Hospital-level 30-day Readmission Following Admission for an Acute Exacerbation of Chronic Obstructive Pulmonary Disease

Measure Methodology Report

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

Laura M. Grosso, PhD, MPH
Peter Lindenauer, MD, MSc
Changqin Wang, MD, MS
Shantal Savage, BA
Jaymie Potteiger, MPH
Zameer Abedin, BA
Lori L. Geary, MPH
Yun Wang, PhD
Elizabeth E. Drye, MD, SM
Harlan M. Krumholz, MD, SM

Contract Number: HHSM-500-2008-0025I/HHSM-500-T0001, Modification No. 000005

Prepared For:

Centers for Medicare & Medicaid Services (CMS)

Submitted September 29th, 2011

ACKNOWLEDGEMENTS

We would like to acknowledge the ongoing support from our working group. These individuals gave generously of their time, providing guidance on key clinical and methodological decisions. Working group members include:

David Au, MD, MS
Investigator, VA Puget Sound Healthcare System, Northwest HSR&D Center of Excellence
Associate Professor of Medicine, Department of Medicine, University of Washington

Jerry Krishnan, MD, PhD
Associate Professor, Departments of Medicine and Health Studies, University of Chicago
Director, Asthma Center and Refractory Obstructive Lung Disorders Clinic, University of Chicago

Todd Lee, PharmD, PhD
Associate Professor, Departments of Pharmacy Practice and Pharmacy Administration, University of Illinois at Chicago
Senior Investigator, Center for Management of Complex Chronic Care (CMC3), Hines VA Hospital

Richard Mularski, MD, MCR, MSHS
Clinical Investigator, Center for Health Research, Kaiser Permanente
Clinical Assistant Professor of Medicine, Oregon Health & Science University

We would also like to thank the Technical Expert Panel members, who provided important insight and feedback on key measure decisions. These members include:

Darlene Bainbridge, MS, NHA, CPHQ, CPHRM
President/CEO, Darlene D. Bainbridge & Associates, Inc.

Robert A. Balk, MD
Director of Pulmonary and Critical Care Medicine, Rush University Medical Center

Dale Bratzler, DO, MPH
President and CEO, Oklahoma Foundation for Medical Quality

Scott Cerreta, RRT
Director of Education, COPD Foundation

Gerard J. Criner, MD
Director of Temple Lung Center and Divisions of Pulmonary and Critical Care Medicine, Temple University
Guy D'Andrea, MBA
President, Discern Consulting

Jonathan Fine, MD
Director of Pulmonary Fellowship, Research and Medical Education, Norwalk Hospital

David Hopkins, MS, PhD
Senior Advisor, Pacific Business Group on Health

Fred Martin Jacobs, MD, JD, FACP, FCCP, FCLM
Executive Vice President and Director, Saint Barnabas Quality Institute

Natalie Napolitano, MPH, RRT-NPS
Respiratory Therapist, Inova Fairfax Hospital

Russell Robbins, MD, MBA
Principal and Senior Clinical Consultant, Mercer

In addition, we would like to acknowledge and thank Angela Merrill, Sandi Nelson, Marian Wrobel, and Eric Schone from Mathematica Policy Research, Inc.; Sharon-Lise Normand from Harvard Medical School; and Lein Han, Joel Andress, and Michael Rapp at the Centers for Medicare & Medicaid Services for their contributions to this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Overview of Measure

Chronic obstructive pulmonary disease (COPD) is a priority area for outcomes measure development because it is a common, debilitating condition associated with considerable morbidity and mortality. In 2008, 12.1 million U.S. adults were estimated to have COPD resulting in approximately 672,000 hospital discharges.[1] It is currently the fourth leading cause of death in the US.[2]

COPD is also a leading cause of readmissions to the hospital.[3] The 30-day readmission rate among patients hospitalized for COPD is 22.6%, accounting for 4% of all 30-day readmissions.[3] In 2007, the Medicare Payment Advisory Committee (MedPAC) published a report to Congress in which it identified the seven conditions associated with the most costly potentially preventable readmissions. Among these seven, COPD ranked fourth.[4]

The Agency for Healthcare Research and Quality (AHRQ) has identified COPD as an ambulatory-care-sensitive condition (ACSC). ACSCs are conditions for which good outpatient care can potentially prevent the need for hospitalization or for which early intervention can prevent complications or more severe disease.[5] Although COPD is an ACSC, readmission rates are also influenced by inpatient care.

To better assess hospital care and care transitions for COPD patients, the Centers for Medicare and Medicaid Services (CMS) has contracted with Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation (YNHHSC/CORE) to develop a hospital-level readmission measure for patients hospitalized with an acute exacerbation of COPD. In this technical report we describe the development of a hospital-level 30-day readmission measure after hospitalization for an acute exacerbation of COPD. We have also developed a complementary 30-day mortality measure. The methodology and results of the mortality measure are detailed in a separate technical report.

The overall methodological approach for developing this measure is consistent with that used to develop three prior CMS readmission measures endorsed by the National Quality Forum (NQF) for acute myocardial infarction (AMI), heart failure (HF), and pneumonia, which are now publicly reported by CMS on Hospital Compare. The YNHHSC/CORE team developed the measure using Medicare claims and enrollment data. To account for the clustering of observations within hospitals and differences in the number of patient admissions across hospitals, we estimated risk-standardized readmission rates (RSRRs) with hierarchical logistic regression models.

1.2 COPD Readmission as a Measure of Quality

Hospital readmission is an important outcome for patients, as it is disruptive to patients and caregivers, costly to the healthcare system, and puts patients at additional risk of hospital-acquired infections and complications. Research has shown that readmission rates are influenced by the quality of inpatient and outpatient care, as well as hospital system characteristics, such as the bed capacity of the local healthcare system.[6] In addition, specific hospital processes such as discharge planning,[7] medication reconciliation, and coordination of outpatient care have been shown to affect readmission rates.[8]

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.

Measurement of patient outcomes allows for a more comprehensive view of quality of care, encompassing more than that captured by individual process-of-care measures. Complex and critical aspects of care, such as communication between providers, prevention of and response to complications, patient safety, and coordinated transitions to the outpatient environment, all contribute to patient outcomes but are difficult to measure by individual processes.[9,10] Clinical trials and observational studies suggest that several aspects of care provided to patients hospitalized for exacerbations of COPD can have significant effects on readmission, thus supporting the essential construct of readmission as an appropriate outcome to measure quality.[11-14]

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 readmission measure was developed to identify hospitals whose performance is better or worse than would be expected based on their patient case-mix, and therefore promote hospital quality improvement and to better inform consumers about care quality.

Measuring and reporting readmission rates will inform healthcare providers about opportunities to improve care, strengthen incentives for quality improvement, and ultimately improve the quality of care received by Medicare patients.

Improvements in care transitions for this condition are likely to reduce costly readmissions.

1.3 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 NQF guidance for outcomes measures,[15] CMS' Measure Management System guidance, and the guidance articulated in the American Heart Association scientific statement, "Standards for Statistical Models Used for Public Reporting of Health Outcomes."[16] 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).

The working group was comprised of three physicians who are board-certified in pulmonary and critical care medicine and a pharmacoepidemiologist with expertise in COPD. 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' Measure Management System, we convened a TEP, a group of recognized experts and stakeholders in relevant fields, to provide input and feedback during measure development. To assemble the TEP, we released a public call for nominations and selected individuals with diverse perspectives and backgrounds, including clinicians, consumers, hospitals, purchasers, and experts in quality improvement. 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 consisting of presentation of key issues, relevant data, and our proposed approach. This presentation was followed by open discussion of these issues with TEP members.

Finally, we publicly posted the measure specifications and a summary of the TEP discussions and made a widely distributed call for public comments. We collected these comments through the Measure Management System Web site (https://www.cms.gov/MMS/17_CallforPublicComment.asp). We summarized the public comments for CMS and posted the verbatim comments on a freely accessible Web site. We took the comments we received into consideration during the final stages of measure development.

2. METHODS

2.1 Overview

We developed a hospital-level readmission measure for patients admitted with an acute exacerbation of COPD 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 fee-for-service (FFS) Medicare beneficiaries hospitalized in calendar year 2008 with an acute exacerbation of COPD. 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 used hierarchical logistic regression modeling to adjust for differences in patient case-mix and hospital volume, and to account for the clustering of patients within a hospital. 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.

2.2 Data Sources

Part A inpatient data - 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 (ICD-9 codes), procedures (ICD-9 procedure codes), Diagnosis Related Groups (DRGs), dates of service, hospital provider, and beneficiary demographic information.

Part A outpatient data - 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 - contains final action claims for the 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) - contains Medicare beneficiary demographic, benefit/coverage, and vital status information.

2.3 Outcome Definition

The outcome for this measure is 30-day all-cause readmission. We define a readmission as a subsequent acute care hospital inpatient admission within 30 days of the discharge date for the index admission.

2.3.1 30-Day Timeframe

A 30-day timeframe is clinically sensible, and is a meaningful timeframe for hospitals because readmissions are more likely attributable to care received within the index hospitalization and during the transition to the outpatient setting. For example, hospitals, in collaboration with their medical communities, take actions to reduce readmission, such as: ensure patients are clinically ready at discharge; reduce risk of infection; reconcile medications; improve communications among providers involved in transition of care; encourage strategies that promote disease management principles; and educate patients about symptoms to monitor, whom to contact with questions, and where and when to seek follow-up care. Furthermore, this outcome period is consistent with other NQF-endorsed publicly reported readmission measures (AMI, heart failure, and pneumonia).

