Hospital 30-Day Mortality Following Acute Ischemic Stroke Hospitalization Measure

Methodology Report

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1. INTRODUCTION

1.1 Overview of Measure

Stroke affects approximately 795,000 people each year in the U.S. with high rates of mortality and morbidity.[1] Stroke is the third most common cause of death after heart disease and cancer.[1] Moreover, stroke is one of the top 20 conditions contributing to Medicare costs. [2] There is evidence of variability in the quality of stroke care in the U.S. and research indicates that improvements in care can lead to better quality of life and lower mortality rates.[3, 4] Ongoing efforts to improve the quality of care for stroke patients, therefore, are needed to improve outcomes.

The Centers for Medicare & Medicaid Services (CMS) has contracted with Yale New Haven Health Services Corporation/Center for Outcomes Research and Evaluation (YNHHSC/CORE) to develop hospital outcomes measures of the quality of care delivered to patients who are hospitalized with stroke. CMS publicly reports outcomes and efficiency measures on the consumer Web site, Hospital Compare (http://www.hospitalcompare.hhs.gov), as mandated by the 2005 Deficit Reduction Act.

In this technical report we describe the development and validation of a hospital-level 30-day measure of mortality after acute ischemic stroke. 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 mortality rates (RSMRs) with hierarchical logistic regression models. The overall methodological approach for developing this measure is consistent with that used to develop three prior CMS mortality measures approved by the National Quality Forum (NQF) which are now publicly reported by CMS on Hospital Compare. We developed this measure in parallel with a hospital measure of readmission following acute ischemic stroke. The methodology and results of the readmission measure are detailed in a separate technical report.

1.2 Stroke Mortality as a Measure of Quality

The goal of this work is to improve patient outcomes by providing patients, physicians, and hospitals with information about hospital-level, risk-standardized mortality rates following hospitalization for acute ischemic stroke. Measurement of patient outcomes allows for a broad view of quality of care that encompasses more than what can be 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 process

measures.[5, 6] The goal of outcomes measurement is to risk-adjust for patients' conditions at the time of hospital admission and then evaluate patient outcomes. This mortality measure was developed to identify institutions whose performance is better or worse than would be expected based on their patient case-mix, and therefore promote hospital quality improvement and better inform consumers about care quality.

Stroke can be a sudden and devastating disease and, in a small proportion of cases, may result in patients being so disabled and debilitated that they and their families elect to not continue aggressive treatment. In such cases the best quality care may ultimately be that which supports patients' goals and comfort at the end of life rather than that which prolongs life. The intent of a mortality rate is not to convey that all deaths are the result of poor care. The goal is not to have zero deaths. The premise is that there are preventable deaths. Knowledge of how an institution performs compared with what might be expected given their case mix is helpful in encouraging efforts to improve outcomes.

1.3 Approach to Measure Development

We developed this measure in accordance with national guidelines, 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 the NQF guidance for outcomes measures, CMS' Measure Management System, 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).

We held regular conference calls with our working group throughout the measure development phase. The working group included clinicians and other professionals with expertise in stroke, biostatistics, measure methodology, and quality improvement. The working group meetings addressed key issues surrounding measure development including detailed discussions regarding the pros and cons of specific decisions (e.g., defining the appropriate measure cohort) to ensure the methodological rigor of the measure.

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 create the TEP, we released a public call for nominations and selected individuals representing a range of perspectives including those of physicians, consumers, hospitals, and purchasers. 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.hhs.gov/apps/QMIS/publicComment.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 measure of ischemic stroke mortality. The measure is a 30-day, all-cause risk-standardized rate of mortality after admission for acute ischemic stroke for any non-federal acute care hospital in the U.S. (including U.S. Virgin Islands, Puerto Rico, Guam, Northern Marianna Islands, and American Samoa).

To develop the measure, we used Medicare administrative data sets that contain hospitalization data for fee-for-service (FFS) Medicare beneficiaries hospitalized in the calendar year 2007 with ischemic stroke. 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 hospital case mix and account for the clustering of patients within a hospital. We risk-adjusted for patients' comorbid conditions, as identified in both inpatient and outpatient visits for the 12 months prior to the ischemic stroke 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.

We randomly selected half of the hospitalizations in 2007 for development of the model. We then evaluated the performance of the model using hospitalizations contained in the other half of the 2007 administrative dataset and ischemic stroke hospitalizations in 2006 and 2008 data.

Additionally, we compared the results of the administrative model to a similar model derived from medical record data. First, we created a de novo medical record-based measure of stroke mortality using the National Stroke Project dataset, a nationally representative cohort of stroke patients using data abstracted from medical records. We then produced state-level results for the administrative model and the medical-record model in a matched cohort of patients with data in both datasets. We compared the results from the two models to determine whether the administrative model was a good surrogate for the medical record-based model. This validation is described in more detail in section 3.3.

2.2 Outcome

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

2.2.1 30-Day Timeframe

We selected the timeframe of 30 days for evaluation of patient outcomes. Outcome measures should have a standard time period of follow-up; measures that have variable follow-up, such as in-hospital mortality measures can be affected by variation in care unrelated to quality (such as variation in patient length-of-stay). Thirty days is a standard time period used in other measures of stroke mortality.[8, 9] It is a timeframe in which a death may reasonably be attributed to the hospital care and transitional period to a non-acute setting.

2.2.2 All-Cause Mortality

We measure all-cause mortality as opposed to stroke-specific mortality for several reasons. First of all, limiting the measure to stroke-related mortalities may limit the focus of efforts to improve care to a narrow set of approaches (such as processes that will prevent recurrent stroke) as opposed to encouraging broader initiatives aimed at improving the overall care within the hospital. 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. For example, a stroke patient who develops a hospital-acquired infection may ultimately die from sepsis. It would be inappropriate to treat this mortality as unrelated to the care the patient received for stroke. Finally, from a patient perspective death of any cause is the outcome that matters.

2.3 Stroke Cohort

The cohort of index hospital admissions included in the measure is restricted to hospitalizations for ischemic stroke. In consultation with our working group and TEP we chose to limit the measure to ischemic stroke hospitalizations for a few reasons. First, ischemic strokes are the most common type of stroke, accounting for the vast majority of stroke hospitalizations.[1] Second, the etiology and prognosis of ischemic stroke is quite different than that of hemorrhagic stroke, so a combined cohort would be more heterogeneous. Such heterogeneity, due to the inconsistency in risk-factors, could lead to less successful risk-standardization and categorization of outliers. Finally, we did not include patients with transient ischemic attacks (TIAs) largely due to concerns about inconsistency in the use of administrative codes to define TIA and potential for inclusion of patients without cerebrovascular conditions. Based on a literature review and expert consultation we selected the principal discharge diagnoses listed in Table 1 to define the cohort.

Table 1 – ICD-9-CM Codes that Define an Ischemic Stroke Admission in Medicare Inpatient Claims

ICD-9 Code	Description
433.01	Occlusion and stenosis of precerebral arteries, Basilar artery with cerebral infarction
433.11	Occlusion and stenosis of precerebral arteries, Carotid artery with cerebral infarction
433.21	Occlusion and stenosis of precerebral arteries, Vertebral artery with cerebral infarction
433.31	Occlusion and stenosis of precerebral arteries, Multiple and bilateral with cerebral infarction
433.81	Occlusion and stenosis of precerebral arteries, Other specified precerebral artery with cerebral infarction
433.91	Occlusion and stenosis of precerebral arteries, Unspecified precerebral artery with cerebral infarction, Precerebral artery NOS
434.01	Occlusion of cerebral arteries, Cerebral thrombosis with cerebral infarction, Thrombosis of cerebral arteries
434.11	Occlusion of cerebral arteries, Cerebral embolism with cerebral infarction
434.91	Occlusion of cerebral arteries, Cerebral artery occlusion, unspecified, with cerebral infarction
436	Acute, but ill-defined, cerebrovascular disease

2.3.1 Inclusion/Exclusion Criteria

We included hospitalizations for patients 65 years or older at the time of index admission and for whom there was a complete 12 months of FFS enrollment to

allow for adequate risk adjustment. As shown in Figure 1, we excluded the following patient stays from the measure cohort:

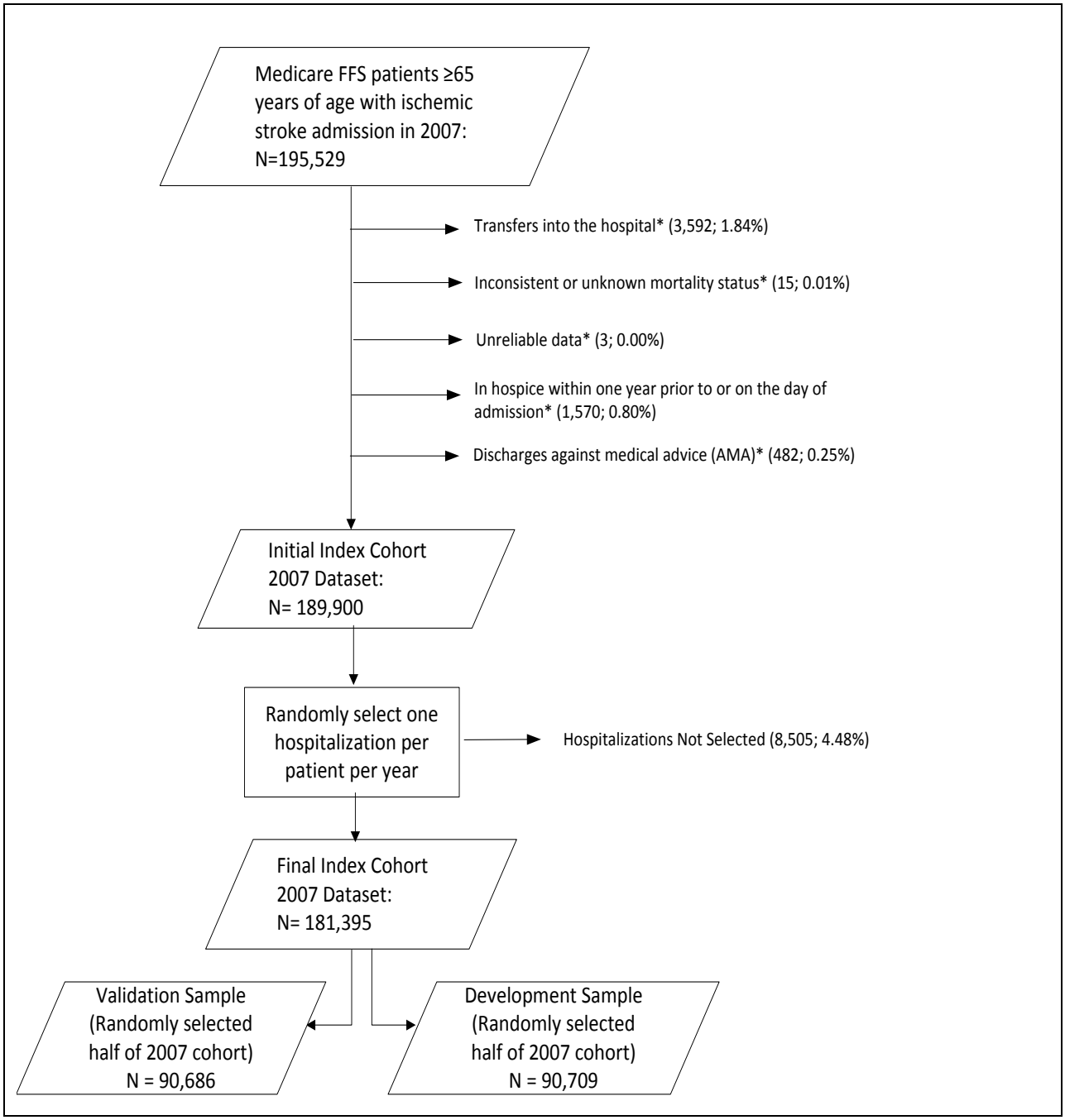
1) Transfer Patients. Admissions for patients having a principal diagnosis of stroke during the index hospitalization who arrived in transfer from another acute care facility are excluded.
   Rationale: We exclude hospitalizations in which a patient was transferred in from another acute care facility because the hospital where the patient was initially admitted made critical acute care decisions (including the decision to transfer and where to transfer).

