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Distinct Trends In 30-Day Observed And Risk-Standardized Mortality Rates Of Acute Myocardial Infarction Patients, 2005-2010

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By

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Distinct trends in 30-day observed and risk-standardized mortality rates of Acute Myocardial Infarction Patients, 2005-2010

Abstract

In the effort of comparing health care quality across hospitals and profiling hospitals, the Centers for Medicare and Medicaid Services (CMS) utilize risk-standardized outcome in which the hospital-level outcome is standardized adjusting for patient-covariates using hierarchical model for patients outcome clustered within hospital. Even though standardized measure is useful for comparing hospitals, we believe the analysis of observed hospital-level outcome without standardization can reveal additional information at the hospital-level. The implication of using both types of mortality rates was studied in the context of analyzing 30-day mortality trend of Acute Myocardial Infarction (AMI) patients. Therefore the objective of this study was 1) describe trend in 30-day all cause mortality rates of AMI patients, 2) identify groups of hospitals with distinct trends and determine patient and hospital characteristics associated with group membership, and 3) examine how the risk-standardization approach affects the trajectory shape.

During 2005-2010, the 30-day mortality trend of AMI patients showed a decreasing trend. The median observed mortality decreased by 4.3% from 18.8% to 14.5%, but the between-hospital variation remained unchanged. Five distinct groups of hospitals were identified based on their patterns of mortality rate over time. Trajectories

using observed rates showed varying trend and level of mortality, whereas all trajectories of risk-standardization rates show decreasing trend that is rather smooth with different, levels and slope of mortality slightly differed. When using observed rates, 9 patient characteristics were associated with group membership including age, history of heart failure, chronic atherosclerosis, valvular heart disease, hypertension, pneumonia, functional disability, metastatic cancer, and chronic liver disease. For hospital characteristics, cumulative AMI volume was the only factor significantly associated ($p < 0.0001$). When using risk-standardized rates, 8 patient characteristics associated with group membership including age, history of heart failure, history of AMI, chronic atherosclerosis, valvular heart disease, COPD, and peripheral vascular disease. For hospital characteristics, four covariates including cumulative AMI volume, urban/rural classification, proportion of Medicaid patients, and region, were significantly associated ($p < 0.0001$). Lastly, we found that the change in trajectory shape between observed and risk-standardized rates was mainly driven by hospital covariates, and not patient covariates.

Introduction

Hospital Profiling

In the past decade, quality improvement of the healthcare system has been an important issue in the United States. As Institute of Medicine reported, the US healthcare has been "insufficiently safe, effective, patient-centered, efficient, timely, or equitable". (Bielaszka-DuVernay 2011) Therefore there have been significant efforts in

understanding such deficiencies and factors affecting healthcare quality and improvement. For example, one of the well-known factors that expanded understanding of the US healthcare was described by the Dartmouth Atlas group. They found that geographical location of the health care system is a key factor in leading to differential capacity and style of the local health care system. (Wennberg, Cooper et al. 1999) In addition, other sources and types of discrepancies and their related outcome have been studied.

The Centers for Medicare and Medicaid Services (CMS) is one of the main healthcare organizations committed to quality improvement. To assess hospital care quality in particular, CMS compares hospital performances via profiling. Profiling is the process of "comparing health care provider's structure, processes of care, or outcomes to a normative or community standard". (Normand and Shahian 2007) It allows evaluating healthcare providers such as physicians, hospitals, or provider networks by quantifying performances. The performances are quantified by developing performance indices and become available to public via a consumer-oriented website called Hospital Compare. It provides information on how well hospitals provide care to their patients. This information can help patients make informed decisions by allowing them to select and compare performance of multiple hospitals for conditions such as heart attack, heart failure, pneumonia, and surgery. (Services 2013)

Current statistical approach used for hospital profiling is risk-standardized measure obtained using hierarchical generalized linear model. (Keenan, Normand et al. 2008)

(Krumholz, Lin et al. 2011) Health care data is typically clustered at multiple levels, such as patients, physicians, hospitals, or network providers. A model estimating the hospital-level outcome needs to take into account both patient- and hospital-level characteristics. To accommodate, a multi-level analysis is needed since a patient-level mortality model will not sufficiently address clustering of patients and different number of patients in the hospital. (Normand, Glickman et al. 1997) Therefore risk-standardization is needed in order to fairly assess hospital performance relative to other providers. For example, it is expected that mortality rate is higher for the hospitals with sicker patients. Therefore, we do not want to penalize the hospitals that treat sicker patients.

Risk-standardization is a two-stage approach designed to simultaneously model both patient- and hospital-levels of data using hierarchical regression model. This allows variance in patient outcomes both within and between hospitals to be appropriately accounted. To obtain risk standardized mortality rate for hospital, first a patient-level regression model is developed to select significant demographic and clinical risk factors after backwards elimination. Next the simultaneous modeling occurs: 1) At the patient level, the log-odds of mortality of a binary outcome, such as mortality within 30 days of admission, is modeled with patient risk factors and a hospital-specific intercept. 2) At the hospital level, the hospital-specific intercepts are modeled as normally distributed. Next, a hospital-level standardized outcome is determined by calculating the ratio of predicted to expected mean mortality multiplied by population-level unadjusted national mean mortality (Bernheim, Wang et al. 2012). The predicted mean mortality of a hospital takes into the account of the hospital specific intercept while the expected mean mortality does

not.

Therefore, parameter estimates of patient risk-adjustment model are used to calculate standardized rate. (Timbie and Normand 2008) However due to aggregation of patient information, risk-standardization provides limited insight into the heterogeneity within both patient- and hospital-level. In other applications that assess education outcome at student- and class-levels, it was shown that the aggregation of student outcome at class level caused errors in student outcomes to distort the assessment of the class-level construct (Ludtke, 2011). Therefore the information about patient-level variation is reduced or lost, and risk-standardization rates of hospitals become more homogeneous. Use of risk-standardized rates is necessary for the purpose of hospital profiling. However, observed rates also provide insightful information since it gives researchers a sense of how hospitals are performing and how the dynamics of patients over time affects the hospital trajectory. Therefore this thesis intends to explore such implication of using observed and risk-standardized rates in the context of mixture modeling of hospitals treating patients with cardiovascular disease.

Acute Myocardial Infarction

Acute Myocardial Infarction (AMI) is a high-risk condition that remains as a leading cause of deaths in the United States. (Go, Mozaffarian et al. 2013) With nationwide efforts to improve hospital quality of care for patients with cardiovascular diseases, it has been shown in a recent study that the short-term mortality rate of AMI patients decreased. (Krumholz, Wang et al. 2009) In addition to reduction in overall mortality, the authors

found that the between-hospital heterogeneity also decreased. However, it is possible that not all hospitals consistently experienced such reduction in the level and rate of mortality. In order to identify ways to improve quality of hospital care, it is helpful to describe how the trend in mortality of AMI patients and obtain more insight into how differential level and rate of mortality is related to patient or hospital characteristics.

Growth Mixture Modeling

Growth mixture modeling (GMM) allows such analysis of trajectories. GMM is a method of analyzing developmental trajectories that complements traditional methods including hierarchical modeling and latent growth curve modeling. (Jones, Nagin et al. 2001) Mixture model assumes the presence of subpopulations an overall population and therefore is useful for modeling unobserved heterogeneity in a population. Based on multinomial modeling strategy, GMM allows grouping of trajectories with distinct pattern. Such partitioning will allows us to see hospitals displaying distinct trend of mortality rate of AMI patients. This method has been widely used for social and psychological sciences, medical studies, and population-based studies investigating differential trajectories. (Jung and Wickrama 2008)

The objectives of this study are three-fold. First we intend to describe nation-wide trend in 30-day all-cause mortality rates AMI patients in the United States between 2005 and 2010 using both observed and risk-standardized rates. We hypothesize that there will be multiple groups of hospitals with distinct trajectories in terms of level, rate, and shape. Secondly, we will identify hospital characteristics associated with differential trajectory

group memberships. It will help better understand factors leading to differential outcome and elucidate possible ways to improve hospital care, especially for hospitals that do not show a favorable trend. Lastly we intend to explore how patient and hospital covariates and hospital-specific random effect involved in the risk-standardization step affects trajectory shape.

