (CC 131)	2,754 (18.5)	1,003 (21.5)	833 (22.0)	918 (14.3)
COPD (CC 108)	2,867 (19.3)	1,051 (22.5)	707 (18.7)	1,109 (17.3)
End-Stage Renal Disease Or Dialysis (CC 130)	341 (2.3)	99 (2.1)	52 (1.4)	190 (3.0)
Liver and Biliary Disease (CC 25-30)	513 (3.5)	146 (3.1)	99 (2.6)	268 (4.2)
Congestive Heart Failure (CC 80)	3,784 (25.4)	1,309 (28.0)	1,064 (28.1)	1,411 (22.0)
Other Gastrointestinal Disorders (CC 36)	3,530 (23.7)	1,230 (26.3)	912 (24.1)	1,388 (21.6)
Unstable Angina And Other Acute Ischemic Heart Disease (CC 82)	5,441 (36.5)	1,703 (36.4)	1,313 (34.7)	2,425 (37.7)
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC 84)	6,785 (45.6)	2,093 (44.8)	1,689 (44.6)	3,003 (46.7)
Hypertension (CC 91)	10,458 (70.2)	3,266 (69.9)	2,729 (72.1)	4,463 (69.4)
Acute Myocardial Infarction (CC 81)	1,578 (10.6)	428 (9.2)	445 (11.8)	705 (11.0)
Angina Pectoris/Old Myocardial Infarction (CC 83)	4,741 (31.8)	1,464 (31.3)	1,253 (33.1)	2,024 (31.5)
Vascular or Circulatory Disease (CC 104-106)	3,568 (24.0)	1,375 (29.4)	1,004 (26.5)	1,189 (18.5)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	251 (1.7)	67 (1.4)	68 (1.8)	116 (1.8)
Cancer (CC 7-12)	498 (3.3)	228 (4.9)	154 (4.1)	116 (1.8)
Stroke (CC 95-96)	331 (2.2)	136 (2.9)	85 (2.2)	110 (1.7)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	613 (4.1)	211 (4.5)	133 (3.5)	269 (4.2)
Dementia or Senility (CC 49-50)	226 (1.5)	100 (2.1)	79 (2.1)	47 (0.7)

Note:
1. FFS is defined as payer category=Medicare and payer type of coverage=Traditional.

Table 1b. Raw Outcome Rates and Prevalence of Risk Factors in CABG <u>Readmission</u> Model for All Patients Aged 18+ Years, FFS 65+ Patients, Non-FFS 65+ Patients, and All Patients 18-64 Years of Age

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Description	All 18+ Total	FFS 65+	Non-FFS 65+	Age 18-64 Years
	N (%)	N (%)	N (%)	N (%)
Raw Readmission Rate, %	14.5	15.8	16.0	12.8
Demographics				
Mean Age (SD)	65.9 (10.6)	73.9 (6.1)	73.2 (5.7)	56.0 (6.2)
Male	10,982 (75.0)	3,217 (70.7)	2,673 (72.1)	5,092 (79.9)
Comorbidities				
History of Prior CABG or Valve Surgery	271 (1.9)	98 (2.2)	69 (1.9)	104 (1.6)
Cardiogenic Shock (ICD-9 Code 785.51)	384 (2.6)	120 (2.6)	93 (2.5)	171 (2.7)
COPD (CC 108)	2,782 (19.0)	1,001 (22.0)	680 (18.4)	1,101 (17.3)
Renal Failure (CC 131)	2,581 (17.6)	916 (20.1)	781 (21.1)	884 (13.9)
Diabetes and DM Complications (CC 15-20, 119, 120)	6,399 (43.7)	1,860 (40.9)	1,591 (42.9)	2,948 (46.2)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	11,731 (80.2)	3,538 (77.7)	3,003 (81.0)	5,190 (81.4)
Congestive Heart Failure (CC 80)	3,621 (24.7)	1,229 (27.0)	1,013 (27.3)	1,379 (21.6)
Arrhythmias (CC 92-93)	5,527 (37.8)	2,148 (47.2)	1,667 (45.0)	1,712 (26.9)
Other Lung Disorders (CC 115)	1,977 (13.5)	633 (13.9)	520 (14.0)	824 (12.9)
Major Psychiatric Disorders (CC 54-56)	239 (1.6)	78 (1.7)	46 (1.2)	115 (1.8)
Vascular or Circulatory Disease (CC 104-106)	3,431 (23.4)	1,310 (28.8)	959 (25.9)	1,162 (18.2)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	2,863 (19.6)	1,074 (23.6)	732 (19.8)	1,057 (16.6)
Pneumonia (CC 111-113)	1,165 (8.0)	429 (9.4)	328 (8.9)	408 (6.4)
Cerebrovascular Disease (CC 97-99, 103)	1,122 (7.7)	471 (10.4)	348 (9.4)	303 (4.8)
Polyneuropathy (CC 71)	727 (5.0)	197 (4.3)	169 (4.6)	361 (5.7)
Protein-Calorie Malnutrition (CC 21)	217 (1.5)	96 (2.1)	60 (1.6)	61 (1.0)
Severe Hematological Disorders (CC 44)	38 (0.3)	16 (0.4)	8 (0.2)	14 (0.2)
Fibrosis Of Lung And Other Chronic Lung Disorders (CC 109)	192 (1.3)	77 (1.7)	57 (1.5)	58 (0.9)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	235 (1.6)	59 (1.3)	65 (1.8)	111 (1.7)
End-Stage Renal Disease Or Dialysis (CC 130)	317 (2.2)	87 (1.9)	48 (1.3)	182 (2.9)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102)	593 (4.1)	203 (4.5)	126 (3.4)	264 (4.1)
Stroke (CC 95-96)	308 (2.1)	126 (2.8)	77 (2.1)	105 (1.7)
Dementia or Senility (CC 49-50)	216 (1.5)	94 (2.1)	77 (2.1)	45 (0.7)
Cancer (CC 7-12)	485 (3.3)	219 (4.8)	152 (4.1)	114 (1.8)

Note:
1. FFS is defined as payer category=Medicare and payer type of coverage=Traditional.