2) Unreliable Data. Admissions for patients with inconsistent or unknown mortality status or other unreliable data are excluded.
   Rationale: We exclude hospitalizations for patients with unreliable data because we cannot be sure of the accuracy of the outcome. This criteria ultimately results in a very small number of exclusions.

3) Enrolled in Medicare Hospice. Admissions for patients enrolled in the Medicare Hospice program any time in the 12 months prior to the index hospitalization, including the first date of the index admission are excluded.
   Rationale: We exclude hospitalizations for patients enrolled in Medicare Hospice because it is likely that these patients are continuing to seek comfort measures and their goal may not be survival.

4) Discharges Against Medical Advice (AMA). Admissions for patients that are discharged alive and AMA are excluded.
   Rationale: We exclude admissions for patients who are discharged alive and AMA because providers did not have the opportunity to deliver full care and prepare the patient for discharge.

Figure 1 – Cohort for Model Development



*Exclusion categories are not mutually exclusive

2.4 Observation Period

For model development and validation, we used observations for one calendar year.

2.5 Data Sources

We obtained index admission and comorbidity data from Medicare's Standard Analytic File (SAF). The Medicare administrative datasets are described below. We also used medical record data from the National Stroke Project (NSP).

1) Part A (inpatient) data
   For purposes of this project, Part A is used to refer to inpatient services only and includes data from two time periods:
   a. Index admission: Index admission data are based on the inclusion/exclusion criteria for stroke, and comorbidities (if any) are identified from the secondary diagnoses associated with the index admission.
   b. Pre-index: 12 months prior to the index admission ("pre-index").

2) Hospital outpatient data – 12 months pre-index
   Hospital outpatient refers to Medicare 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.

3) Part B data – 12 months pre-index
   Part B data refers to Medicare claims for the services of physicians (regardless of setting) and other outpatient care, services, and supplies. 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.

4) Medicare Enrollment Database
   This database contains Medicare beneficiary demographic, benefit/coverage, and vital status information.

5) NSP Medical Record Abstracted data
   NSP data is medical record-abstracted data from a nationally-representative population of patients hospitalized with stroke that was collected as part of a quality improvement organization (QIO) collaboration during March 1, 1998-March 31, 1999 and July 1, 2000-June 30, 2001. (See Section 3.2)

2.6 Administrative Model Development

2.6.1 Model Overview

We used Medicare administrative datasets that contain FFS hospitalizations for ischemic stroke, as well as administrative data for each patient in the year before each index admission. The administrative model was developed using a randomly selected half of the hospitalizations in 2007 ("development sample"). We then evaluated the performance of the model using hospitalizations in the remaining half of the 2007 administrative dataset. In order to assess variability of the model over time, we also evaluated the model in administrative data in 2006 and 2008. Finally, we validated the measure in a medical record model using a matched cohort of admissions (a sample of patients for whom there are both medical record-based and administrative claims data). We developed a medical record model in the matched cohort and then compared the risk-standardized mortality rates estimated by the administrative and medical record models. Specific information about each step in the process is described below.

2.6.2 Developmental Dataset

We used Medicare ischemic stroke admissions occurring in 2007 to develop the measure. Figure 1 shows the total number of ischemic stroke admissions, the proportion excluded as a result of the each exclusion criteria, and the number included in the final sample as index admissions. We use a randomly selected half of the 2007 cohort for the development sample. The development cohort consisted of 90,709 index admissions at 4,288 hospitals, with an overall unadjusted 30-day mortality rate of 15.46%.

2.7 Candidate and Final Risk-adjustment Variables

Our goal was to develop a parsimonious model that included clinically relevant variables that are strongly associated with risk of 30-day 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 (for any condition); outpatient hospital data; and Part B physician data.

To select candidate variables for the model from the claims codes, we used publicly available "condition categories" (CCs) that combine more than 15,000 ICD-9-CM codes into 189 clinically coherent diagnostic groups.[10] The CCs incorporate all physician and hospital encounter diagnoses. We used the April 2010 version of the ICD-9-CM to CC assignment map, which is maintained by CMS and posted at http://www.qualitynet.org/.

To select candidate variables, a team of clinicians and researchers reviewed all 189 CC variables. A total of 137 CCs determined to be clinically relevant to the mortality outcome were included for consideration. We further combined some CCs into clinically coherent groupings. Our set of candidate variables (see Table 2) therefore included 99 CC-based variables and two demographic variables (age and gender).

For each CC, the team determined whether that particular condition might represent a complication of care that developed during the hospitalization and was not present at the time of arrival to the hospital. Risk-adjustment did not include such variables if they were only coded during the index admission. A list of the CCs that were considered possible complications is presented in Appendix A.

To inform final variable selection, a modified approach to stepwise logistic regression was performed. The developmental dataset was used to create 1000 bootstrap samples with replacement from the development dataset. For each sample, we ran a logistic stepwise regression, with both backward and forward selection, that included the 99 candidate variables. The results were summarized to show the percentage of times that each of the candidate variables was significantly associated with mortality (at the $p<0.001$ level) in each of the 1000 samples (e.g., 80 percent would mean that the candidate variable was identified as significant at $p<0.001$ 800 times from the 1000 regression models). We also assessed the direction and magnitude of the regression coefficients.

The team reviewed these results and decided to retain all risk adjustment variables above a 90% cutoff, since they demonstrated a relatively strong association with mortality and were clinically relevant (37 variables). A small number of variables were also retained in the final model despite being selected in less than 90% of the bootstrap samples because they were considered clinically important to stroke (based on consultation with clinical experts). These variables are:

- Cerebral hemorrhage
- Ischemic or unspecified stroke
- Hemiplegia/Hemiparesis
- Gender

Consistent with NQF guidelines, the model does not adjust for socioeconomic status (SES) or race because risk adjusting for these characteristics would hold hospitals with a large proportion of minority or low SES patients at a different standard of care than other hospitals. The goal of this work was to illuminate quality differences that such risk-adjustment would obscure.

Additionally the model does not risk adjust for patient admission source (e.g. skilled nursing facility) because these factors may be strongly influenced by regional variation in patterns of care and bed availability rather than patient characteristics.

This resulted in a final risk-adjustment model that included 41 variables. Table 3 lists the final model variables.

Table 2 – Stroke Mortality Model Candidate Variables

Category	Variable	CC
Demographics	Age	
	Male	
Cardiovascular/ Cerebrovascular	Cardio-Respiratory Failure and Shock	CC 79
	Congestive Heart Failure	CC 80
	Acute Myocardial Infarction	CC 81
	Unstable Angina and Other Acute Ischemic Heart Disease	CC 82
	Chronic Atherosclerosis	CC 83-84
	Valvular and Rheumatic Heart Disease	CC 86
	Congenital Cardiac/Circulatory Defects	CC 87-88
	Hypertensive Heart Disease	CC 90
	Specified Heart Arrhythmias	CC 92
	Other and Unspecified Heart Disease	CC 94
	Cerebral Hemorrhage	CC 95
	Ischemic or Unspecified Stroke	CC 96
	Precerebral Arterial Occlusion and Transient Cerebral Ischemia	CC 97
	Cerebral Atherosclerosis and Aneurysm	CC 98
	Cerebrovascular Disease, Unspecified	CC 99
	Hemiplegia/Hemiparesis	CC 100
	Late Effects of Cerebrovascular Disease	CC 101B
	Cerebrovascular Disease Late Effects, Unspecified	CC 103
Comorbidities	History of Infection	CC 1, 3-6
	Septicemia/Shock	CC 2
	Metastatic Cancer and Acute Leukemia and other major cancers	CC 7, 8
	Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers	CC 9-13
	Benign Neoplasms of Skin, Breast, Eye	CC 14
	Diabetes with Renal Manifestation	CC 15
	Other Diabetes or DM Complications	CC 16-20, 119-120
	Protein-Calorie Malnutrition	CC 21
	Other Significant Endocrine and Metabolic Disorders	CC 22-24
	Chronic Liver Disease	CC 25-28
	Other Hepatitis and Liver Disease	CC 29
	Gallbladder and Biliary Tract Disorders	CC 30
	Intestinal Obstruction/Perforation	CC 31
	Pancreatic Disease	CC 32
	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 and Disorders of Immunity	CC 44-45
	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 senility	CC 49, 50
	Substance Abuse	CC 51-53
	Major Psychiatric Disorders	CC 54-56

Category	Variable	CC
	Depression	CC 58
	Anxiety Disorders	CC 59
	Other Psychiatric Disorders	CC 60
	Quadriplegia, Other Extensive Paralysis	CC 67-69
	Polyneuropathy	CC 71
	Multiple Sclerosis	CC 72
	Parkinson's and Huntington's Diseases	CC 73
	Seizure Disorders and Convulsions	CC 74
	Coma, Brain Compression/Anoxic Damage	CC 75
	Mononeuropathy, Other Neurological Conditions/Injuries	CC 76
	Respirator Dependence/Tracheostomy Status	CC 77
	Respiratory Arrest	CC 78
	Heart Infection/Inflammation, Except Rheumatic	CC 85
	Hypertension	CC 89, 91
	Cerebral Palsy	CC 101A
	Speech, Language, Cognitive, Perceptual Deficits	CC 102
	Peripheral Vascular Disease	CC 104-105
	Other Circulatory Disease	CC 106
	Chronic Obstructive Pulmonary Disease	CC 108
	Fibrosis of Lung and Other Chronic Lung	CC 109
	Asthma	CC 110
	Pneumonia	CC 111-113
	Pleural Effusion/Pneumothorax	CC 114
	Other Lung Disorders	CC 115
	Retinal Detachment/Retinal Disorders	CC 118, 121
	Glaucoma	CC 122
	Cataract	CC 123
	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
	Dialysis Status	CC 130
	Renal Failure	CC 131
	Urinary Obstruction and Retention	CC 133
	Incontinence	CC 134
	Urinary Tract Infection	CC 135
	Other Urinary Tract Disorders	CC 136
	Pelvic Inflammatory Disease and Other Specified Female Genital Disorders	CC 138
	Other Female Genital Disorders	CC 139
	Male Genital Disorders	CC 140
	Decubitus Ulcer of Skin	CC 148
	Chronic Ulcer of Skin, Except Decubitus	CC 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
	Major Complications of Medical Care and Trauma	CC 164
	Other Complications of Medical Care	CC 165
	Artificial Openings for Feeding or Elimination	CC 176

Table 3 – Final Stroke Mortality Model Variables

Category	Variable	CCs
Demographic	Age-65 (continuous)	
	Male	
Cardiovascular/ Cerebrovascular	Congestive Heart Failure	CC 80
	Valvular and Rheumatic Heart Disease	CC 86
	Congenital Cardiac/Circulatory Defects	CC 87-88
	Hypertensive Heart Disease	CC 90
	Specified Heart Arrhythmias	CC 92
	Cerebral Hemorrhage	CC 95
	Ischemic or Unspecified Stroke	CC 96
	Precerebral Arterial Occlusion and Transient Cerebral Ischemia	CC 97
	Cerebral Atherosclerosis and Aneurysm	CC 98
	Hemiplegia/Hemiparesis	CC 100
Comorbidities	History of Infection	CC 1, 3-6
	Metastatic Cancer and Acute Leukemia and Other Major Cancers	CC 7, 8
	Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers	CC 9-13
	Protein-Calorie Malnutrition	CC 21
	Other Significant Endocrine and Metabolic Disorders	CC 22-24
	Other Gastrointestinal Disorders	CC 36
	Disorders of the Vertebrae and Spinal Discs	CC 39
	Osteoarthritis of Hip or Knee	CC 40
	Other Musculoskeletal and Connective Tissue Disorders	CC 43
	Iron Deficiency and Other/Unspecified Anemia and Blood Disease	CC 47
	Dementia or senility	CC 49, 50
	Major Psychiatric Disorders	CC 54-56
	Quadriplegia, Other Extensive Paralysis	CC 67-69
	Multiple Sclerosis	CC 72
	Seizure Disorders and Convulsions	CC 74
	Hypertension	CC 89, 91
	Peripheral Vascular Disease	CC 104-105
	Chronic Obstructive Pulmonary Disease	CC 108
	Pneumonia	CC 111-113
	Pleural Effusion/Pneumothorax	CC 114
	Other Eye Disorders	CC 124
	Other Ear, Nose, Throat, and Mouth Disorders	CC 127
	Dialysis Status	CC 130
	Renal Failure	CC 131
	Urinary Tract Infection	CC 135
	Male Genital Disorders	CC 140
	Decubitus Ulcer of Skin	CC 148
	Chronic Ulcer of Skin, Except Decubitus	CC 149
	Other Dermatological Disorders	CC 153

2.8 Statistical Approach to Model Development

Due to the natural clustering of the observations within hospitals, we estimated hierarchical generalized linear models (HGLMs). We modeled the log-odds of mortality within 30 days of discharge from an index ischemic stroke hospitalization as a function of both patient demographic and clinical characteristics and an estimated 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 facilities being evaluated lead to systematic differences in outcomes.

