Hospital 30-Day Readmission Following Acute Ischemic Stroke Hospitalization Measure

Measure Methodology Report

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Rosters with more detailed information about working group and Technical Expert Panel member can be found in Appendices B and C.

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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, and stroke survivors frequently experience significant disability and increased dependence on the healthcare system.[1] Moreover, stroke is one of the top 20 conditions contributing to Medicare costs.[2] Improvements in the quality of care for patients experiencing a stroke, therefore, have the potential to lead to both substantial improvements in patient quality of life and lower overall health care expenditures.

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 that reflect 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 readmission 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 admission across hospitals, we estimated risk-standardized readmission rates (RSRRs) with hierarchical logistic regression models. The overall methodological approach for this measure is consistent with that used to develop three prior CMS readmission measures that the National Quality Forum (NQF) approved, which CMS now publicly reports on Hospital Compare. We developed this measure in parallel with a hospital measure of mortality following acute ischemic stroke. The methodology and results of the mortality measure are detailed in a separate report.

The goal of this work is to improve patient outcomes by providing patients, physicians, and hospitals with information about hospital-level, risk-standardized readmission rates following hospitalization for acute ischemic stroke.

1.2 Readmission after Stroke as a Quality Measure

Ischemic stroke affects hundreds of thousands of adults in the U.S. each year and leaves many with new disability and at increased risk for complications, recurrent stroke and clinical deterioration. Approximately 10% of stroke survivors will have a recurrent stroke within a year and one out of four stroke patients will be readmitted to the hospital.[3-5]

Hospital readmission, for any reason, is disruptive to patients and caregivers, costly to the healthcare system, and puts patients at additional risk of hospital acquired infections and complications. Hospital readmissions after stroke may result from the progression of disease, but may also be an indicator of poor care. Research has shown that readmission rates are influenced by the quality of inpatient and outpatient care, and that improvements in care, such as improved discharge processes, can reduce readmission rates.[6-8] Given the high risk of readmission for patients following an ischemic stroke, measurement and reporting of stroke readmission rates will inform health care providers about opportunities to improve care and will strengthen incentives for quality improvement. Improved quality of stroke care has the potential to reduce readmissions, lower the cost of care associated with those readmissions, and improve patient 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's scientific statement "Standards for Statistical Models Used for Public Reporting of Health Outcomes."[9] Throughout the process of developing this measure, 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 (such as defining the appropriate measure cohort and excluding planned readmissions) 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 held three TEP conference calls during the course of measure development. In contrast to the working group meetings, each TEP call 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 posted the measure specifications, widely distributed a call for public comments, and collected public comments through the Measure Management System Web site (https://www.cms.hhs.gov/apps/QMIS/publicComment.asp). We summarized the public comments 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 readmission following hospitalization for acute ischemic stroke. The measure is a 30-day, all-cause risk-standardized rate of readmission to 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 to develop the measure. The datasets also include data on each patient for the 12 months prior to the index admission and the 30 days following discharge. 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 data 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 readmission using the National Stroke Project dataset, a nationally representative cohort of stroke patients using data abstracted from medical records. We then compared the administrative model performance and the medical-record model performance in a matched cohort of patients with data in both datasets. We compared the output 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 3.2.

2.2 Outcome

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

2.2.1 Accounting for Planned Readmissions

We did not count planned readmissions in the measure. Specifically, readmissions to a hospital that are scheduled for the purpose of a planned follow-up procedure, such as carotid endarterectomy, and that are not associated with a recurrent stroke are not counted as readmissions in this measure. The rationale for this exclusion is that physicians caring for stroke patients may opt to perform these procedures as a continuation of treatment for the stroke after discharge from the index admission. We defined planned readmissions as readmissions for any of the procedures listed in Table 1, unless acute stroke is listed as a principal discharge diagnosis code (ICD-9 433.x1, 434.x1, and 436), suggesting the readmission is for a recurrent stroke. This approach to planned readmissions is consistent with that used by the NQF-approved acute myocardial infarction (AMI) readmission measure.

Table 1 – Procedures Codes Used to Identify Planned Readmissions

Procedure[a]	Procedure Code
Carotid Endarterectomy	38.12
Carotid Stenting	00.63
Percutaneous Carotid Stenting	00.61
Intracranial and Inter-vertebral Stenting	00.64, 00.65
Patent Foramen Ovale Closure	35.51, 35.52, 35.61, 35.71
Ablation	37.33, 37.34
Aortic or Mitral Valve Replacement	35.21, 35.22, 35.23, 35.24
Cranioplasty	02.01, 02.02, 02.03, 02.04, 02.05, 02.06, 02.07

[a] Considered as planned readmissions unless the principal discharge diagnosis was ICD-9 433.x1, 434.x1, or 436

2.2.2 30-Day Timeframe

We selected the outcome timeframe of 30 days because this is a timeframe in which a readmission may reasonably be attributed to care during the hospitalization and the transitional period to a non-acute setting. A number of studies have demonstrated that improvements in care at the time of patient discharge can reduce 30-day readmission rates.[6, 10, 11] Hospitals, in collaboration with their medical communities, can take actions to reduce readmissions, such as: ensure patients are clinically ready at discharge; reduce risk of infection; reconcile medications; improve communication among providers at transitions of care; encourage strategies that promote disease management principles; and educate patients on what symptoms to monitor, whom to contact with questions, and the way to seek follow-up care. [7, 10, 12-14] Such initiatives are likely to reduce 30-day readmissions.

2.2.3 All-Cause Readmission

We measured all-cause readmission (excluding the planned readmissions listed in Table 1) rather than stroke-specific readmissions for several reasons. First, from the patient perspective, readmission for any reason is likely to be an undesirable outcome of care, even though not all readmissions are preventable. Second, limiting the measure to stroke-related readmissions 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 overall at improving the care within the hospital and transitions from the hospital setting. Moreover, it is often hard to exclude quality issues and accountability based on the documented cause of readmission. For example, a stroke patient who develops aspiration pneumonia may ultimately be readmitted for respiratory distress. It would be inappropriate to treat this readmission as unrelated to the care the patient received for stroke. In addition, the range of potentially avoidable readmissions also includes those not directly related to stroke, such as those resulting from poor communication at discharge or inadequate follow-up post-discharge. As such, creating a comprehensive list of potential stroke-related complications would be arbitrary and, ultimately, challenging to implement. The goal of this measure is not to reduce readmissions to zero, but to assess hospital performance relative to what is expected given the performance of other hospitals with similar case mixes.

2.2.4 Handling of Deaths Without a Readmission

The current measure focuses on 30-day readmission and not death. If a patient dies within 30 days post-discharge without a readmission, we coded the outcome as no readmission. This has the effect of counting such a death as “no

event" outcome. In 15,060 index cases (8.65% of full 2007 cohort), the patient died within 30 days without being readmitted. Given our approach, this stroke readmission measure is best reported concurrently with the paired mortality measure for stroke so that deaths following an ischemic stroke are fully reflected in quality measurement efforts.

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.[15] 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 the 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 2 to define the cohort.

Table 2 – 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) In-hospital Deaths. Admissions for patients with in-hospital deaths are excluded.
   Rationale: Patients who die during the initial hospitalization are not eligible for readmission.