Table 2a. Odds Ratios for Risk Factors in CABG <u>Mortality</u> Measure for All Patients 18+ Years (Logistic Regression Model, N=14,889, C Statistic=0.84)

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Description	OR (95% CI)
Demographics	
Age-65 (Continuous)	1.05 (1.03-1.06)
Male	0.68 (0.52-0.90)
Comorbidities	
Cardiogenic Shock (ICD-9 Code 785.51)	7.51 (5.43-10.38)
History of Prior CABG or Valve Surgery	1.54 (0.81-2.94)
Pneumonia (CC 111-113)	1.61 (1.17-2.22)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	0.57 (0.43-0.76)
Protein-Calorie Malnutrition (CC 21)	0.59 (0.29-1.17)
Renal Failure (CC 131)	3.23 (2.37-4.39)
COPD (CC 108)	1.23 (0.92-1.64)
End-Stage Renal Disease Or Dialysis (CC 130)	1.56 (0.91-2.68)
Liver and Biliary Disease (CC 25-30)	1.76 (1.12-2.77)
Congestive Heart Failure (CC 80)	1.25 (0.93-1.68)
Other Gastrointestinal Disorders (CC 36)	0.63 (0.46-0.87)
Unstable Angina And Other Acute Ischemic Heart Disease (CC 82)	0.96 (0.71-1.28)
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC 84)	1.41 (1.06-1.87)
Hypertension (CC 91)	1.25 (0.92-1.69)
Acute Myocardial Infarction (CC 81)	0.92 (0.64-1.31)
Angina Pectoris/Old Myocardial Infarction (CC 83)	1.07 (0.81-1.42)
Vascular or Circulatory Disease (CC 104-106)	1.59 (1.22-2.08)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	0.41 (0.17-1.00)
Cancer (CC 7-12)	0.84 (0.44-1.60)
Stroke (CC 95-96)	2.03 (1.20-3.43)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	1.24 (0.75-2.05)
Dementia or Senility (CC 49-50)	1.51 (0.79-2.89)

Table 2b. Odds Ratios for Risk Factors in CABG <u>Readmission</u> Measure for All Patients 18+ Years (Logistic Regression Model, N=14,635, C Statistic=0.66)

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Description	OR (95% CI)
Demographics	
Age-65 (Continuous)	1.01 (1.01-1.02)
Male	0.69 (0.62-0.76)
Comorbidities	
History of Prior CABG or Valve Surgery	0.84 (0.59-1.18)
Cardiogenic Shock (ICD-9 Code 785.51)	1.27 (0.98-1.63)
COPD (CC 108)	1.27 (1.13-1.42)
Renal Failure (CC 131)	1.40 (1.24-1.59)
Diabetes and DM Complications (CC 15-20, 119, 120)	1.45 (1.31-1.60)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	0.97 (0.86-1.09)
Congestive Heart Failure (CC 80)	1.34 (1.20-1.50)
Arrhythmias (CC 92-93)	1.20 (1.09-1.33)
Other Lung Disorders (CC 115)	0.95 (0.83-1.09)
Major Psychiatric Disorders (CC 54-56)	1.49 (1.09-2.05)
Vascular or Circulatory Disease (CC 104-106)	1.08 (0.97-1.21)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	1.18 (1.05-1.33)
Pneumonia (CC 111-113)	1.19 (1.01-1.39)
Cerebrovascular Disease (CC 97-99, 103)	1.13 (0.96-1.34)
Polyneuropathy (CC 71)	1.21 (1.00-1.47)
Protein-Calorie Malnutrition (CC 21)	1.14 (0.83-1.56)
Severe Hematological Disorders (CC 44)	2.00 (0.94-4.26)
Fibrosis Of Lung And Other Chronic Lung Disorders (CC 109)	1.41 (0.99-2.01)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	1.29 (0.95-1.75)
End-Stage Renal Disease Or Dialysis (CC 130)	1.15 (0.87-1.51)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102)	1.38 (1.11-1.71)
Stroke (CC 95-96)	1.05 (0.78-1.41)
Dementia or Senility (CC 49-50)	1.46 (1.06-2.00)
Cancer (CC 7-12)	0.94 (0.73-1.21)

Table 3a. CABG <u>Mortality</u> Model Performance for Models with All 18+ Patients and by Subgroups of Patients

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Model with*	N	Unadjusted Mortality Rate (%)	C statistic	SE	Lower C statistic	Upper C-statistic	Predictive ability[#], % (lowest decile – highest decile)
All 65+	8,460	2.5	0.84	0.02	0.81	0.87	0.4 - 14.2
FFS, 65+	4,673	2.6	0.83	0.02	0.79	0.88	0.4 - 15.6
Non-FFS, 65+	3,787	2.4	0.85	0.02	0.80	0.89	0.3 - 12.7
All 18-64	6,429	1.0	0.79	0.04	0.72	0.86	0.0 - 5.3
All 18+ (overall)	14,889	1.8	0.84	0.01	0.81	0.87	0.5 - 10.7

*Note that a single overall model for all 18+ is applied to the subgroups of patients.
#Mean observation mortality in the lowest and the highest decile of the predicted mortality.