We used the above strategy to calculate the hospital-specific RSMRs. These rates are calculated as the ratio of predicted number of mortalities to expected number of mortalities, multiplied by the national unadjusted mortality rate. The expected number of mortalities for each hospital is estimated using its patient mix and the average hospital-specific intercept. Essentially, for each patient in the dataset, the estimated regression coefficients are multiplied by the observed characteristics and the average of the hospital-specific intercepts is added to this quantity. Then, the quantity is transformed to the probability scale. For each patient within a hospital these probabilities are summed.

The predicted number of mortalities for each hospital is calculated by summing the predicted mortality rate for all patients in the hospital. The predicted mortality 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 re-estimate the model coefficients using that year's data.

More specifically, we estimate two types of regression models. First, we fit a generalized linear model (GLM) linking the outcome to the risk factors.[11] Let Y_{ij} denote the outcome (equal to 1 if patient died within 30 days, zero otherwise) for the j^{th} patient discharged from the i^{th} hospital; $\mathbf{Z}_{ij}$ denotes a set of risk factors, identified via administrative 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

$$\text{GLM} \qquad h(Y_{ij}) = \alpha + \beta \mathbf{Z}_{ij} \qquad (1)$$

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 HGLM that links the risk factors to the same outcome and a hospital-specific random effect,

HGLM $h(Y_{ij}) = \alpha_i + \beta \mathbf{Z}_{ij}$ (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.[12] This model separates within-hospital variation from between-hospital variation. Both HGLMs and GLMs are estimated using the SAS software system (GLIMMIX and LOGISTIC procedures, respectively).

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

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

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

2.9 Hospital Performance Reporting

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

2.9.1 Creating Interval Estimates

Because the statistic described in Equation 6 in section 2.9 is a complex function of parameter estimates, we use re-sampling techniques, bootstrapping, to derive an interval estimate. The bootstrap has the advantage of avoiding unnecessary distributional assumptions.

2.9.2 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.

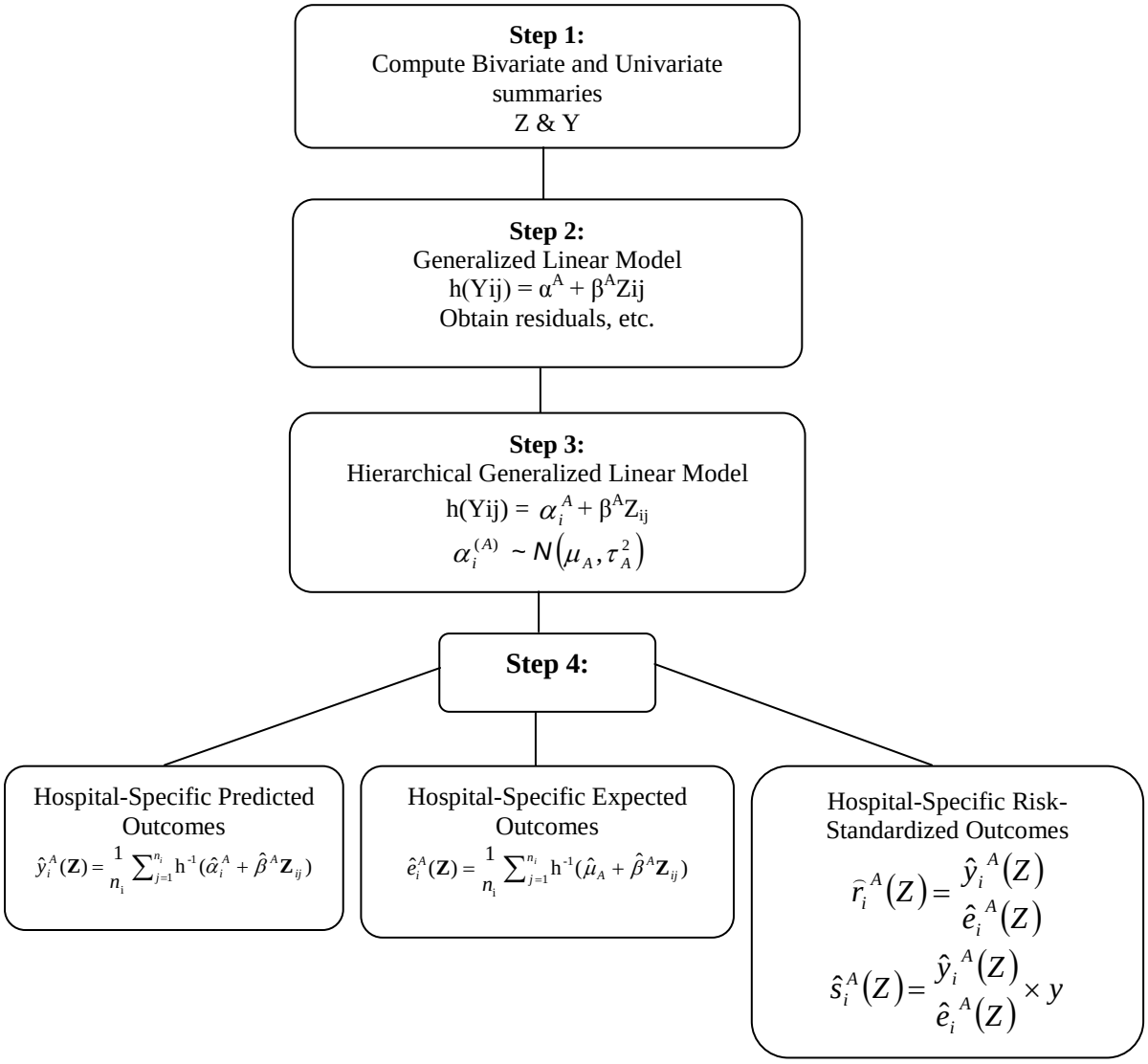
2. Fit the HGLM using all patients within each sampled hospital. We use as starting values the parameter estimates obtained by fitting the model to all hospitals. If some hospitals are selected more than once in a bootstrapped sample, we treat them as distinct so that we have *I* random effects to estimate 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, $\{\hat{\alpha}_i^{(b)}, \hat{\text{var}}\left(\alpha_i^{(b)}\right); i = 1,2,\ldots,I\}$.

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 $\alpha_i^{(b^*)} \sim N\left(\hat{\alpha}_i^{(b)}, \hat{\text{var}}\left(\hat{\alpha}_i^{(b)}\right)\right)$ 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 $\hat{s}_i\left(Z\right)^{(b)}$ 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 the B standardized estimates (or the percentiles corresponding to the alternative desired intervals).[13] (See Figure 2 below for a diagram of the analysis steps.)

Figure 2 – Analysis Steps



3. RESULTS

3.1 Model Results

3.1.1 Development Sample

The variable descriptions, standardized estimates, and standard errors for the development sample HGLM model are shown in Table 4. The standardized estimates are regression coefficients expressed in units of standard deviations and can range between -1 and 1, with ±1 indicating a perfect linear relationship and 0 indicating no linear relationship.[a]

3.1.2 Model Performance

We computed five summary statistics for assessing model performance[14]: over-fitting indices[b], predictive ability, area under the receiver operating characteristic (ROC) curve, distribution of residuals, and model chi-square[c] (see Table 6).

The development model has strong discrimination and fit. The mortality rate ranges from 10.7% in the lowest predicted decile to 23.5% in the highest predicted decile, a range of 12.8%. The area under the ROC curve is 0.736.

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[a] Standardized estimates are like correlation coefficients. We compute them in order to compare the size of the coefficients by standardizing the coefficients to be unitless. We used the following equation to compute the standardized estimate,

$$S_i = \frac{E_i * \sigma_i}{\pi / \sqrt{3}}$$

where S_i =standardized estimate for the i-th variable, E_i =unstandardized estimate of the i-th variable, σ_i =standard deviation of the i-th variable.

[b] Over-fitting refers to the phenomenon in which a model well describes the relationship between predictive variables and outcome in the development dataset, but fails to provide valid predictions in new patients.

[c] 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)

Table 4 – 30-Day Mortality Administrative Model (50% 2007 Development Sample-HGLM Results)[de]

Description	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% Confidence Interval
Demographics					
Age-65 (continuous)	0.066	0.001	0.287	1.069	(1.066 - 1.071)
Male	-0.008	0.023	-0.002	0.992	(0.948 - 1.038)
Cardiovascular/Cerebrovascular					
Congestive Heart Failure (CC 80)	0.293	0.023	0.071	1.341	(1.281 - 1.404)
Valvular and Rheumatic Heart Disease (CC 86)	-0.147	0.023	-0.035	0.863	(0.825 - 0.902)
Congenital Cardiac/Circulatory Defects (CC 87-88)	-0.282	0.086	-0.019	0.754	(0.637 - 0.893)
Hypertensive Heart Disease (CC 90)	-0.116	0.039	-0.016	0.890	(0.825 - 0.961)
Specified Heart Arrhythmias (CC 92)	0.490	0.021	0.122	1.632	(1.565 - 1.702)
Cerebral Hemorrhage (CC 95)	0.132	0.068	0.009	1.141	(0.998 - 1.304)
Ischemic or Unspecified Stroke (CC 96)	-0.016	0.024	-0.004	0.984	(0.938 - 1.032)
Precerebral Arterial Occlusion and Transient Cerebral Ischemia (CC 97)	-0.235	0.026	-0.054	0.791	(0.752 - 0.832)
Cerebral Atherosclerosis and Aneurysm (CC 98)	-0.134	0.033	-0.022	0.875	(0.820 - 0.933)
Hemiplegia/Hemiparesis (CC 100)	0.180	0.042	0.022	1.197	(1.102 - 1.300)
Comorbid Conditions					
History of Infection (CC 1, 3-6)	0.109	0.022	0.026	1.115	(1.068 - 1.164)
Metastatic Cancer and Acute Leukemia and Other Major Cancers (CC 7-8)	0.963	0.044	0.100	2.619	(2.405 - 2.853)
Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers (CC 9-13)	-0.101	0.024	-0.024	0.904	(0.862 - 0.948)
Protein-Calorie Malnutrition (CC 21)	0.392	0.038	0.045	1.480	(1.373 - 1.595)
Other Significant Endocrine and Metabolic Disorders (CC 22-24)	-0.313	0.022	-0.076	0.731	(0.700 - 0.763)
Other Gastrointestinal Disorders (CC 36)	-0.119	0.020	-0.032	0.888	(0.853 - 0.925)
Disorders of the Vertebrae and Spinal Discs (CC 39)	-0.134	0.027	-0.027	0.875	(0.829 - 0.923)
Osteoarthritis of Hip or Knee (CC 40)	-0.211	0.033	-0.036	0.809	(0.758 - 0.864)
Other Musculoskeletal and Connective Tissue Disorders (CC 43)	-0.119	0.021	-0.032	0.888	(0.852 - 0.925)
Iron Deficiency and Other/Unspecified Anemia and Blood Disease (CC 47)	0.128	0.021	0.033	1.136	(1.090 - 1.185)
Dementia or senility (CC 49-50)	0.221	0.021	0.055	1.247	(1.196 - 1.301)
Major Psychiatric Disorders (CC 54-56)	0.166	0.032	0.026	1.180	(1.109 - 1.256)
Quadriplegia, Other Extensive Paralysis (CC 67-69)	0.395	0.072	0.026	1.484	(1.289 - 1.708)
Multiple Sclerosis (CC 72)	-0.209	0.035	-0.034	0.812	(0.758 - 0.870)
Seizure Disorders and Convulsions (CC 74)	0.249	0.034	0.036	1.283	(1.201 - 1.371)
Hypertension (CC 89, 91)	-0.232	0.027	-0.043	0.793	(0.752 - 0.837)
Peripheral Vascular Disease (CC 104-105)	0.074	0.023	0.017	1.077	(1.029 - 1.127)
Chronic Obstructive Pulmonary Disease (CC 108)	0.080	0.023	0.019	1.083	(1.035 - 1.133)
Pneumonia (CC 111-113)	0.429	0.024	0.089	1.536	(1.464 - 1.611)
Pleural Effusion/Pneumothorax (CC 114)	0.193	0.034	0.026	1.213	(1.133 - 1.297)
Other Eye Disorders (CC 124)	-0.133	0.025	-0.029	0.875	(0.834 - 0.919)
Other Ear, Nose, Throat, and Mouth Disorders (CC 127)	-0.101	0.022	-0.025	0.904	(0.865 - 0.944)