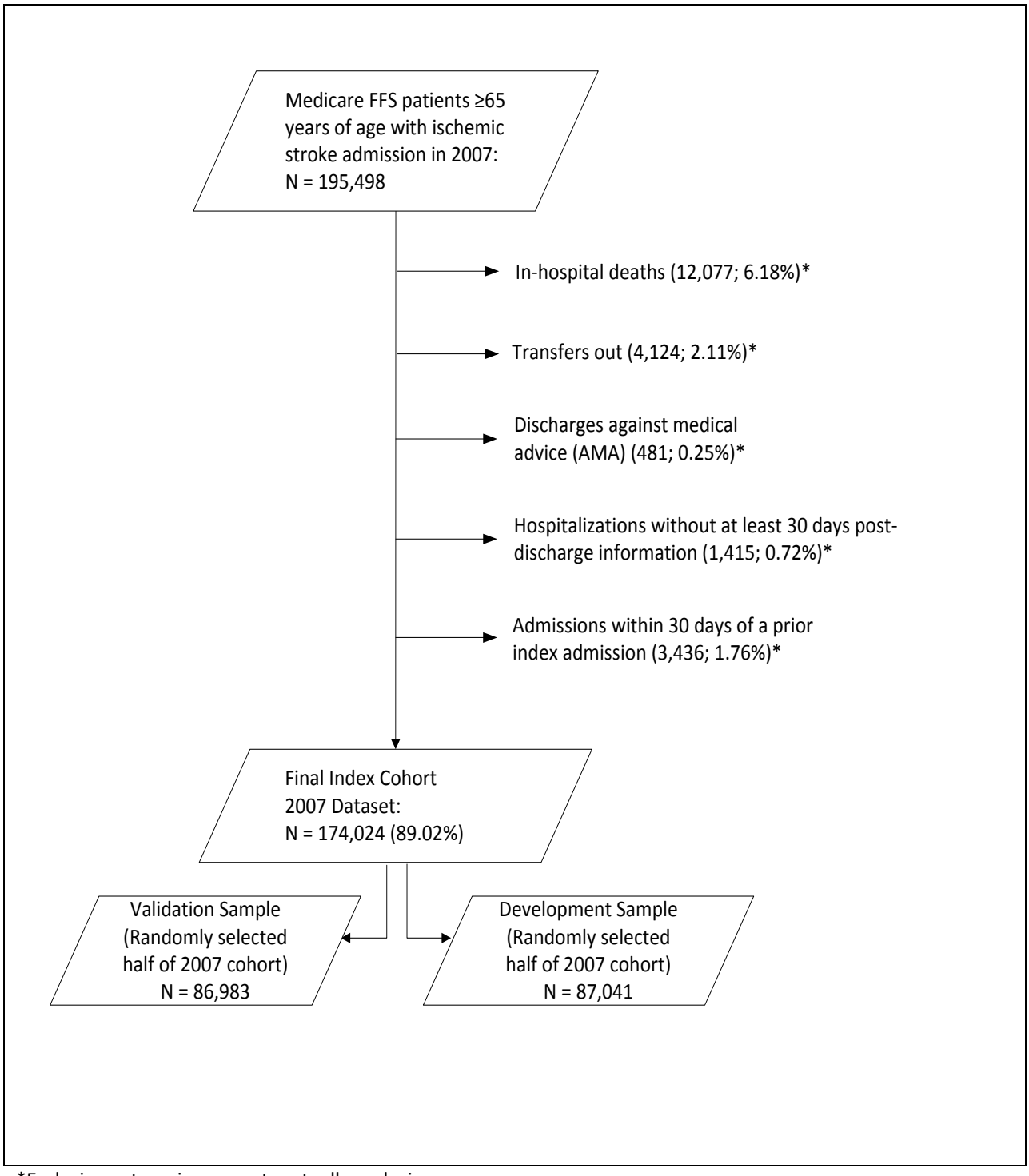
2) Transfer patients. Admissions for patients having a principal diagnosis of stroke during the index hospitalization and subsequently transferred to another acute care facility are excluded.
   Rationale: We exclude hospitalizations that result in a transfer to another acute care facility because the measure's focus is on hospitals that discharge patients to a non-acute setting (e.g. to home or a skilled nursing facility).

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

4) Without at Least 30 Days Post-Discharge Information. Admissions for patients without at least 30-days post-discharge enrollment in Medicare FFS are excluded.
   Rationale: We exclude these admissions because the 30-day readmission outcome cannot be assessed in this group.

5) Additional Stroke Admissions within 30 Days. Additional stroke admissions for patients within 30 days of discharge from an index stroke admission will be considered readmissions and not additional index admissions.
   Rationale: No admission is counted both as a readmission and an index admission. The next eligible admission after the 30-day time period following an index admission will be considered another index admission.

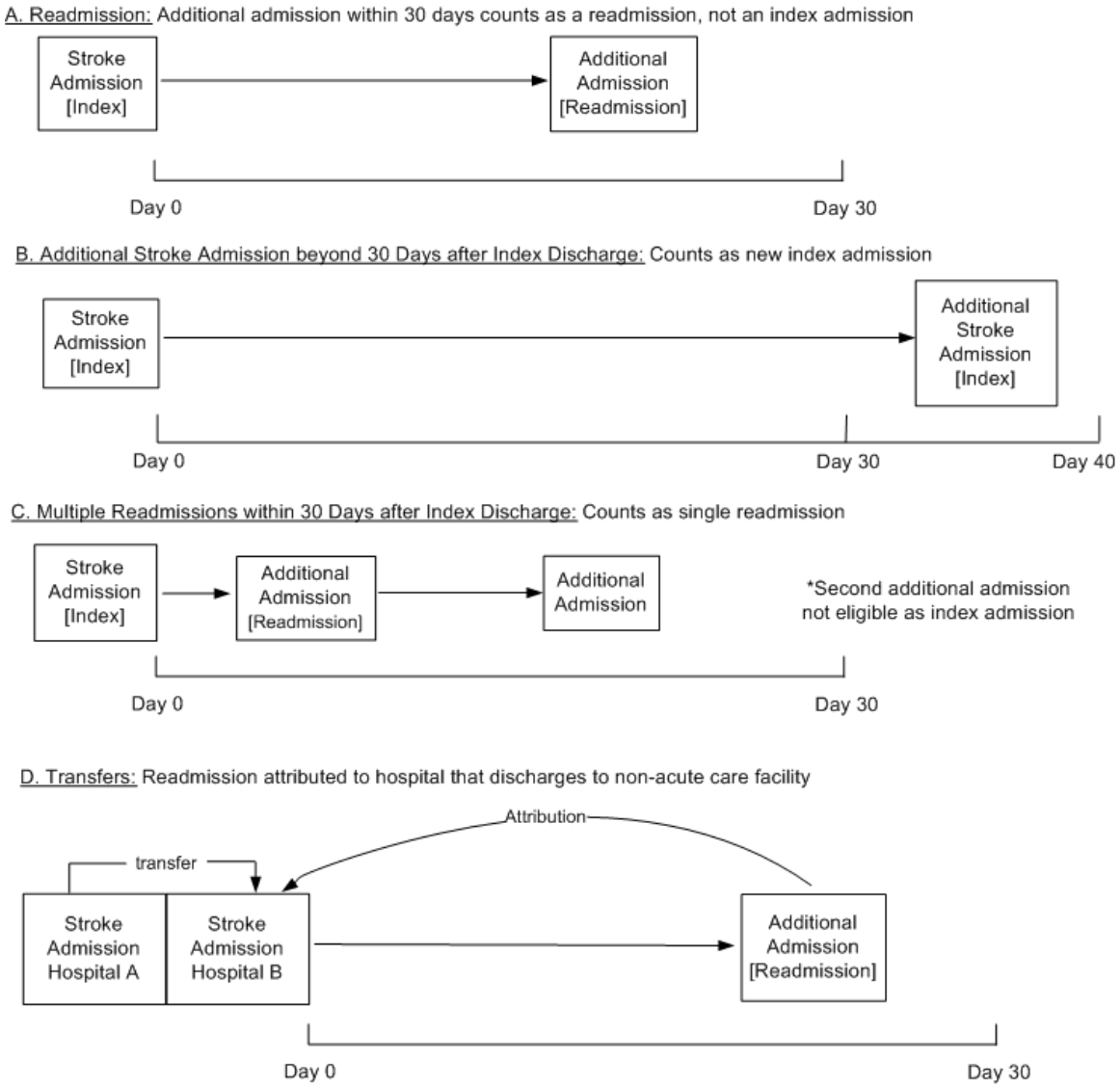
Figure 1 – Cohort for Model Development



*Exclusion categories are not mutually exclusive

Figure 2 below demonstrates how subsequent admissions following an ischemic stroke admission are attributed. Importantly, no hospitalization is counted as both a readmission and index admission. If a patient has one or more admissions within 30 days of discharge from the index admission, only one is counted as a readmission.

Figure 2 – 30-Day Stroke Readmission Outcome Attribution



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 the purposes of this project, Part A is used to refer to inpatient services only and includes data from three 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").
c. Post-index admission: Post 30-day hospitalization from the discharge date of an index hospitalization.

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 the purposes of this project, Part B services included only face-to-face encounters between a care provider and patient. Thus, we 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

The NSP dataset is medical record-abstracted data from a nationally-representative population of patients hospitalized with stroke. The NSP data were collected as part of a quality improvement organization (QIO) collaboration between 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"). The performance of the model was then evaluated 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 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 and administrative data). We developed a medical record model in the matched cohort and then compared the risk-standardized readmission 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 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 randomly selected half of the 2007 cohort for the development sample. The development cohort consisted of 87,041 index admissions at 4,242 hospitals, with an overall unadjusted 30-day readmission rate of 14.8%.

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 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 (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.[16] 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 of the 189 CC variables. A total of 123 CCs determined to be clinically relevant to the readmission outcome were included for consideration. We further combined some CCs into clinically coherent groupings. Our set of candidate variables (Table 3) therefore included 74 CC-based variables and two demographic variables (age and gender).

For each CC, the team determined whether the 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 as possible complications is presented in Appendix A.