Table 3b. CABG <u>Readmission</u> Model Performance for Models with All 18+ Patients and by Subgroups of Patients

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Model with*	N	Unadjusted Readmission Rate (%)	C statistic	SE	Lower C statistic	Upper C statistic	Predictive ability[#], % (lowest decile – highest decile)
All 65+	8,258	15.9	0.65	0.01	0.63	0.66	7.3 -30.3
FFS, 65+	4,552	15.8	0.64	0.01	0.62	0.66	7.7 - 27.0
Non-FFS, 65+	3,706	16.0	0.66	0.01	0.63	0.68	7.0 - 34.3
All 18-64	6,377	12.8	0.67	0.01	0.65	0.69	6.7 - 30.9
All 18+ (overall)	14,635	14.5	0.66	0.01	0.65	0.67	6.4 - 30.2

*Note that a single overall model for all 18+ is applied to the subgroups of patients.
#Mean observation readmission in the lowest and highest decile of the predicted readmission

Table 4a. Distribution of Pearson Chi-Square Residuals for CABG <u>Mortality</u> Model by Patient Subgroups

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

	All 18+ (TOTAL) N (%)	All 65+ N (%)	FFS 65+ N (%)	Non-FFS 65+ N (%)	All 18-64 N (%)
Residual < -2	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
-2 <= Residual < 0	14,619 (98.2)	8,252 (97.5)	4,554 (97.5)	3,698 (97.7)	6,367 (99.0)
0 <= Residual < 2	49 (0.3)	43 (0.5)	28 (0.6)	15 (0.4)	6 (0.1)
Residual >= 2	221 (1.5)	165 (2.0)	91 (2.0)	74 (2.0)	56 (0.9)

Table 4b. Distribution of Pearson Chi-Square Residuals for CABG <u>Readmission</u> Model by Patient Subgroups

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

	All 18+ (TOTAL) N (%)	All 65+ N (%)	FFS 65+ N (%)	Non-FFS 65+ N (%)	All 18-64 N (%)
Residual < -2	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
-2 <= Residual < 0	12,507 (85.5)	6,944 (84.1)	3,831 (84.2)	3,113 (84.0)	5,563 (87.2)
0 <= Residual < 2	718 (4.9)	505 (6.1)	270 (5.9)	235 (6.3)	213 (3.3)
Residual >= 2	1,410 (9.6)	809 (9.8)	451 (9.9)	358 (9.7)	601 (9.4)

Table 5a. Odds Ratios for Risk Factors in CABG <u>Mortality</u> Measure – Stratified Results for FFS Patients 65+, Non-FFS Patients 65+, All Patients 65+, and All Patients 18-64 Years of Age

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Risk Factor	OR (95% CI) for All 65+ (N=8,460, C statistic=0.84)	OR (95% CI) for FFS 65+ (N=4,673, C statistic=0.84)	OR (95% CI) for Non-FFS 65+ (N=3,787, C statistic= 0.86)	OR (95% CI) for All 18-64 (N=6,429, C statistic=0.82)
Demographics				
Age-65 (Continuous)	1.07 (1.04-1.09)	1.08 (1.04-1.11)	1.05 (1.01-1.09)	1.00 (0.96-1.05)
Male	0.71 (0.52-0.97)	0.87 (0.57-1.33)	0.54 (0.33-0.87)	0.60 (0.34-1.05)
Comorbidities				
Cardiogenic Shock (ICD-9 Code 785.51)	7.40 (5.07-10.80)	8.02 (4.85-13.28)	7.25 (4.01-13.12)	7.60 (3.93-14.69)
History of Prior CABG or Valve Surgery	1.96 (0.98-3.91)	0.43 (0.10-1.92)	5.50 (2.31-13.14)	0.56 (0.07-4.49)
Pneumonia (CC 111-113)	1.78 (1.24-2.55)	1.80 (1.12-2.89)	1.63 (0.93-2.87)	1.01 (0.47-2.18)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	0.56 (0.40-0.78)	0.64 (0.41-0.99)	0.47 (0.28-0.78)	0.70 (0.38-1.31)
Protein-Calorie Malnutrition (CC 21)	0.68 (0.33-1.38)	0.78 (0.32-1.86)	0.60 (0.17-2.18)	<0.001 (<0.001->999.999)
Renal Failure (CC 131)	3.35 (2.35-4.76)	3.36 (2.09-5.42)	3.37 (1.98-5.73)	3.21 (1.66-6.21)
COPD (CC 108)	1.48 (1.07-2.05)	1.79 (1.17-2.74)	1.29 (0.76-2.19)	0.54 (0.26-1.13)
End-Stage Renal Disease Or Dialysis (CC 130)	1.81 (0.93-3.51)	1.57 (0.67-3.70)	2.07 (0.69-6.22)	1.39 (0.51-3.78)
Liver and Biliary Disease (CC 25-30)	1.65 (0.95-2.86)	1.70 (0.84-3.46)	1.38 (0.55-3.47)	2.03 (0.89-4.65)
Congestive Heart Failure (CC 80)	1.29 (0.92-1.81)	1.26 (0.80-1.96)	1.40 (0.84-2.34)	1.14 (0.62-2.09)
Other Gastrointestinal Disorders (CC 36)	0.65 (0.45-0.93)	0.63 (0.39-1.01)	0.61 (0.34-1.09)	0.52 (0.25-1.08)
Unstable Angina And Other Acute Ischemic Heart Disease (CC 82)	0.99 (0.71-1.38)	0.93 (0.60-1.46)	1.05 (0.62-1.77)	0.78 (0.42-1.44)
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC 84)	1.24 (0.89-1.72)	1.37 (0.88-2.12)	1.09 (0.66-1.80)	2.05 (1.10-3.81)
Hypertension (CC 91)	1.32 (0.93-1.88)	1.55 (0.96-2.49)	1.08 (0.63-1.86)	1.17 (0.63-2.18)
Acute Myocardial Infarction (CC 81)	0.83 (0.54-1.26)	0.64 (0.35-1.19)	1.09 (0.60-2.00)	1.18 (0.60-2.33)
Angina Pectoris/Old Myocardial Infarction (CC 83)	1.10 (0.79-1.53)	1.07 (0.69-1.67)	1.10 (0.67-1.83)	1.06 (0.59-1.91)
Vascular or Circulatory Disease (CC 104-106)	1.49 (1.09-2.02)	1.48 (0.98-2.22)	1.56 (0.98-2.51)	2.18 (1.25-3.81)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	0.50 (0.19-1.34)	0.96 (0.30-3.04)	0.19 (0.02-1.47)	0.24 (0.03-1.94)
Cancer (CC 7-12)	0.73 (0.36-1.51)	1.18 (0.53-2.62)	0.21 (0.03-1.63)	1.75 (0.40-7.70)
Stroke (CC 95-96)	1.92 (1.03-3.57)	1.58 (0.69-3.64)	3.21 (1.21-8.50)	2.60 (0.91-7.43)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	1.43 (0.79-2.58)	1.35 (0.63-2.88)	1.23 (0.44-3.43)	0.91 (0.33-2.49)
Dementia or Senility (CC 49-50)	1.02 (0.47-2.23)	1.17 (0.46-2.98)	0.68 (0.15-3.24)	8.20 (2.44-27.59)