2.3.2 All-Cause Readmission

We used all-cause readmission, rather than readmission for acute exacerbations of COPD, for several reasons. First, from the patient perspective, readmission for any reason is likely to be an undesirable outcome of care after an acute hospitalization. Second, readmissions not directly related to the COPD exacerbation may still be a result of the care received during the index hospitalization. For example, a patient hospitalized for COPD who develops a hospital-acquired infection may ultimately be readmitted for sepsis. It would be inappropriate to treat this readmission as unrelated to the care the patient received during the index hospitalization. Another patient might experience a hospitalization-related complication following the index COPD admission, which may go untreated and result in renal failure. The resulting readmission for renal failure could have been prevented with higher quality of care during the admission for COPD that could have reduced the risk for the complication. Furthermore, the range of potentially avoidable readmissions also includes those not directly related to the initial hospitalization, such as those resulting from poor communication at discharge or inadequate follow-up. [7] As such, creating a comprehensive list of potential complications related

to COPD hospitalizations would be arbitrary and, ultimately, impossible to implement. Using all-cause readmission, on the other hand, will undoubtedly include a mix of unavoidable and avoidable readmissions. Thus, the goal of this measure is not to reduce readmissions to zero, but to instead assess hospital performance relative to what is expected given the performance of other hospitals with similar case mixes.

2.4 Cohort Definition

COPD is a group of lung diseases characterized by airway obstruction. Patients hospitalized for an acute exacerbation of COPD (AECOPD) present with varying degrees of severity ranging from a worsening of baseline symptoms (dyspnea, cough, and/or sputum) to respiratory failure. To capture the full spectrum of severity of patients hospitalized for an AECOPD, we included patients with a principal diagnosis of COPD, as well as those with a principal diagnosis of respiratory failure who had a secondary diagnosis of an AECOPD. Requiring AECOPD as a secondary code helps to identify respiratory failure due to COPD exacerbation versus another condition (e.g., heart failure).

Table 1. Final COPD Measure Cohort

ICD-9 Code	Description
491.21	Obstructive chronic bronchitis; With (acute) exacerbation; acute exacerbation of COPD, decompensated COPD, decompensated COPD with exacerbation.
491.22	Obstructive chronic bronchitis; with acute bronchitis
491.8	Other chronic bronchitis. Chronic: tracheitis, tracheobronchitis.
491.9	Unspecified chronic bronchitis
492.8	Other emphysema; emphysema (lung or pulmonary): NOS, centriacinar, centrilobular, obstructive, panacinar, panlobular, unilateral, vesicular. MacLeod's syndrome; Swyer-James syndrome; unilateral hyperlucent lung
493.20	Chronic obstructive asthma; asthma with COPD, chronic asthmatic bronchitis, unspecified
493.21	Chronic obstructive asthma; asthma with COPD, chronic asthmatic bronchitis, with status asthmaticus
493.22	Chronic obstructive asthma; asthma with COPD, chronic asthmatic bronchitis, with (acute) exacerbation
496	Chronic: nonspecific lung disease, obstructive lung disease, obstructive pulmonary disease (COPD) NOS. NOTE: This code is not to be used with any code from categories 491-493.
518.81*	Other diseases of lung; acute respiratory failure; respiratory failure NOS
518.82*	Other diseases of lung; acute respiratory failure; other pulmonary insufficiency, acute respiratory distress
518.84*	Other diseases of lung; acute respiratory failure; acute and chronic respiratory failure
799.1*	Other ill-defined and unknown causes of morbidity and mortality; respiratory arrest, cardiorespiratory failure
**Principal diagnosis when combined with a secondary diagnosis of AECOPD (491.21, 491.22, 493.21, or 493.22)*	

2.5 Inclusion/Exclusion Criteria

We used all admissions in 2008 Part A inpatient data to identify the cohort for inclusion in the measure. Admissions eligible for inclusion in the measure are those for patients aged 65 or older admitted to acute care hospitals with AECOPD. The flow chart depicting eligible admissions is presented in Figure 2. An index admission is any eligible admission to an acute care hospital assessed in the measure for the outcome (readmitted or not within 30 days). Eligible index admissions are identified using the ICD-9 codes listed in Table 1.

Patients may have more than one admission during an acute episode of care for AECOPD (see Figure 1 below). For example, a patient may be admitted to hospital A and then transferred to hospital B. The initial admission to hospital A and the admission to hospital B are considered one 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.

We excluded the following admissions from the measure:

- Admissions for patients without continuous enrollment in Medicare FFS for one year prior to the date of the index admission
  Rationale: This ensures full data availability for risk adjustment.
- Admissions for patients transferred to another acute care facility
  Rationale: We assign the outcome for the acute episode of care to the hospital that discharges the patient to the non-acute care setting because the discharging hospital initiates the discharge and the transition to the outpatient setting (see Figure 1 D below). Therefore, the last admission in the acute care setting for the episode of care is eligible to be an index admission in the measure (Hospital B). Prior admissions within a single episode of care are excluded from the measure.

- Admissions for patients without at least 30 days post-discharge enrollment in Medicare FFS
  Rationale: The 30-day readmission outcome cannot be assessed for the standardized time period.

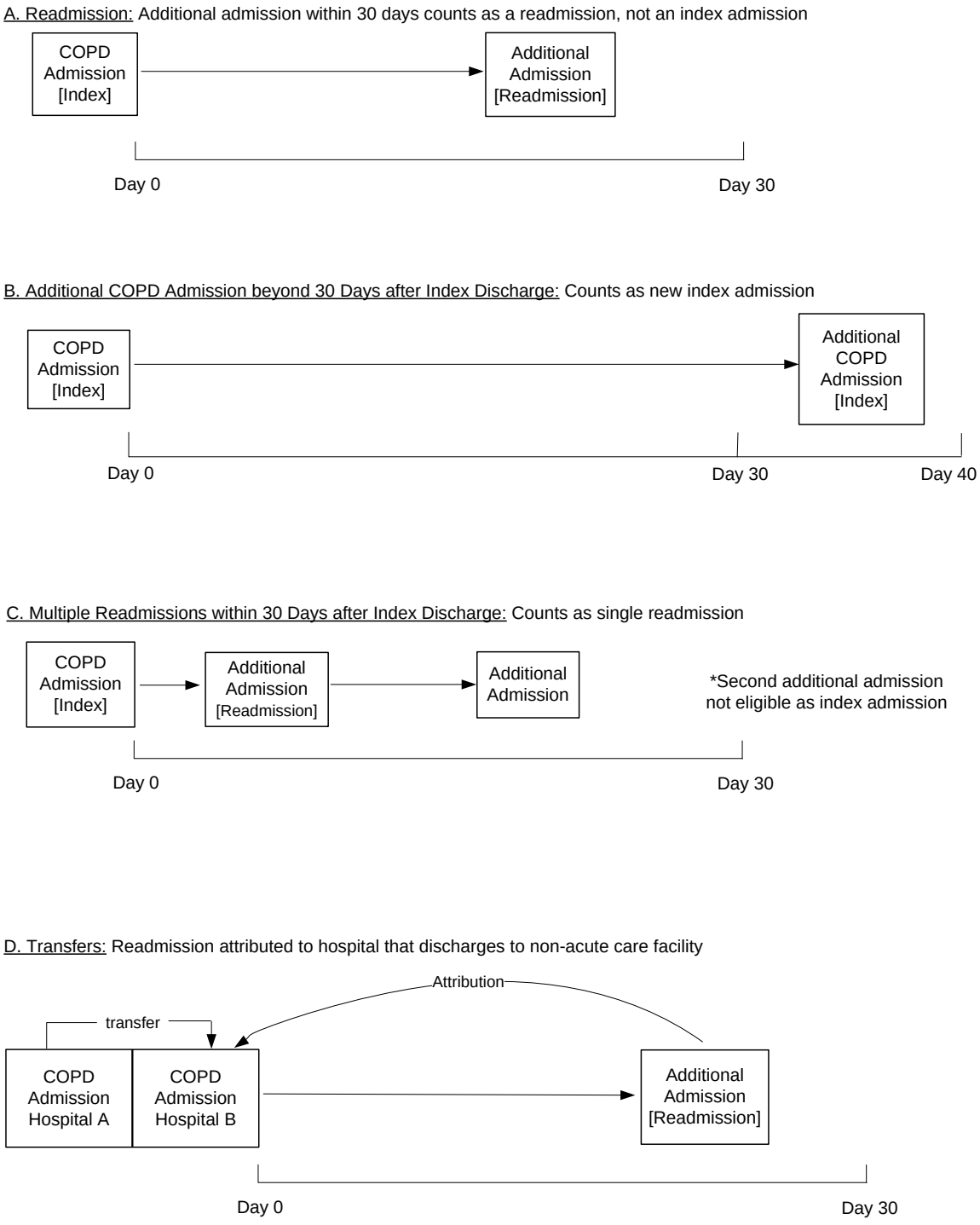
- Admissions for patients who die during the index admission
  Rationale: Patients who die during the initial hospitalization are not eligible for readmission.

- Admissions for patients who leave the hospital against medical advice (AMA).
  Rationale: Hospitals and physicians do not have the opportunity to provide the highest quality care for these patients.

  Additionally, admissions that occur within 30 days of the discharge date of an earlier index admission are not themselves considered to be index admissions. They are considered readmissions. Any COPD admission is either an index admission or a readmission, but not both.

Figure 1 below indicates how the readmission outcome is attributed for several scenarios following a COPD admission. Importantly, no hospitalization is counted as both a readmission and index admission. If a patient has one or more than one admissions within 30 days of discharge from the index admission, the outcome is considered the same – readmitted within 30 days.