To inform final variable selection, a modified approach to stepwise logistic regression was performed. The development dataset was used to create 1000 bootstrap samples. For each sample, we ran a logistic stepwise regression, with both backward and forward selection, that included the 76 candidate variables. The results were summarized to show the percentage of times that each of the candidate variables was significantly associated with readmission (at the $p<0.001$ level) in each of the 1000 repeated samples (e.g., 80 percent would mean that a 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 70% cutoff, since they demonstrated a relatively strong association with readmission and were clinically relevant (18 variables). Variables selected in less than 70% of the bootstrap samples were also included in the final model if:

1) they were markers for end of life/frailty:

- Decubitus ulcer or chronic skin ulcer
- Dementia and senility

2) certain hospitals might have a disproportionate share of patients with the condition:

- Cancer

3) they were clinically important to include (based on consultation with clinical experts)

- Cerebral hemorrhage
- Precerebral Arterial Occlusion and Transient Cerebral Ischemia
- Ischemic or unspecified stroke
- Hemiplegia, paraplegia, paralysis, functional disability
- Quadriplegia, paraplegia, functional disability

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 27 variables. Table 4 lists the final model variables.

Table 3 – Stroke Readmission Model Candidate Variables

Category	Variable	CC
Demographics	Age-65 (continuous)	
	Gender (Male)	
Cardiovascular/	Cardio-Respiratory Failure and Shock	CC 79
Cerebrovascular	Congestive Heart Failure	CC 80
	Acute Coronary Syndrome	CC 81-82
	Chronic Atherosclerosis	CC 83-84
	Valvular and Rheumatic Heart Disease	CC 86
	Hypertensive heart disease	CC 90
	Arrhythmias	CC 92, 93
	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, paraplegia, paralysis, functional disability	CC 100-102
	Cerebrovascular Disease Late Effects, Unspecified	CC 103
Comorbidities	History of Infection	CC 1, 3-6
	Septicemia/shock	CC 2
	Metastatic cancer and acute leukemia	CC 7
	Cancer	CC 8-12
	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
	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
	Other Musculoskeletal and Connective Tissue Disorders	CC 43
	Severe Hematological Disorders	CC 44
	Disorders of Immunity	CC 45
	Coagulation Defects and Other Specified Hematological Disorders	CC 46
	Iron Deficiency and Other/Unspecified Anemias and Blood Disease	CC 47
	Delirium and Encephalopathy	CC 48
	Dementia and senility	CC 49, 50
	Drug/alcohol abuse/dependence/psychosis	CC 51-53
	Major psych disorders	CC 54-56
	Depression	CC 58
	Other psychiatric disorders	CC 60
	Quadriplegia, paraplegia, functional disability	CC 67-69, 177-178
	Polyneuropathy	CC 71
	Seizure Disorders and Convulsions	CC 74
	Mononeuropathy, Other Neurological Conditions/Injuries	CC 76

Category	Variable	CC
	Heart Infection/Inflammation, Except Rheumatic	CC 85
	Congenital cardiac/circulatory defect	CC 87, 88
	Hypertension	CC 89, 91
	Other and Unspecified Heart Disease	CC 94
	Vascular or circulatory disease	CC 104-106
	COPD	CC 108
	Fibrosis of lung or other chronic lung disorder	CC 109
	Asthma	CC 110
	Pneumonia	CC 111-113
	Pleural effusion/pneumothorax	CC 114
	Other lung disorder	CC 115
	End-stage renal disease or dialysis	CC 129, 130
	Renal Failure	CC 131
	Nephritis	CC 132
	Urinary Obstruction and Retention	CC 133
	Urinary Tract Infection	CC 135
	Other urinary tract disorders	CC 136
	Male genital disorders	CC 140
	Decubitus ulcer or chronic skin ulcer	CC 148, 149
	Cellulitis, Local Skin Infection	CC 152
	Trauma	CC 154-156, 158-161
	Vertebral Fractures	CC 157
	Other Injuries	CC 162
	Poisonings 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

Table 4 – Final Stroke Readmission Model Variables

Category	Variable	CCs
Demographic	Age-65 (continuous)	
	Male	
Cardiovascular/ Cerebrovascular	Congestive Heart Failure	CC 80
	Hypertensive heart disease	CC 90
	Cerebral Hemorrhage	CC 95
	Ischemic or Unspecified Stroke	CC 96
	Cerebrovascular Disease	CC 97
	Hemiplegia, paraplegia, paralysis, functional disability	CC 100-102
Comorbidities	Metastatic cancer and acute leukemia	CC 7
	Cancer	CC 8-12
	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
	Severe Hematological Disorders	CC 44
	Iron Deficiency and Other/Unspecified Anemias and Blood Disease	CC 47
	Dementia and senility	CC 49-50
	Quadriplegia, paraplegia, functional disability	CC 67-69, 177-178
	Seizure Disorders and Convulsions	CC 74
	Vascular or circulatory disease	CC 104-106
	COPD	CC 108
	Other lung disorder	CC 115
	End-stage renal disease or dialysis	CC 130
	Renal Failure	CC 131
	Other urinary tract disorders	CC 136
	Decubitus ulcer or chronic skin ulcer	CC 148-149
	Major Symptoms, Abnormalities	CC 166

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 readmission within 30 days of discharge from an index ischemic stroke admission as a function of 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 RSRRs. These rates are calculated as the ratio of predicted number of readmissions to expected number of readmissions, multiplied by the national unadjusted readmission rate. The expected number of readmissions for each hospital is estimated using its patient mix and the average hospital-specific intercept. The predicted number of readmissions in each hospital was estimated given the same patient mix but an estimated hospital-specific intercept. Operationally, the expected number of readmissions for each hospital is obtained by summing the expected readmission rates for all patients in the hospital. The expected readmission rate for each patient is calculated via the hierarchical model by applying the subsequent estimated regression coefficients to the observed patient characteristics and adding the average of the hospital-specific intercepts.

The predicted number of readmissions for each hospital is 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 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.[17] Let Y_{ij} denote the outcome (equal to 1 if patient readmitted 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,

$$\text{HGLM} \qquad h(Y_{ij}) = \alpha_i + \beta \mathbf{Z}_{ij} \qquad (2)$$

$$\alpha_i = \mu + \omega_i; \qquad \omega_i \sim N(0, \tau^2) \qquad (3)$$

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.[18] 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 readmissions to the number of expected readmissions, multiplied by the unadjusted overall readmission rate, $\bar{y}$. Specifically, we calculate

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

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

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

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) (See Figure 3 for analysis steps).

2.9.1 Creating Interval Estimates

Because the statistic described in Equation 6 (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, $\{\hat{\alpha}_i^{(b)}, \hat{\text{var}}\left(\alpha_i^{(b)}\right); i = 1,2,\ldots,I\}$.

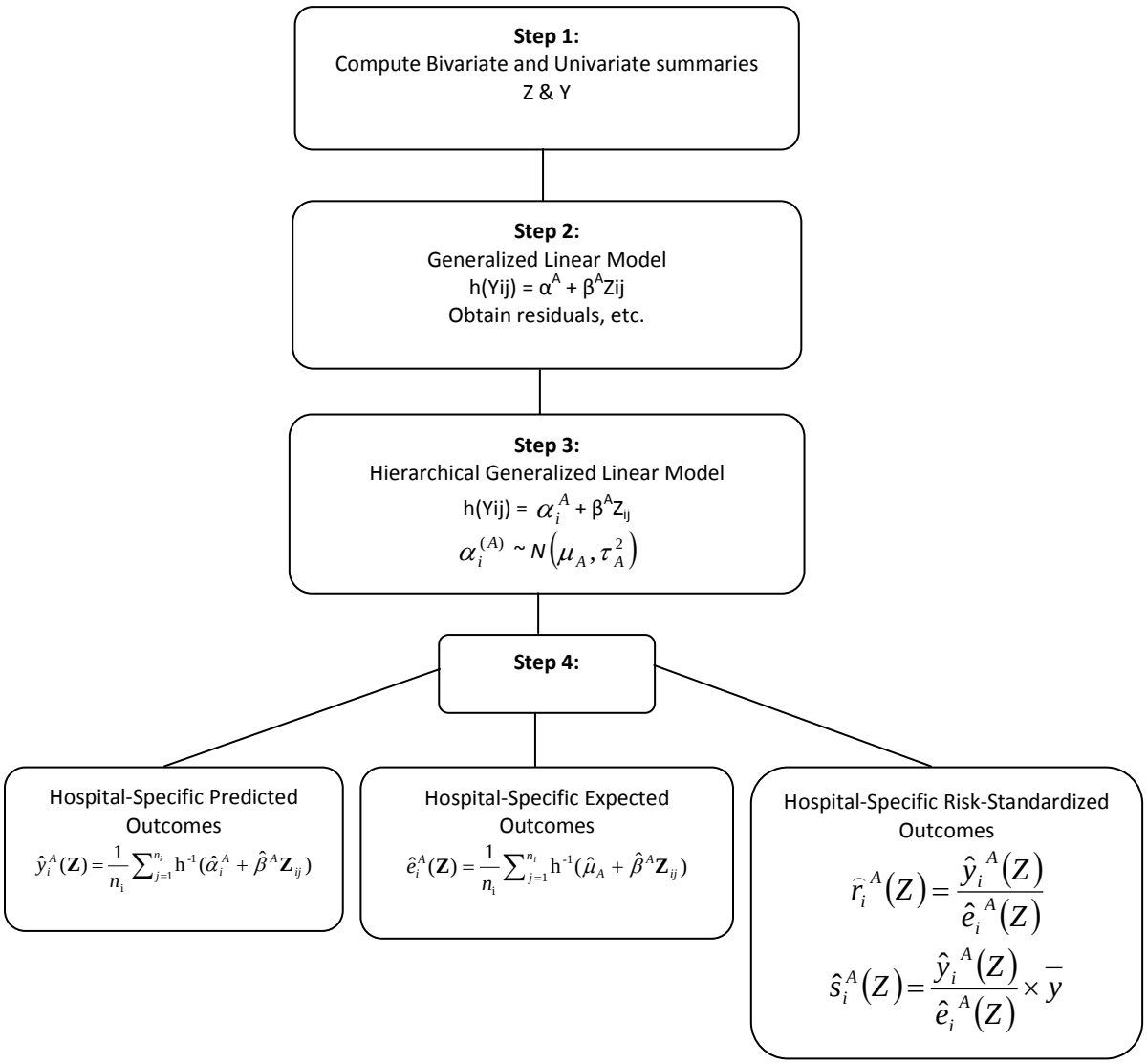
3. We generate a hospital random effect by sampling from the distribution of the hospital-specific distribution obtained in Step 2c. We approximate the distribution for each random effect by a normal distribution. Thus, we draw $\alpha_i^{(b*)} \sim N\left(\hat{\alpha}_i^{(b)}, \hat{\text{var}}\left(\hat{\alpha}_i^{(b)}\right)\right)$ 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 estimates (or the percentiles corresponding to the alternative desired intervals).[19]