Table 5b. Odds Ratios for Risk Factors in CABG <u>Readmission</u> Measure – Stratified Results for FFS Patients 65+, Non-FFS Patients 65+, All Patients 65+, and All Patients 18-64 Years of Age

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Risk Factor	OR (95% CI) for All 65+ (N=8,258, C statistic=0.65)	OR (95% CI) for FFS 65+ (N=4,552, C statistic=0.65)	OR (95% CI) for Non-FFS 65+ (N=3,706, C statistic=0.67)	OR (95% CI) for All 18-64 (N= 6,377, C statistic=0.67)
Demographics				
Age-65 (Continuous)	1.03 (1.02-1.04)	1.03 (1.01-1.04)	1.03 (1.01-1.05)	1.00 (0.98-1.01)
Male	0.72 (0.64-0.82)	0.73 (0.61-0.87)	0.71 (0.59-0.87)	0.64 (0.54-0.76)
Comorbidities				
History of Prior CABG or Valve Surgery	0.68 (0.43-1.07)	0.48 (0.24-0.94)	0.89 (0.47-1.68)	1.19 (0.71-2.01)
Cardiogenic Shock (ICD-9 Code 785.51)	1.25 (0.90-1.73)	1.49 (0.96-2.30)	1.08 (0.65-1.78)	1.30 (0.87-1.95)
COPD (CC 108)	1.26 (1.09-1.46)	1.34 (1.10-1.63)	1.21 (0.96-1.52)	1.34 (1.11-1.62)
Renal Failure (CC 131)	1.37 (1.17-1.59)	1.48 (1.20-1.82)	1.26 (1.00-1.58)	1.45 (1.16-1.81)
Diabetes and DM Complications (CC 15-20, 119, 120)	1.38 (1.21-1.57)	1.35 (1.14-1.61)	1.43 (1.18-1.73)	1.65 (1.40-1.95)
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	0.96 (0.82-1.11)	0.97 (0.79-1.18)	0.97 (0.77-1.23)	1.03 (0.84-1.26)
Congestive Heart Failure (CC 80)	1.33 (1.15-1.53)	1.16 (0.96-1.42)	1.55 (1.27-1.91)	1.35 (1.12-1.62)
Arrhythmias (CC 92-93)	1.17 (1.04-1.33)	1.22 (1.03-1.44)	1.14 (0.94-1.37)	1.23 (1.04-1.46)
Other Lung Disorders (CC 115)	0.92 (0.77-1.09)	0.87 (0.69-1.10)	0.96 (0.74-1.24)	1.03 (0.83-1.28)
Major Psychiatric Disorders (CC 54-56)	1.28 (0.82-1.99)	1.24 (0.70-2.20)	1.38 (0.68-2.83)	1.77 (1.12-2.80)
Vascular or Circulatory Disease (CC 104-106)	1.04 (0.91-1.20)	1.05 (0.87-1.26)	1.06 (0.86-1.30)	1.15 (0.94-1.39)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	1.20 (1.03-1.38)	1.03 (0.85-1.26)	1.44 (1.16-1.80)	1.14 (0.94-1.39)
Pneumonia (CC 111-113)	1.20 (0.99-1.46)	0.96 (0.73-1.26)	1.54 (1.16-2.05)	1.18 (0.89-1.55)
Cerebrovascular Disease (CC 97-99, 103)	1.20 (0.99-1.45)	1.33 (1.03-1.70)	1.07 (0.80-1.44)	1.00 (0.72-1.38)
Polyneuropathy (CC 71)	0.94 (0.72-1.24)	0.90 (0.61-1.31)	0.99 (0.66-1.48)	1.53 (1.16-2.01)
Protein-Calorie Malnutrition (CC 21)	1.22 (0.85-1.77)	1.48 (0.92-2.38)	0.98 (0.54-1.79)	0.90 (0.48-1.72)
Severe Hematological Disorders (CC 44)	1.50 (0.57- 3.94)	2.84 (0.98-8.23)	<0.001 (<0.001->999.999)	2.95 (0.88-9.95)
Fibrosis Of Lung And Other Chronic Lung Disorders (CC 109)	1.22 (0.79-1.88)	1.08 (0.60-1.96)	1.60 (0.85-3.02)	2.03 (1.08-3.82)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	1.21 (0.79-1.84)	1.45 (0.80-2.64)	0.94 (0.51-1.74)	1.38 (0.88-2.16)
End-Stage Renal Disease Or Dialysis (CC 130)	1.34 (0.91-1.99)	1.39 (0.85-2.29)	1.41 (0.74-2.71)	0.97 (0.66-1.45)
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102)	1.37 (1.03-1.82)	1.10 (0.75-1.60)	1.80 (1.16-2.81)	1.38 (0.99-1.92)
Stroke (CC 95-96)	1.03 (0.71-1.49)	1.24 (0.78-1.97)	0.84 (0.45-1.55)	1.16 (0.70-1.93)
Dementia or Senility (CC 49-50)	1.66 (1.17-2.36)	1.48 (0.92-2.38)	1.98 (1.18-3.32)	0.79 (0.35-1.78)
Cancer (CC 7-12)	0.90 (0.68-1.21)	1.25 (0.88-1.77)	0.55 (0.32-0.93)	1.15 (0.68-1.93)