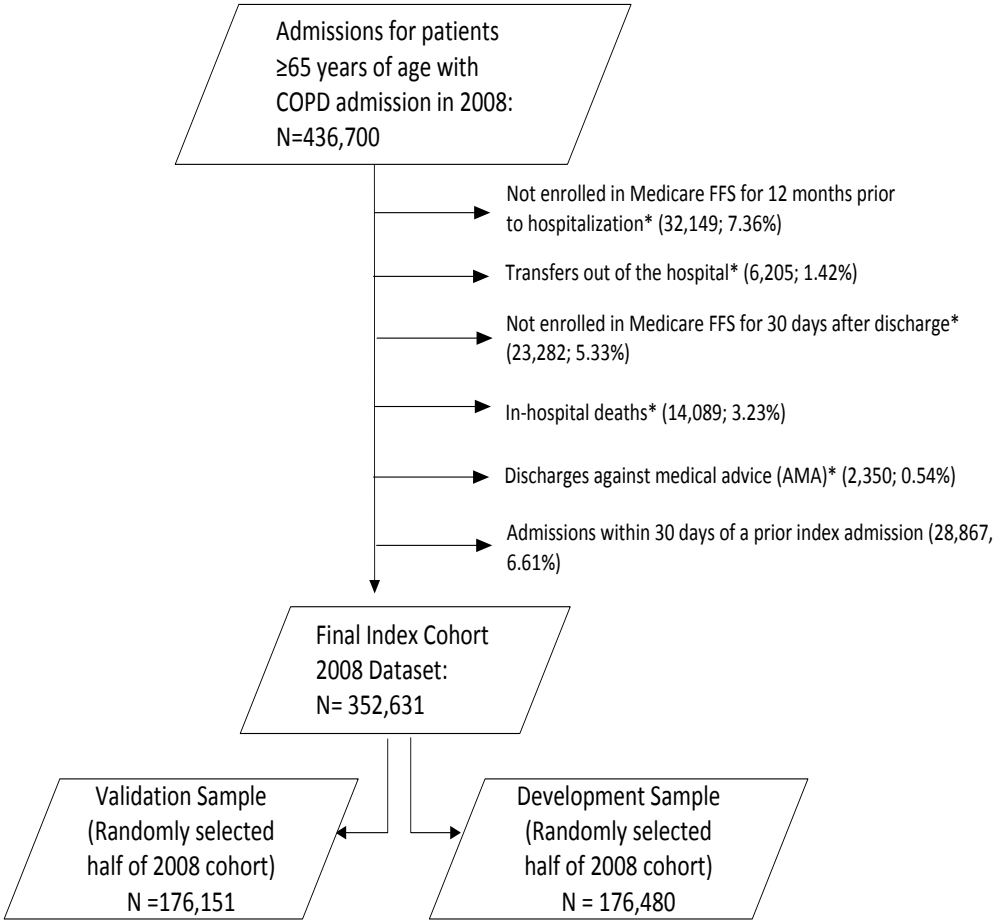
Figure 1. Attribution of Readmission Outcome



2.6 Model Development and Validation Samples

To create the model development and validation samples, we applied the inclusion and exclusion criteria to all 2008 admissions. We randomly selected half of all COPD admissions in 2008 that met the inclusion and exclusions criteria to create a model development sample and used the remaining admissions as our model validation sample.

Figure 2. Model Development and Validation Samples



*Categories are not mutually exclusive

2.7 Approach to Risk Adjustment

The goal of risk adjustment is to account for patient demographic and clinical characteristics in order to illuminate important differences in care quality. 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 readmission, 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 A 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.

The model does not adjust for socioeconomic status (SES), race, ethnicity, or sex. Variation in quality associated with these characteristics may be indicative of disparities in the quality of the care provided to vulnerable populations, and adjusting for these factors in a model 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. This approach is consistent with NQF guidelines (http://www.qualityforum.org/docs/measure_evaluation_criteria.aspx).

2.8 Candidate and Final Risk-adjustment Variables

Our goal was to develop a parsimonious model that included clinically relevant variables that are associated with risk of readmission. 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' Hierarchical Condition Categories. The Hierarchical Condition Category (HCC) system groups the ICD-9-CM codes into larger groups that are used in models to predict medical care utilization, spending mortality or other related measures. CCs are clinically relevant diagnostic groups of the more than 15,000 ICD-9 codes.[17] We used the ICD-9 to CC assignment map, which is maintained by CMS and posted at www.qualitynet.org.

To select candidate variables, a team of clinicians reviewed all 189 CCs and excluded those that were not relevant to the Medicare population (Appendix B) or that were not clinically relevant to the readmission outcome (e.g., attention deficit disorder, female infertility). 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, history of mechanical ventilation, and sleep apnea (Table 2).

Table 2. Candidate Model Variables for Risk Adjustment

Category	Variable	CC
Demographics	Age	
Cardiovascular/ Respiratory	History of Mechanical Ventilation	ICD-9 procedure codes: 93.90, 96.70, 96.71, 96.72
	Sleep Apnea	ICD-9 diagnosis codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57
	Respirator Dependence/Respiratory Arrest	CC 77-78
	Cardio-Respiratory Failure and Shock	CC 79
	Congestive Heart Failure	CC 80
	Acute Coronary Syndrome	CC 81-82
	Chronic Atherosclerosis	CC 83-84
	Valvular and Rheumatic Heart Disease	CC 86
	Arrhythmias	CC 92-93
	Other and Unspecified Heart Disease	CC 94
	Vascular or Circulatory Disease	CC 104-106
	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
Comorbidities	History of Infection	CC 1, 3-6
	Septicemia/Shock	CC 2
	Metastatic Cancer and Acute Leukemia	CC 7
	Lung, Upper Digestive Tract, and Other Severe Cancers	CC 8
	Lymphatic, Head and Neck, Brain, and Other Major Cancers; Breast, Colorectal and other Cancers and Tumors; Other Respiratory and Heart Neoplasms	CC 9-11
	Other Digestive and Urinary Neoplasms	CC 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
	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

Category	Variable	CC
	Iron Deficiency and Other/Unspecified Anemia and Blood Disease	CC 47
	Delirium and Encephalopathy	CC 48
	Dementia or Senility	CC 49-50
	Drug/Alcohol Induced Dependence/Psychosis	CC 51-52
	Drug/Alcohol Abuse, without Dependence	CC 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
	Heart Infection/Inflammation, Except Rheumatic	CC 85
	Hypertensive Heart and Renal Disease or Encephalopathy	CC 89
	Hypertension	CC 90-91
	Stroke	CC 95-96
	Cerebrovascular Disease	CC 97-99, 103
	Retinal Disorders, except Detachment and Vascular Retinopathies	CC 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	CC 132
	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
	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 were summarized to show the percentage of times that each of the candidate variables was significantly associated with readmission ($p<0.001$) 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 the majority of risk adjustment variables above a 90% cutoff, because they demonstrated a relatively strong and stable association with risk for readmission and were clinically relevant. Additionally, specific variables with particular clinical relevance to the risk of readmission were forced into the model (regardless of % selection) to ensure appropriate risk-adjustment for COPD. These included:

Clinical variables associated with COPD:

- history of mechanical ventilation (ICD-9 procedure codes: 93.90, 96.70, 96.71, 96.72)
- history of sleep apnea (ICD-9 diagnosis codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57)

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 3.

Table 3. Final Model Variables

Category	Variable	CC
Demographics	Age	
Cardiovascular/ Respiratory	History of Mechanical Ventilation	ICD-9 procedure codes: 93.90, 96.70, 96.71, 96.72
	Sleep Apnea	ICD-9 diagnosis codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57
	Respirator Dependence/Respiratory Failure	CC 77-78
	Cardio-Respiratory Failure and Shock	CC 79
	Congestive Heart Failure	CC 80
	Acute Coronary Syndrome	CC 81-82
	Chronic Atherosclerosis	CC 83-84
	Arrhythmias	CC 92-93
	Other and Unspecified Heart Disease	CC 94
	Vascular or Circulatory Disease	CC 104-106
	Fibrosis of Lung and Other Chronic Lung Disorder	CC 109
	Pneumonia	CC 111-113
Comorbidities	History of Infection	CC 1, 3-6
	Metastatic Cancer and Acute Leukemia	CC 7
	Lung, Upper Digestive Tract, and Other Severe Cancers	CC 8
	Lymphatic, Head and Neck, Brain, and Other Major Cancers; Breast, Colorectal and other Cancers and Tumors; Other Respiratory and Heart Neoplasms	CC 9-11
	Other Digestive and Urinary Neoplasms	CC 12
	Diabetes and DM Complications	CC 15-20, 119-120
	Protein-Calorie Malnutrition	CC 21
	Disorders of Fluid/Electrolyte/Acid-Base	CC 22-23
	Other Endocrine/Metabolic/Nutritional Disorders	CC 24
	Pancreatic Disease	CC 32
	Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders	CC 34
	Other Gastrointestinal Disorders	CC 36
	Severe Hematological Disorders	CC 44
	Iron Deficiency and Other/Unspecified Anemia and Blood Disease	CC 47
	Dementia or Senility	CC 49-50
	Drug/Alcohol Induced Dependence/Psychosis	CC 51-52
	Major Psychiatric Disorders	CC 54-56
	Depression	CC 58
	Anxiety Disorders	CC 59
	Other Psychiatric Disorders	CC 60
	Quadripelgia, Paraplegia, Paralysis, Functional Disability	CC 67-69, 100-102, 177-178
	Polyneuropathy	CC 71
	Hypertensive Heart and Renal Disease or Encephalopathy	CC 89
	Stroke	CC 95-96
	Renal Failure	CC 131
	Decubitus Ulcer or Chronic Skin Ulcer	CC 148-149
	Cellulitis, Local Skin Infection	CC 152
	Vertebral Fractures	CC 157

2.9 Statistical Approach to Model Development

We used a randomly selected split sample of 2008 admissions for model development and candidate variable selection. We used the remaining half of COPD admissions in 2008 to validate the model. We then selected all qualifying COPD admissions in 2007 and 2009 data to assess model reliability across years of data.

Due to the natural clustering of observations within hospitals, we used hierarchical logistic regression models to model the log-odds of readmission. Readmission was modeled as a function of patient-level 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 healthcare facilities being evaluated lead to systematic differences in outcomes.