Materials and Methods

Data Source and Study Population

The patient data were obtained from the standard analytics files from the Center for Medicare and Medicaid Services. The denominator population is 100% fee-for-service Medicare Beneficiaries. The numerator population is Medicare beneficiaries discharged with a primary diagnosis of acute myocardial infarction from acute care hospitals from January 1, 2005 to December 31, 2010 (ICD-9 code 410.xx (except 410.x2)). The inclusion criterion was 65 years old or older who were enrolled in fee-for-service 12-month prior to the index hospitalization. Exclusion criteria includes same or next day discharge when patient did not die or get transferred, transfers into the hospital, In hospice within one year prior to including on the day of admission, discharges against medical advice, inconsistent or unknown vital status, and unreliable data. Also for the 2007-2010 period, VA beneficiaries who are added to the analytic files were excluded for the analysis. Once initial index cohort was identified, among patients with more than one admission in a given year for AMI, only one index admission for AMI was randomly selected for inclusion in the cohort. Additionally, hospitals with 5-year cumulative AMI volume less than 10 (n=662) and corresponding patients (n=2863) were excluded. The

hospital data were obtained from the American Hospital Association Annual Survey Database for the fiscal year 2009.

Patient and hospital characteristics

The outcome variable of interest is 30-day all-cause mortality for AMI patients, which is defined as death of AMI patients within 30 days of admission for any cause either in or outside hospital. The patient covariates considered are two demographic variables (age as a continuous variable and sex), eight cardiovascular history variables (history of PTCA, CABG, heart failure, AMI, unstable angina, chronic atherosclerosis, cardiopulmonary-respiratory failure and shock, valvular heart disease). Also 15 comorbidities considered are hypertension, stroke, cerebrovascular disease, renal failure, COPD, pneumonia, diabetes mellitus, protein-calorie malnutrition, dementia, functional disability, peripheral vascular disease, metastatic cancer, trauma in the past year, major psychiatric disorder, and chronic liver disease. Lastly, seven hospital characteristics were considered including teaching status, geographic location, proportion of Medicaid/ population, urban/rural classification, ownership type, total bed count, and cumulative AMI volume during 2005-2010.

Statistical Method and Analysis

Descriptive statistics (mean and percentages) was calculated to describe sample patient and hospital characteristics. Three types of mortality rates were calculated for each analytic period: 1) Patient-level mortality rate, which is the proportion of patients died

across all hospitals), 2) Hospital-level observed mortality rate (OR), which is the proportion of patients died for each hospital), and 3) Hospital-level risk-standardized mortality rate (RSR), which is the proportion of patients died for each hospitals adjusted for case-mix such as age and comorbidities.

Hierarchical Generalized Linear Model

To account for the natural clustering of observations within hospitals, risk-standardized mortality rate was estimated using hierarchical generalized linear model using Proc GLIMMIX procedure in SAS. It links the outcome to the risk factors and a hospital-specific random effect. (Krumholz, Normand et al. 2005)

The following gives the notations for describing the model:

k: Hospital

i: Patient

j: Time period

μ_{ijk} : Probability of each for the i^{th} patient discharged from the k^{th} hospital at time j

X_{ijk}: A vector of patient risk factors

β_{oj}: Overall intercept for combining all hospitals in the sample at time j

β_{xj}: Fixed effects coefficients at time j

b_{jk}: Hospital-specific random effect at time j

The hierarchical model for mortality:

$$logit(\mu_{ijk}) = \beta_{oj} + \beta_{xj}^{T} X_{ijk} + b_{jk}$$

$$logit(\mu_{ijk}) = \beta_{o1} + \beta_{o2} t_{i2k} + \cdots + \beta_{oJ} t_{ijk} + \beta_{x1}^{T} X_{i1k} + \beta_{x2}^{T} X_{i2k} t_{i2k} + \cdots + \beta_{xJ}^{T} X_{ijk} t_{ijk} + b_{1k} + b_{2k} t_{i2k} + \cdots + b_{Jk} t_{ijk}$$

$$logit(\mu_{ijk}) = \beta_{o1} + \beta_{x1}^{T} X_{i1k} + b_{1k} + \left(\sum_{j=2}^{J} \beta_{oj} + \beta_{xj}^{T} X_{ijk} + b_{jk} \right) * t_{ijk}$$

Next, based on estimated parameters, we calculated a standardized outcome, s_{jk}, for each hospital by computing the ratio of the predicted to expected mean outcomes multiplied by the unadjusted national mean.

For each j,

Predicted and expected mortality for patient i in hospital k at time j are given respectively as:

$$\hat{P}_{ijk} = logit^{-1}(\hat{\beta}_{oj} + \hat{\beta}_{xj}^{T} X_{ijk} + \hat{b}_{jk}) \text{ and } \hat{E}_{ijk} = logit^{-1}(\hat{\beta}_{oj} + \hat{\beta}_{xj}^{T} X_{ijk})$$

n_k: Number of patients at hospital k

$$\hat{s}_{jk} = \frac{\sum_{i=1}^{n_k} \hat{P}_{ijk}}{\sum_{i=1}^{n_k} \hat{E}_{ijk}} \times \bar{y} = \frac{\sum_{i=1}^{n_k} logit^{-1}(\hat{\beta}_{oj} + \hat{\beta}_{xj}^{T} X_{ijk} + \hat{b}_{jk})}{\sum_{i=1}^{n_k} logit^{-1}(\hat{\beta}_{oj} + \hat{\beta}_{xj}^{T} X_{ijk})} \times \bar{y}$$

Growth Mixture Modeling

To identify distinct groups of hospitals, growth mixture modeling approach was applied to both observed and risk-standardized rates via a SAS macro Proc TRAJ. Assuming that the population consists of a mixture of G underlying trajectory groups:

g: Trajectory group

Y_k = Trajectory of an hospital k = $\left[y_{k1}, y_{k2}, y_{k3}, \ldots, y_{kj}\right]$

$P(Y_k) =$ Probability of $Y_K = \sum_g \pi_g P^g(Y_k)$

π_g = Probability of group g membership: $\pi_g = \frac{e^{\theta g}}{\sum_1^G e^{\theta g}}$

$P^g(Y_k)$= Probability of Y_k given group membership in group g: $\prod^J p^{gj}(y_{kj})$.

The group membership probabilities, π_g, are indirectly estimated by a multinomial logit function, $\pi_g = e^{\theta_g} / \sum_1^G e^{\theta_g}$ where $\theta_1$is normalized to zero for identifiability purposes. This method of estimation ensures that each group probability is within the range of 0 and 1. The form of $p^{gj}(y_{kj})$ was selected based on the type of response variable. For our analysis, even though the original source of mortality rate arises from binary outcome of death, we considered calculated observed mortality as a continuous variable. Since the frequency of mortality rates decrease as the rate increases, the censored normal model was chosen as appropriate for modeling these data. The link between mortality rates and time is established via a latent variable, ${y_{kj}^*}^g$, where ${y_{kj}^*}^g$ and time assume a third-order polynomial relationship: ${y_{kj}^*}^g = \beta_0^g + \beta_1^g Time_{kj} + \beta_2^g Time_{kj}^2 + \beta_3^g Time_{kj}^3 + \varepsilon_{kj}$. ε_{kj} is normally distributed with a zero mean and a constant standard deviation σ. (Jones 2007)

For model selection, the Bayesian Information Criterion (BIC) value was used, which favors more parsimonious model. The model with the largest negative BIC value was chosen. Reliability of the trajectory was evaluated using average posterior probabilities of group membership. It is calculated by averaging the posterior probabilities of individual

hospital having been assigned group membership to a trajectory using the maximum probability assignment rule. Average posterior probabilities of group membership greater than 0.70 to 0.80 indicate that the modeled trajectories group individuals with similar patterns of change and discriminate between individuals with dissimilar patterns of change. (Andruff, Carraro et al. 2009)

Association between patient and hospital characteristics and group assignment

For both observed and risk-standardized rates, patient and hospital characteristics of hospitals in each trajectory group were compared. For patient characteristics, the hospital-level proportion of patient risk factor was first computed and averaged within each group. Bivariate analyses between a covariate and group membership were conducted using Kruskal-Wallis or Chi-square tests. For multivariate association between covariates and trajectory group membership, multinomial logistic regression analysis was performed. Stepwise selection was performed to determine covariates for the final model. Estimates with $p < 0.05$ were considered statistically significant. We conducted all analyses using SAS version 9.3 (SAS Institute Inc., Cary, North Carolina).