Table 6a. CABG Mortality Model with Interaction Terms – Logistic Regression Model (N=14,889, C Statistic=0.85)

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Description	Estimate	Standard Error	Wald Chi-Square	P value	OR	LOR	UOR
Demographics							
Age-65 (Continuous)	0.05	0.01	21.75	0.00	1.05	1.03	1.08
Male	-0.51	0.29	3.13	0.08	0.60	0.34	1.06
Comorbidities							
Cardiogenic Shock (ICD-9 Code 785.51)	2.07	0.34	37.63	0.00	7.94	4.09	15.38
History of Prior CABG or Valve Surgery	-0.62	1.06	0.34	0.56	0.54	0.07	4.28
Pneumonia (CC 111-113)	0.01	0.39	0.00	0.98	1.01	0.47	2.18
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	-0.36	0.32	1.25	0.26	0.70	0.38	1.31
Protein-Calorie Malnutrition (CC 21)	-13.11	364.90	0.00	0.97	0.00	0.00	999.99
Renal Failure (CC 131)	1.13	0.34	11.18	0.00	3.09	1.60	5.99
COPD (CC 108)	-0.66	0.38	3.01	0.08	0.52	0.25	1.09
End-Stage Renal Disease Or Dialysis (CC 130)	0.30	0.51	0.34	0.56	1.35	0.49	3.70
Liver and Biliary Disease (CC 25-30)	0.78	0.42	3.45	0.06	2.19	0.96	4.99
Congestive Heart Failure (CC 80)	0.12	0.31	0.16	0.69	1.13	0.62	2.08
Other Gastrointestinal Disorders (CC 36)	-0.69	0.37	3.40	0.07	0.50	0.24	1.04
Unstable Angina And Other Acute Ischemic Heart Disease (CC 82)	-0.26	0.31	0.68	0.41	0.77	0.42	1.43
Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC 84)	0.76	0.32	5.78	0.02	2.14	1.15	3.98
Hypertension (CC 91)	0.13	0.32	0.17	0.68	1.14	0.61	2.13
Acute Myocardial Infarction (CC 81)	0.17	0.35	0.23	0.63	1.18	0.60	2.35
Angina Pectoris/Old Myocardial Infarction (CC 83)	0.06	0.30	0.05	0.83	1.07	0.59	1.91
Vascular or Circulatory Disease (CC 104-106)	0.73	0.28	6.68	0.01	2.08	1.19	3.63
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	-1.45	1.07	1.82	0.18	0.24	0.03	1.92
Cancer (CC 7-12)	0.52	0.76	0.46	0.50	1.68	0.38	7.43
Stroke (CC 95-96)	0.90	0.54	2.80	0.09	2.45	0.86	7.00
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	-0.11	0.51	0.04	0.84	0.90	0.33	2.45
Dementia or Senility (CC 49-50)	2.01	0.62	10.54	0.00	7.45	2.22	25.02
Age interaction							

Description	Estimate	Standard Error	Wald Chi-Square	P value	OR	LOR	UOR
Variables with interaction term							
Demographics							
Older (Age >=65)	-0.19	0.58	0.11	0.74	0.82	0.26	2.58
Older and Male	0.16	0.33	0.23	0.63	1.17	0.61	2.25
Comorbidities							
Older and Cardiogenic Shock (ICD-9 Code 785.51)	-0.06	0.39	0.03	0.87	0.94	0.44	2.01
Older and History of Prior CABG or Valve Surgery	1.28	1.11	1.31	0.25	3.58	0.40	31.84
Older and Pneumonia (CC 111-113)	0.57	0.43	1.70	0.19	1.76	0.75	4.13
Older and Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	-0.24	0.36	0.45	0.50	0.79	0.39	1.59
Older and Protein-Calorie Malnutrition (CC 21)	12.73	364.90	0.00	0.97	339,286.20	0.00	.
Older and Renal Failure (CC 131)	0.09	0.38	0.05	0.82	1.09	0.52	2.31
Older and COPD (CC 108)	1.04	0.41	6.31	0.01	2.83	1.26	6.37
Older and End-Stage Renal Disease Or Dialysis (CC 130)	0.25	0.62	0.16	0.69	1.28	0.38	4.27
Older and Liver and Biliary Disease (CC 25-30)	-0.31	0.51	0.37	0.54	0.74	0.27	1.98
Older and Congestive Heart Failure (CC 80)	0.14	0.35	0.16	0.69	1.15	0.57	2.30
Older and Other Gastrointestinal Disorders (CC 36)	0.26	0.42	0.40	0.53	1.30	0.58	2.94
Older and Unstable Angina And Other Acute Ischemic Heart Disease (CC 82)	0.25	0.36	0.49	0.49	1.28	0.64	2.59
Older and Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease (CC 84)	-0.54	0.36	2.28	0.13	0.58	0.29	1.17
Older and Hypertension (CC 91)	0.14	0.37	0.15	0.70	1.15	0.56	2.36
Older and Acute Myocardial Infarction (CC 81)	-0.36	0.41	0.77	0.38	0.70	0.31	1.56
Older and Angina Pectoris/Old Myocardial Infarction (CC 83)	0.03	0.34	0.01	0.94	1.03	0.52	2.01
Older and Vascular or Circulatory Disease (CC 104-106)	-0.34	0.32	1.09	0.30	0.71	0.38	1.35
Older and Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	0.73	1.18	0.38	0.54	2.07	0.20	21.05
Older and Cancer (CC 7-12)	-0.82	0.84	0.95	0.33	0.44	0.08	2.30
Older and Stroke (CC 95-96)	-0.25	0.62	0.16	0.69	0.78	0.23	2.65
Older and Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102, 177-178)	0.44	0.59	0.55	0.46	1.56	0.49	4.99
Older and Dementia or Senility (CC 49-50)	-1.97	0.74	7.14	0.01	0.14	0.03	0.59