We then calculated hospital risk-standardized readmission rates (RSRRs) using a hierarchical logistic regression model. These rates were calculated as the ratio of the predicted number of readmissions to the expected number of readmissions, multiplied by the national unadjusted readmission rate. The expected number of readmissions for each hospital was estimated using that hospital's patient mix and the average intercept. Specifically, for each patient in the dataset, the estimated regression coefficients were multiplied by the observed characteristics and the average of the hospital-specific intercepts is added to this quantity. Then, the quantity was transformed to the probability scale. For each patient within a hospital, these probabilities were summed. The predicted number of readmissions in each hospital employed a similar calculation. The predicted number of readmissions for each hospital was calculated by summing the predicted readmission rates for all patients in the hospital. The predicted readmission rate for each patient is calculated through the hierarchical model by applying the estimated regression coefficients to the patient characteristics observed and adding the hospital-specific intercept. In order to assess hospital performance in any specific year (e.g., the validation cohort), we estimated the model coefficients using that year's data.

More specifically, we estimated a logistic regression and a hierarchical logistic regression model which accounts for the clustering of observations within hospitals. The logistic regression model links the outcome to the patient-level risk factors.[18] Let Y_{ij} denote the outcome (equal to 1 if patient is readmitted, zero otherwise) for the j^{th} patient who had a COPD admission at the i^{th} hospital; $\mathbf{Z}_{ij}$ denotes a set of risk factors based on the data. Let I denote the total number of hospitals and n_i the number of index patient stays in hospital i. We assume the outcome is related linearly to the covariates via a known linked function, h, where

Logistic regression model: $$h(Y_{ij}) = \alpha + \beta\mathbf{Z}_{ij} \quad (1)$$

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 then estimated a hierarchical logistic regression model that links the risk factors to the same outcome and a hospital-specific random effect,

Hierarchical logistic regression model: $h(Y_{ij}) = \alpha_i + \beta \mathbf{Z}_{ij}$ (2)

$\alpha_i = \mu + \omega_i; \quad \omega_i \sim N(0, \tau^2)$ (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.[19] 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, respectively).

We first fit the logistic regression model described in Equation (1) using the logit link. Having identified the covariates that were selected, 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.

2.10 Hospital Performance Reporting

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, $\hat{\mu}$, $\{\hat{\alpha}_1, \hat{\alpha}_2, ..., \hat{\alpha}_I\}$, $\hat{\beta}$, and $\hat{\tau}^2$. We calculate a standardized outcome, s_i, for each hospital by computing the ratio of the number of predicted readmissions to the number of expected readmissions, multiplied by the unadjusted overall readmission rate, $\bar{y}$. Specifically, we calculate

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

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

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

If more (fewer) "predicted" cases than "expected" cases have the outcome in a hospital, then $\hat{s}_i$ will be higher (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).

2.10.1 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. The bootstrapping simulation has the advantage of avoiding unnecessary distributional assumptions.

2.10.2 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, $\{\hat{\alpha}_i^{(b)}, \hat{\text{var}}(\alpha_i^{(b)}); i = 1,2,...,I\}$.

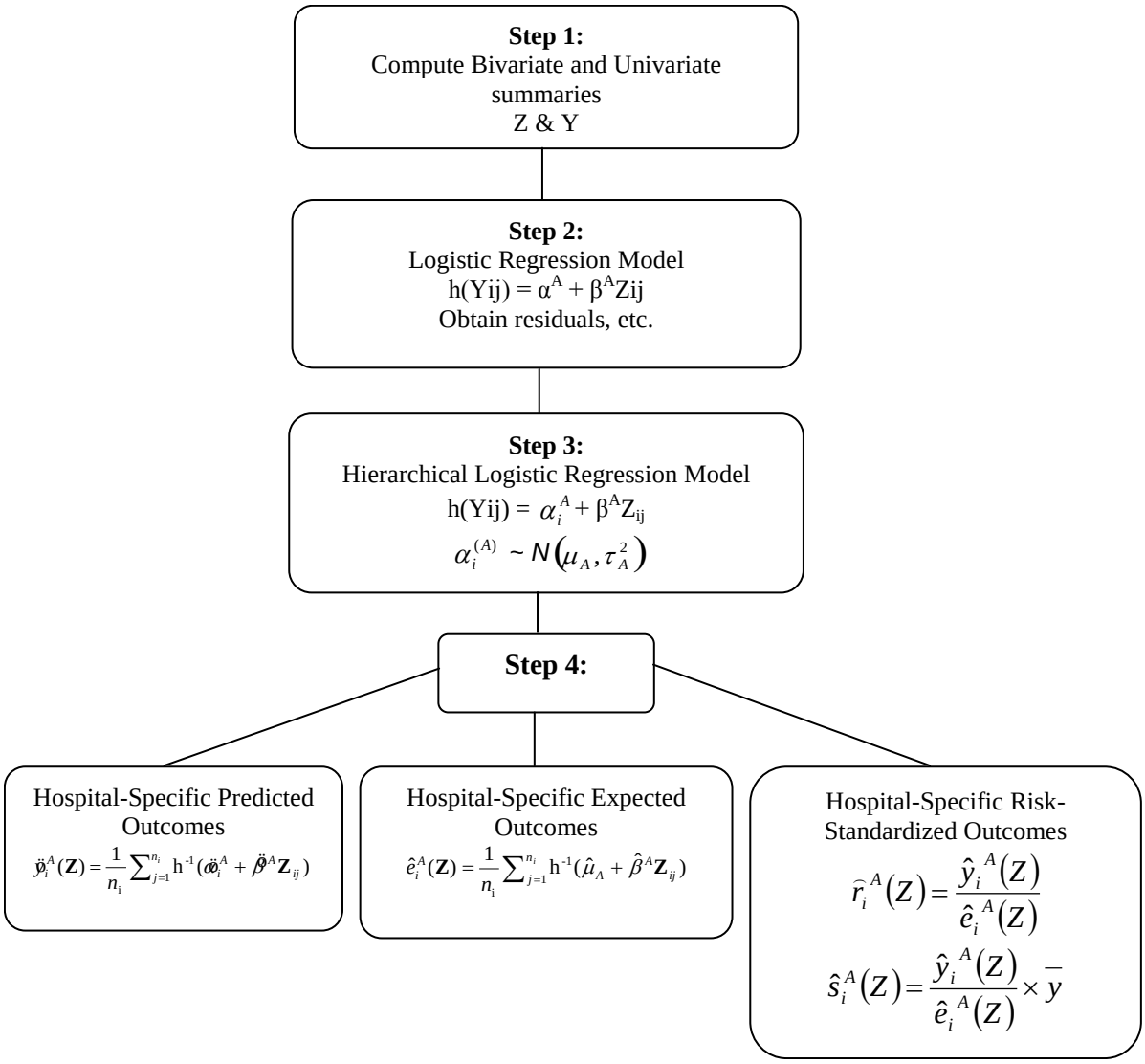
3. We generate a hospital random effect by sampling from the distribution of the hospital-specific distribution obtained in Step 2c. We approximate the distribution for each random effect by a normal distribution. Thus, we draw $\alpha_i^{(b*)} \sim N(\hat{\alpha}_i^{(b)}, \hat{\text{var}}(\hat{\alpha}_i^{(b)}))$ 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 2.5th and 97.5th percentiles of randomly half of the B estimates (or the

percentiles corresponding to the alternative desired intervals).[20] (See Figure 3 below for a diagram of the analysis steps).

Figure 3. Analysis Steps



3. RESULTS

3.1 Model Results

3.1.1 Development and Validation Models

The sample for model development included 176,480 admissions from 4,546 hospitals. The model validation sample included 176,151 admissions from 4,553 hospitals. Results tables are presented at the end of Section 3.

Table 4 conveys the risk factor frequencies, parameter estimates, standard errors, odds ratios (OR), and 95% confidence intervals for the model risk factors in the development and validation samples. Variable frequencies and odds ratios are similar in both samples.

3.1.2 Model Validation

We computed several summary statistics for assessing model performance which included:[21] over-fitting indices,[a] predictive ability, area under the (ROC) curve, distribution of residuals, and model chi-square.[b] Table 5 conveys model performance results for the development and validation samples. Model performance is similar in the development and validation samples with strong model discrimination and fit. Predictive ability is also similar in both samples. The C statistic (area under the receiver operator curve) is 0.63 when the model is applied to either the development or validation sample (Table 5).

---

[a] 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.

[b] 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)

3.1.3 Hierarchical Logistic Regression Model

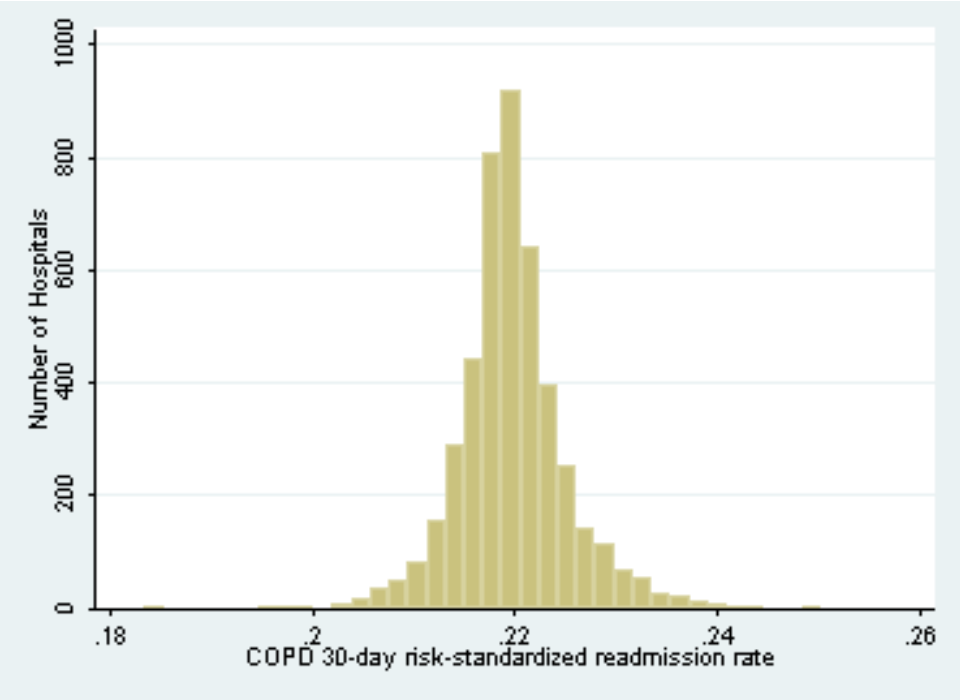
Table 6 conveys the adjusted odds ratios for the development and validation samples calculated via the hierarchical logistic regression model. The odds ratios are nearly identical to those calculated using the logistic regression model (Table 5).