Figure 3 – Analysis Steps



3. RESULTS

3.1 Model Results

3.1.1 Developmental Sample

The variable descriptions, standardized estimates, and standard errors for the HGLM model are shown in Table 5. 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.[b]

3.1.2 Model Performance

We computed five summary statistics for assessing model performance[20]: over-fitting indices[c], predictive ability, area under the receiver operating characteristic (ROC) curve, distribution of residuals, and model chi-square[d] (see Table 7).

The development model has good discrimination and fit. The readmission rate ranges from 8.4% in the lowest predicted decile to 24.7% in the highest predicted decile, a range of 16.3%. The area under the ROC curve is 0.602.

Readmissions are inherently more difficult to predict than mortality based on patient characteristics alone, since the risk of readmission is affected by system factors such as discharge practices and bed availability and local practice patterns as well as patient characteristics. In addition, we did not consider covariates such as potential complications, certain patient demographics (e.g., race), and patients' admission paths (e.g., outpatient, emergency department), and discharge destination (e.g. discharged to home versus other facilities, both

[b] We compute standardized estimates in order to compare the size of the coefficients by standardizing the coefficients to be unitless. We used the following equation to computer the standardized estimate,

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

[c] 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.

[d] 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)

non-acute and acute care). These characteristics may be associated with readmission and thus could increase the model performance to predict patient readmission. However, these variables may be related to quality or supply factors that should not be included in an adjustment that seeks to control solely for patient clinical characteristics.

Table 5 – 30-Day Readmission Administrative Model (2007 Development Sample-HGLM Results)[ef]

Description	Estimates	Standard Error	Standardized Estimates	Odds Ratio	95% Confidence Interval
Demographics					
Age-65 (continuous)	0.006	0.001	0.024	1.006	(1.003 - 1.008)
Male	0.074	0.020	0.020	1.077	(1.035 - 1.120)
Cardiovascular/Cerebrovascular					
Congestive Heart Failure (CC 80)	0.203	0.023	0.049	1.225	(1.171 - 1.282)
Hypertensive heart disease (CC 90)	0.121	0.036	0.017	1.128	(1.052 - 1.210)
Cerebral Hemorrhage (CC 95)	0.134	0.064	0.010	1.143	(1.008 - 1.296)
Ischemic or Unspecified Stroke (CC 96)	0.051	0.024	0.013	1.053	(1.004 - 1.104)
Cerebrovascular Disease (CC 97)	0.013	0.024	0.003	1.013	(0.967 - 1.062)
Hemiplegia, paraplegia, paralysis, functional disability (CC 100-102)	-0.031	0.034	-0.005	0.969	(0.907 - 1.035)
Comorbid Conditions					
Metastatic cancer and acute leukemia (CC 7)	0.273	0.060	0.022	1.314	(1.169 - 1.477)
Cancer (CC 8-12)	0.025	0.026	0.005	1.026	(0.975 - 1.079)
Diabetes and DM complications (CC 15-20, 119-120)	0.132	0.020	0.035	1.141	(1.097 - 1.187)
Protein-calorie malnutrition (CC 21)	0.266	0.041	0.030	1.304	(1.204 - 1.413)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	0.122	0.024	0.029	1.130	(1.077 - 1.185)
Obesity/disorders of thyroid, cholesterol, lipids (CC 24)	-0.051	0.021	-0.013	0.950	(0.912 - 0.990)
Severe Hematological Disorders (CC 44)	0.296	0.067	0.020	1.345	(1.178 - 1.535)
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	0.139	0.022	0.035	1.149	(1.100 - 1.200)
Dementia and senility (CC 49-50)	0.032	0.022	0.008	1.032	(0.989 - 1.077)
Quadriplegia, paraplegia, functional disability (CC 67-69, 177-178)	0.165	0.062	0.013	1.179	(1.044 - 1.331)
Seizure Disorders and Convulsions (CC 74)	0.174	0.034	0.025	1.190	(1.113 - 1.272)
Vascular or circulatory disease (CC 104-106)	0.044	0.022	0.011	1.045	(1.001 - 1.091)
COPD (CC 108)	0.127	0.023	0.029	1.136	(1.086 - 1.188)
Other lung disorder (CC 115)	0.074	0.023	0.017	1.077	(1.029 - 1.127)
End-stage renal disease or dialysis (CC 130)	0.311	0.066	0.021	1.365	(1.199 - 1.554)
Renal Failure (CC 131)	0.150	0.029	0.029	1.162	(1.097 - 1.230)
Other urinary tract disorders (CC 136)	0.086	0.025	0.018	1.090	(1.038 - 1.144)
Decubitus ulcer or chronic skin ulcer (CC 148-149)	0.064	0.036	0.009	1.066	(0.993 - 1.144)
Major Symptoms, Abnormalities (CC 166)	0.074	0.023	0.020	1.077	(1.029 - 1.127)

[e] N=87,041 in 4,242 hospitals; 14.77% crude readmission rate

[f] Between-hospital variance = 0.049, Standard Error = 0.00796

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 86,983 cases discharged from 4,260 hospitals. This validation sample had a crude readmission rate of 14.8%.

The standardized estimates and standard errors for the 2007 validation dataset are shown in Table 6, and the performance metrics are shown in Table 7. The performance was not substantively different in this validation sample (ROC=0.602), as compared to the development sample (ROC=0.602).

The model variables were then similarly tested among ischemic stroke admissions in 2006 and 2008. The unadjusted readmission rates were 14.7% and 14.8% respectively. As the results in Table 7 show, model performance using the 2006 data (ROC area = 0.602) and 2008 data (ROC area = 0.593) 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 (0.02, 1.02) and (-0.06, 0.97), respectively.

We also examined the temporal variation in the standardized estimates and frequencies of the model variables (Table 8 and Table 9). The frequencies and regression coefficients are fairly consistent over the two years of data.

Table 6 – 30-Day Readmission Model (2007 Validation Sample-HGLM Results)[g h]