Comparison of trajectory shapes using observed and risk-standardized rates

Next, we examined factors that cause drastic change in trajectory shapes between observed and risk-standardized rates. More specifically, the role of patient covariates, hospital covariates, and hospital random effect in trajectory shape was investigated. To systematically examine each effect, the hierarchical modeling in the first stage was

approached to the following types of mortality rates for each time period and the growth mixture modeling was followed, where P represent predicted mortality and E represent expected mortality:

Approaches in Hierarchical Modeling of Mortality:

1) Observed: Using observed hospital-level mortality rate without regression modeling

2) E(Intercept + Patient): Obtaining expected hospital-level mortality rate using only patient covariates

3) E(Intercept + Hospital): Obtaining expected hospital-level mortality rate using only hospital covariates

4) E(Intercept + Hospital + Patient): Obtaining expected hospital-level mortality rate using patient and hospital covariates

5) P(Random Effect + Intercept + Patient): Obtaining predicted hospital-level mortality rate using only patient covariates

6) P(Random Effect + Intercept + Hospital): Obtaining predicted hospital-level mortality rate using only hospital covariates

7) P(Random Effect + Intercept + Hospital + Patient): Obtaining predicted hospital-level mortality rate using only hospital covariates

8) E(Intercept + Hospital + Patient) / E(Intercept + Patient): Obtaining expected hospital-level mortality rate using patient and hospital covariates after removing the effect of patient covariates, and multiplied by the unadjusted national mean for each time period

9) E(Intercept + Hospital + Patient) / E(Intercept + Hospital): Obtaining expected hospital-level mortality rate using patient and hospital covariates after removing the

effect of hospital covariates, and multiplied by the unadjusted national mean for each time period

10) P(Random Effect + Intercept+ Patient) / E(Intercept + Patient) = "RSR": Obtaining predicted hospital-level mortality rate using patient covariates divided by the expected hospital-level mortality rate using patient covariates, and multiplied by the unadjusted national mean for each time period

11) P(Random Effect + Intercept + Hospital) / E(Intercept + Hospital) : Obtaining predicted hospital-level mortality rate using hospital covariates divided by the expected hospital-level mortality rate using hospital covariates, and multiplied by the unadjusted national mean for each time period

12) P(Random Effect + Intercept + Hospital + Patient) / E(Intercept + Hospital + Patient) : Obtaining predicted hospital-level mortality rate using patient and hospital covariates divided by the expected hospital-level mortality rate using patient and hospital covariates, and multiplied by the unadjusted national mean for each time period

Results

Sample patient characteristics

Trends in overall patient characteristics between 2005 and 2010 are described. (Table 1) Total number of AMI hospitalizations decreased by 29% from 222,826 to 171,566 between 2005 and 2010. Demographic characteristics, such as age and proportion of males, did not vary. Prevalence of some cardiovascular history and comorbidities increased, including history of percutaneous transluminal coronary angioplasty (PTCA),

chronic atherosclerosis, cardiopulmonary-respiratory failure and shock, hypertension, renal failure, diabetes, protein-calorie malnutrition, peripheral vascular disease, and major psychiatric disorders. For some comorbidities, such as valvular heart disease and stroke, the proportion decreased.

Table 1. Sample Patient Characteristics

		No. or %					
Characteristic		**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
	Total AMI Hospitalization, No.	222826	200843	189075	187642	175497	171566
Demographic	**Age (yr)**	78.7	78.7	78.9	79.0	78.8	78.8
	Male	48.9%	49.0%	49.0%	49.8%	50.5%	50.7%
Cardiovascular	**History of PTCA**	6.9%	7.5%	7.6%	7.8%	7.9%	8.4%
	History of CABG	6.7%	6.4%	6.2%	6.2%	5.9%	6.0%
	History of Heart Failure	32.0%	31.2%	31.4%	31.3%	31.2%	30.9%
	History of AMI	14.0%	13.6%	13.7%	13.6%	13.6%	13.7%
	AMI Location - Anterior or Anterolateral	11.4%	11.5%	10.7%	9.7%	9.1%	9.0%
	AMI Location - Inferolateral, inferoposterior, inferior, other lateral, and true posterior	15.0%	15.2%	14.5%	13.1%	12.9%	12.7%
	Unstable Angina	14.9%	14.2%	13.8%	13.5%	13.5%	13.2%
	Chronic atherosclerosis	75.6%	76.0%	76.3%	77.1%	77.4%	77.9%
	Cardiopulmonary-respiratory failure and shock	7.8%	7.8%	8.7%	9.2%	9.3%	9.5%
	Valvular heart disease	30.0%	31.0%	31.2%	27.3%	26.6%	26.2%
Comorbid conditions	**Hypertension**	78.2%	79.1%	81.7%	83.3%	84.0%	84.7%
	Stroke	8.7%	8.3%	8.2%	8.3%	8.0%	7.8%
	Cerebrovascular disease	18.4%	18.7%	19.2%	19.8%	19.8%	19.8%
	Renal failure	13.2%	16.5%	19.2%	20.5%	21.9%	23.7%
	COPD	31.0%	30.4%	30.4%	28.7%	28.1%	28.1%
	Pneumonia	23.9%	23.0%	23.5%	25.0%	24.2%	23.6%
	Diabetes mellitus	40.2%	40.4%	41.2%	42.1%	42.9%	43.8%
	Protein-calorie malnutrition	3.6%	3.6%	4.0%	4.9%	5.4%	5.6%
	Dementia	17.4%	17.3%	17.7%	18.4%	18.3%	18.3%
	Hemiplegia paraplegia, paralysis, functional disability	5.5%	5.3%	5.4%	5.9%	5.8%	6.0%

	Peripheral vascular disease	23.3%	24.0%	25.0%	25.3%	26.1%	26.4%
	Metastatic cancer	3.5%	3.6%	3.8%	3.9%	3.9%	3.9%
	Trauma in past year	27.0%	27.6%	27.9%	27.9%	28.9%	29.4%
	Major psychiatric disorders	6.4%	6.3%	6.5%	6.9%	7.0%	7.1%
	Chronic liver disease	0.9%	0.9%	1.0%	1.0%	1.0%	1.1%

Sample hospital characteristics

Distribution of hospital characteristics was examined at both hospital- and hospitalization-level (Table 2). When analyzed at hospital-level, the majority of hospitals was non-teaching (68.9%), private (73.7%), and were located in urban (73.4%), South (30.4%) and Midwest (32.4%) regions. Also the hospital sample has an average bed count of 187, 5-year cumulative AMI volume of 280, and 17.6% Medicaid patients. Analyzed at hospitalization-level, many hospitalizations were performed at non-teaching (50.2%), private (86.6%), and were located in urban (93.9%) and in the South (38.7%). Also the sample has an average bed count of 367, 5-year cumulative AMI volume of 732, and 17.5% Medicaid patients. The discrepancy in distribution at different level of analysis indicates disproportionate number of AMI patients in each hospital.

Table 2. Sample Hospital Characteristics

		Hospital		**Hospitalization**	
		N	**%**	**N**	**%**
	Total Hospitals or Hospitalization	4270		1147449	
Number of beds	**0-200**	2650	62.1	319092	27.8
	201-400	877	20.5	419404	36.6
	400+	451	10.6	378528	33.0
	Missing	292	6.8	30425	2.7
Teaching Status	**No**	2944	68.9	575779	50.2

	Yes	1034	24.2	541245	47.2
	Missing	292	6.8	30425	2.7
Region	**Northeast**	557	13.0	224867	19.6
	South	1296	30.4	443888	38.7
	Midwest	1384	32.4	294680	25.7
	West	694	16.3	148236	12.9
	Missing	339	7.9	35778	3.1
Urban/Rural	**Urban**	3136	73.4	1077549	93.9
	Rural	842	19.7	39475	3.4
	Missing	292	6.8	30425	2.7
Ownership	**Public**	832	19.5	123300	10.7
	Private	3146	73.7	993724	86.6
	Missing	292	6.8	30425	2.7
AMI volume (5yr Cumulative)					
	0-25	594	13.9	11220	1.0
	26-200	1752	41.0	165079	14.4
	201-500	897	21.0	306616	26.7
	501-1000	525	12.3	365274	31.8
	1001-3000	210	4.9	299260	26.1
Proportion of Medicaid					
	0-20	2651	62.1	736803	64.2
	21-40	1195	28.0	357266	31.1
	40+	132	3.1	22955	2.0
	Missing	292	6.8	30425	2.7

Trend in observed- and risk-standardized mortality rates

Trend in observed and risk-standardized mortality rates from 2005 to 2010 were examined (Table 3, Figure 1). Over the 6-year period, the 30-day mortality trend of AMI patients shows a decreasing trend. The median observed mortality decreased by 4.3% from 18.8% to 14.5%. The width of the interquartile range was similar throughout the period, meaning the between-hospital variation remained unchanged. When using hierarchical models, the variance for hospital-specific intercepts looks similar across the 6 years. Mortality showed a decreasing trend even after risk standardization. The median

RSR decreased by 3.3% from 19.3% to 16.0%. The width of IQR also remained the same throughout the period.