3.1.4 Unadjusted and Adjusted Readmission Rates

The unadjusted mean hospital readmission rate is 21.84% and ranges from 0.00%-100%. The median unadjusted readmission rate is 21.84% (data not shown). Figure 4 displays the hospital risk-standardized rates for the development sample, calculated via the hierarchical logistic regression model. The rates are normally distributed with a mean of 22.00%, and range from 18.33% - 25.03%. The median risk- standardized rate is 21.96%.

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 4. Distribution of Hospital-Level Risk-Standardized Readmission Rates (2008 Development Sample; n=176,480 Admissions from 4,546 Hospitals)



3.2 Measure Testing

3.2.1 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 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 this standard. 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 date and discharge date.

In addition, CMS has in place several hospital auditing programs used to assess overall claims code accuracy, ensure appropriate billing, and for overpayment recoupment. 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.

The data elements we use are stable over time. We used data from 2007, 2008, and 2009 to assess the rates of the data elements over time: 302,560 admissions from 4,638 hospitals in 2007, 352, 631 admissions and 4,637 hospitals in 2008 and 332,184 admissions from 4,574 hospitals in 2009. Table 7 conveys the model risk factor frequencies in these samples. Overall, the rates of risk factor frequency changed very little across the three years. The percentage of patients with a history of pneumonia (CC111-113) increased from 47% in 2007 to 52% in 2009. The percentage of patients with a history of diabetes and diabetic complications (CC 15-20) increased from 38% in 2007 to 42% in 2009. The percentage of patients diagnosed with other endocrine/metabolic/nutritional disorders (CC 24) increased from 66% in 2007 to 72% in 2009. There were no other notable changes.

Table 8 shows the adjusted odds ratios for the logistic regression (patient-level) model variables and mortality in the 2007, 2008, and 2009 data samples. There are no notable differences in the odds ratios across the samples. The consistency in the rates of the risk adjustment variables and in their relationship to the outcome across the split year sample (development and validation) and the three years of data all demonstrate the reliability of the measure data elements.

3.2.2 Reliability of Model

To test the reliability of the model, we assessed model performance (Table 5) and the effect of the risk adjustment variables on the outcome across the years of data (Table 8). Model performance is similar across years with strong model discrimination and fit. Predictive ability is also similar in both samples. The C statistic (area under the receiver operator curve) is 0.63 in 2007 and 0.63 in 2009 for the model in 2009 data (Table 5). No notable differences were observed in risk factor ORs across the years of data.

3.2.3 Validity

CMS has validated the six NQF-endorsed measures currently used in public reporting (mortality and readmission measures for AMI, heart failure, and pneumonia). They validated the claims-based measures by building comparable models using medical record data for risk adjustment

for heart failure patients (National Heart Failure data), AMI patients (Cooperative Cardiovascular Project data), and pneumonia patients (National Pneumonia Project dataset). When the medical record-based models were applied to the corresponding patient population, the hospital risk-standardized rates estimated using the claims-based risk adjustment models had a high level of agreement with the results based on the medical record model, thus supporting the use of the claims-based models for public reporting.

YNHHSC/CORE has also conducted two national, multi-site validation studies for two procedure-based complications measures (primary elective hip/knee arthroplasty and implantable cardioverter defibrillator [ICD]). Both validation studies demonstrated strong agreement between complications coded in claims and those documented in the medical record. These validation efforts suggest that claims data variables are valid across a variety of conditions and therefore can be used reliably for developing new claims-based outcome measures.

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 readmission rates obtained from the readmission measure as specified will provide an accurate reflection of quality.”

Ten of 12 TEP members responded: 1- Strongly Disagreed, 2 Somewhat Agreed, 4- Moderately Agreed, and 3- Strongly Agreed. Of the TEP members who responded 90% agreed (70% moderately or strongly agreed) that the measure will provide an accurate reflection of quality.

4. MAIN FINDINGS / SUMMARY

This proposed 30-day all-cause readmission measure will inform healthcare providers about opportunities to improve care, and strengthen incentives for quality improvement, particularly for care at the time of transitions (e.g., discharge to home or a skilled nursing facility). Improvements in inpatient care and care transitions for this common, costly condition are likely to reduce costly readmissions. We found significant differences in risk-standardized readmission rates across hospitals suggesting that there are differences in quality of care. The proposed risk-standardized model is consistent with the consensus standards for publicly reported outcomes measures, and can be implemented using available data. This measure was developed with input from experts with clinical and methodological expertise relevant to pulmonary quality measurement. The study sample reflects the full spectrum of patients hospitalized for exacerbations of COPD, and will allow for valid comparisons of hospital quality across institutions. We excluded covariates that are not appropriate for inclusion in a quality measure, such as race, socioeconomic status, and hospital-level factors (e.g., hospital bed size and volume of COPD cases). The hierarchical modeling accounts for hospital case-mix, the clustering of patients within hospitals, and differences in sample size across hospitals, thereby making the measure suitable for public reporting.

Table 4. Adjusted OR* for Model Risk Factors and Readmission in Development and Validation Samples (Logistic Regression Model)

	Development Sample (176,480 admissions at 4,546 hospitals)					Validation Sample (176,151 admissions at 4,553 hospitals)				
Variable	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**
Demographics										
Age-65 (continuous)	-	-0.0009	0.0009	1.00	(1.00-1.00)	-	-0.002	0.0009	1.00	(1.00-1.00)
Cardiovascular/Respiratory										
Sleep Apnea (ICD-9 codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57)	10.46	-0.005	0.02	1.00	(0.96-1.03)	10.39	0.008	0.02	1.01	(0.97-1.05)
History of Mechanical Ventilation (ICD-9 codes: 93.90, 96.70, 96.71, 96.72)	7.33	0.12	0.02	1.13	(1.08-1.18)	7.27	0.11	0.02	1.12	(1.07-1.17)
Respirator Dependence/Respiratory Failure (CC 77-78)	1.38	0.12	0.05	1.12	(1.03-1.23)	1.35	0.09	0.05	1.09	(1.00-1.19)
Cardio-Respiratory Failure and Shock (CC 79)	29.84	0.19	0.01	1.21	(1.18-1.24)	29.80	0.18	0.01	1.20	(1.16-1.23)
Congestive Heart Failure (CC 80)	43.86	0.19	0.01	1.21	(1.18-1.24)	43.66	0.22	0.01	1.25	(1.21-1.28)
Chronic Atherosclerosis (CC 83-84)	51.57	0.10	0.01	1.11	(1.08-1.13)	51.57	0.09	0.01	1.09	(1.06-1.12)
Arrhythmias (CC 92-93)	38.48	0.13	0.01	1.14	(1.11-1.17)	38.40	0.15	0.01	1.16	(1.13-1.19)
Other and Unspecified Heart Disease (CC 94)	19.45	0.08	0.01	1.08	(1.05-1.11)	19.30	0.06	0.01	1.06	(1.03-1.09)
Vascular or Circulatory Disease (CC 104-106)	39.42	0.08	0.01	1.09	(1.06-1.11)	39.20	0.10	0.01	1.10	(1.07-1.13)
Fibrosis of Lung and Other Chronic Lung Disorder (CC 109)	18.12	0.09	0.02	1.09	(1.06-1.12)	18.22	0.09	0.02	1.09	(1.06-1.13)
Pneumonia (CC 111-113)	51.51	0.09	0.01	1.10	(1.07-1.13)	51.25	0.09	0.01	1.09	(1.06-1.12)
Other Comorbid Conditions										
History of Infection (CC 1, 3-6)	32.16	0.07	0.01	1.08	(1.05-1.11)	32.19	0.07	0.01	1.07	(1.04-1.10)
Metastatic Cancer and Acute Leukemia (CC 7)	2.64	0.21	0.04	1.24	(1.15-1.33)	2.54	0.16	0.04	1.17	(1.09-1.26)
Lung, Upper Digestive Tract, and Other Severe Cancers (CC 8)	5.91	0.17	0.03	1.19	(1.13-1.25)	5.95	0.16	0.03	1.17	(1.11-1.23)
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)	13.88	0.04	0.02	1.04	(1.01-1.08)	13.98	0.04	0.02	1.04	(1.01-1.08)
Other Digestive and Urinary Neoplasms(CC 12)	7.06	-0.04	0.02	0.96	(0.92-1.01)	7.05	-0.002	0.02	1.00	(0.95-1.04)
Diabetes and DM Complications (CC 15-20, 119-120)	39.15	0.08	0.01	1.08	(1.06-1.11)	39.38	0.06	0.01	1.06	(1.04-1.09)
Protein-calorie Malnutrition (CC 21)	7.57	0.13	0.02	1.14	(1.09-1.19)	7.44	0.15	0.02	1.16	(1.11-1.21)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	34.57	0.15	0.01	1.17	(1.14-1.20)	34.05	0.13	0.01	1.14	(1.11-1.17)
Other Endocrine/Metabolic/Nutritional Disorders (CC 24)	68.61	-0.09	0.01	0.91	(0.89-0.94)	68.68	-0.07	0.01	0.94	(0.91-0.96)
Pancreatic Disease (CC 32)	4.85	0.11	0.03	1.12	(1.06-1.17)	4.90	0.11	0.03	1.12	(1.07-1.18)
Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders (CC 34)	12.58	0.07	0.02	1.07	(1.03-1.11)	12.35	0.09	0.02	1.10	(1.06-1.14)
Other Gastrointestinal Disorders (CC 36)	58.29	0.04	0.01	1.04	(1.02-1.07)	58.34	0.09	0.01	1.09	(1.06-1.12)