Description	Estimates	Standard Error	Standardized Estimates	Odds Ratio	95% Confidence Interval
Demographics					
Age-65 (continuous)	0.003	0.001	0.012	1.003	(1.000 - 1.006)
Male	0.011	0.020	0.003	1.011	(0.972 - 1.052)
Cardiovascular/Cerebrovascular					
Congestive Heart Failure (CC 80)	0.197	0.023	0.048	1.218	(1.164 - 1.274)
Hypertensive heart disease (CC 90)	0.081	0.036	0.011	1.084	(1.010 - 1.164)
Cerebral Hemorrhage (CC 95)	0.017	0.069	0.001	1.017	(0.889 - 1.163)
Ischemic or Unspecified Stroke (CC 96)	0.032	0.024	0.008	1.033	(0.985 - 1.083)
Cerebrovascular Disease (CC 97)	0.074	0.024	0.017	1.077	(1.027 - 1.128)
Hemiplegia, paraplegia, paralysis, functional disability (CC 100-102)	-0.069	0.034	-0.011	0.934	(0.873 - 0.998)
Comorbid Conditions					
Metastatic cancer and acute leukemia (CC 7)	0.195	0.060	0.016	1.215	(1.080 - 1.367)
Cancer (CC 8-12)	0.042	0.026	0.009	1.043	(0.992 - 1.097)
Diabetes and DM complications (CC 15-20, 119-120)	0.161	0.020	0.043	1.175	(1.129 - 1.223)
Protein-calorie malnutrition (CC 21)	0.242	0.042	0.027	1.273	(1.174 - 1.382)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	0.143	0.024	0.034	1.154	(1.100 - 1.210)
Obesity/disorders of thyroid, cholesterol, lipids (CC 24)	-0.127	0.021	-0.033	0.880	(0.845 - 0.917)
Severe Hematological Disorders (CC 44)	0.176	0.068	0.012	1.192	(1.044 - 1.361)
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	0.129	0.022	0.033	1.137	(1.089 - 1.188)
Dementia and senility (CC 49-50)	0.002	0.022	0.000	1.002	(0.959 - 1.046)
Quadriplegia, paraplegia, functional disability (CC 67-69, 177-178)	0.097	0.062	0.008	1.102	(0.976 - 1.244)
Seizure Disorders and Convulsions (CC 74)	0.128	0.035	0.018	1.136	(1.061 - 1.216)
Vascular or circulatory disease (CC 104-106)	0.093	0.022	0.024	1.098	(1.052 - 1.146)
COPD (CC 108)	0.122	0.023	0.028	1.130	(1.081 - 1.182)
Other lung disorder (CC 115)	0.082	0.023	0.019	1.086	(1.037 - 1.136)
End-stage renal disease or dialysis (CC 130)	0.297	0.066	0.020	1.345	(1.181 - 1.532)
Renal Failure (CC 131)	0.154	0.029	0.030	1.167	(1.102 - 1.235)
Other urinary tract disorders (CC 136)	0.107	0.025	0.023	1.113	(1.060 - 1.168)
Decubitus ulcer or chronic skin ulcer (CC 148-149)	0.091	0.036	0.013	1.096	(1.021 - 1.175)
Major Symptoms, Abnormalities (CC 166)	0.112	0.023	0.030	1.119	(1.069 - 1.171)

[g] N=86,983 in 4,260 hospitals; 14.8% crude readmission rate

[h] Between-hospital variance = 0.042, Standard Error = 0.00763

Table 7 – 30-Day Readmission Model Performance - HGLM

Indices	Development Sample	Validation Sample		
Year	2007	2006	2007*	2008
N	87,041	182,927	86,983	168,511
Risk-Standardized Readmission Rate (mean)	14.8	14.7	14.8	14.8
Calibration (γ0, γ1)[i]	(0.03, 1.02)	(0.02, 1.01)	(0.031 1.018)	(-0.06, 0.97)
Discrimination -Predictive Ability[j] (lowest decile %, highest decile %)	(9.10, 24.30)	(8.60, 24.60)	(8.41, 24.73)	(9.20, 24.13)
Discrimination – ROC	0.602	0.602	0.602	0.593
Residuals Lack of Fit (Pearson Residual Fall %)				
<-2	0.00	0.00	0.00	0.00
[-2, 0)	85.23	85.36	85.24	85.24
[0, 2)	2.88	2.88	3.11	2.66
[2+	11.89	11.76	11.64	12.10
Model χ^2 [Number of Covariates][k]	1501.27 [27]	3095.68 [27]	1502.24 [27]	2461.65 [27]

*2007 validation sample is comprised of half of 2007 admissions

[i] 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.

[j] Observed Rates

[k] Wald Chi-Square

Table 8 – 30-Day Readmission Model Risk Factor Frequency by Year of Discharge (2006-2008)

Description	2006	2007	2008
Demographics (%)			
Male	40.27	40.44	40.25
Cardiovascular/Cerebrovascular (%)			
Congestive Heart Failure (CC 80)	25.74	25.68	25.53
Hypertensive heart disease (CC 90)	7.38	6.91	6.64
Cerebral Hemorrhage (CC 95)	1.76	1.81	1.98
Ischemic or Unspecified Stroke (CC 96)	27.06	26.41	26.32
Cerebrovascular Disease (CC 97)	23.36	23.75	23.86
Hemiplegia, paraplegia, paralysis, functional disability (CC 100-102)	9.80	9.70	10.29
Vascular or circulatory disease (CC 104-106)	30.20	31.09	31.43
Comorbid Conditions (%)			
Metastatic cancer and acute leukemia (CC 7)	2.17	2.27	2.20
Cancer (CC 8-12)	18.21	18.52	18.68
Diabetes and DM complications (CC 15-20, 119-120)	37.25	37.84	38.54
Protein-calorie malnutrition (CC 21)	4.09	4.45	5.30
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	22.78	23.72	23.86
Obesity/disorders of thyroid, cholesterol, lipids (CC 24)	65.71	68.03	70.75
Severe Hematological Disorders (CC 44)	1.61	1.53	1.58
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	29.90	30.90	31.74
Dementia and senility (CC 49-50)	28.54	28.56	29.10
Quadriplegia, paraplegia, functional disability (CC 67-69, 177-178)	2.00	1.99	2.16
Seizure Disorders and Convulsions (CC 74)	7.79	7.45	6.99
COPD (CC 108)	23.28	22.96	21.71
Other lung disorder (CC 115)	21.93	22.04	23.51
End-stage renal disease or dialysis (CC 130)	1.38	1.51	1.41
Renal Failure (CC 131)	12.32	14.29	15.32
Other urinary tract disorders (CC 136)	18.88	18.57	17.84
Decubitus ulcer or chronic skin ulcer (CC 148-149)	6.55	6.79	6.91
Major Symptoms, Abnormalities (CC 166)	61.44	61.63	62.14

Table 9 – 30-Day Readmission 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)	0.003	0.001	0.011	0.004	0.001	0.019	0.004	0.001	0.016
Male	0.028	0.014	0.008	0.044	0.014	0.012	0.026	0.015	0.007
Cardiovascular/Cerebrovascular									
Congestive Heart Failure (CC 80)	0.191	0.016	0.046	0.200	0.016	0.048	0.158	0.017	0.038
Hypertensive heart disease (CC 90)	0.052	0.025	0.007	0.096	0.026	0.013	0.070	0.027	0.010
Cerebral Hemorrhage (CC 95)	-0.023	0.048	-0.002	0.076	0.047	0.006	0.070	0.046	0.005
Ischemic or Unspecified Stroke (CC 96)	-0.013	0.017	-0.003	0.041	0.017	0.010	0.054	0.017	0.013
Cerebrovascular Disease (CC 97)	0.033	0.017	0.008	0.044	0.017	0.010	0.008	0.017	0.002
Hemiplegia, paraplegia, paralysis, functional disability (CC 100-102)	0.003	0.023	0.001	-0.050	0.024	-0.008	0.018	0.024	0.003
Comorbid Conditions									
Metastatic cancer and acute leukemia (CC 7)	0.308	0.042	0.025	0.234	0.042	0.019	0.278	0.044	0.022
Cancer (CC 8-12)	0.008	0.018	0.002	0.033	0.018	0.007	0.024	0.018	0.005
Diabetes and DM complications (CC 15-20, 119-120)	0.151	0.014	0.040	0.145	0.014	0.039	0.133	0.015	0.036
Protein-calorie malnutrition (CC 21)	0.257	0.030	0.028	0.253	0.029	0.029	0.280	0.028	0.035
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	0.120	0.017	0.028	0.133	0.017	0.031	0.077	0.018	0.018
Obesity/disorders of thyroid, cholesterol, lipids (CC 24)	-0.116	0.014	-0.030	-0.088	0.015	-0.023	-0.107	0.015	-0.027
Severe Hematological Disorders (CC 44)	0.185	0.046	0.013	0.236	0.048	0.016	0.227	0.048	0.016
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	0.106	0.016	0.027	0.133	0.016	0.034	0.128	0.016	0.033
Dementia and senility (CC 49-50)	0.055	0.015	0.014	0.015	0.016	0.004	0.024	0.016	0.006
Quadriplegia, paraplegia, functional disability (CC 67-69, 177-178)	-0.039	0.045	-0.003	0.131	0.044	0.010	0.167	0.042	0.013
Seizure Disorders and Convulsions (CC 74)	0.187	0.023	0.028	0.150	0.024	0.022	0.085	0.026	0.012
Vascular or circulatory disease (CC 104-106)	0.080	0.015	0.020	0.068	0.016	0.017	0.065	0.016	0.017
COPD (CC 108)	0.176	0.016	0.041	0.125	0.016	0.029	0.134	0.017	0.030
Other lung disorder (CC 115)	0.066	0.016	0.015	0.079	0.016	0.018	0.048	0.017	0.011
End-stage renal disease or dialysis (CC 130)	0.367	0.047	0.024	0.305	0.047	0.020	0.355	0.049	0.023
Renal Failure (CC 131)	0.210	0.021	0.038	0.151	0.021	0.029	0.190	0.020	0.038
Other urinary tract disorders (CC 136)	0.088	0.017	0.019	0.096	0.018	0.021	0.048	0.018	0.010
Decubitus ulcer or chronic skin ulcer (CC 148-149)	0.059	0.025	0.008	0.076	0.025	0.011	0.077	0.026	0.011
Major Symptoms, Abnormalities (CC 166)	0.100	0.016	0.027	0.093	0.017	0.025	0.110	0.017	0.029