[d] N=90,709 in 4,288 hospitals; 15.46% crude mortality rate

[e] Between-hospital variance = 0.073; Standard Error = 0.0088

Description	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% Confidence Interval
Dialysis Status (CC 130)	0.417	0.069	0.028	1.518	(1.326 - 1.737)
Renal Failure (CC 131)	0.162	0.028	0.031	1.176	(1.113 - 1.242)
Urinary Tract Infection (CC 135)	0.126	0.024	0.028	1.134	(1.083 - 1.188)
Male Genital Disorders (CC 140)	-0.237	0.036	-0.042	0.789	(0.736 - 0.846)
Decubitus Ulcer of Skin (CC 148)	0.232	0.054	0.019	1.261	(1.134 - 1.402)
Chronic Ulcer of Skin, Except Decubitus (CC 149)	0.203	0.038	0.026	1.224	(1.136 - 1.320)
Other Dermatological Disorders (CC 153)	-0.103	0.022	-0.026	0.902	(0.865 - 0.942)

3.1.3 Administrative Model Validation

We compared the model performance in the development sample to performance in the 2007 validation sample, which is the remaining half of ischemic stroke admissions not selected for the development sample. The 2007 validation sample included 90,633 cases discharged from 4,307 hospitals. This validation sample had a crude mortality rate of 15.2%.

The standardized estimates and standard errors for the 2007 validation dataset are shown in Table 5, and the performance metrics are shown Table 6. The performance was not substantively different in this validation sample (ROC=0.732), as compared to the development sample (ROC=0.736).

The model variables were then similarly tested among ischemic stroke admissions in 2006 and 2008. The unadjusted mortality rates were 15.27% and 15.56% respectively. As the results in Table 6 show, model performance using the 2006 data (ROC area = 0.728) and 2008 data (ROC area = 0.733) were consistent with model performance using the 2007 development and validation half-samples. The 2006 and 2008 validation models appear similarly well-calibrated, with over-fitting indices of (0.01, 0.99) and (0.00, 0.99) respectively.

We also examined the temporal variation of the standardized estimates and frequencies of the model variables (Table 7 and Table 8). The frequencies and regression coefficients are fairly consistent over the two years of data.

Table 5 – 30-Day Mortality Model (2007 Validation Sample-HGLM Results)[fg]

Description	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% Confidence Interval
Demographics					
Age-65 (continuous)	0.064	0.001	0.278	1.066	(1.064 - 1.069)
Male	0.013	0.023	0.004	1.013	(0.968 - 1.060)
Cardiovascular/Cerebrovascular					
Congestive Heart Failure (CC 80)	0.292	0.024	0.071	1.339	(1.278 - 1.402)
Valvular and Rheumatic Heart Disease (CC 86)	-0.121	0.023	-0.029	0.886	(0.847 - 0.926)
Congenital Cardiac/Circulatory Defects (CC 87-88)	-0.385	0.090	-0.027	0.680	(0.570 - 0.811)
Hypertensive Heart Disease (CC 90)	-0.217	0.040	-0.030	0.805	(0.745 - 0.870)
Specified Heart Arrhythmias (CC 92)	0.478	0.022	0.119	1.613	(1.546 - 1.683)
Cerebral Hemorrhage (CC 95)	0.107	0.066	0.008	1.113	(0.977 - 1.268)
Ischemic or Unspecified Stroke (CC 96)	-0.010	0.024	-0.003	0.990	(0.943 - 1.038)
Precerebral Arterial Occlusion and Transient Cerebral Ischemia (CC 97)	-0.159	0.025	-0.037	0.853	(0.812 - 0.896)
Cerebral Atherosclerosis and Aneurysm (CC 98)	-0.252	0.034	-0.042	0.777	(0.727 - 0.831)
Hemiplegia/Hemiparesis (CC 100)	0.115	0.043	0.014	1.122	(1.031 - 1.221)
Comorbid Conditions					
History of Infection (CC 1, 3-6)	0.106	0.022	0.026	1.112	(1.064 - 1.162)
Metastatic Cancer and Acute Leukemia and Other Major Cancers (CC 7-8)	1.008	0.044	0.104	2.739	(2.515 - 2.983)
Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers (CC 9-13)	-0.094	0.024	-0.022	0.910	(0.868 - 0.955)
Protein-Calorie Malnutrition (CC 21)	0.469	0.038	0.054	1.599	(1.485 - 1.722)
Other Significant Endocrine and Metabolic Disorders (CC 22-24)	-0.306	0.022	-0.074	0.736	(0.705 - 0.769)
Other Gastrointestinal Disorders (CC 36)	-0.132	0.021	-0.036	0.876	(0.841 - 0.912)
Disorders of the Vertebrae and Spinal Discs (CC 39)	-0.123	0.028	-0.025	0.885	(0.838 - 0.934)
Osteoarthritis of Hip or Knee (CC 40)	-0.184	0.034	-0.031	0.832	(0.779 - 0.888)
Other Musculoskeletal and Connective Tissue Disorders (CC 43)	-0.171	0.021	-0.045	0.843	(0.808 - 0.879)
Iron Deficiency and Other/Unspecified Anemia and Blood Disease (CC 47)	0.131	0.022	0.033	1.139	(1.092 - 1.189)
Dementia or senility (CC 49-50)	0.246	0.021	0.061	1.279	(1.226 - 1.334)
Major Psychiatric Disorders (CC 54-56)	0.076	0.032	0.012	1.079	(1.013 - 1.149)
Quadriplegia, Other Extensive Paralysis (CC 67-69)	0.330	0.074	0.021	1.391	(1.203 - 1.608)
Multiple Sclerosis (CC 72)	-0.197	0.035	-0.033	0.821	(0.766 - 0.879)
Seizure Disorders and Convulsions (CC 74)	0.281	0.034	0.041	1.325	(1.239 - 1.416)
Hypertension (CC 89, 91)	-0.218	0.028	-0.040	0.804	(0.761 - 0.849)
Peripheral Vascular Disease (CC 104-105)	0.108	0.023	0.025	1.114	(1.064 - 1.166)
Chronic Obstructive Pulmonary Disease (CC 108)	0.074	0.023	0.017	1.076	(1.029 - 1.126)
Pneumonia (CC 111-113)	0.423	0.025	0.088	1.527	(1.455 - 1.602)
Pleural Effusion/Pneumothorax (CC 114)	0.177	0.035	0.024	1.193	(1.114 - 1.277)
Other Eye Disorders (CC 124)	-0.069	0.025	-0.015	0.934	(0.890 - 0.980)
Other Ear, Nose, Throat, and Mouth Disorders (CC 127)	-0.103	0.022	-0.025	0.902	(0.864 - 0.943)

[f] N=90,686 in 4,307 hospitals; ROC = 0.732

[g] Between-hospital variance = 0.068 (Standard Error = 0.0089)

escription	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% Confidence Interval
Dialysis Status (CC 130)	0.241	0.070	0.017	1.272	(1.109 - 1.459)
Renal Failure (CC 131)	0.198	0.028	0.038	1.219	(1.154 - 1.288)
Urinary Tract Infection (CC 135)	0.169	0.024	0.038	1.184	(1.131 - 1.240)
Male Genital Disorders (CC 140)	-0.261	0.036	-0.046	0.771	(0.718 - 0.827)
Decubitus Ulcer of Skin (CC 148)	0.257	0.054	0.021	1.293	(1.164 - 1.437)
Chronic Ulcer of Skin, Except Decubitus (CC 149)	0.181	0.038	0.023	1.198	(1.113 - 1.290)
Other Dermatological Disorders (CC 153)	-0.078	0.022	-0.019	0.925	(0.886 - 0.966)

Table 6 – 30-Day Mortality Model Performance - HGLM

Indices	Development Sample	Validation Sample		
Year	2007	2006	2007*	2008
N	90,709	191,275	90,686	175,267
Risk-Standardized Mortality Rate (mean)	15.5	15.2	15.0	15.5
Calibration (γ0, γ1)[h]	(0.00, 1.00)	(0.01, 0.99)	(0.00, 1.00)	(0.00, 0.99)
Discrimination -Predictive Ability[i] (lowest decile %, highest decile %)	(2.89, 38.97)	(2.88, 37.91)	(2.94, 38.49)	(2.69, 39.03)
Discrimination – ROC	0.736	0.728	0.732	0.733
Residuals Lack of Fit (Pearson Residual Fall %)				
<-2	0.00	0.01	0.01	0.01
[-2, 0)	84.54	84.73	84.82	84.43
[0, 2)	8.19	7.74	7.83	8.23
[2+	7.27	7.52	7.34	7.33
Model χ^2 [Number of Covariates][j]	7248.04 [41]	14351.27 [41]	7024.55 [41]	13827.35 [41]

*2007 validation sample is comprised of half of 2007 admissions

[h] 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.

[i] Observed Rates

[j] Wald Chi-Square

Table 7 – 30-Day Mortality Model Risk Factor Frequency by Year of Discharge (2006-2008)

Description	2006	2007	2008
Demographics (%)			
Male	40.31	40.45	40.28
Cardiovascular/Cerebrovascular (%)			
Congestive Heart Failure (CC 80)	26.38	26.25	26.04
Valvular and Rheumatic Heart Disease (CC 86)	25.23	25.64	23.04
Congenital Cardiac/Circulatory Defects (CC 87-88)	1.47	1.61	2.04
Hypertensive Heart Disease (CC 90)	7.28	6.83	6.53
Specified Heart Arrhythmias (CC 92)	27.99	28.75	29.37
Cerebral Hemorrhage (CC 95)	1.70	1.72	1.88
Ischemic or Unspecified Stroke (CC 96)	25.64	24.97	24.79
Precerebral Arterial Occlusion and Transient Cerebral Ischemia (CC 97)	22.31	22.74	22.82
Cerebral Atherosclerosis and Aneurysm (CC 98)	9.54	10.00	10.67
Hemiplegia/Hemiparesis (CC 100)	5.50	5.27	5.60
Comorbid Conditions (%)			
History of Infection (CC 1, 3-6)	25.57	26.04	26.72
Metastatic Cancer and Acute Leukemia and Other Major Cancers (CC 7-8)	3.54	3.65	3.65
Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers (CC 9-13)	23.34	23.57	23.92
Protein-Calorie Malnutrition (CC 21)	4.23	4.56	5.42
Other Significant Endocrine and Metabolic Disorders (CC 22-24)	71.74	73.92	76.00
Other Gastrointestinal Disorders (CC 36)	42.44	43.51	43.61
Disorders of the Vertebrae and Spinal Discs (CC 39)	16.07	16.72	17.04
Osteoarthritis of Hip or Knee (CC 40)	10.08	10.46	10.36
Other Musculoskeletal and Connective Tissue Disorders (CC 43)	61.89	63.02	63.49
Iron Deficiency and Other/Unspecified Anemia and Blood Disease (CC 47)	30.09	31.09	31.87
Dementia or senility (CC 49-50)	28.12	28.14	28.66
Major Psychiatric Disorders (CC 54-56)	8.87	8.85	9.12
Quadriplegia, Other Extensive Paralysis (CC 67-69)	1.39	1.38	1.55
Multiple Sclerosis (CC 72)	9.59	9.88	10.26
Seizure Disorders and Convulsions (CC 74)	7.85	7.48	6.92
Hypertension (CC 89, 91)	85.77	87.14	88.01
Peripheral Vascular Disease (CC 104-105)	21.84	22.79	23.00
Chronic Obstructive Pulmonary Disease (CC 108)	23.48	23.13	21.93
Pneumonia (CC 111-113)	16.96	16.95	17.35
Pleural Effusion/Pneumothorax (CC 114)	6.22	6.56	6.92
Other Eye Disorders (CC 124)	18.90	19.23	19.35
Other Ear, Nose, Throat, and Mouth Disorders (CC 127)	26.55	26.50	26.97
Dialysis Status (CC 130)	1.48	1.56	1.48
Renal Failure (CC 131)	12.62	14.51	15.46
Urinary Tract Infection (CC 135)	20.51	21.04	21.57
Male Genital Disorders (CC 140)	11.20	11.69	11.95
Decubitus Ulcer of Skin (CC 148)	2.16	2.25	2.52
Chronic Ulcer of Skin, Except Decubitus (CC 149)	5.51	5.65	5.51
Other Dermatological Disorders (CC 153)	27.82	28.61	29.38