	Development Sample (176,480 admissions at 4,546 hospitals)					Validation Sample (176,151 admissions at 4,553 hospitals)				
Variable	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**
Severe Hematological Disorders (CC 44)	2.07	0.11	0.04	1.12	(1.04-1.20)	2.08	0.16	0.04	1.17	(1.09-1.26)
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	42.09	0.12	0.01	1.13	(1.10-1.16)	42.08	0.12	0.01	1.13	(1.10-1.15)
Dementia and Senility (CC 49-50)	17.07	0.003	0.02	1.00	(0.97-1.04)	17.00	-0.02	0.02	0.98	(0.95-1.01)
Drug/Alcohol Induced Dependence/Psychosis (CC 51-52)	3.67	0.14	0.03	1.15	(1.09-1.22)	3.71	0.12	0.03	1.12	(1.06-1.19)
Major Psych Disorders (CC 54-56)	10.79	0.08	0.02	1.08	(1.04-1.12)	10.65	0.05	0.02	1.05	(1.01-1.09)
Depression (CC 58)	19.63	0.05	0.02	1.06	(1.03-1.09)	19.51	0.03	0.02	1.03	(1.00-1.07)
Anxiety Disorders (CC 59)	3.27	0.14	0.03	1.15	(1.08-1.22)	3.25	0.12	0.03	1.12	(1.06-1.19)
Other Psychiatric Disorders (CC 60)	18.37	0.11	0.02	1.11	(1.08-1.15)	18.35	0.14	0.02	1.15	(1.11-1.18)
Quadriplegia, paraplegia, functional disability (CC 67-69, 100-102, 177-178)	5.02	0.07	0.03	1.08	(1.02-1.13)	5.02	0.04	0.03	1.04	(0.99-1.10)
Polyneuropathy (CC 71)	7.91	0.10	0.02	1.10	(1.06-1.16)	7.96	0.09	0.02	1.10	(1.06-1.15)
Acute Coronary Syndrome (CC 81-82)	9.54	0.07	0.02	1.08	(1.04-1.12)	9.42	0.12	0.02	1.13	(1.08-1.17)
Hypertensive Heart and Renal Disease or Encephalopathy (CC 89)	13.20	0.12	0.02	1.13	(1.09-1.17)	12.88	0.11	0.02	1.11	(1.07-1.16)
Stroke (CC 95-96)	6.84	0.04	0.02	1.04	(1.00-1.09)	6.70	0.02	0.02	1.02	(0.97-1.07)
Renal Failure (CC 131)	18.61	0.09	0.02	1.10	(1.06-1.14)	18.33	0.10	0.02	1.10	(1.06-1.14)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	7.43	0.03	0.02	1.03	(0.99-1.08)	7.51	0.09	0.02	1.09	(1.05-1.14)
Cellulitis, Local Skin Infection (CC 152)	12.50	0.06	0.02	1.07	(1.03-1.11)	12.43	0.05	0.02	1.05	(1.02-1.09)
Vertebral Fractures (CC 157)	5.24	0.13	0.02	1.14	(1.08 -1.19)	5.36	0.19	0.02	1.21	(1.15-1.27)

Grey highlighting indicates variable forced into the model.

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

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

Table 5. Model Performance for Development and Validation Samples (Logistic Regression Model)

Indices	**Development Sample**	**Validation Samples**		
Year	**2008**	**2008**	**2007**	**2009**
Number of Discharges	176,480	176,151	302,560	332,184
Number of Hospitals	4,546	4,553	4,638	4,574
Mean Risk-Standardized Readmission Rate % (SD)	22.00 (0.72)	21.95 (1.06)	22.06 (1.31)	22.06 (1.31)
Calibration (γ0, γ1)[‡]	(-0.034, 0.970)	(0.0189, 1.0169)	(0.007, 0.996)	(-0.017, 1.003)
Discrimination -Predictive Ability (lowest decile %, highest decile %)	(11.57 - 38.08)	(11.73 - 39.19)	(11.67 - 38.10)	(11.53 - 38.23)
Discrimination – Area Under Receiver Operator Curve (C statistic)[§]	0.627	0.629	0.628	0.631
Residuals Lack of Fit (Pearson Residual Fall %)				
<-2	0.00	0.00	0.00	0.00
[-2, 0)	78.09	78.11	78.02	78.04
[0, 2)	14.17	14.02	14.22	14.24
[2+	7.80	7.86	7.75	7.71
Model Wald χ^2 [Number of Covariates] (p-value)	6144.77 [41] (<.0001)	6360.14 [41] (<.0001)	10602.64 [41] (<.0001)	12024.40 [41] (<.0001)
Between-Hospital Variance (τ) (Standard Error)	0.014 (0.003)	0.021 (0.003)	0.022 (0.002)	0.021 (0.002)

[‡] 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)) = $\gamma_0 + \gamma_1 Z$. Estimated values of γ_0 far from 0 and estimated values of γ_1 far from 1 provide evidence of over-fitting.

[§] Calculated using logistic regression model

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

	Development Sample (176,480 admissions at 4,546 hospitals)					Validation Sample (176,151 admissions at 4,553 hospitals)				
Variable	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**
Demographics										
Age-65 (continuous)	-	0.00	0.00	1.00	(1.00-1.00)	-	0.00	0.00	1.00	(1.00-1.00)
Cardiovascular/Respiratory										
Sleep Apnea (ICD-9 codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57)	10.46	0.00	0.02	1.00	(0.96-1.04)	10.39	0.01	0.02	1.01	(0.97-1.05)
History of Mechanical Ventilation (ICD-9 codes: 93.90, 96.70, 96.71, 96.72)	7.33	0.12	0.02	1.12	(1.08-1.18)	7.27	0.11	0.02	1.12	(1.07-1.17)
Respirator Dependence/Respiratory Failure (CC 77-78)	1.38	0.12	0.05	1.12	(1.03-1.23)	1.35	0.09	0.05	1.09	(1.00-1.20)
Cardio-Respiratory Failure and Shock (CC 79)	29.84	0.19	0.01	1.21	(1.18-1.25)	29.80	0.18	0.01	1.20	(1.17-1.23)
Congestive Heart Failure (CC 80)	43.86	0.19	0.01	1.21	(1.18-1.24)	43.66	0.22	0.01	1.25	(1.21-1.28)
Chronic Atherosclerosis (CC 83-84)	51.57	0.10	0.01	1.10	(1.08-1.13)	51.57	0.08	0.01	1.09	(1.06-1.12)
Arrhythmias (CC 92-93)	38.48	0.13	0.01	1.14	(1.11-1.17)	38.40	0.15	0.01	1.16	(1.13-1.19)
Other and Unspecified Heart Disease (CC 94)	19.45	0.08	0.01	1.08	(1.05-1.11)	19.30	0.06	0.01	1.06	(1.03-1.09)
Vascular or Circulatory Disease (CC 104-106)	39.42	0.08	0.01	1.09	(1.06-1.11)	39.20	0.10	0.01	1.10	(1.07-1.13)
Fibrosis of Lung and Other Chronic Lung Disorder (CC 109)	18.12	0.09	0.01	1.09	(1.06-1.12)	18.22	0.09	0.01	1.09	(1.06-1.13)
Pneumonia (CC 111-113)	51.51	0.09	0.01	1.10	(1.07-1.13)	51.25	0.09	0.01	1.09	(1.06-1.12)
Other Comorbid Conditions										
History of Infection (CC 1, 3-6)	32.16	0.07	0.01	1.08	(1.05-1.10)	32.19	0.06	0.01	1.07	(1.04-1.09)
Metastatic Cancer and Acute Leukemia (CC 7)	2.64	0.21	0.04	1.23	(1.15-1.33)	2.54	0.16	0.04	1.17	(1.09-1.26)
Lung, Upper Digestive Tract, and Other Severe Cancers (CC 8)	5.91	0.17	0.03	1.18	(1.13-1.25)	5.95	0.16	0.03	1.17	(1.11-1.23)
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)	13.88	0.04	0.02	1.04	(1.01-1.08)	13.98	0.04	0.02	1.04	(1.01-1.08)
Other Digestive and Urinary Neoplasms(CC 12)	7.06	-0.04	0.02	0.96	(0.92-1.01)	7.05	0.00	0.02	1.00	(0.95-1.04)
Diabetes and DM complications (CC 15-20, 119-120)	39.15	0.08	0.01	1.08	(1.06-1.11)	39.38	0.06	0.01	1.06	(1.03-1.09)
Protein-calorie Malnutrition (CC 21)	7.57	0.13	0.02	1.14	(1.09-1.19)	7.44	0.15	0.02	1.16	(1.11-1.21)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	34.57	0.15	0.01	1.17	(1.14-1.20)	34.05	0.13	0.01	1.14	(1.11-1.17)
Other Endocrine/Metabolic/Nutritional Disorders (CC 24)	68.61	-0.09	0.01	0.91	(0.89-0.94)	68.68	-0.07	0.01	0.93	(0.91-0.96)
Pancreatic Disease (CC 32)	4.85	0.11	0.03	1.12	(1.06-1.17)	4.90	0.12	0.03	1.12	(1.07-1.18)