Table 6b. CABG Readmission Model with Interaction Terms – Logistic Regression Model (N=14,635, C statistic= 0.66)

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Description	Estimate	Standard Error	Wald Chi-Square	P value	OR	LOR	UOR
Demographics							
Age-65 (Continuous)	0.01	0.00	11.66	0.00	1.01	1.01	1.02
Male	-0.44	0.09	25.48	0.00	0.64	0.54	0.76
Comorbidities							
History of Prior CABG or Valve Surgery	0.16	0.27	0.37	0.55	1.18	0.70	1.99
Cardiogenic Shock (ICD-9 Code 785.51)	0.28	0.21	1.79	0.18	1.32	0.88	1.97
COPD (CC 108)	0.27	0.10	7.93	0.00	1.31	1.09	1.59
Renal Failure (CC 131)	0.36	0.11	10.21	0.00	1.44	1.15	1.79
Diabetes and DM Complications (CC 15-20, 119, 120)	0.50	0.08	35.17	0.00	1.65	1.40	1.95
Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	0.02	0.10	0.04	0.85	1.02	0.83	1.25
Congestive Heart Failure (CC 80)	0.30	0.09	10.34	0.00	1.35	1.13	1.63
Arrhythmias (CC 92-93)	0.19	0.09	4.69	0.03	1.20	1.02	1.42
Other Lung Disorders (CC 115)	0.03	0.11	0.06	0.81	1.03	0.83	1.28
Major Psychiatric Disorders (CC 54-56)	0.59	0.23	6.38	0.01	1.80	1.14	2.84
Vascular or Circulatory Disease (CC 104-106)	0.12	0.10	1.59	0.21	1.13	0.93	1.37
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	0.14	0.10	1.92	0.17	1.15	0.94	1.40
Pneumonia (CC 111-113)	0.17	0.14	1.44	0.23	1.19	0.90	1.56
Cerebrovascular Disease (CC 97-99, 103)	-0.04	0.17	0.05	0.82	0.96	0.69	1.34
Polyneuropathy (CC 71)	0.43	0.14	9.39	0.00	1.53	1.17	2.02
Protein-Calorie Malnutrition (CC 21)	-0.11	0.33	0.10	0.75	0.90	0.47	1.71
Severe Hematological Disorders (CC 44)	1.09	0.62	3.08	0.08	2.96	0.88	9.97
Fibrosis Of Lung And Other Chronic Lung Disorders (CC 109)	0.73	0.32	5.17	0.02	2.08	1.11	3.92
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	0.33	0.23	2.05	0.15	1.39	0.89	2.17
End-Stage Renal Disease Or Dialysis (CC 130)	-0.02	0.20	0.01	0.94	0.98	0.66	1.46
Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102)	0.31	0.17	3.38	0.07	1.37	0.98	1.91
Stroke (CC 95-96)	0.15	0.26	0.32	0.57	1.16	0.70	1.93
Dementia or Senility (CC 49-50)	-0.29	0.42	0.48	0.49	0.75	0.33	1.70
Cancer (CC 7-12)	0.12	0.27	0.20	0.65	1.13	0.67	1.90
Age interaction							
Variables with interaction term							

Description	Estimate	Standard Error	Wald Chi-Square	P value	OR	LOR	UOR
Demographics							
Older (Age >=65)	0.07	0.18	0.17	0.68	1.08	0.76	1.53
Older and Male	0.11	0.11	0.94	0.33	1.11	0.90	1.38
Comorbidities	-0.56	0.36	2.47	0.12	0.57	0.28	1.15
Older and History of Prior CABG or Valve Surgery	-0.05	0.12	0.17	0.68	0.95	0.75	1.21
Older and Cardiogenic Shock (ICD-9 Code 785.51)	-0.04	0.14	0.08	0.77	0.96	0.73	1.26
Older and COPD (CC 108)	-0.07	0.13	0.33	0.57	0.93	0.72	1.20
Older and Renal Failure (CC 131)	-0.01	0.12	0.01	0.92	0.99	0.78	1.25
Older and Diabetes and DM Complications (CC 15-20, 119, 120)	-0.01	0.11	0.00	0.96	0.99	0.81	1.22
Older and Obesity/Disorders of Thyroid, Cholesterol, Lipids (CC 24)	-0.11	0.14	0.65	0.42	0.89	0.67	1.18
Older and Congestive Heart Failure (CC 80)	-0.05	0.27	0.03	0.86	0.95	0.57	1.60
Older and Arrhythmias (CC 92-93)	-0.36	0.32	1.21	0.27	0.70	0.37	1.32
Older and Other Lung Disorders (CC 115)	-0.08	0.12	0.42	0.52	0.93	0.73	1.17
Older and Major Psychiatric Disorders (CC 54-56)	0.04	0.13	0.12	0.73	1.04	0.82	1.34
Older and Vascular or Circulatory Disease (CC 104-106)	0.02	0.17	0.01	0.91	1.02	0.73	1.43
Older and Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	0.23	0.19	1.36	0.24	1.25	0.86	1.83
Older and Pneumonia (CC 111-113)	-0.49	0.20	6.25	0.01	0.61	0.41	0.90
Older and Cerebrovascular Disease (CC 97-99, 103)	0.32	0.38	0.70	0.40	1.37	0.65	2.89
Older and Polyneuropathy (CC 71)	-0.67	0.79	0.72	0.40	0.51	0.11	2.41
Older and Protein-Calorie Malnutrition (CC 21)	-0.53	0.39	1.84	0.18	0.59	0.27	1.27
Older and Severe Hematological Disorders (CC 44)	-0.16	0.31	0.25	0.62	0.85	0.46	1.58
Older and Fibrosis Of Lung And Other Chronic Lung Disorders (CC 109)	0.28	0.28	1.00	0.32	1.33	0.76	2.32
Older and Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	-0.01	0.22	0.00	0.98	0.99	0.64	1.54
Older and End-Stage Renal Disease Or Dialysis (CC 130)	-0.12	0.32	0.15	0.70	0.88	0.47	1.66
Older and Hemiplegia, Paraplegia, Paralysis, Functional Disability (CC 67-69, 100-102)	0.82	0.45	3.29	0.07	2.28	0.94	5.55
Older and Stroke (CC 95-96)	-0.21	0.30	0.49	0.48	0.81	0.44	1.47
Older and Dementia or Senility (CC 49-50)	0.07	0.18	0.17	0.68	1.08	0.76	1.53
Older and Cancer (CC 7-12)	0.11	0.11	0.94	0.33	1.11	0.90	1.38