Table 8 – 30-Day Mortality Model (HGLM) Standardized Estimates by Year of Discharge (2006-2008)

Description	2006			2007			2008		
	Estimate	Standard Error	Standardized Estimate	Estimate	Standard Error	Standardized Estimate	Estimate	Standard Error	Standardized Estimate
Demographics									
Age-65 (continuous)	0.064	0.001	0.277	0.066	0.001	0.283	0.067	0.001	0.292
Male	0.014	0.016	0.004	0.007	0.024	0.000	-0.001	0.017	0.000
Cardiovascular/Cerebrovascular									
Congestive Heart Failure (CC 80)	0.314	0.016	0.076	0.294	0.024	0.070	0.328	0.017	0.079
Valvular and Rheumatic Heart Disease (CC 86)	-0.121	0.016	-0.029	-0.103	0.023	-0.032	-0.143	0.017	-0.033
Congenital Cardiac/Circulatory Defects (CC 87-88)	-0.416	0.065	-0.028	-0.370	0.092	-0.023	-0.318	0.056	-0.025
Hypertensive Heart Disease (CC 90)	-0.215	0.027	-0.031	-0.171	0.040	-0.022	-0.194	0.029	-0.026
Specified Heart Arrhythmias (CC 92)	0.454	0.015	0.112	0.518	0.022	0.121	0.464	0.015	0.117
Cerebral Hemorrhage (CC 95)	0.117	0.046	0.008	0.164	0.069	0.009	0.152	0.046	0.011
Ischemic or Unspecified Stroke (CC 96)	-0.016	0.017	-0.004	0.020	0.025	-0.003	0.000	0.018	0.000
Precerebral Arterial Occlusion and Transient Cerebral Ischemia (CC 97)	-0.178	0.018	-0.041	-0.194	0.026	-0.045	-0.199	0.018	-0.046
Cerebral Atherosclerosis and Aneurysm (CC 98)	-0.198	0.024	-0.032	-0.217	0.034	-0.032	-0.176	0.023	-0.030
Hemiplegia/Hemiparesis (CC 100)	0.141	0.029	0.018	0.071	0.044	0.018	0.153	0.030	0.019
Comorbid Conditions									
History of Infection (CC 1, 3-6)	0.091	0.015	0.022	0.105	0.023	0.027	0.135	0.016	0.033
Metastatic Cancer and Acute Leukemia and Other Major Cancers (CC 7-8)	0.931	0.031	0.095	0.957	0.045	0.102	1.015	0.031	0.105
Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers (CC 9-13)	-0.042	0.017	-0.010	-0.120	0.025	-0.023	-0.077	0.017	-0.018
Protein-Calorie Malnutrition (CC 21)	0.516	0.027	0.057	0.416	0.039	0.050	0.519	0.025	0.065
Other Significant Endocrine and Metabolic Disorders (CC 22-24)	-0.255	0.015	-0.063	-0.299	0.023	-0.075	-0.288	0.016	-0.068
Other Gastrointestinal Disorders (CC 36)	-0.119	0.014	-0.033	-0.113	0.021	-0.035	-0.104	0.015	-0.028
Disorders of the Vertebrae and Spinal Discs (CC 39)	-0.101	0.019	-0.020	-0.167	0.028	-0.027	-0.113	0.020	-0.023
Osteoarthritis of Hip or Knee (CC 40)	-0.172	0.023	-0.028	-0.191	0.034	-0.033	-0.201	0.024	-0.034
Other Musculoskeletal and Connective Tissue Disorders (CC 43)	-0.139	0.015	-0.037	-0.143	0.022	-0.038	-0.148	0.015	-0.039
Iron Deficiency and Other/Unspecified Anemia and Blood Disease (CC 47)	0.107	0.015	0.027	0.130	0.022	0.033	0.084	0.015	0.022
Dementia or senility (CC 49-50)	0.200	0.015	0.050	0.203	0.022	0.058	0.210	0.015	0.052
Major Psychiatric Disorders (CC 54-56)	0.027	0.022	0.004	0.125	0.033	0.019	0.086	0.023	0.014

Description	2006			2007			2008		
	Estimate	Standard Error	Standardized Estimate	Estimate	Standard Error	Standardized Estimate	Estimate	Standard Error	Standardized Estimate
Quadriplegia, Other Extensive Paralysis (CC 67-69)	0.356	0.050	0.023	0.338	0.075	0.023	0.314	0.050	0.021
Multiple Sclerosis (CC 72)	-0.199	0.024	-0.032	-0.226	0.036	-0.034	-0.186	0.025	-0.031
Seizure Disorders and Convulsions (CC 74)	0.351	0.023	0.052	0.255	0.035	0.038	0.221	0.026	0.031
Hypertension (CC 89, 91)	-0.230	0.018	-0.044	-0.226	0.028	-0.041	-0.257	0.020	-0.046
Peripheral Vascular Disease (CC 104-105)	0.091	0.016	0.021	0.071	0.024	0.021	0.069	0.017	0.016
Chronic Obstructive Pulmonary Disease (CC 108)	0.098	0.016	0.023	0.080	0.024	0.018	0.058	0.017	0.013
Pneumonia (CC 111-113)	0.399	0.017	0.083	0.410	0.025	0.088	0.396	0.018	0.083
Pleural Effusion/Pneumothorax (CC 114)	0.164	0.024	0.022	0.196	0.035	0.025	0.116	0.025	0.016
Other Eye Disorders (CC 124)	-0.103	0.017	-0.022	-0.143	0.026	-0.022	-0.101	0.018	-0.022
Other Ear, Nose, Throat, and Mouth Disorders (CC 127)	-0.125	0.015	-0.030	-0.105	0.023	-0.025	-0.139	0.016	-0.034
Dialysis Status (CC 130)	0.409	0.048	0.027	0.360	0.070	0.022	0.312	0.052	0.021
Renal Failure (CC 131)	0.227	0.020	0.042	0.187	0.029	0.035	0.150	0.020	0.030
Urinary Tract Infection (CC 135)	0.135	0.016	0.030	0.152	0.024	0.033	0.127	0.017	0.029
Male Genital Disorders (CC 140)	-0.272	0.025	-0.047	-0.243	0.037	-0.044	-0.253	0.026	-0.045
Decubitus Ulcer of Skin (CC 148)	0.292	0.038	0.023	0.219	0.055	0.020	0.253	0.037	0.022
Chronic Ulcer of Skin, Except Decubitus (CC 149)	0.171	0.027	0.022	0.190	0.039	0.025	0.140	0.028	0.018
Other Dermatological Disorders (CC 153)	-0.065	0.015	-0.016	-0.063	0.022	-0.023	-0.083	0.016	-0.021

Table 9 – 30-Day Mortality (2007 Full Sample – HGLM Results)[k][l]

Description	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% Confidence Interval
Demographics					
Age-65 (continuous)	0.066	0.001	0.283	1.067	(1.065 – 1.069)
Male	0.007	0.016	0.000	1.001	(0.969 – 1.034)
Cardiovascular/Cerebrovascular					
Congestive Heart Failure (CC 80)	0.294	0.017	0.070	1.337	(1.294 – 1.382)
Valvular and Rheumatic Heart Disease (CC 86)	-0.103	0.016	-0.032	0.875	(0.848 – 0.903)
Congenital Cardiac/Circulatory Defects (CC 87-88)	-0.370	0.062	-0.023	0.718	(0.635 – 0.811)
Hypertensive Heart Disease (CC 90)	-0.171	0.028	-0.022	0.853	(0.807 – 0.901)
Specified Heart Arrhythmias (CC 92)	0.518	0.015	0.121	1.622	(1.574 – 1.671)
Cerebral Hemorrhage (CC 95)	0.164	0.048	0.009	1.127	(1.027 – 1.238)
Ischemic or Unspecified Stroke (CC 96)	0.020	0.017	-0.003	0.988	(0.955 – 1.022)
Precerebral Arterial Occlusion and Transient Cerebral Ischemia (CC 97)	-0.194	0.018	-0.045	0.823	(0.794 – 0.852)
Cerebral Atherosclerosis and Aneurysm (CC 98)	-0.217	0.024	-0.032	0.826	(0.788 – 0.865)
Hemiplegia/Hemiparesis (CC 100)	0.071	0.030	0.018	1.159	(1.092 – 1.229)
Comorbid Conditions					
History of Infection (CC 1, 3-6)	0.105	0.016	0.027	1.118	(1.084 – 1.153)
Metastatic Cancer and Acute Leukemia and Other Major Cancers (CC 7-8)	0.957	0.031	0.102	2.679	(2.522 – 2.846)
Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers (CC 9-13)	-0.120	0.017	-0.023	0.907	(0.877 – 0.938)
Protein-Calorie Malnutrition (CC 21)	0.416	0.027	0.050	1.544	(1.464 – 1.627)
Other Significant Endocrine and Metabolic Disorders (CC 22-24)	-0.299	0.016	-0.075	0.734	(0.712 – 0.757)
Other Gastrointestinal Disorders (CC 36)	-0.113	0.015	-0.035	0.881	(0.856 – 0.906)
Disorders of the Vertebrae and Spinal Discs (CC 39)	-0.167	0.020	-0.027	0.878	(0.845 – 0.912)
Osteoarthritis of Hip or Knee (CC 40)	-0.191	0.024	-0.033	0.822	(0.784 – 0.861)
Other Musculoskeletal and Connective Tissue Disorders (CC 43)	-0.143	0.015	-0.038	0.866	(0.841 – 0.892)
Iron Deficiency and Other/Unspecified Anemia and Blood Disease (CC 47)	0.130	0.015	0.033	1.139	(1.105 – 1.174)
Dementia or senility (CC 49-50)	0.203	0.015	0.058	1.265	(1.228 – 1.303)
Major Psychiatric Disorders (CC 54-56)	0.125	0.023	0.019	1.129	(1.080 – 1.180)
Quadriplegia, Other Extensive Paralysis (CC 67-69)	0.338	0.052	0.023	1.440	(1.301 – 1.593)
Multiple Sclerosis (CC 72)	-0.226	0.025	-0.034	0.814	(0.775 – 0.855)
Seizure Disorders and Convulsions (CC 74)	0.255	0.024	0.038	1.303	(1.243 – 1.366)
Hypertension (CC 89, 91)	-0.226	0.020	-0.041	0.799	(0.769 – 0.830)
Peripheral Vascular Disease (CC 104-105)	0.071	0.017	0.021	1.097	(1.062 – 1.133)
Chronic Obstructive Pulmonary Disease (CC 108)	0.080	0.016	0.018	1.081	(1.047 – 1.116)
Pneumonia (CC 111-113)	0.410	0.017	0.088	1.532	(1.480 – 1.585)
Pleural Effusion/Pneumothorax (CC 114)	0.196	0.025	0.025	1.201	(1.145 – 1.261)
Other Eye Disorders (CC 124)	-0.143	0.018	-0.022	0.905	(0.874 – 0.937)
Other Ear, Nose, Throat, and Mouth Disorders (CC 127)	-0.105	0.016	-0.025	0.903	(0.876 – 0.931)
Dialysis Status (CC 130)	0.360	0.049	0.022	1.389	(1.262 – 1.530)

[k] N=181,395 in 4,479 hospitals

[l] Between hospital variance = 0.061; Standard error = 0.0055

Description	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% Confidence Interval
Renal Failure (CC 131)	0.187	0.020	0.035	1.197	(1.151 – 1.244)
Urinary Tract Infection (CC 135)	0.152	0.017	0.033	1.159	(1.121 – 1.198)
Male Genital Disorders (CC 140)	-0.243	0.025	-0.044	0.781	(0.743 – 0.821)
Decubitus Ulcer of Skin (CC 148)	0.219	0.038	0.020	1.282	(1.189 – 1.382)
Chronic Ulcer of Skin, Except Decubitus (CC 149)	0.190	0.027	0.025	1.213	(1.150 – 1.278)
Other Dermatological Disorders (CC 153)	-0.063	0.016	-0.023	0.914	(0.886 – 0.942)

3.1.4 30-Day Mortality Rate Distribution - With and Without Risk-Adjustment

Figure 3 and Figure 4 display the frequency distributions of the hospital-level 30-day mortality rates, with and without risk-standardization in the 2007 development cohort.