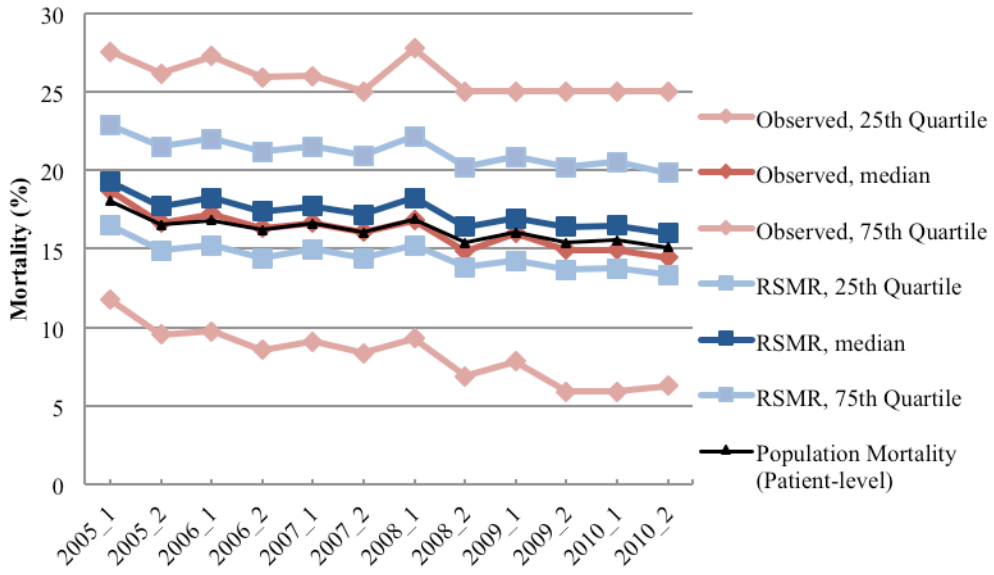


Figure 1. Trend in observed- and risk-standardized mortality rates, 2005-2010, by 6-month

Table 3. Trend in observed- and risk-standardized mortality rates, 2005-2010, by 6-month

Year	# Hospitals	Observed		RSR		Population Mortality (Patient-level)
		Mean	Median (IQR)	Mean	Median (IQR)	
2005_1	3966	21.9	18.8 (11.8, 27.5)	20.2	19.3 (16.5, 22.9)	18.0
2005_2	3928	20.7	16.7 (9.5, 26.2)	18.8	17.7 (14.9, 21.5)	16.5
2006_1	3913	20.7	17.2 (9.8, 27.3)	19.2	18.3 (15.2, 22.0)	16.8
2006_2	3867	20.4	16.4 (8.6, 25.9)	18.5	17.4 (14.4, 21.2)	16.2
2007_1	3879	20.5	16.7 (9.1, 26.0)	18.8	17.7 (14.9, 21.5)	16.6
2007_2	3825	20.8	16.1 (8.3, 25.0)	18.4	17.2 (14.4, 20.9)	16.0
2008_1	3969	21.5	16.9 (9.3, 27.8)	19.3	18.2 (15.2, 22.2)	16.9
2008_2	3877	19.6	14.9 (6.9, 25.0)	17.6	16.4 (13.8, 20.2)	15.4
2009_1	3860	20.5	16.0 (7.8, 25.0)	18.2	16.9 (14.2, 20.9)	16.0
2009_2	3832	19.9	14.9 (5.9, 25.0)	17.6	16.4 (13.7, 20.2)	15.4
2010_1	3838	19.7	15.0 (5.9, 25.0)	17.7	16.5 (13.7, 20.5)	15.6
2010_2	3762	20.2	14.5 (6.3, 25.0)	17.3	16.0 (13.3, 19.8)	15.1

Distinct trends in 30-day observed and risk-standardized mortality rates

To find group of hospitals with distinct mortality trajectories between 2005-2010, growth mixture modeling was applied to hospital-level observed and risk-standardized mortality rates. For RSR trajectory, BIC value peaked at a model using five groups (Figure 2). Based on this result, the five-group model was favored and used for further analyses. Therefore we identified five distinct groups of hospitals based on their patterns of mortality rate over time.

The shape of trajectories between observed and risk-standardized rates greatly differ (Figure 3a, 4a). Five groups of observed rates show dynamic trajectories, with varying trend and level of mortality. Using observed groups, Group 3 that includes 87.7% of the hospitals shows a trend similar to overall trend in mean observed rates described in Figure 1. Two groups (Group 2 and 5) show a sharp increase in average mortality above 70% in 2007 and 2008, whereas average mortality rates of Group 4 hospitals sharply decreased from 50% to below 10%. Also the average posterior probabilities of each group assignment ranges from 83.9% to 97.7%, meaning that trajectories are reliable.

On the other hand, all trajectories of risk-standardization rates show decreasing trend and all the trajectories look rather smooth, although the level and rates of decrease vary across groups. The highest mortality group (Group 3) includes 2.3% of the hospitals with average risk-standardized mortality rates of 20% in the first half-year of 2005 to 16% in the second half-year of 2010. On the other hand, the lowest mortality group (Group 1)

includes 1.0% of the hospitals with average risk-standardized mortality rates of 16.2% in the first half-year of 2005 to 14.8% in the second half-year of 2010. The group with majority of hospitals (Group 5) includes 87.6% of the hospitals with average risk-standardized mortality rates of 18.0% in the first half-year of 2005 to 15.8% in the second half-year of 2010.

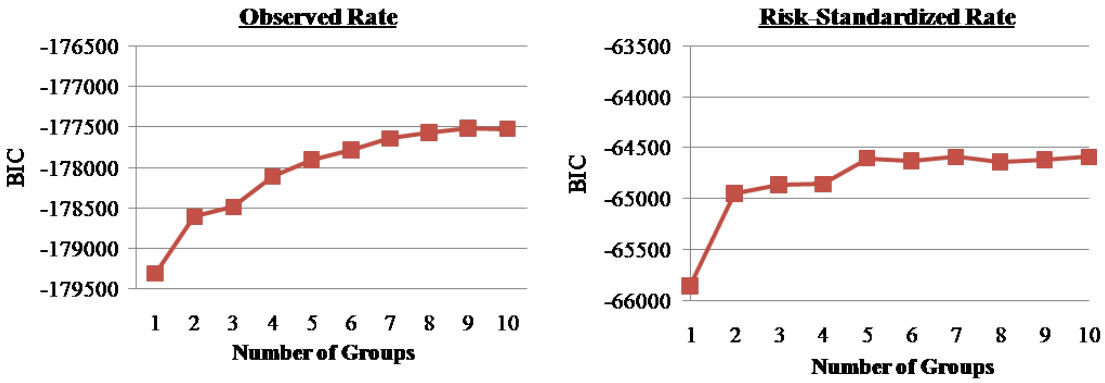
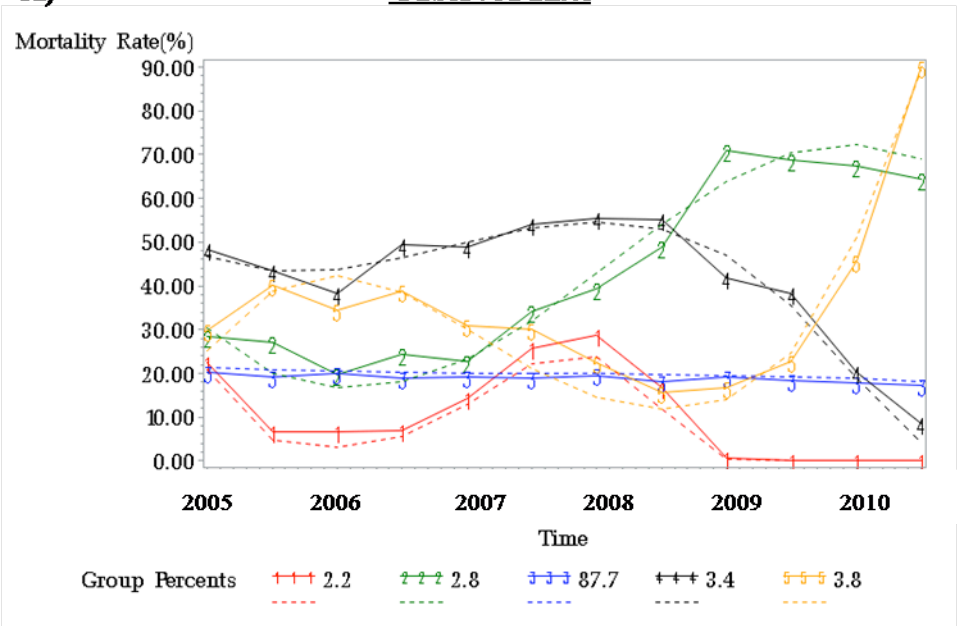