Table 10 – 30-Day Readmission* Model (2007 Full Sample-HGLM Results)[lm]

Description	Estimates	Standard Error	Standardized Estimates	Odds Ratio	95% Confidence Interval
Demographics					
Age-65 (continuous)	0.004	0.001	0.019	1.004	(1.003 – 1.006)
Male	0.044	0.014	0.012	1.045	(1.016 – 1.074)
Cardiovascular/Cerebrovascular					
Congestive Heart Failure (CC 80)	0.200	0.016	0.048	1.221	(1.182 – 1.261)
Hypertensive heart disease (CC 90)	0.096	0.026	0.013	1.100	(1.047 – 1.157)
Cerebral Hemorrhage (CC 95)	0.076	0.047	0.006	1.079	(0.954 – 1.182)
Ischemic or Unspecified Stroke (CC 96)	0.041	0.017	0.010	1.042	(1.008 – 1.078)
Cerebrovascular Disease (CC 97)	0.044	0.017	0.010	1.045	(1.010 – 1.080)
Hemiplegia, paraplegia, paralysis, functional disability (CC 100-102)	-0.050	0.024	-0.008	0.951	(0.907 – 0.997)
Vascular or circulatory disease (CC 104-106)	0.068	0.016	0.017	1.070	(1.038 – 1.103)
Comorbid Conditions					
Metastatic cancer and acute leukemia (CC 7)	0.234	0.042	0.019	1.264	(1.163 – 1.373)
Cancer (CC 8-12)	0.033	0.018	0.007	1.034	(0.998 – 1.071)
Diabetes and DM complications (CC 15-20, 119-120)	0.145	0.014	0.039	1.156	(1.124 – 1.189)
Protein-calorie malnutrition (CC 21)	0.253	0.029	0.029	1.288	(1.216 – 1.364)
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	0.133	0.017	0.031	1.142	(1.104 – 1.181)
Obesity/disorders of thyroid, cholesterol, lipids (CC 24)	-0.088	0.015	-0.023	0.916	(0.890 – 0.943)
Severe Hematological Disorders (CC 44)	0.236	0.048	0.016	1.266	(1.153 – 1.391)
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	0.133	0.016	0.034	1.142	(1.108 – 1.178)
Dementia and senility (CC 49-50)	0.015	0.016	0.004	1.015	(0.985 – 1.047)
Quadriplegia, paraplegia, functional disability (CC 67-69, 177-178)	0.131	0.044	0.010	1.139	(1.046 – 1.242)
Seizure Disorders and Convulsions (CC 74)	0.150	0.024	0.022	1.161	(1.107 – 1.218)
COPD (CC 108)	0.125	0.016	0.029	1.133	(1.098 – 1.170)
Other lung disorder (CC 115)	0.079	0.016	0.018	1.082	(1.047 – 1.117)
End-stage renal disease or dialysis (CC 130)	0.305	0.047	0.020	1.356	(1.237 – 1.487)
Renal Failure (CC 131)	0.151	0.021	0.029	1.163	(1.117 – 1.211)
Other urinary tract disorders (CC 136)	0.096	0.018	0.021	1.101	(1.064 – 1.140)
Decubitus ulcer or chronic skin ulcer (CC 148-149)	0.076	0.025	0.011	1.079	(1.026 – 1.134)

[l] N=174,024 in 4,441 hospitals;
[m] Between hospital variance = 0.041; Standard Error = 0.00464

Description	Estimates	Standard Error	Standardized Estimates	Odds Ratio	95% Confidence Interval
Major Symptoms, Abnormalities (CC 166)	0.093	0.017	0.025	1.098	(1.063 – 1.134)

3.1.4 30-Day Readmission Rate Distribution – With and Without Risk-Adjustment

Figure 4 and Figure 5 display the frequency distributions of the hospital-level 30-day readmission rates, with and without risk-standardization in the 2007 development cohort.

The unadjusted readmission rate ranged from 0% to 100% across 4,242 hospitals with a median (quartile range) of 14.0% (10.0%, 18.9%; Figure 4). After adjusting for patient and clinical characteristics, the risk-standardized rates were more normally distributed (Figure 5 with a mean of 14.8%, ranging from 11.6% to 19.4% across 4,242 hospitals. The median adjusted readmission rate is 14.7%.

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

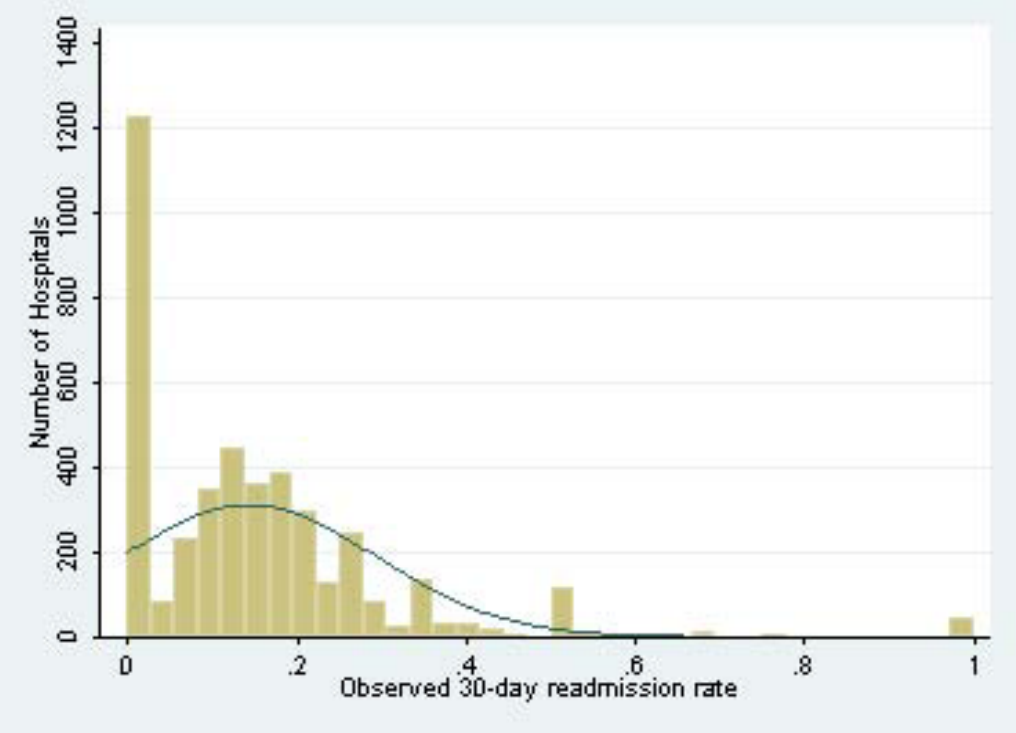
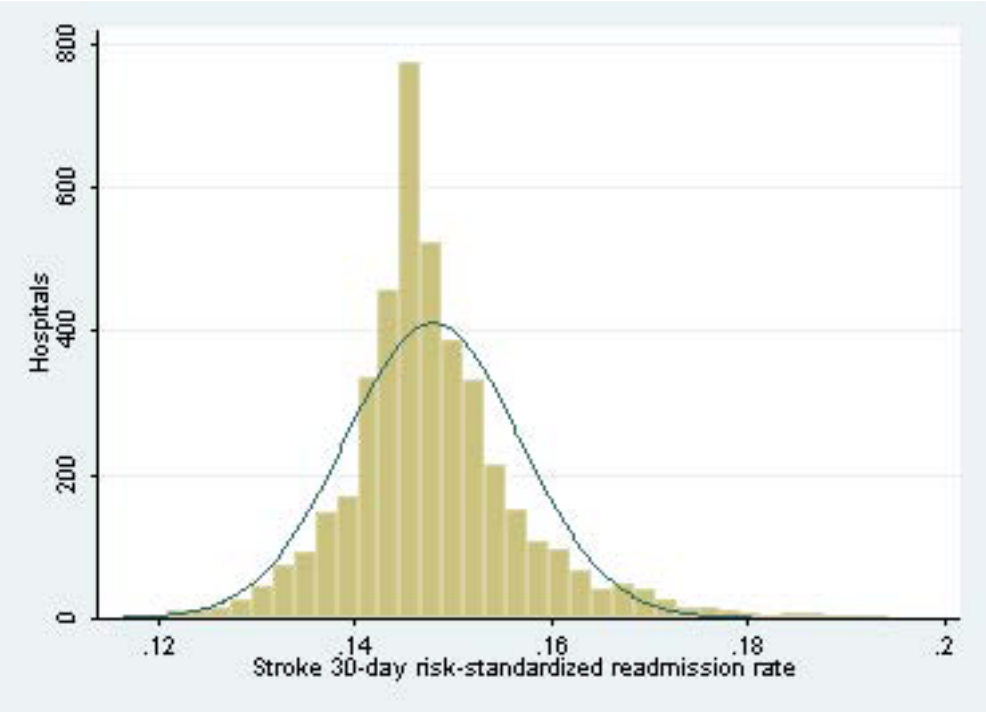


Figure 5 – Distribution of 30-Day Hospital-level RSRRs Following Acute Ischemic Stroke (2007 Development Sample)



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 derived 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 sample is 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.[21 8]

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 65 years of age or older, hospitalized for acute ischemic stroke (based on principal discharge diagnoses detailed in Table 2). We then identified eligible hospitalizations present in both Medicare claims data and the NSP dataset. 38,598 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). However, for the medical-record model we dropped the requirement of 12-months continuous FFS enrollment prior to the index admission due to data availability.