The unadjusted mortality rate ranged from 0% to 100% across 4,288 hospitals with a median (quartile range) of 14.9% (10.6%, 19.4%; Figure 3). After adjusting for patient and clinical characteristics, the risk-standardized rates were more normally distributed (Figure 4) with a mean of 15.5%, ranging from 10.7% to 23.5% across 4,288 hospitals. The median adjusted mortality rate is 15.3%.

Figure 3 – Distribution of Unadjusted Hospital-level 30-Day Mortality Rates Following Acute Ischemic Stroke (2007 Development Sample)

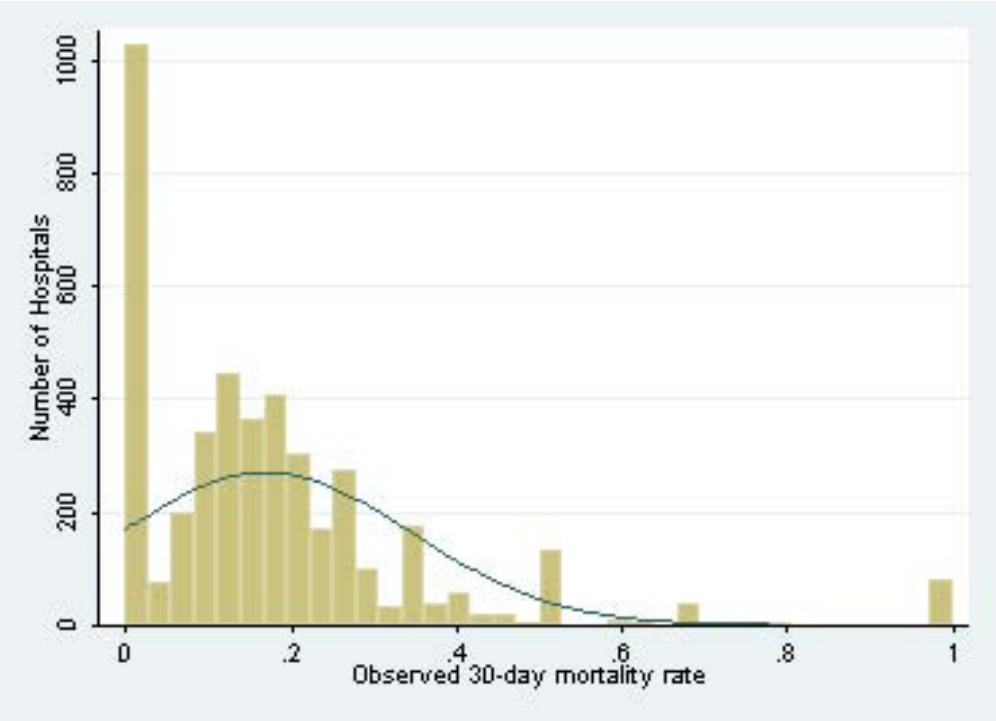
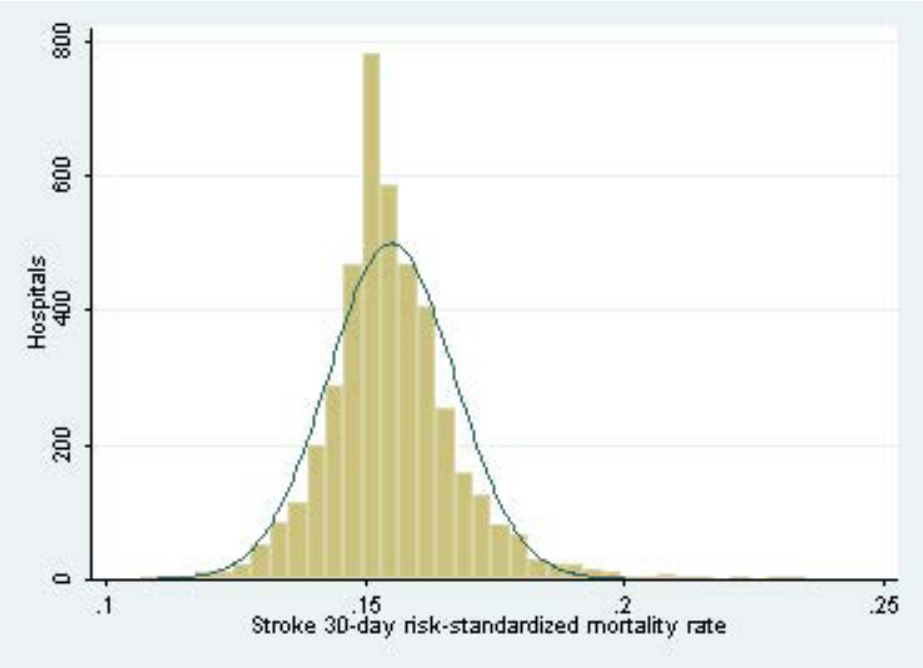


Figure 4 – Distribution of 30-Day Hospital-level RSMRs Following Acute Ischemic Stroke (2007 Development Sample)



3.2 Development of Medical Record Model

We validated the administrative model by comparing it to a medical record model in a matched cohort of admissions for which stroke medical record data and administrative claim data were available. The goal of the medical record validation was to determine if the output of the administrative claims-based measure was similar to that of a measure built from medical record data.

3.2.1 Medical Record Dataset

To build the medical record model, we used the Medicare Health Care Quality Improvement Program's National Stroke Project (NSP) data. The NSP data is medical record-abstracted data that was collected as part of a national quality improvement project. The data comes from a representative population of patients hospitalized with stroke from all states (plus Puerto Rico and the District of Columbia) during March 1, 1998-March 31, 1999 and July 1, 2000-June 30, 2001. Based on the principal discharge diagnosis, up to 750 stroke discharges per state were identified. Two clinical abstraction centers abstracted the corresponding medical records with computerized abstraction tools, and the sample was checked for reliability of abstraction.[15, 16]

3.2.2 Matched Cohort for Medical Record Measurement Development

The cohort of index hospitalizations used to develop the medical record measure consisted of hospitalizations for patients with data in both the medical record dataset (NSP) and administrative claims data. Our inclusion criteria for the matched cohort were consistent with those used in the development of the administrative measure: fee-for-service beneficiaries age 65 years of age or older, hospitalized for acute ischemic stroke (based on principal discharge diagnoses detailed in Table 1). We identified eligible hospitalizations present in both Medicare claims data and the NSP dataset. 38,604 hospitalizations were identified in both data sources. We excluded admissions using criteria consistent with those described for the administrative model development (see Section 2.3.1). However, for the medical-record model we dropped the requirement of 12-months continuous FFS enrollment prior to the index admission and did not exclude on the basis of prior hospice enrollment based on data availability. (The medical record model did adjust for patients that had terminal illness or were classified as comfort care only prior to, or on, the day of admission.)

After exclusion of patients a total of 38,074 cases were in included in the matched cohort for the NSP medical record model. (Table 10) The unadjusted 30-day mortality rate was 15.76%.

Table 10 – Stroke Medical Record Data Study Sample (NSP Dataset)

Data Source	Total[a]	Exclusion (%)				Final Sample
		Transfer	Unreliable Data	Repeat Admissions[b]	Discharged AMA	N
March 1, 1998-March 31, 1999 & July 1, 2000-June 30, 2001	38,604	97 (0.25)	6 (0.02)	530 (1.37)	60 (0.16)	38,074

*Exclusion categories are not mutually exclusive

3.2.3 Medical Record Model Building

To select variables for the model, a team of clinicians and health services researchers reviewed the list of potential candidate variables in the NSP dataset. Based on clinical sensibility, knowledge from the medical literature, and consensus amongst the team, we selected potentially important predictors of mortality. We also identified clinically important variables that should be retained in the model regardless of statistical significance. Next we used a backwards step-wise approach to select the final variables for the model. This

[a] Represents patients 65 and older with the ICD 9 codes that matched in the administrative claims data.
[b] Indicates that we randomly selected one hospitalization for patients with more than one admission.

selection resulted in a final stroke mortality medical record risk-adjusted model that included 32 variables.

Because the medical record dataset included only a limited number of cases from each state, and the sampling frame was at the state level. We did not have the ability to compare the administrative and medical record models at the hospital level. As a result, our comparison was performed at the state level. We have previously successfully validated claims-based measures with medical record measures at the state level. The suitability of the state-level comparison is supported by the fact that there is notable variation in quality and outcomes for stroke among states, as documented in prior research and our findings.[15, 17]

Based on the 38,074 cases with linked administrative and medical record data, we estimated state-specific risk-adjusted 30-day mortality rates. The HGLM model included a random intercept for each state. The performance of the medical record model is shown in Table 11. The corresponding parameter estimates, standardized estimates, and significance levels for the HGLM medical record model and HGLM administrative model in the matched cohort are shown in Table 12 and Table 13, respectively.

Table 11– Stroke Medical Record Model Performance –HGLM

Model	Calibration (γ_0, γ_1)	Discrimination Predictive Ability[p] (lowest decile %, highest decile %)	ROC	Residuals Lack of Fit (Pearson Residual Fall %) <-2	[-2, 0)	[0, 2)	[2+	Model χ^2 [Number of Covariates][o]
Medical Record Model Development Sample (NSP)								
N = 38,074	(0.00, 1.00)	(2.57, 56.53)	0.80	0.28	83.96	9.44	6.32	4892.40 [32]
Linked Administrative Model Sample								
N = 38,074	(0.00, 1.00)	(4.36, 37.14)	0.71	0.01	84.23	7.49	8.28	2477.25 [41]

[o] Wald Chi-Square
[p] Observed Rates

Table 12– Stroke Mortality Medical Record Model– HGLM (State Random Effects)

Variable	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% CI	p-value
Age	0.058	0.002	0.249	1.060	(0.054 - 0.063)	<.0001
Male	0.151	0.033	0.041	1.163	(0.085 - 0.216)	<.0001
History of CVA	0.044	0.033	0.012	1.045	(-0.021 - 0.108)	0.184
History of hemorrhagic CVA	0.132	0.104	0.010	1.141	(-0.071 - 0.336)	0.203
History of atrial fibrillation	0.021	0.047	0.005	1.021	(-0.071 - 0.113)	0.657
History of CHF	0.198	0.041	0.043	1.219	(0.117 - 0.279)	<.0001
History of TIA	-0.216	0.047	-0.042	0.806	(-0.308 - (-0.125))	<.0001
History/current finding of pulmonary edema	0.615	0.064	0.069	1.850	(0.490 - 0.741)	<.0001
History/current finding alcoholism/drug abuse	0.193	0.093	0.018	1.213	(0.011 - 0.375)	0.038
History or current finding of extensive or metastatic cancer	1.031	0.091	0.079	2.803	(0.853 - 1.209)	<.0001
History/Current finding of hypertension	-0.136	0.039	-0.030	0.873	(-0.212 - (-0.060))	0.001
History/current finding Diabetes	0.122	0.035	0.031	1.129	(0.053 - 0.191)	0.001
History/current finding of a heart valve replacement or repair	0.124	0.106	0.010	1.132	(-0.084 - 0.331)	0.243
History/current finding rheumatic/valvular heart disease	-0.555	0.035	-0.150	0.574	(-0.623 - (-0.486))	<.0001
History/Current finding IHD/angina	0.046	0.043	0.013	1.047	(-0.038 - 0.131)	0.283
History/current finding cardiomyopathy	0.107	0.071	0.012	1.113	(-0.032 - 0.245)	0.131
History/Current finding MI	0.169	0.044	0.043	1.184	(0.083 - 0.255)	<.0001
Terminal illness or comfort care on day of arrival	2.020	0.067	0.204	7.535	(1.888 - 2.152)	<.0001
Modified Rankin pre-event = Needs Assistance	-0.043	0.037	-0.011	0.958	(-0.115 - 0.030)	0.249
Modified Rankin pre-event - Dependent	0.795	0.051	0.119	2.215	(0.696 - 0.895)	<.0001
Modified Rankin pre-event - UTD/Missing	1.149	0.143	0.054	3.154	(0.869 - 1.428)	<.0001
Atrial fibrillation on the day of arrival or during stay	0.498	0.045	0.116	1.645	(0.410 - 0.586)	<.0001
Current finding stroke/TIA was anterior circulation event	0.466	0.034	0.117	1.594	(0.400 - 0.533)	<.0001
Current finding of CHF	0.470	0.044	0.092	1.599	(0.383 - 0.556)	<.0001
New/acute hemorrhagic CVA	0.831	0.063	0.093	2.295	(0.707 - 0.954)	<.0001
Visual deficit	0.274	0.040	0.057	1.315	(0.195 - 0.353)	<.0001
Speech deficit	0.069	0.033	0.019	1.072	(0.003 - 0.135)	0.039
Motor deficit	-0.055	0.041	-0.012	0.946	(-0.137 - 0.026)	0.182
Sensory deficit	1.037	0.032	0.274	2.820	(0.973 - 1.100)	<.0001
Systolic blood pressure < 100	2.487	0.359	0.050	12.021	(1.782 - 3.191)	<.0001
Systolic blood pressure 100 to 140	0.350	0.048	0.058	1.420	(0.256 - 0.445)	<.0001
Systolic blood pressure > 220	0.359	0.060	0.049	1.433	(0.241 - 0.478)	<.0001