Table 7a. CABG <u>Mortality</u> Model Performance for Models with Interaction Terms by Patient Subgroups

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Model with	N	C statistic	SE	Lower C statistic	Upper C statistic	Predictive Ability*
All 65+	8,460	0.84	0.015	0.81	0.87	0.4 - 14.3
FFS, 65+	4,673	0.84	0.02	0.80	0.88	0.4 - 15.4
Non-FFS, 65+	3,787	0.85	0.02	0.80	0.89	0.3 - 12.9
All 18-64	6,429	0.81	0.03	0.75	0.87	0.0 - 5.3
All 18+	14,889	0.85	0.01	0.82	0.87	0.1 - 10.7

*Mean observation readmission in the lowest and the highest decile of the predicted mortality.

Table 7b. CABG <u>Readmission</u> Model Performance for Models with Interaction Terms by Patient Subgroups

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Model with	N	C statistic	SE	Lower C statistic	Upper C statistic	Predictive Ability*
All 65+	8,258	0.65	0.01	0.64	0.67	7.2 - 30.4
FFS, 65+	4,552	0.64	0.01	0.62	0.67	7.0 - 27.9
Non-FFS, 65+	3,706	0.66	0.01	0.64	0.68	6.7 - 35.7
All 18-64	6,377	0.67	0.01	0.65	0.69	6.3 - 31.1
All 18+	14,635	0.66	0.01	0.65	0.68	6.0 - 31.2

*Mean observation readmission in the lowest and the highest decile of the predicted readmission.

Table 8a. Reclassification Table of Risk Categories for CABG <u>Mortality</u> Model *With* and *Without* Interaction Terms

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Model With Interaction	Model Without Interaction				
	Risk Category				
Risk Category	≤15%	15% to <20%	20% to <25%	≥25%	Total
Among All 18+ Patients (overall agreement = 99.2%)					
0 to <15%	14,605	24	1	3	**14,633**
15% to <20%	38	37	12	9	**87**
20% to <25%	3	15	21	9	**48**
>=25%	2	4	7	108	**121**
Total	**14,648**	**80**	**41**	**120**	**14,889**
In All 65+ Patients (overall agreement = 99.1%)					
0 to <15%	8,233	17	0	0	**8,250**
15% to <20%	25	33	9	0	**67**
20% to <25%	0	12	18	9	**39**
>=25%	0	1	5	98	**104**
Total	**8,258**	**63**	**32**	**107**	**8,460**
In FFS 65+ Patients (overall agreement = 98.9%)					
0 to <15%	4,535	12	0	0	**4,547**
15% to <20%	18	18	5	0	**41**
20% to <25%	0	8	7	3	**18**
>=25%	0	1	3	63	**67**
Total	**4,553**	**39**	**15**	**66**	**4,673**
In Non-FFS 65+ Patients (overall agreement = 99.3%)					
0 to <15%	3,698	5	0	0	**3,703**
15% to <20%	7	15	4	0	**26**
20% to <25%	0	4	11	6	**21**
>=25%	0	0	2	35	**37**
Total	**3,705**	**24**	**17**	**41**	**3,787**
In All 18-64 Patients (overall agreement = 99.4%)					
0 to <15%	6,372	7	1	3	**6,383**
15% to <20%	13	4	3	0	**20**
20% to <25%	3	3	3	0	**9**
>=25%	2	3	2	10	**17**
Total	**6,390**	**17**	**9**	**13**	**6,429**

Table 8b. Reclassification Table of Risk Categories for CABG <u>Readmission</u> Model *With* and *Without* Interaction Terms