After exclusion of patients based on these criteria a total of 35,209 cases were included in the matched cohort for the NSP medical record model (Table 11). The unadjusted 30-day readmission rate was 12.60%

Table 11– Stroke Medical Record Data Study Sample (NSP Dataset)

Data Source	Total[n]	Exclusion (%)				Final Sample
		Transfers-out	Repeat Admissions[o]	Discharged AMA	In-Hospital Deaths	N
March 1, 1998-March 31, 1999 & July 1, 2000-June 30, 2001	38,598	95 (0.25)	130 (0.34)	60 (0.16)	3,105 (8.04)	35,209

*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 review, and consensus amongst the team, we selected potentially important predictors of readmission. We also identified clinically important variables that should be

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

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 selection resulted in a final stroke readmission medical record risk-adjusted model that included 24 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.[21,22]

Based on the 35,209 cases with linked administrative and medical record data, we estimated state-specific risk-adjusted 30-day readmission rates. The HGLM model included a random intercept for each state. 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. The performance of the medical record model is shown in Table 14.

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

Variable	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% CI	p-value
Age	0.001	0.002	0.003	1.001	(-0.004 - 0.005)	0.722
Male	0.078	0.034	0.021	1.081	(0.012 - 0.144)	0.020
History of CVA	0.124	0.034	0.034	1.133	(0.058 - 0.191)	<.0001
History of hemorrhagic CVA	-0.305	0.129	-0.024	0.738	(-0.557 - (-0.052)	0.018
History of hemorrhage/bleeding	0.115	0.054	0.020	1.121	(0.009 - 0.220)	0.033
History of CHF	0.094	0.045	0.020	1.098	(0.005 - 0.182)	0.038
History or current finding of extensive or metastatic cancer	0.143	0.116	0.011	1.154	(-0.085 - 0.371)	0.219
History/current finding Diabetes	0.166	0.035	0.042	1.181	(0.097 - 0.235)	<.0001
History/Current finding IHD/angina	0.141	0.043	0.039	1.152	(0.057 - 0.225)	0.001
History/current finding cardiomyopathy	0.160	0.074	0.018	1.173	(0.014 - 0.305)	0.031
History/Current finding MI	-0.001	0.045	0.000	0.999	(-0.089 - 0.086)	0.975
Terminal illness or comfort care on day of arrival	-0.482	0.131	-0.039	0.617	(-0.740 - (-0.225))	<.0001
Modified Rankin pre-event = Needs Assistance	0.137	0.037	0.035	1.147	(0.065 - 0.209)	<.0001
Modified Rankin pre-event - Dependent	0.276	0.060	0.040	1.318	(0.159 - 0.393)	<.0001
Modified Rankin pre-event - UTD/Missing	0.557	0.175	0.024	1.746	(0.214 - 0.900)	0.002
Current finding of CHF	0.316	0.048	0.059	1.372	(0.222 - 0.410)	<.0001
New/acute hemorrhagic CVA	0.321	0.079	0.033	1.378	(0.166 - 0.476)	<.0001
Visual deficit	0.040	0.045	0.008	1.041	(-0.048 - 0.128)	0.369
Speech deficit	0.052	0.034	0.014	1.053	(-0.014 - 0.118)	0.124
Motor deficit	-0.020	0.041	-0.004	0.981	(-0.100 - 0.061)	0.633
Sensory deficit	-0.093	0.036	-0.024	0.911	(-0.164 - (-0.023))	0.009
Systolic blood pressure < 100	-0.840	1.033	-0.010	0.432	(-2.865 - 1.185)	0.416
Systolic blood pressure 100 to 140	0.156	0.052	0.025	1.168	(0.054 - 0.257)	0.003
Systolic blood pressure > 220	0.023	0.068	0.003	1.023	(-0.110 - 0.155)	0.739

- Between-state variance = 0.03854; standard error = 0.01038

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

Variable	Estimate	Standard Error	Standardized Estimate	Odds Ratio	95% CI	p-value
Demographics						
Age-65 (continuous)	0.004	0.002	0.019	1.004	(1.000 - 1.009)	0.045
Male	0.071	0.033	0.019	1.073	(1.005 - 1.146)	0.035
Cardiovascular/Cerebrovascular						
Congestive Heart Failure (CC 80)	0.167	0.049	0.030	1.181	(1.073 - 1.301)	0.001
Hypertensive heart disease (CC 90)	0.104	0.082	0.011	1.110	(0.945 - 1.304)	0.205
Cerebral Hemorrhage (CC 95)	0.101	0.200	0.004	1.106	(0.748 - 1.637)	0.613
Ischemic or Unspecified Stroke (CC 96)	0.111	0.063	0.017	1.117	(0.988 - 1.263)	0.078
Cerebrovascular Disease (CC 97)	-0.016	0.070	-0.002	0.984	(0.858 - 1.130)	0.822
Hemiplegia, paraplegia, paralysis, functional disability (CC 100-102)	0.060	0.074	0.008	1.061	(0.918 - 1.228)	0.422
Comorbid Conditions						
Metastatic cancer and acute leukemia (CC 7)	0.071	0.108	0.006	1.073	(0.869 - 1.326)	0.511
Cancer (CC 8-12)	0.151	0.065	0.020	1.163	(1.025 - 1.321)	0.020
Diabetes and DM complications (CC 15-20, 119-120)	0.167	0.035	0.042	1.181	(1.102 - 1.266)	<.0001
Protein-calorie malnutrition (CC 21)	0.293	0.081	0.028	1.340	(1.142 - 1.572)	<.0001
Disorders of Fluid/Electrolyte/Acid-Base (CC 22-23)	-0.052	0.035	-0.014	0.950	(0.887 - 1.017)	0.138
Obesity/disorders of thyroid, cholesterol, lipids (CC 24)[p]	-	-	-	-	-	-
Severe Hematological Disorders (CC 44)	0.354	0.160	0.016	1.424	(1.040 - 1.950)	0.027
Iron Deficiency and Other/Unspecified Anemias and Blood Disease (CC 47)	0.132	0.045	0.026	1.141	(1.046 - 1.245)	0.003
Dementia and senility (CC 49-50)	0.039	0.044	0.008	1.040	(0.954 - 1.133)	0.377
Quadriplegia, paraplegia, functional disability (CC 67-69, 177-178)	0.017	0.149	0.001	1.018	(0.759 - 1.364)	0.907
Seizure Disorders and Convulsions (CC 74)	0.323	0.060	0.043	1.382	(1.228 - 1.554)	<.0001
Vascular or circulatory disease (CC 104-106)	0.168	0.055	0.026	1.183	(1.061 - 1.319)	0.002
COPD (CC 108)	0.266	0.056	0.039	1.305	(1.169 - 1.457)	<.0001
Other lung disorder (CC 115)	0.107	0.077	0.011	1.113	(0.957 - 1.295)	0.166
End-stage renal disease or dialysis (CC 130)	0.595	0.178	0.023	1.813	(1.278 - 2.571)	0.001
Renal Failure (CC 131)	0.341	0.083	0.034	1.407	(1.196 - 1.655)	<.0001
Other urinary tract disorders (CC 136)	0.238	0.056	0.034	1.269	(1.137 - 1.416)	<.0001
Decubitus ulcer or chronic skin ulcer (CC 148-149)	0.410	0.178	0.016	1.507	(1.063 - 2.137)	0.021
Major Symptoms, Abnormalities (CC 166)	0.143	0.055	0.022	1.154	(1.035 - 1.286)	0.010

- Between-state variance = 0.05198; standard error = 0.01684

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

Table 14 – Stroke Medical Record Model Performance –HGLM

Model	Calibration (γ_0, γ_1)	Discrimination Predictive Ability[r] - (lowest decile %, - highest decile %)	ROC	Residuals Lack of Fit - (Pearson Residual Fall %) <-2	[-2, 0)	[0, 2)	[2+	Model χ^2 - [Number of Covariates][q]
Medical Record Model Development Sample (NSP)								
N = 35,209	(0.00, 1.00)	(8.21, 18.94)	0.582	0.00	87.40	0.80	11.80	332.78 [24]
Linked Administrative Model Sample								
N = 35,209	(0.00, 1.00)	(8.39, 21.70)	0.589	0.00	87.40	1.30	11.30	464.44 [26]