- Between-state variance = 0.0208; standard error = 0.0068

Table 13 – Stroke Mortality Administrative Model (Matched Cohort: 1998-2001) – HGLM

Variable	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% CI	p-value
Demographics						
Age-65 (continuous)	0.060	0.002	0.256	1.061	(1.057 - 1.066)	<.0001
Male	-0.008	0.031	-0.002	0.992	(0.934 - 1.055)	0.807
Cardiovascular/Cerebrovascular						
Congestive Heart Failure (CC 80)	0.323	0.046	0.060	1.382	(1.263 - 1.512)	<.0001
Valvular and Rheumatic Heart Disease (CC 86)	-0.090	0.043	-0.017	0.914	(0.840 - 0.994)	0.036
Congenital Cardiac/Circulatory Defects (CC 87-88)	-0.363	0.282	-0.012	0.696	(0.400 - 1.209)	0.198
Hypertensive Heart Disease (CC 90)	-0.524	0.093	-0.052	0.592	(0.493 - 0.711)	<.0001
Specified Heart Arrhythmias (CC 92)	0.328	0.044	0.059	1.388	(1.272 - 1.514)	<.0001
Cerebral Hemorrhage (CC 95)	0.367	0.169	0.015	1.444	(1.036 - 2.011)	0.030
Ischemic or Unspecified Stroke (CC 96)	0.094	0.059	0.014	1.099	(0.979 - 1.233)	0.110
Precerebral Arterial Occlusion and Transient Cerebral Ischemia (CC 97)	-0.160	0.070	-0.019	0.852	(0.743 - 0.977)	0.022
Cerebral Atherosclerosis and Aneurysm (CC 98)	-0.216	0.082	-0.022	0.806	(0.686 - 0.947)	0.009
Hemiplegia/Hemiparesis (CC 100)	0.080	0.077	0.009	1.083	(0.931 - 1.260)	0.301
Comorbid Conditions						
History of Infection (CC 1, 3-6)	0.032	0.063	0.004	1.033	(0.912 - 1.170)	0.610
Metastatic Cancer and Acute Leukemia and Other Major Cancers (CC 7-8)	1.016	0.081	0.082	2.762	(2.355 - 3.239)	<.0001
Lymphatic, Head and Neck, Brain, Breast, Colorectal and Other Major Cancers (CC 9-13)	0.013	0.060	0.002	1.013	(0.901 - 1.140)	0.824
Protein-Calorie Malnutrition (CC 21)	0.429	0.069	0.042	1.536	(1.343 - 1.756)	<.0001
Other Significant Endocrine and Metabolic Disorders (CC 22-24)	-0.202	0.033	-0.053	0.817	(0.767 - 0.871)	<.0001
Other Gastrointestinal Disorders (CC 36)	-0.161	0.041	-0.033	0.851	(0.786 - 0.922)	<.0001
Disorders of the Vertebrae and Spinal Discs (CC 39)	-0.437	0.088	-0.046	0.646	(0.543 - 0.768)	<.0001
Osteoarthritis of Hip or Knee (CC 40)	-0.310	0.108	-0.026	0.734	(0.594 - 0.906)	0.004
Other Musculoskeletal and Connective Tissue Disorders (CC 43)	-0.381	0.038	-0.086	0.683	(0.634 - 0.737)	<.0001
Iron Deficiency and Other/Unspecified Anemia and Blood Disease (CC 47)	0.116	0.040	0.023	1.123	(1.039 - 1.214)	0.003
Dementia or senility (CC 49-50)	0.185	0.038	0.037	1.203	(1.117 - 1.296)	<.0001
Major Psychiatric Disorders (CC 54-56)	-0.091	0.091	-0.008	0.913	(0.763 - 1.092)	0.319
Quadriplegia, Other Extensive Paralysis (CC 67-69)	0.969	0.144	0.043	2.635	(1.988 - 3.491)	<.0001
Multiple Sclerosis (CC 72)	-0.382	0.095	-0.037	0.683	(0.567 - 0.822)	<.0001
Seizure Disorders and Convulsions (CC 74)	0.463	0.053	0.063	1.589	(1.433 - 1.762)	<.0001
Hypertension (CC 89, 91)	-0.278	0.030	-0.073	0.758	(0.714 - 0.804)	<.0001
Peripheral Vascular Disease (CC 104-105)	0.230	0.060	0.029	1.258	(1.118 - 1.417)	<.0001
Chronic Obstructive Pulmonary Disease (CC 108)	0.149	0.053	0.022	1.160	(1.046 - 1.287)	0.005
Pneumonia (CC 111-113)	0.625	0.045	0.097	1.868	(1.711 - 2.040)	<.0001
Pleural Effusion/Pneumothorax (CC 114)	0.075	0.105	0.005	1.078	(0.877 - 1.324)	0.478
Other Eye Disorders (CC 124)	-0.071	0.090	-0.006	0.931	(0.781 - 1.110)	0.427
Other Ear, Nose, Throat, and Mouth Disorders (CC 127)	-0.477	0.087	-0.050	0.620	(0.523 - 0.737)	<.0001
Dialysis Status (CC 130)	-0.025	0.197	-0.001	0.975	(0.662 - 1.435)	0.897
Renal Failure (CC 131)	0.474	0.075	0.048	1.606	(1.386 - 1.861)	<.0001

Variable	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% CI	p-value
Urinary Tract Infection (CC 135)	0.231	0.059	0.033	1.260	(1.123 - 1.414)	<.0001
Male Genital Disorders (CC 140)	0.031	0.145	0.002	1.031	(0.776 - 1.371)	0.832
Decubitus Ulcer of Skin (CC 148)[q]	-	-	-	-	-	-
Chronic Ulcer of Skin, Except Decubitus (CC 149)	0.499	0.163	0.020	1.647	(1.197 - 2.266)	0.002
Other Dermatological Disorders (CC 153)	-0.287	0.115	-0.021	0.751	(0.599 - 0.941)	0.013

- Between-state variance = 0.06129; standard error = 0.01562

[q] Due to small sample size the frequency is too low to report

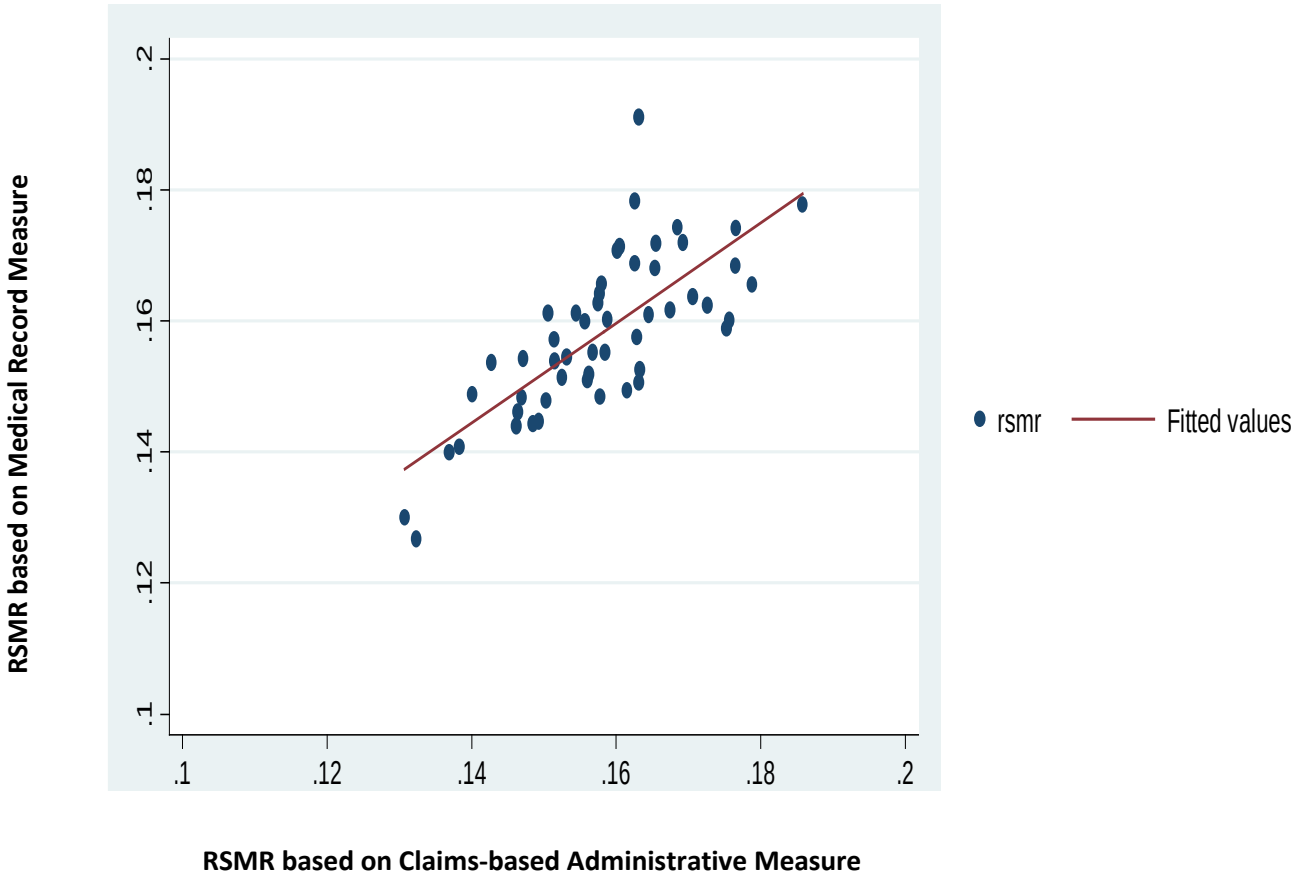
3.3 Comparison of Administrative Model with Medical Record Model

The medical record model showed good discrimination and fit. The area under the ROC curve for the medical record model in the matched cohort was 0.80 and was 0.71 for the administrative model. They were similar with respect to predictive ability. For the administrative model, the predicted mortality rate ranges from 4.36% in the lowest predicted decile to 37.14% in the highest predicted decile, a range of 32.78%. For the medical record model, the corresponding range is wider, 2.57% to 56.83%, a range of 54.26%.

We estimated state-level RSMRs using the corresponding HGLM administrative and medical record models for the matched cohort. We then examined the linear relationship between the two sets of estimates using regression techniques and weighting by the total number of cases in each state. The correlation coefficient of the standardized rates from the administrative and medical record models is 0.75 (Figure 5). While this correlation estimate does not account for the standard errors associated with each point estimate, it does indicate a strong relationship between the two models with respect to the mortality outcome.