Figure 2. BIC Curves for growth mixture model selection

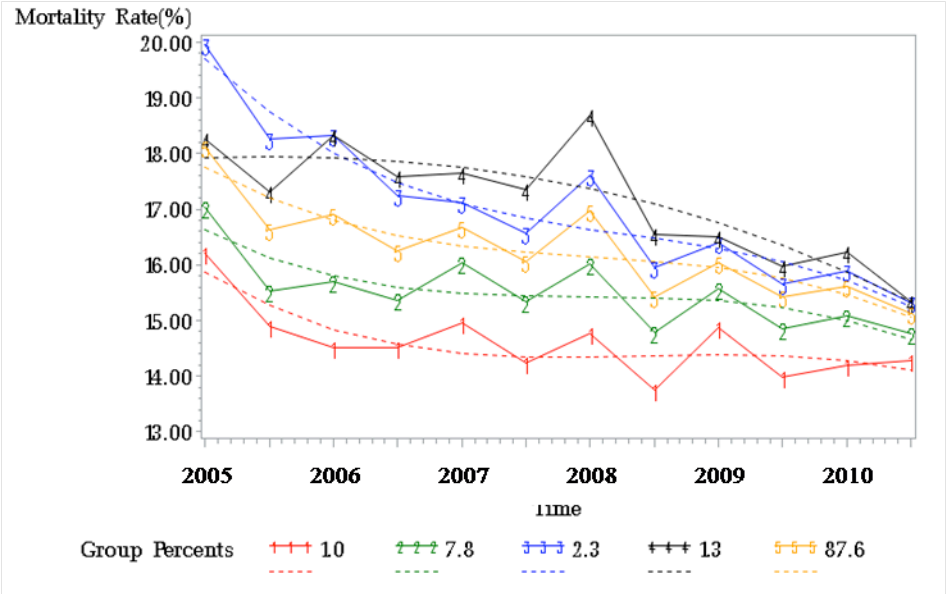
A) **Observed Rate**



B)

Group	No. Hosp (%)	Avg. Posterior Prob. (%)
1	91 (2.2)	83.9
2	111 (2.8)	87.7
3	3783 (87.7)	97.7
4	135 (3.4)	87.0
5	150 (3.8)	88.7

Figure 3. A) Distinct patterns of observed mortality rates, 2005-2010; B) Average posterior probability table of group assignment



Group	No. Hosp (%)	Avg. Posterior Prob. (%)
1	41 (1.0)	87.9
2	278 (7.8)	83.0
3	82 (2.3)	78.4
4	44 (1.3)	78.3
5	3825 (87.6)	96.2

Figure 4. A) Distinct patterns of risk-standardized rates, 2005-2010; B) Average posterior probability table of group assignment

Group membership between observed- and risk-standardized rates

Distribution of hospitals across trajectory groups was similar for observed and risk-standardized mortalities (Figure 3b, 4b). For both types of mortality rates, there was one group where the majority of hospitals (>86%) were assigned, while remaining hospitals were distributed among four other groups.

Once hospitals are categorized into groups, an agreement table was created to examine how group membership using observed rates change after standardization (Table 4). Instead of each group from observed rates remaining distinct, most of the hospitals in the four smaller groups (OR Group 1, 2, 4, and 5) folded into the major group (RSR Group 5) after standardization. On the other hand, 11.6% of hospitals in the major group (OR Group 3) of observed rates dispersed into four smaller distinct groups after risk-standardization.

Table 4. Agreement table of hospital group membership between observed and risk-standardized rates

Group Membership by Observed Rate	Group Membership by Risk-standardized Rate					
	1	**2**	**3**	**4**	**5**	**Total**
1	0	0	0	0	91	91
2	0	0	1	0	110	111
3	41	278	78	42	3344	3783
4	0	0	2	2	131	135
5	0	0	1	0	149	150
Total	41	278	82	44	3825	4270

Association between patient and hospital characteristics and observed rate group assignment

Patient and hospital characteristics of hospitals in each trajectory group were compared. To compare patient characteristics, the hospital-level proportion of each patient risk factor across all time periods was first computed and averaged for each trajectory group. For example, 42.8% of males in Group 1 should be interpreted as the average proportion of males among Group 1 hospitals (Table 5). Bivariate analyses between each covariate and group membership show that all patient covariates were associated with different

group membership ($p < 0.0001$) except anterior/anterolateral AMI location, hypertension, cerebrovascular disease, renal failure, COPD. In multivariate regression analysis, nine patient characteristics including age, history of heart failure, chronic atherosclerosis, valvular heart disease, hypertension, pneumonia, functional disability, metastatic cancer, and chronic liver disease were associated with observed rate group membership (Table 6).

Hospital characteristics of the each group were similarly compared (Table 7). In bivariate analyses, all hospital covariates were associated with group membership ($p < 0.0001$). However in multivariate regression analysis, only cumulative AMI volume was significantly associated with group membership of observed rates ($p < 0.0001$). Number of hospital bed was almost significant at $p= 0.0531$ (Table 8).

Compared to Group 3 that includes 88.6% of hospitals, hospitals with small AMI volume were more likely to be in Group 1, 2, 4, and 5 between 2005 and 2010 (Odds ratio = 0.006, 0.009, 0.024, and 0.061 per increase in 100 hospitalizations) (Table 9). Also hospitals with greater number of beds were less likely to be in Group 5 compared to Group 3 (Odds ratio = 0.061 per increase in 100 hospitalizations, $p = 0.0153$). Lastly it is worthwhile to note that even though region was not a significant factor in multivariate analyses, none of the hospitals in Group 2 was located in the Northeast (Table 7).

Table 5. Comparison of patient characteristics (hospital-level average) by observed group membership

	Group 1	Group 2	Group 3	Group 4	Group 5	p-value
No. of Hospitals (n)	91	111	3783	135	150	
Obs. MR (%)	11.7	37.4	19.3	41.1	33.2	<0.0001
Age (yr)	81.0	82.8	79.8	82.6	82.6	<0.0001
Male (%)	42.8	39.0	47.4	41.3	40.9	<0.0001
AMI Location - Anterior or Anterolateral (%)	10.5	9.8	9.2	9.3	8.6	0.1272
AMI Location - Inferolateral, inferoposterior, inferior, other lateral, and true posterior (%)	9.6	8.7	11.2	9.3	9.3	<0.0001
History of PTCA (%)	4.4	3.1	6.3	2.8	3.1	<0.0001
History of CABG (%)	6.2	4.4	6.8	5.5	5.3	<0.0001
History of Heart Failure (%)	37.4	44.3	35.6	44.6	43.3	<0.0001
History of AMI (%)	12.8	13.5	13.8	13.4	12.9	0.0119
Unstable Angina (%)	11.0	12.5	13.6	12.5	11.7	<0.0001
Chronic atherosclerosis (%)	57.5	54.5	68.7	53.0	55.8	<0.0001
Cardiopulmonary-respiratory failure and shock (%)	7.9	9.0	9.2	9.2	8.7	0.0062
Valvular heart disease (%)	21.5	21.1	26.6	20.4	21.8	<0.0001
Hypertension (%)	80.9	82.1	82.4	79.7	81.7	0.0768
Stroke (%)	7.4	10.5	8.9	10.2	9.4	0.0019
Cerebrovascular disease (%)	17.6	20.3	19.4	20.5	20.0	0.0852
Renal failure (%)	19.5	19.3	19.6	19.5	18.3	0.1062
COPD (%)	29.5	31.9	31.3	31.9	30.8	0.3155
Pneumonia (%)	27.1	35.0	27.2	36.3	32.3	<0.0001
Diabetes mellitus (%)	40.4	39.4	42.5	38.6	39.1	<0.0001
Protein-calorie malnutrition (%)	3.2	4.9	4.6	4.4	3.6	<0.0001
Dementia (%)	22.4	31.0	21.7	32.8	30.0	<0.0001
Hemiplegia paraplegia, paralysis, functional disability (%)	6.3	8.1	6.4	8.3	8.0	<0.0001
Peripheral vascular dissease (%)	21.6	23.1	24.6	23.6	23.7	0.0017
Metastatic cancer (%)	2.2	2.9	3.7	3.0	3.0	<0.0001
Trauma in past year (%)	30.2	33.2	29.7	35.5	31.8	<0.0001
Major psychiatric disorders (%)	8.6	10.4	7.9	11.4	11.3	<0.0001
Chronic liver disease (%)	0.4	0.8	1.0	0.8	1.2	<0.0001

Table 6. Patient characteristics associated with observed rate group membership (multivariate analysis)

Patient characteristics	P-value
Age (yr)	<.0001
History of Heart Failure	0.0006
Chronic atherosclerosis	<.0001
Valvular heart disease	<.0001
Hypertension	0.0275
Pneumonia	0.0003
Hemiplegia paraplegia, paralysis, functional disability	0.0145
Metastatic cancer	0.0090
Chronic liver disease	0.0022