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

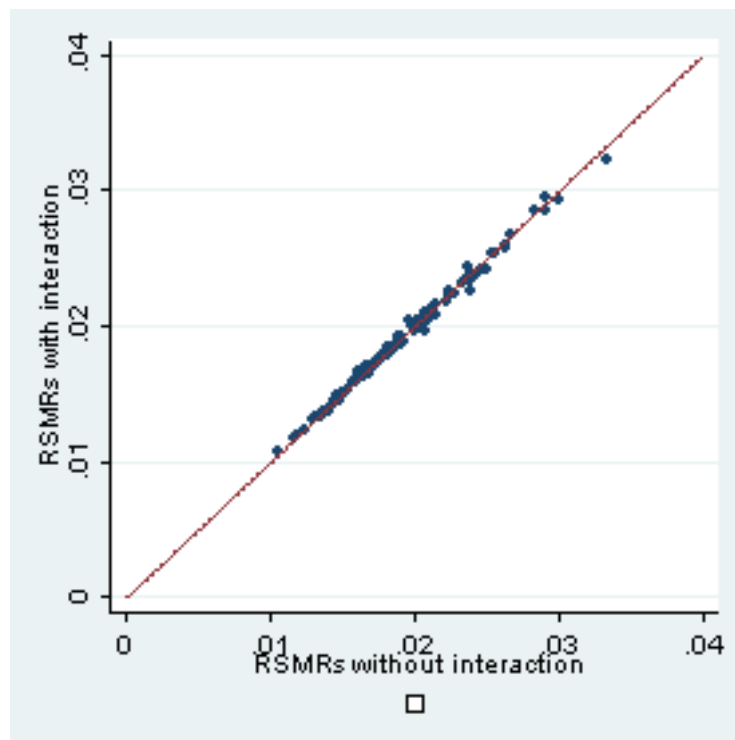| Model With Interaction	Model Without Interaction				
	Risk Category				
Risk Category	≤15%	15% to <20%	20% to <25%	≥25%	Total
Among All 18+ Patients (overall agreement = 88.5%)					
0 to <15%	9,165	312	9	1	**9,487**
15% to <20%	415	1,823	244	21	**2,503**
20% to <25%	14	262	790	192	**1,258**
>=25%	0	15	196	1,176	**1,387**
Total	**9,594**	**2412**	**1,239**	**1,390**	**14,635**
In All 65+ Patients (overall agreement = 88.6%)					
0 to <15%	4,505	229	3	0	**4,737**
15% to <20%	179	1,358	207	17	**1,761**
20% to <25%	0	84	607	167	**858**
>=25%	0	0	56	846	**902**
Total	**4,684**	**1,671**	**873**	**1,030**	**8,258**
In FFS 65+ Patients (overall agreement = 89.0%)					
0 to <15%	2,446	117	1	0	**2,564**
15% to <20%	100	769	109	10	**988**
20% to <25%	0	44	342	88	**474**
>=25%	0	0	31	495	**526**
Total	**2,546**	**930**	**483**	**593**	**4,552**
In Non-FFS 65+ Patients (overall agreement = 88.1%)					
0 to <15%	2,059	112	2	0	**2,173**
15% to <20%	79	589	98	7	**773**
20% to <25%	0	40	265	79	**384**
>=25%	0	0	25	351	**376**
Total	**2,138**	**741**	**390**	**437**	**3,706**
In All 18-64 Patients (overall agreement = 85.3%)					
0 to <15%	4,460	83	6	1	**4,750**
15% to <20%	236	465	37	4	**742**
20% to <25%	14	178	183	25	**400**
>=25%	0	15	140	330	**485**
Total	**4,910**	**741**	**366**	**360**	**6,377**

Table 9a. CABG Mortality Model Performance for Models *With* and *Without* Interaction Terms (N = 14,889)

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

CABG Mortality Model	C statistic	SE	Lower C statistic	Upper C statistic
With interaction terms	0.85	0.013	0.821	0.873
Without interaction terms	0.84	0.014	0.813	0.867

Figure 1a. Scatterplot of CABG Risk-Standardized Mortality Rates (RSMRs) from Models *With* and *Without* Interaction Terms

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Intra-class Correlation Coefficient (ICC): 0.998

Note: 1) RSMRs are presented as proportions.
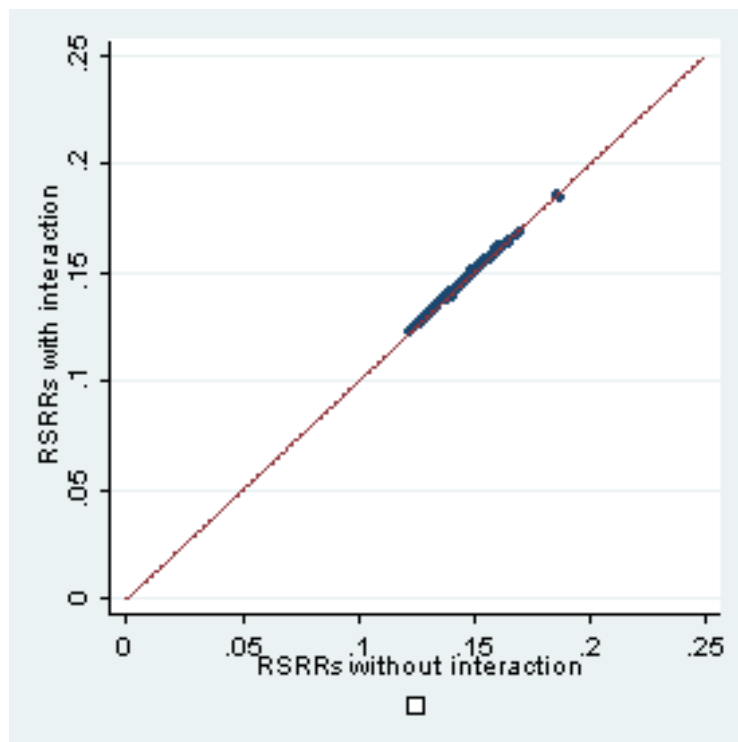2) Diagonal line represents the line of equality.

Table 9b. CABG <u>Readmission</u> Model Performance for Models *With* and *Without* Interaction Terms (N =14,635)

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

CABG Readmission Model	C statistic	SE	Lower C statistic	Upper C statistic
With interaction terms	0.66	0.006	0.650	0.675
Without interaction terms	0.66	0.006	0.648	0.673

Figure 1b. Scatterplot of CABG Risk-Standardized <u>Readmission</u> Rates (RSRRs) from Models *With* and *Without* Interaction Terms

Data Source: 2006 California Patient Discharge Data for All-payer Patients 18+ Admitted to California Hospitals

Intra-class Correlation Coefficient (ICC): 0.998

Note: 1) RSRRs are presented as proportions.
         2) Diagonal line represents the line of equality.