In the course of analyzing the state data it became apparent that the medical record data from Puerto Rico showed a different pattern than other states with many covariates showing substantially lower frequencies than any other state. This may be due either to a distinctly different cohort of patients or different documentation practices. In order to understand how these differences might influence our findings we re-ran state-level RSMRs from both models without including index hospitalizations from Puerto Rico. The RSMRs for the states changed very little but the correlation went up to 0.80.

Figure 5 – Correlation of Administrative and Medical Record Models (HGLM) – Standardized 30-Day Stroke Mortality Rates



Correlation coefficient = 0.75

Correlation coefficient without Puerto Rico = 0.80

4. MAIN FINDINGS / SUMMARY

We present a hierarchical logistic regression model for 30-day mortality following hospitalization for ischemic stroke that is based on administrative claims data for FFS Medicare beneficiaries 65 years and older. Our approach to model development and risk adjustment is consistent with quality measure methods recommendations for publicly-reported outcomes measures from NQF, CMS, and the American Heart Association scientific statement.[7] This measure was developed with extensive input from clinical and measurement experts as well as other stakeholders. The study sample is well defined (patients hospitalized with ischemic stroke), and our risk adjustment strategy is statistically rigorous. The use of hierarchical modeling accounts for the clustering of patients within hospitals and differences in sample size across hospitals.

We have tested the measure across multiple years of data and found the results to be consistent. In addition we have compared the output of this measure with one developed with medical record-abstracted data and find a high level of agreement. These characteristics make this outcome measure suitable for public reporting.

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APPENDICES

Appendix A. Potential Complications in the Index Admission for Stroke Models

CC #	Description	Potential Complication in Index Admission
1	HIV/AIDS	
2	Septicemia/Shock	x
3	Central Nervous System Infection	
4	Tuberculosis	
5	Opportunistic Infections	
6	Other Infectious Diseases	x
7	Metastatic Cancer and Acute Leukemia	
8	Lung, Upper Digestive Tract, and Other Severe Cancers	
9	Lymphatic, Head and Neck, Brain, and Other Major Cancers	
10	Breast, Prostate, Colorectal and Other Cancers and Tumors	
11	Other Respiratory and Heart Neoplasms	
12	Other Digestive and Urinary Neoplasms	
13	Other Neoplasms	
14	Benign Neoplasms of Skin, Breast, Eye	
15	Diabetes with Renal or Peripheral Circulatory Manifestation	
16	Diabetes with Neurologic or Other Specified Manifestation	
17	Diabetes with Acute Complications	x
18	Diabetes with Ophthalmologic or Unspecified Manifestation	
19	Diabetes without Complication	
20	Type I Diabetes Mellitus	
21	Protein-Calorie Malnutrition	
22	Other Significant Endocrine and Metabolic Disorders	
23	Disorders of Fluid/Electrolyte/Acid-Base Balance	x
24	Other Endocrine/Metabolic/Nutritional Disorders	
25	End-Stage Liver Disease	
26	Cirrhosis of Liver	
27	Chronic Hepatitis	
28	Acute Liver Failure/Disease	x
29	Other Hepatitis and Liver Disease	
30	Gallbladder and Biliary Tract Disorders	
31	Intestinal Obstruction/Perforation	x
32	Pancreatic Disease	
33	Inflammatory Bowel Disease	
34	Peptic Ulcer, Hemorrhage, Other Specified Gastrointestinal Disorders	x
35	Appendicitis	
36	Other Gastrointestinal Disorders	
37	Bone/Joint/Muscle Infections/Necrosis	
38	Rheumatoid Arthritis and Inflammatory Connective Tissue Disease	
39	Disorders of the Vertebrae and Spinal Discs	
40	Osteoarthritis of Hip or Knee	
41	Osteoporosis and Other Bone/Cartilage Disorders	
42	Congenital/Developmental Skeletal and Connective Tissue Disorders	
43	Other Musculoskeletal and Connective Tissue Disorders	
44	Severe Hematological Disorders	
45	Disorders of Immunity	
46	Coagulation Defects and Other Specified Hematological Disorders	x
47	Iron Deficiency and Other/Unspecified Anemias and Blood Disease	
48	Delirium and Encephalopathy	x

CC #	Description	otential Complication in Index Admission
49	Dementia/Cerebral Degeneration	
50	Nonpsychotic Organic Brain Syndromes/Conditions	
51	Drug/Alcohol Psychosis	
52	Drug/Alcohol Dependence	
53	Drug/Alcohol Abuse, Without Dependence	
54	Schizophrenia	
55	Major Depressive, Bipolar, and Paranoid Disorders	
56	Reactive and Unspecified Psychosis	
57	Personality Disorders	
58	Depression	
59	Anxiety Disorders	
60	Other Psychiatric Disorders	
61	Profound Mental Retardation/Developmental Disability	
62	Severe Mental Retardation/Developmental Disability	
63	Moderate Mental Retardation/Developmental Disability	
64	Mild Mental Retardation, Autism, Downs Syndrome	
65	Other Developmental Disability	
67	Quadriplegia, Other Extensive Paralysis	
68	Paraplegia	
69	Spinal Cord Disorders/Injuries	
70	Muscular Dystrophy	
71	Polyneuropathy	
72	Multiple Sclerosis	
73	Parkinsons and Huntingtons Diseases	
74	Seizure Disorders and Convulsions	
75	Coma, Brain Compression/Anoxic Damage	x
76	Mononeuropathy, Other Neurological Conditions/Injuries	
77	Respirator Dependence/Tracheostomy Status	x
78	Respiratory Arrest	x
79	Cardio-Respiratory Failure and Shock	x
80	Congestive Heart Failure	x
81	Acute Myocardial Infarction	x
82	Unstable Angina and Other Acute Ischemic Heart Disease	x
83	Angina Pectoris/Old Myocardial Infarction	
84	Coronary Atherosclerosis/Other Chronic Ischemic Heart Disease	
85	Heart Infection/Inflammation, Except Rheumatic	
86	Valvular and Rheumatic Heart Disease	
87	Major Congenital Cardiac/Circulatory Defect	
88	Other Congenital Heart/Circulatory Disease	
89	Hypertensive Heart and Renal Disease or Encephalopathy	
90	Hypertensive Heart Disease	
91	Hypertension	
92	Specified Heart Arrhythmias	x
93	Other Heart Rhythm and Conduction Disorders	x
94	Other and Unspecified Heart Disease	
95	Cerebral Hemorrhage	x
96	Ischemic or Unspecified Stroke	x
97	Precerebral Arterial Occlusion and Transient Cerebral Ischemia	x
98	Cerebral Atherosclerosis and Aneurysm	
99	Cerebrovascular Disease, Unspecified	
100	Hemiplegia/Hemiparesis	x
101	Cerebral Palsy and Other Paralytic Syndromes	x
102	Speech, Language, Cognitive, Perceptual Deficits	x

CC #	Description	otential Complication in Index Admission
103	Cerebrovascular Disease Late Effects, Unspecified	
104	Vascular Disease with Complications	x
105	Vascular Disease	x
106	Other Circulatory Disease	x
107	Cystic Fibrosis	
108	Chronic Obstructive Pulmonary Disease	
109	Fibrosis of Lung and Other Chronic Lung Disorders	
110	Asthma	
111	Aspiration and Specified Bacterial Pneumonias	x
112	Pneumococcal Pneumonia, Empyema, Lung Abscess	x
113	Viral and Unspecified Pneumonia, Pleurisy	
114	Pleural Effusion/Pneumothorax	x
115	Other Lung Disorders	
116	Legally Blind	
117	Major Eye Infections/Inflammations	
118	Retinal Detachment	
119	Proliferative Diabetic Retinopathy and Vitreous Hemorrhage	
120	Diabetic and Other Vascular Retinopathies	
121	Retinal Disorders, Except Detachment and Vascular Retinopathies	
122	Glaucoma	
124	Other Eye Disorders	x
125	Significant Ear, Nose, and Throat Disorders	
126	Hearing Loss	
127	Other Ear, Nose, Throat, and Mouth Disorders	
128	Kidney Transplant Status	
130	Dialysis Status	x
131	Renal Failure	x
132	Nephritis	x
133	Urinary Obstruction and Retention	x
134	Incontinence	
135	Urinary Tract Infection	x
136	Other Urinary Tract Disorders	
138	Pelvic Inflammatory Disease & Other Specified Female Genital Disorders	
139	Other Female Genital Disorders	
140	Male Genital Disorders	
148	Decubitus Ulcer of Skin	x
149	Chronic Ulcer of Skin, Except Decubitus	
150	Extensive Third-Degree Burns	
151	Other Third-Degree and Extensive Burns	
152	Cellulitis, Local Skin Infection	x
153	Other Dermatological Disorders	
154	Severe Head Injury	x
155	Major Head Injury	x
156	Concussion or Unspecified Head Injury	x
157	Vertebral Fractures without Spinal Cord Injury	
158	Hip Fracture/Dislocation	x
159	Major Fracture, Except of Skull, Vertebrae, or Hip	x
160	Internal Injuries	
161	Traumatic Amputation	
162	Other Injuries	
163	Poisonings and Allergic Reactions	x
164	Major Complications of Medical Care and Trauma	x
165	Other Complications of Medical Care	x

CC #	Description	otential Complication in Index Admission
166	Major Symptoms, Abnormalities	x
167	Minor Symptoms, Signs, Findings	
174	Major Organ Transplant Status	x
175	Other Organ Transplant/Replacement	x
177	Amputation Status, Lower Limb/Amputation Complications	x
178	Amputation Status, Upper Limb	x

Appendix B. Technical Expert Panel Member Roster

Name	Title	Organization	Area of Expertise
Joseph V. Agostini, M.D.	Medical Director	Aetna	Purchaser Perspective
Mark J. Alberts, M.D.	Professor of Neurology; Director, Stroke Program	Northwestern University Feinburg School of Medicine	Topic Knowledge
William Bloom	Stroke Survivor	N/A	Consumer Perspective
Mary George, M.D., M.S.P.H.	Medical Officer, Division for Heart Disease and Stroke Prevention	Centers for Disease Control and Prevention	Performance Management
Robert Holloway, M.D., M.P.H.	Professor of Neurology	University of Rochester Medical Center	Performance Measurement/ Topic Knowledge
Irene Katzan, M.D., M.S.	Director, Neurological Institute Center for Outcomes Research & Evaluation	Cleveland Clinic	Performance Management
Dawn Kleindorfer, M.D.	Associate Professor	University of Cincinnati	Health Care Disparities/ Topic Knowledge
Elaine Miller, Ph.D., R.N.	Professor of Nursing; Editor, Rehabilitation Nursing	Association of Rehabilitation Nurses	Topic Knowledge
Mathew Reeves, Ph.D.	Associate Professor	Michigan State University / P.I. MASCOTS Program (Stroke Registry and Quality Improvement)	Quality Improvement/ Topic Knowledge
Joseph Schindler, M.D.	Assistant Professor of Neurology and Neurosurgery; Clinical Director of Stroke Program	Yale New Haven Stroke Center	Topic Knowledge
Kevin Tabb, M.D.	Chief Medical Officer	Stanford Hospital and Clinics	Quality Improvement/ Consumer Perspective
Linda Williams, M.D. *	Associate Professor of Neurology; Research Coordinator, VA Stroke QUERI	Roudebush VAMC, Indiana University School of Medicine	Quality Improvement

*TEP Chair

Appendix C. Working Group Member Roster

Name	Title/Affiliation
Dawn Bravata, MD	• Associate Professor of Medicine & Adjunct Professor of Neurology, Indiana University School of Medicine
Pierre Fayad, MD, FAHA, FAAN	• Reynolds Centennial Professor & Chairman, Department of Neurological Sciences • Director, Stroke Center, The Nebraska Medical Center • Chairman, American Stroke Association Advisory Committee
Larry Goldstein, MD, FAAN, FAHA	• Professor of Medicine (Neurology), Duke University Medical Center • Director, Duke Stroke Center
Ralph Sacco, MD, MS, FAHA, FAAN	• Professor and Chairman, Department of Neurology, Miller School of Medicine, University of Miami • President, American Heart Association
Lee Schwamm, MD, FAHA	• Associate Professor of Neurology, Harvard Medical School • Vice Chairman, Department of Neurology