Table 7. Comparison of hospital characteristics by observed group membership

		Group 1	Group 2	Group 3	Group 4	Group 5	p-value
No. of hospitals (n)		91	111	3783	135	150	
No. of beds (mean, n)		69.7	58.6	204.7	55.4	54.8	<0.0001
Cumulative AMI volume (mean, n)		26.5	27.1	314.8	29.2	33.1	<0.0001
Proportion of Medicaid (mean, %)		14.3	13.2	18.0	14.6	14.6	<0.0001
Teaching Status	**No (%)**	83.5	85.6	66.3	91.1	93.3	<0.0001
	Yes (%)	8.8	11.7	26.3	7.4	6.0	
	Missing (%)	7.7	2.7	7.4	1.5	0.7	
Region	**Northeast (%)**	44.0	0	14.4	2.2	3.3	<0.0001
	South (%)	18.7	24.3	31.3	20.0	28.0	
	Midwest (%)	42.9	56.8	29.7	57.8	54.0	
	West (%)	25.3	14.4	16.2	17.8	12.7	
	Missing (%)	8.8	4.5	8.5	2.2	2.0	
Urban/Rural	**Urban (%)**	40.7	45.0	77.3	44.4	42.7	<0.0001
	Rural (%)	51.6	52.3	15.3	54.1	56.7	
	Missing (%)	7.7	2.7	7.4	1.5	0.7	
Ownership	**Private (%)**	67.9	57.7	75.4	58.5	62.7	<0.0001
	Public (%)	32.1	39.6	17.2	40.0	36.7	
	Missing (%)	7.7	2.7	7.4	1.5	0.7	

Table 8. Hospital characteristics associated with observed rate group membership (multivariate analysis)

Hospital characteristics	P-value
No. of beds (mean, n)	0.0531
Cumulative AMI volume (mean, n)	<.0001

Table 9. Association between hospital characteristics and distinct patterns of observed rate

	Group 1 vs. Group 3				Group 2 vs. Group 3			
	OR	**95% CI**		**p-value**	**OR**	**95% CI**		**p-value**
Cumulative AMI Volume[1]	0.006	0.002	0.024	<.0001	0.009	0.003	0.029	<.0001
No. of Beds[2]	1.16	0.86	1.56	0.3351	0.88	0.62	1.25	0.4835

	Group 4 vs. Group 3				Group 5 vs. Group 3			
	OR	**95% CI**		**p-value**	**OR**	**95% CI**		**p-value**
Cumulative AMI Volume[1]	0.024	0.01	0.059	<.0001	0.061	0.03	0.13	<.0001
No. of Beds[2]	0.77	0.55	1.09	0.1447	0.63	0.44	0.92	0.0153

1: The unit for OR effect of cumulative AMI volume is 100 hospitalizations
2: The unit for OR effect of the number of bed is 100 hospitalizations

Association between patient and hospital characteristics and risk-standardized rates group assignment

Bivariate analyses between each covariate and group membership show that all patient covariates were associated with different group membership ($p < 0.0001$) except history of Coronary Artery Bypass Grafting (CABG), history of AMI, cardiopulmonary-respiratory failure and shock, cerebrovascular disease, renal failure, and protein-calorie malnutrition (Table 10). In multivariate regression analysis, eight patient characteristics including age, history of heart failure, history of AMI, chronic atherosclerosis, valvular heart disease, COPD, and peripheral vascular disease were associated with RSR group membership (Table 11).

Hospital characteristics of the each RSR group were similarly compared (Table 12). In bivariate analyses, all hospital covariates were associated with group membership ($p < 0.0001$). However in multivariate regression analysis, only four covariates including cumulative AMI volume, urban/rural classification, proportion of Medicaid patients, and region, were significantly associated with group membership of observed rates ($p < 0.0001$) (Table 13).

Compared to Group 5 that includes 89.6% of hospitals, all four smaller groups (Group 1, 2, 3, and 4) were more likely to be urban and have greater cumulative AMI volume (Table 14). In addition, Group 1 hospitals were more likely to be located in the Northeast (OR=3.38) and have less Medicaid patients (OR=0.44 per 10% increase in proportion of Medicaid patients). Group 2 hospitals were less likely to be located in the South (OR=0.53, p=0.023) and have less Medicaid patients (OR=0.74 per 10% increase). On the other hand, Group 3 and 4 are likely to have more Medicaid patients (OR=1.3 and 1.26, respectively, per 10% increase). Also Group 4 was more likely to be located in the Midwest (OR=2.09) compared to Group 5.

Table 10. Comparison of patient characteristics (hospital-level average) by RSR group membership

	Group 1	Group 2	Group 3	Group 4	Group 5	p-value
No. of Hospitals (n)	41	278	82	44	3825	
Obs. MR (%)	11.0	12.8	24.0	22.1	21.4	<0.0001
Age (yr)	78.9	78.9	78.7	78.5	80.2	<0.0001
Male (%)	51.8	50.2	48.5	49.3	46.2	<0.0001
AMI Location - Anterior or Anterolateral (%)	11.5	10.7	9.1	9.1	9.1	<0.0001
AMI Location - Inferolateral, inferoposterior, inferior, other lateral, and true posterior (%)	15.8	14.6	12.4	12.3	10.6	<0.0001
History of PTCA (%)	9.0	7.8	6.7	8.2	5.7	<0.0001

History of CABG (%)	5.6	5.8	6.4	7.5	6.7	0.0577
History of Heart Failure (%)	28.8	30.5	33.9	33.7	37.0	<0.0001
History of AMI (%)	13.2	13.9	13.6	14.2	13.7	0.6316
Unstable Angina (%)	14.6	14.2	14.8	15.6	13.3	<0.0001
Chronic atherosclerosis (%)	83.4	78.8	74.6	76.0	65.9	<0.0001
Cardiopulmonary-respiratory failure and shock (%)	7.5	8.9	8.9	8.9	9.2	0.1154
Valvular heart disease (%)	33.7	29.9	26.5	27.6	25.6	<0.0001
Hypertension (%)	81.0	81.2	81.8	82.5	82.3	0.0006
Stroke (%)	7.7	8.1	9.1	9.0	9.1	0.0041
Cerebrovascular disease (%)	19.1	19.3	19.1	18.9	19.4	0.9857
Renal failure (%)	17.6	18.8	19.1	19.5	19.6	0.3028
COPD (%)	24.5	28.3	31.9	30.5	31.6	<0.0001
Pneumonia (%)	20.2	23.5	25.3	25.3	28.4	<0.0001
Diabetes mellitus (%)	39.4	40.7	45.1	43.6	42.2	0.0001
Protein-calorie malnutrition (%)	3.8	4.4	4.7	4.7	4.6	0.1404
Dementia (%)	14.8	17.5	19.9	18.0	23.1	<0.0001
Hemiplegia paraplegia, paralysis, functional disability (%)	4.9	5.4	6.0	6.2	6.7	<0.0001
Peripheral vascular disasese (%)	27.7	25.7	23.8	24.1	24.3	0.0013
Metastatic cancer (%)	4.2	3.8	3.6	3.6	3.6	0.001
Trauma in past year (%)	28.3	28.2	28.0	28.0	30.3	<0.0001
Major psychiatric disorders (%)	6.5	6.9	6.6	7.0	8.4	<0.0001
Chronic liver disease (%)	1.0	1.0	1.1	1.1	1.0	<0.0001

Table 11 . Patient characteristics associated with RSR group membership (multivariate analysis)

Patient characteristics	P-value
Age (yr)	0.0051
History of Heart Failure (%)	<.0001
History of AMI (%)	0.0013
Chronic atherosclerosis (%)	<.0001
Valvular heart disease (%)	<.0001
COPD (%)	<.0001
Diabetes mellitus (%)	<.0001
Peripheral vascular disease (%)	<.0001