	Development Sample (176,480 admissions at 4,546 hospitals)					Validation Sample (176,151 admissions at 4,553 hospitals)				
Variable	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**	**Frequency (%)**	**Estimate**	**SE**	**OR**	**95% CI**
Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders (CC 34)	12.58	0.06	0.02	1.07	(1.03-1.10)	12.35	0.09	0.02	1.10	(1.06-1.13)
Other Gastrointestinal Disorders (CC 36)	58.29	0.04	0.01	1.04	(1.02-1.07)	58.34	0.08	0.01	1.09	(1.06-1.12)
Severe Hematological Disorders (CC 44)	2.07	0.11	0.04	1.11	(1.03-1.20)	2.08	0.16	0.04	1.17	(1.09-1.26)
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	42.09	0.12	0.01	1.13	(1.10-1.16)	42.08	0.12	0.01	1.13	(1.10-1.15)
Dementia and Senility (CC 49-50)	17.07	0.00	0.02	1.00	(0.97-1.03)	17.00	-0.02	0.02	0.98	(0.95-1.01)
Drug/Alcohol Induced Dependence/Psychosis (CC 51-52)	3.67	0.14	0.03	1.15	(1.09-1.22)	3.71	0.12	0.03	1.13	(1.06-1.19)
Major Psych Disorders (CC 54-56)	10.79	0.08	0.02	1.08	(1.04-1.12)	10.65	0.04	0.02	1.04	(1.01-1.09)
Depression (CC 58)	19.63	0.05	0.02	1.06	(1.02-1.09)	19.51	0.03	0.02	1.03	(1.00-1.07)
Anxiety Disorders (CC 59)	3.27	0.13	0.03	1.14	(1.07-1.21)	3.25	0.11	0.03	1.12	(1.05-1.19)
Other Psychiatric Disorders (CC 60)	18.37	0.10	0.02	1.11	(1.08-1.14)	18.35	0.14	0.02	1.14	(1.11-1.18)
Quadriplegia, paraplegia, functional disability (CC 67-69, 100-102, 177-178)	5.02	0.07	0.03	1.07	(1.02-1.13)	5.02	0.04	0.03	1.04	(0.99-1.10)
Polyneuropathy (CC 71)	7.91	0.11	0.02	1.11	(1.07-1.16)	7.96	0.10	0.02	1.10	(1.06-1.15)
Acute Coronary Syndrome (CC 81-82)	9.54	0.07	0.02	1.07	(1.03-1.12)	9.42	0.11	0.02	1.12	(1.08-1.16)
Hypertensive Heart and Renal Disease or Encephalopathy (CC 89)	13.20	0.12	0.02	1.13	(1.09-1.17)	12.88	0.11	0.02	1.11	(1.07-1.16)
Stroke (CC 95-96)	6.84	0.04	0.02	1.04	(1.00-1.09)	6.70	0.02	0.02	1.02	(0.97-1.07)
Renal Failure (CC 131)	18.61	0.09	0.02	1.10	(1.06-1.14)	18.33	0.10	0.02	1.10	(1.06-1.14)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	7.43	0.03	0.02	1.03	(0.99-1.08)	7.51	0.09	0.02	1.09	(1.04-1.14)
Cellulitis, Local Skin Infection (CC 152)	12.50	0.06	0.02	1.07	(1.03-1.10)	12.43	0.05	0.02	1.05	(1.02-1.09)
Vertebral Fractures (CC 157)	5.24	0.13	0.02	1.14	(1.08 -1.19)	5.36	0.19	0.02	1.21	(1.16-1.27)

Grey highlighting indicates variable forced into the model.

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

Table 7. Risk Factor Frequency (%) in Data Years

Description	2007 n= 302,560	2008 n= 352,631	2009 n= 332,184
Demographics			
Age-65 (continuous)	-	-	-
Cardiovascular/Respiratory			
Sleep Apnea (ICD-9 codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57)	9.51	10.42	11.59
History of Mechanical Ventilation (ICD-9 codes: 93.90, 96.70, 96.71, 96.72)	7.12	7.30	8.09
Respirator Dependence/Respiratory Failure (CC 77-78)	1.53	1.37	1.36
Acute Coronary Syndrome (CC 81-82)	9.65	9.48	9.39
Cardio-Respiratory Failure and Shock (CC 79)	29.67	29.82	31.45
Congestive Heart Failure (CC 80)	44.84	43.76	44.62
Chronic Atherosclerosis (CC 83-84)	51.43	51.57	52.15
Arrhythmias (CC 92-93)	37.86	38.44	39.60
Other and Unspecified Heart Disease (CC 94)	19.64	19.38	19.47
Vascular or Circulatory Disease (CC 104-106)	38.61	39.31	40.59
Fibrosis of Lung and Other Chronic Lung Disorder (CC 109)	18.83	18.17	18.37
Pneumonia (CC 111-113)	46.84	51.38	51.84
Comorbidities			
History of Infection (CC 1, 3-6)	31.61	32.17	33.09
Metastatic Cancer and Acute Leukemia (CC 7)	2.63	2.59	2.64
Lung, Upper Digestive Tract, and Other Severe Cancers (CC 8)	5.84	5.93	6.17
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)	13.81	13.93	14.03
Other Digestive and Urinary Neoplasms(CC 12)	7.14	7.05	6.89
Diabetes and DM Complications (CC 15-20, 119-120)	38.21	39.26	41.55
Protein-calorie Malnutrition (CC 21)	6.73	7.50	8.38
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	34.59	34.31	35.91
Other Endocrine/Metabolic/Nutritional Disorders (CC 24)	65.72	68.64	71.45
Pancreatic Disease (CC 32)	5.21	4.88	2.67
Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders (CC 34)	12.92	12.46	12.48
Other Gastrointestinal Disorders (CC 36)	58.58	58.32	59.13
Severe Hematological Disorders (CC44)	1.76	2.08	2.21
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	40.68	42.09	44.34
Dementia and Senility (CC 49-50)	16.38	17.03	17.28
Drug/Alcohol Induced Dependence/Psychosis (CC 51-52)	3.72	3.69	3.83
Major Psych Disorders (CC 54-56)	10.33	10.72	11.13
Depression (CC 58)	19.62	19.57	20.48
Anxiety Disorders (CC 59)	3.18	3.26	3.59
Other Psychiatric Disorders (CC 60)	18.57	18.36	19.14
Quadriplegia, Paraplegia, Functional Disability (CC 67-69, 100-102, 177-178)	4.73	5.02	5.33
Polyneuropathy (CC 71)	7.41	7.93	8.55
Hypertensive Heart and Renal Disease or Encephalopathy (CC 89)	9.48	13.04	14.89
Stroke (CC 95-96)	6.86	6.77	6.73
Renal Failure (CC 131)	17.15	18.47	20.35
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	6.98	7.47	7.57
Cellulitis, Local Skin Infection (CC 152)	12.29	12.47	13.02
Vertebral Fractures (CC 157)	5.50	5.30	5.37

Table 8. Temporal Trends in Adjusted OR* for Model Risk Factors and Readmission in Development and Validation Samples (Logistic Regression Model)