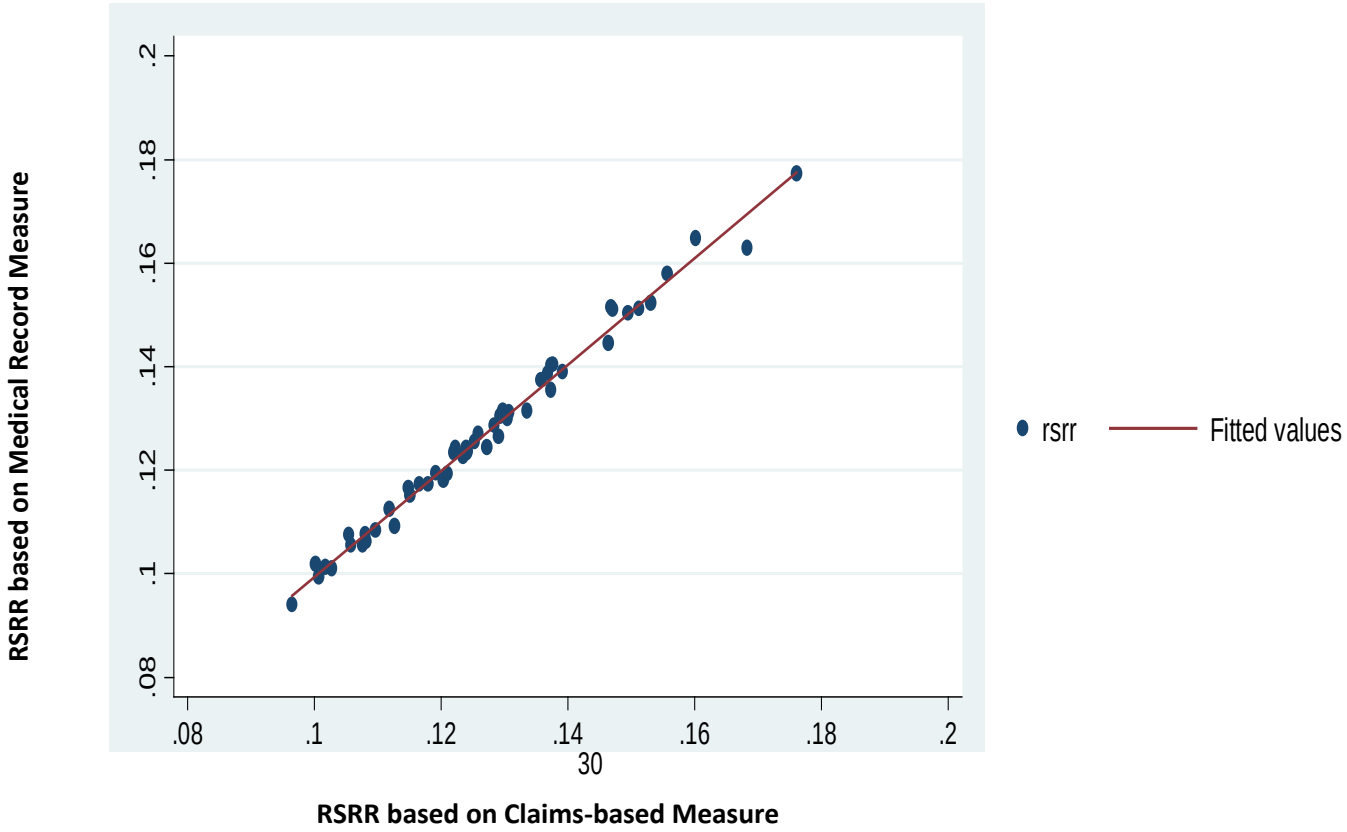
[q] Wald Chi-Square
[r] Observed Rates

3.3 Comparison of Administrative Model with Medical Record Model

The performance of the administrative and medical record models is similar. The areas under the ROC curve are 0.59 and 0.58, respectively, for the two models. In addition, they are similar with respect to predictive ability. For the administrative model, the predicted readmission rate ranges from 8.39% in the lowest predicted decile to 21.70% in the highest predicted decile, a range of 13.31%. For the medical record model, the corresponding range is 8.21% to 18.94%, a range of 10.73%.

We estimated state-level RSRRs 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 0.99 (Figure 6). 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 readmission outcome.

Figure 6 – Correlation of Administrative and Medical Record Models (HGLM) – Standardized 30-day Stroke Readmission Rates



Correlation coefficient= 0.99

4. MAIN FINDINGS / SUMMARY

We present a hierarchical logistic regression model for 30-day readmission 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.[9] 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. These characteristics make this outcome measure suitable for public reporting.

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.

REFERENCES

1. American Heart Association. Heart Disease and Stroke Statistics - 2010 Update. Dallas: American Heart Association; 2010.

2. Andrews RM. The National Hospital Bill: The Most Expensive Conditions by Payer, 2006. Rockville: Agency for Healthcare Research and Quality; 2008.

3. Sacco RL, Hauser WA, Mohr JP, Foulkes MA. One-year outcome after cerebral infarction in whites, blacks, and Hispanics. Stroke 1991;22:305-11.

4. Andersen HE, Schultz-Larsen K, Kreiner S, Forchhammer BH, Eriksen K, Brown A. Can readmission after stroke be prevented? Results of a randomized clinical study: a postdischarge follow-up service for stroke survivors. Stroke 2000;31:1038-45.

5. Gooding J, Jette AM. Hospital readmissions among the elderly. Journal of the American Geriatric Society 1985;33:595-601.

6. Jack BW, Chetty VK, Anthony D, et al. A Reengineered Hospital Discharge Program to Decrease Rehospitalization. Annals of Internal Medicine 2009;150:178-88.

7. Naylor MD, Brooten D, Cambell R, et al. Comprehensive Discharge Planning and Home Follow-up of Hospitalized Elders: A Randomized Clinical Trial. The Journal of the American Medical Association 1999;281:613-20.

8. Bravata DM, Ho SY, Meehan TP, Brass LM, Concato J. Readmission and death after hospitalization for acute ischemic stroke: 5-year follow-up in the Medicare population. Stroke 2007;38:1899-904.

9. Krumholz HM, Brindis RG, Brush JE, et al. 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 2006;113:456-62.

10. Coleman EA, Parry C, Chalmers S, Min S-j. The Care Transitions Intervention: Results of a Randomized Controlled Trial. Archives of Internal Medicine 2006;166:1822-8.

11. Anderson C, Deepak BV, Amoateng-Adjepong Y, Zarich S. Benefits of Comprehensive Inpatient Education and Discharge Planning Combined With Outpatient Support in Elderly Patients With Congestive Heart Failure. Congestive Heart Failure 2005;November-December:315-21.

12. Krumholz H, Amatruda J, Smith GL, et al. Randomized Trial of an Education and Support Intervention to Prevent Readmission of Patients With Heart Failure. Journal of the American College of Cardiology 2002;39:83-9.

13. Phillips CO, Wright SM, Kern DE, Singa RM, Shepperd S, Rubin H. Comprehensive Discharge Planning With Postdischarge Support for Older Patients With Congestive Heart Failure: A Meta-analysis. The Journal of the American Medical Association 2004;291:1358-67.

14. Boutwell AS. Effective Interventions to Reduce Rehospitalizations: A Survey of the Published Evidence. Cambridge, MA: Institute for Healthcare Improvement; 2009.

15. Thom T, Haase N, Rosamond W, et al. Heart Disease and Stroke Statistics-2006 Update: A Report From the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Journal of the American Heart Association 2006:85-151.

16. Pope GC, Ellis RP, Ash AS, et al. Diagnostic Cost Group Hierarchical Condition Category Models for Medicare Risk Adjustment. Washington D.C.: Health Economics Research, Inc.; 2000.

17. McCullagh P, Nelder JA. Generalized linear models. 2nd ed. London ; New York: Chapman and Hall; 1989.

18. Daniels MJ, Gatsonis C. Hierarchical Generalized Linear Models in the Analysis of Variations in Health Care Utilization. J Am Stat Assoc 1999;94:29-42.

19. Normand S-L, Wang Y, Krumholz H. Assessing surrogacy of data sources for institutional comparisons. Health Services and Outcomes Research Methodology 2007;7:79-96.

20. Harrell FE, ed. Regression modeling strategies, with applications to linear models, logistic regression, and survival analysis. 2, illustrated ed: Springer; 2001.

21. Jencks SF, Huff ED, Cuerdon T. Change in the Quality of Care Delivered to Medicare Beneficiaries, 1998-1999 to 2000-2001. The Journal of the American Medical Association 2003;289:305-12.

22. Glymour MM, Avendano M. Can Self-Reported Strokes Be Used to Study Stroke Incidence and Risk Factors?: Evidence From the Health and Retirement Study. Journal of the American Heart Association 2009:873-9.

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	

CC #	Description	Potential Complication in Index Admission
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
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

CC #	Description	Potential Complication in Index Admission
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
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

CC #	Description	Potential Complication in Index Admission
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
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