Table 12. Comparison of hospital characteristics by RSR group membership

		Group 1	Group 2	Group 3	Group 4	Group 5	p-value
No. of hospitals (n)		41	278	82	44	3825	
No. of beds (mean, n)		554.7	379.3	273.0	335.0	164.9	<0.0001
Cumulative AMI volume (mean, n)		1338.1	782.8	436.1	529.4	224.3	<0.0001
Proportion of Medicaid (mean, %)		13.9	16.0	20.7	20.6	17.6	<0.0001
Teaching Status	**No (%)**	29.3	44.2	58.5	54.6	71.6	<0.0001
	Yes (%)	68.3	53.2	32.9	40.9	21.3	
	Missing (%)	2.4	2.5	8.5	4.6	7.2	
Region	**Northeast (%)**	48.8	24.1	7.3	9.1	12.0	<0.0001
	South (%)	31.7	35.6	25.6	27.3	30.1	
	Midwest (%)	12.2	20.1	30.5	43.2	33.4	
	West (%)	4.9	17.6	20.7	11.4	16.2	
	Missing (%)	2.4	2.5	15.9	9.1	8.2	
Urban/Rural	**Urban (%)**	97.6	97.1	86.6	90.9	71.0	<0.0001
	Rural (%)	0.0	0.4	4.9	4.6	21.8	
	Missing (%)	2.4	2.5	8.5	4.6	7.2	
Ownership	**Private (%)**	97.6	89.9	79.3	68.2	72.2	<0.0001
	Public (%)	0.0	7.6	12.2	27.3	20.6	
	Missing (%)	2.4	2.5	8.5	4.6	7.2	

Table 13. Hospital characteristics associated with RSR group membership (multivariate analysis)

Hospital characteristics	P-value
Urban/Rural	0.0024
Cumulative AMI volume (mean, n)	<0.0001
Proportion of Medicaid (mean, %)	<0.0001
Region	<0.0001

Table 14. Association between hospital characteristics and distinct patterns of risk-standardized rate

	RSR Group 1 vs. Group 5				RSR Group 2 vs. Group 5			
	OR	**95% CI**		**p-value**	**OR**	**95% CI**		**p-value**
Northeast vs. West	3.38	0.74	15.37	<.0001	0.93	0.61	1.42	0.0138
South vs. West	0.53	0.11	2.67	0.1388	0.53	0.36	0.79	0.023
Midwest vs. West	0.34	0.06	1.98	0.0262	0.44	0.29	0.69	0.0009
Urban vs. Rural	>999.9*	<0.001	>999.9	0.9557	23.1	3.2	166.8	0.0018
Cumulative AMI Volume[1]	1.56	1.46	1.66	<0.0001	1.33	1.29	1.38	<0.0001
Prop. Of Medicaid[2]	0.44	0.26	0.72	0.0013	0.74	0.62	0.88	0.0007

	RSR Group 3 vs. Group 5				RSR Group 4 vs. Group 5			
	OR	**95% CI**		**p-value**	**OR**	**95% CI**		**p-value**
Northeast vs. West	0.37	0.14	0.95	0.0839	0.77	0.20	2.92	0.3448
South vs. West	0.56	0.29	1.10	0.5421	1.00	0.34	2.94	0.6879
Midwest vs. West	0.82	0.44	1.56	0.2218	2.09	0.76	5.71	0.0155
Urban vs. Rural	2.8	0.96	7.9	0.0599	6.7	0.88	50.7	0.0662
Cumulative AMI Volume[1]	1.19	1.12	1.27	<0.0001	1.23	1.15	1.31	<0.0001
Prop. Of Medicaid[2]	1.3	1.05	1.6	0.0162	1.26	0.94	1.69	0.1166

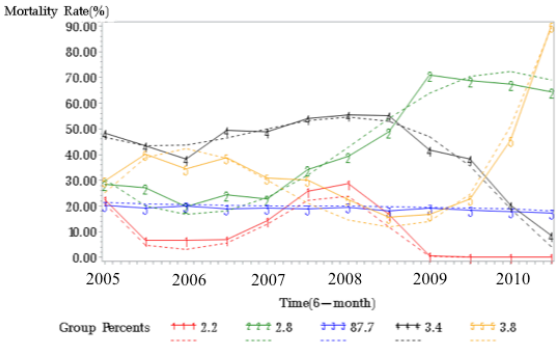
* OR cannot be computed due to quasi-separation of the data
1: The unit for OR effect of cumulative AMI volume is 100 hospitalizations
2: The unit for OR effect of the proportion of Medicaid patients is 10%

Comparison of trajectory shapes using observed and risk-standardized rates

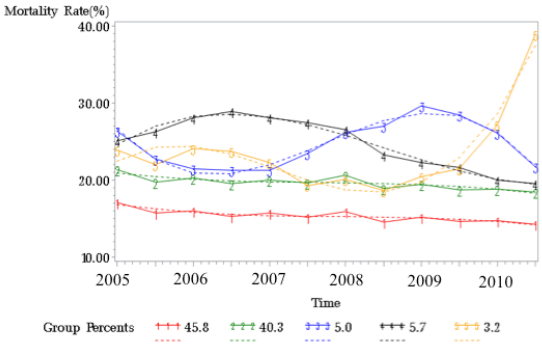
The role of patient covariates, hospital covariates, and hospital random effect in trajectory shape during risk-standardization step was investigated. As seen in Figure 3, trajectories using observed and risk-standardized rates are very different in terms of overall shape,

level, and slope. We intend to identify the factors used in hierarchical model that make RSR trajectory lose the patient dynamics. By using estimated mortalities based on patient characteristics alone in the first stage for the growth mixture model in the second stage, the hospital dynamic of mortality over time was preserved as in the observed mortality rates (Figure 5-2). So whether or not to use patient covariates for estimating mortality does not seem to significantly affect the shape of the hospital trajectories. However, when using estimated mortalities based on hospital characteristics alone, the patient dynamic over time is lost and trajectories become similar to those from risk-standardized rates (Figure 5-3). Figure 5-8 depicts when mortalities are estimated from both patient and hospital covariates and standardized by expected mortality from patient covariates alone. In this case, standardization step removes the effect of patient covariates, but this is not the reason that the dynamics of hospital trajectory disappears and becomes similar to the graph of risk-standardized rates; it is the use of hospital covariates that made the dynamic start disappearing. For non-standardized rates, adding hospital random effects to each of three types of mortalities caused migration of some hospitals to a different group, but did not significantly alter trajectory shape (Figure 5-5, 5-6, 5-7). Therefore we find that hospital covariate is one of the components of the standardization step that drive trajectories become smoother over time.

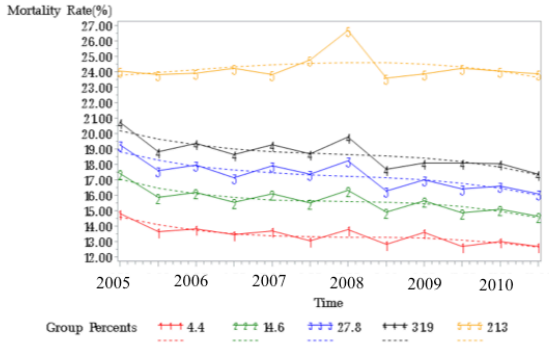
1) Observed



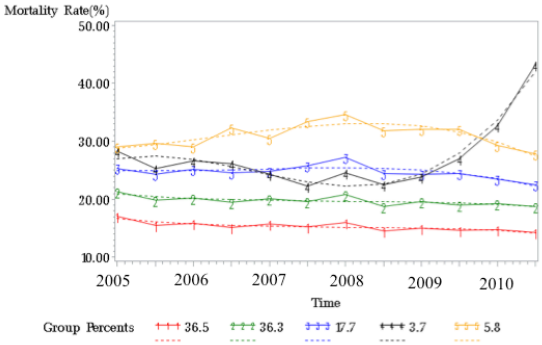
2) E(Intercept + Patient)



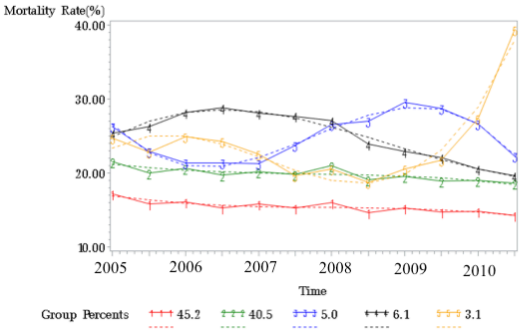
3) E(Intercept + Hospital)



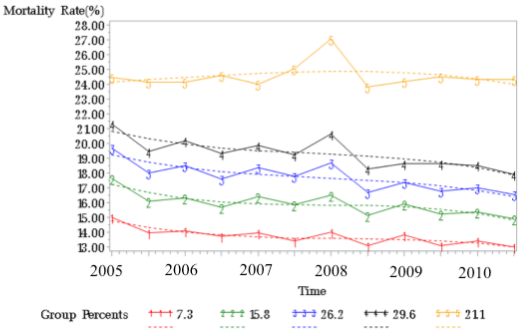
4) E(Intercept + Hospital + Patient)