	2007 n= 302,560		2008 n= 352,631		2009 n= 332,184	
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Demographics						
Age-65 (continuous)	1.00	(1.00-1.00)	1.00	(1.00-1.00)	1.00	(1.00-1.00)
Cardiovascular/Respiratory						
Sleep Apnea (ICD-9 codes: 327.20, 327.21, 327.23, 327.27, 327.29, 780.51, 780.53, 780.57)	1.00	(0.97-1.03)	1.00	(0.98-1.03)	0.98	(0.95-1.00)
History of Mechanical Ventilation (ICD-9 codes: 93.90, 96.70, 96.71, 96.72)	1.11	(1.07-1.15)	1.13	(1.09-1.16)	1.14	(1.11-1.18)
Respirator Dependence/Respiratory Failure (CC 77-78)	1.09	(1.02-1.16)	1.11	(1.04-1.18)	1.05	(0.98-1.12)
Acute Coronary Syndrome (CC 81-82)	1.11	(1.08-1.14)	1.10	(1.07-1.13)	1.11	(1.08-1.14)
Cardio-Respiratory Failure and Shock (CC 79)	1.18	(1.15-1.20)	1.20	(1.18-1.23)	1.23	(1.20-1.25)
Congestive Heart Failure (CC 80)	1.20	(1.17-1.22)	1.23	(1.21-1.25)	1.25	(1.22-1.27)
Chronic Atherosclerosis (CC 83-84)	1.12	(1.10-1.14)	1.10	(1.08-1.12)	1.08	(1.06-1.10)
Arrhythmias (CC 92-93)	1.16	(1.14-1.19)	1.15	(1.13-1.17)	1.17	(1.15-1.19)
Other and Unspecified Heart Disease (CC 94)	1.07	(1.04-1.09)	1.07	(1.05-1.09)	1.06	(1.04-1.08)
Vascular or Circulatory Disease (CC 104-106)	1.08	(1.06-1.10)	1.09	(1.07-1.11)	1.08	(1.06-1.10)
Fibrosis of Lung and Other Chronic Lung Disorder (CC 109)	1.11	(1.09-1.14)	1.09	(1.07-1.12)	1.10	(1.08-1.13)
Pneumonia (CC 111-113)	1.16	(1.13-1.18)	1.10	(1.08-1.12)	1.08	(1.06-1.10)
Comorbidities						
History of Infection (CC 1, 3-6)	1.09	(1.06-1.11)	1.07	(1.05-1.09)	1.06	(1.04-1.08)
Metastatic Cancer and Acute Leukemia (CC 7)	1.18	(1.12-1.25)	1.20	(1.14-1.27)	1.22	(1.16-1.29)
Lung, Upper Digestive Tract, and Other Severe Cancers (CC 8)	1.23	(1.18-1.28)	1.18	(1.14-1.22)	1.22	(1.18-1.26)
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)	1.04	(1.01-1.06)	1.04	(1.02-1.07)	1.02	(0.99-1.04)
Other Digestive and Urinary Neoplasms(CC 12)	0.94	(0.90-0.97)	0.98	(0.95-1.01)	0.96	(0.93-0.99)
Diabetes and DM Complications (CC 15-20, 119-120)	1.06	(1.04-1.08)	1.07	(1.05-1.09)	1.08	(1.06-1.10)
Protein-calorie Malnutrition (CC 21)	1.14	(1.10-1.18)	1.15	(1.12-1.18)	1.09	(1.06-1.12)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	1.14	(1.12-1.16)	1.15	(1.13-1.18)	1.16	(1.14-1.18)
Other Endocrine/Metabolic/Nutritional Disorders (CC 24)	0.92	(0.90-0.94)	0.92	(0.91-0.94)	0.95	(0.93-0.97)
Pancreatic Disease (CC 32)	1.12	(1.07-1.16)	1.12	(1.08-1.16)	1.10	(1.05-1.16)
Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders (CC 34)	1.06	(1.04-1.09)	1.08	(1.06-1.11)	1.07	(1.05-1.10)
Other Gastrointestinal Disorders (CC 36)	1.08	(1.06-1.10)	1.07	(1.05-1.09)	1.07	(1.05-1.09)
Severe Hematological Disorders (CC44)	1.07	(1.01-1.14)	1.14	(1.09-1.21)	1.17	(1.11-1.23)
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	1.12	(1.10-1.14)	1.13	(1.11-1.15)	1.14	(1.12-1.16)
Dementia and Senility (CC 49-50)	1.01	(0.98-1.03)	0.99	(0.97-1.01)	0.99	(0.97-1.01)
Drug/Alcohol Induced Dependence/Psychosis (CC 51-52)	1.12	(1.07-1.17)	1.14	(1.09-1.18)	1.17	(1.12-1.22)
Major Psych Disorders (CC 54-56)	1.02	(0.99-1.05)	1.06	(1.04-1.09)	1.06	(1.03-1.09)
Depression (CC 58)	1.04	(1.02-1.07)	1.05	(1.02-1.07)	1.05	(1.03-1.08)
Anxiety Disorders (CC 59)	1.10	(1.05-1.16)	1.13	(1.09-1.18)	1.10	(1.05-1.15)
Other Psychiatric Disorders (CC 60)	1.14	(1.11-1.17)	1.13	(1.11-1.15)	1.14	(1.11-1.16)
Quadriplegia, Paraplegia, Functional Disability (CC 67-69, 100-102, 177-178)	1.03	(0.99-1.07)	1.06	(1.02-1.10)	1.07	(1.03-1.10)
Polyneuropathy (CC 71)	1.10	(1.06-1.13)	1.10	(1.07-1.14)	1.09	(1.06-1.12)
Hypertensive Heart and Renal Disease or	1.06	(1.02-1.09)	1.12	(1.09-1.15)	1.10	(1.07-1.13)

	2007 n= 302,560		2008 n= 352,631		2009 n= 332,184	
Variable	**OR**	**95% CI**	**OR**	**95% CI**	**OR**	**95% CI**
Encephalopathy (CC 89)						
Stroke (CC 95-96)	1.04	(1.01-1.08)	1.03	(1.00-1.07)	1.03	(1.00-1.06)
Renal Failure (CC 131)	1.15	(1.12-1.19)	1.10	(1.07-1.13)	1.11	(1.08-1.13)
Decubitus Ulcer or Chronic Skin Ulcer (CC 148-149)	1.10	(1.06-1.13)	1.06	(1.03-1.09)	1.07	(1.03-1.10)
Cellulitis, Local Skin Infection (CC 152)	1.03	(1.01-1.06)	1.06	(1.03-1.09)	1.04	(1.02-1.07)
Vertebral Fractures (CC 157)	1.17	(1.12-1.21)	1.17	(1.13-1.21)	1.20	(1.16-1.24)

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

5. REFERENCES

1. American Lung Association.Trends in COPD (Chronic Bronchitis and Emphysema): Morbidity and Mortality. 2010; http://www.lungusa.org/finding-cures/our-research/trend-reports/copd-trend-report.pdf.

2. Heron M, Hoyert DL, Murphy SL, Xu X, Kochanek KD, Tejada-Vera B. Deaths: Final Data for 2006: Centers for Disease Control and Prevention. 2009; http://www.cdc.gov/nchs/data/nvsr/nvsr57/nvsr57_14.pdf.

3. Jencks SF, Williams MV, Coleman EA. Rehospitalizations among patients in the Medicare fee-for-service program. *N Engl J Med.* April 2 2009;360(14):1478-1428.

4. Committee MPA. Report to the Congress: Promoting Greater Efficiency in Medicare. 2007.

5. AHRQ Quality Indicators. Fact Sheet: Prevention Quality Indicators. 2006; http://qualityindicators.ahrq.gov/downloads/pqi/2006-Feb-PreventionQualityIndicators.pdf. Accessed December 21, 2010.

6. Fisher ES, Wennberg JE, Stukel TA, Sharp SM. Hospital Readmission Rates for Cohorts of Medicare Beneficiaries in Boston and New Haven. *New England Journal of Medicine.* 1994;331(15):989-995.

7. Gulshan Sharma, Kou Yong-Fang, Freeman Jean L, Zhang Dong D, Goodwin James S. Outpatient Follow-up Visit and 30-Day Emergency Department Visit and Readmission in Patients Hospitalized for Chronic Obstructive Pulmonary Disease. *Arch Intern Med.* Oct. 2010;170:1664-1670.

8. Nelson EA, Maruish ME, Axler JL. Effects of Discharge Planning and Compliance with Outpatient Appointments on Readmission Rates. *Psychiatr Serv.* July 1 2000;51(7):885-889.

9. Krumholz H, Normand S-L, Spertus JA, Shahian DM, Bradley EH. Measure Performance for Treating Heart Attacks and Heart Failure: The Case for the Outcomes Measurement. *Health Affairs.* 2007;26:75-85.

10. Bradley EH, Herrin J, Elbel B, et al. Hospital Quality for Acute Myocardial Infarction: Correlation Among Process Measures and Relationship With Short-Term Mortality. *The Journal of the American Medical Association.* 2006;296:72-78.

11. Global strategy for Diagnosis, Management, and Prevention of COPD. 2009; http://www.goldcopd.org/.

12. National Institute for Health and Clinical Excellence. Chronic Obstructive Pulmonary Disease: Management of Chronic Obstructive Pulmonary Disease in Adults in Primary and Secondary Care (Partial Update):. *National Collaborating Centre for Acute and Chronic Conditions* http://www.nice.org.uk/nicemedia/live/13029/49397/49397.pdf.

13. Walters JA, PG Gibson, R Wood-Baker, M Hannay, EH Walters. Systemic corticosteroids for acute exacerbations of chronic obstructive pulmonary disease. *Cochrane Database Syst Rev.* 2009;CD001288(1).

14. Lightowler JV, Wedzicha JA, Elliott MW, Ram FS. Non-invasive positive pressure ventilation to treat respiratory Failure resulting from exacerbations of chronic obstructive pulmonary disease: Cochrane systematic review and meta-analysis. *Bmj.* 2003;326(7382).
15. National Quality Forum. National Voluntary Consensus Standards for Patient Outcomes. *First report phases 1 and 2: A consensus report.*
16. Krumholz HM, Brindis RG, JE. B. Standards for Statistical Models Used for Public Reporting of Health Outcomes: An American Heart Association Scientific Statement from the Quality of Care and Outcomes Research Interdisciplinary Writing Group: Cosponsored by the Council on Epidemiology and Prevention and the Stroke Council. Endorsed by the American College of Cardiology Foundation. *Circulation.* January 24 2006;113(3):456-462.
17. Pope G, Ellis R, Ash A, et al. Principal Inpatient Diagnosis Cost Group Models for Medicare Risk Adjustment. *Health Care Financing Review.* 2000;21(3):26.
18. McCallagh PNJ. Generalized Linear Models. 1989.
19. Daniels M, Gatsonic C. Hierarchical Generalized Linear Models in the Analysis of Variations in Health Care Utilization. *Journal of the American Statistical Association.* 1999;94(445):14.
20. Normand S, Wang Y, Kromholz H. Assessing surrogacy of data sources for institutional comparisons. *Health Services and Outcomes Research Methodology.* 2007;7:79-96.
21. Harrell F, Shih Y. Using full probability models to compute probabilities of actual interest to decision makers. *Int J Technol Assess Health Care.* Winter 2001;17(1):10.

6. APPENDIX

6.1 Appendix A: Conditions 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 Balance
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
48	Delirium and Encephalopathy
75	Coma, Brain Compression/Anoxic Damage
77	Respirator Dependence/Tracheostomy Status
78	Respiratory Arrest
79	Cardio-Respiratory Failure and Shock
80	Congestive Heart Failure
81	Acute Myocardial Infarction
82	Unstable Angina and Other Acute Ischemic 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 Deficits
104	Vascular Disease with Complications
105	Vascular Disease
106	Other Circulatory Disease
111	Aspiration and Specified Bacterial Pneumonias
112	Pneumococcal Pneumonia, Empyema, Lung Abscess
114	Pleural Effusion/Pneumothorax
130	Dialysis Status
131	Renal Failure
132	Nephritis
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
159	Major Fracture, Except of Skull, Vertebrae, or Hip
163	Poisonings and Allergic Reactions

CC #	Description
164	Major Complications of Medical Care and Trauma
165	Other Complications of Medical Care
174	Major Organ Transplant Status
175	Other Organ Transplant/Replacement
177	Amputation Status, Lower Limb/Amputation Complications
178	Amputation Status, Upper Limb

6.2 Appendix B: CCs 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