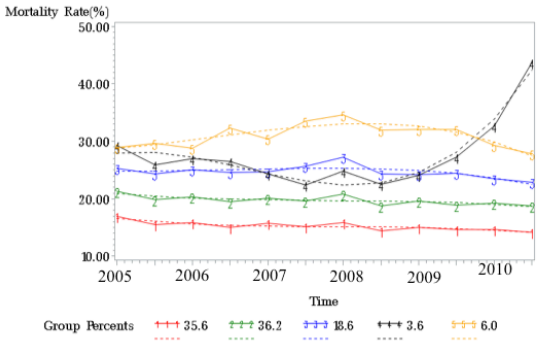
5) P(Random Effect + Intercept + Patient)



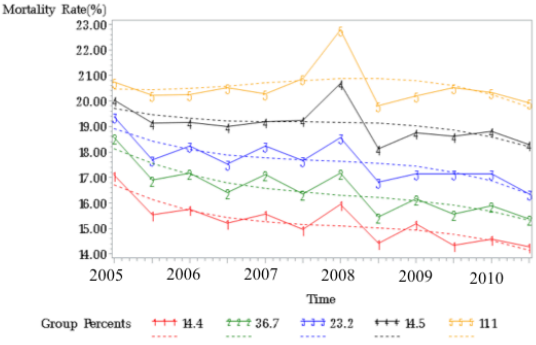
6) P(Random Effect + Intercept + Hospital)



7) P(Random Effect + Intercept + Hospital + Patient)



8) E(Intercept + Hospital + Patient) / E(Intercept + Patient)



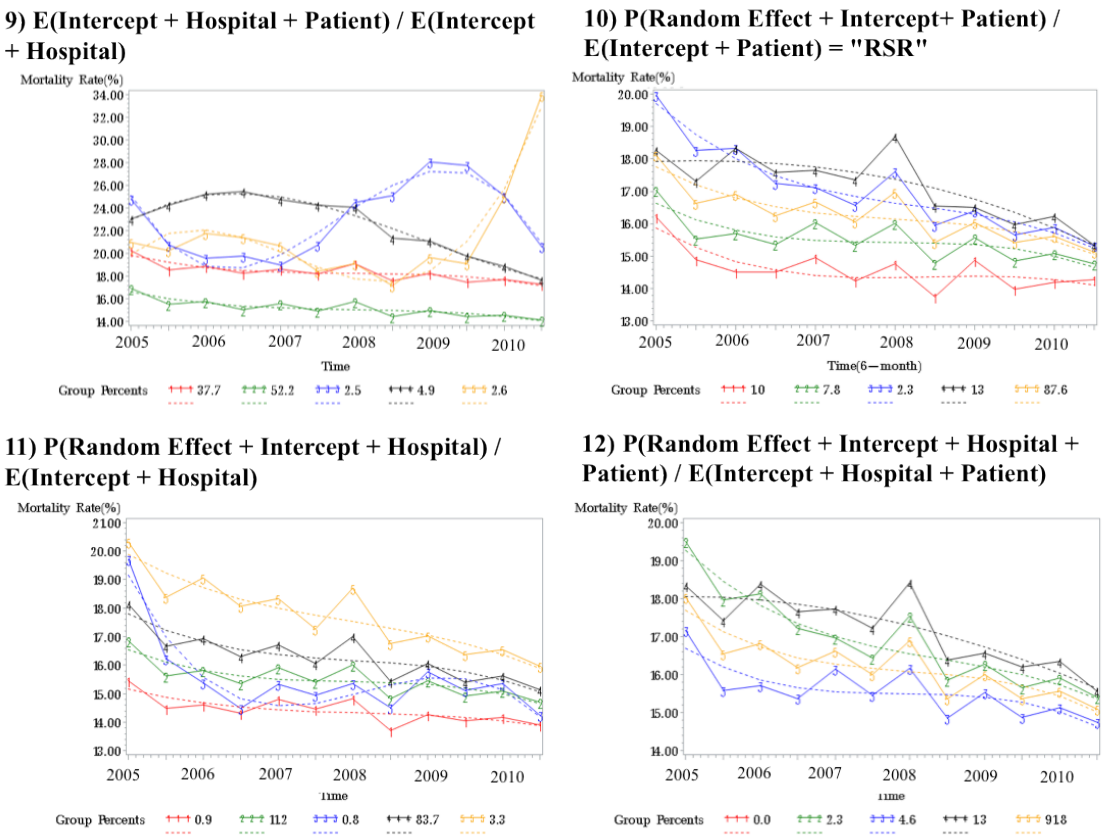


Figure 5. Change in trajectory shape upon varying fixed effects, random effects, and standardization step. Note: for Figure 5-12), growth mixture modeling was not able to find five distinct groups.

Discussion

We analyzed trends in 30-day mortality of AMI patients between 2005-2010 and identify five groups of hospitals with distinct trends. However, using two types of mortality rates – observed and risk-standardized rates, the mortality level and shapes of trajectories greatly differed. Also, the hospitals in each trajectory group did not remain in their respective group after standardization but instead folded into the group that includes the majority of the hospital. Such phenomenon can be explained by the use of shrinkage estimator in the risk-standardization step. The shrinkage estimator incorporates the effect

of shrinkage by calculating weighted average of the unshrunk estimator of each hospital and the average mortality rate of all hospitals, where the weight is determined by sample size and within- and between-hospital variance. Therefore, the shrinkage estimator will be close to the unshrunk estimator of each hospital if the sample is large or close to the grand mean when a hospital has a small sample size and precise estimation of unshrunk estimator is not possible (Mukamel, Glance et al. 2010). Indeed all four smaller groups of distinct observed mortality trend had a low AMI volume of around 20. However after standardization they were folded into the group that includes the majority of the hospital with mean mortality close to the population-level average.

AMI volume was the only hospital factor associated with group membership based on observed hospital mortality rates whereas four hospital factors such as AMI volume, urban/rural classification, the proportion of Medicaid patients, and region were significantly associated with group membership of distinct risk-standardized trends. These are hospital factors that were previously found to be associated with hospital performance. For example, a 2010 study found that increased hospital AMI volume was associated with lower 30-day risk-standardized mortality rate of patients with AMI (Ross, Normand et al. 2010). Also our finding that 48.8% of the hospitals in the group with lowest risk-standardized rate (RSR Group 1) were located in the Northeast is consistent with a 2009 study that reduced AMI mortality was found in small, densely populated hospital referral regions primarily in the Northeast. (Krumholz, Merrill et al. 2009) Lastly we did not find that ownership of the hospital was significantly associated in neither observed nor risk-standardized membership. A previous study also showed that the

mortality outcome did not vary between public and for-profit hospitals. (Sloan, Trogdon et al. 2003)

In conclusion, the trend in 30-day mortality of AMI patients were modeled using both observed and risk-standardized rates. For both types of mortality, shape and level of trajectories and hospital characteristics associated with group membership were drastically different. Examination of standardization components shows that it is the adjustment of hospital covariates that causes the smoothing of the trajectory, and not the patient covariates. The distinction and common feature between hospital covariates and hospital random effects need to be investigated further.

Appendix

Note: The following codes are courtesy of Dr. Shu-Xia Li at the Yale Center for Outcomes Research and Evaluation

```
/*** Hierarchical generalized linear model for calculating risk-
standardized rate***/

%macro glmx mr(i);
      data temp;
            set hq.hglm_6m(where=(time_h=&i));
      run;

      proc glimmix data=temp;
            class prov num en /*hosp*/;
            model obs30 = age &pat /*&hosp*//D=B LINK=LOGIT SOLUTION
oddsratio s;
            random int/subject=prov_num_en s;
            random _residual_;

      OUTPUT OUT = go1.glimmix outPred &i
                  PRED(BLUP ILINK)=PREDPROB PRED(NOBLUP ILINK)=EXPPROB;

                  ods  output ParameterEstimates=go1.glimmix_param_&i;
                  ods  output SolutionR=go1. solnr &i;
                  ods  output CovParms=go1._cov_&i;
            NLOPTIONS TECH=NMSIMP;
      run;

      proc datasets lib=work;
            delete temp;
      quit;
%mend;

%macro run glmx all(time);
      %do j=1 %to &time;
```

```
            %glmx_mr(&j);
      %end;
%mend;

%run_glmx_all(12);

%macro calculate RSMR(ds, unit, y, time);
      %local rawr;
      %let rawr = ;
      proc sql noprint;
            select mean(&y) into :rawr
            from &ds;
      quit;

      PROC SQL;
            CREATE TABLE dsout&time AS
            SELECT DISTINCT &unit, MEAN(&y) AS OBS&time,
                  MEAN(PREDPROB) AS PRED&time,
                  MEAN(EXPPROB) AS EXP&time,
                  (CALCULATED PRED&time)/(CALCULATED EXP&time) AS
SR&time,
                  (CALCULATED SR&time)*&rawr AS RSMR&time,
                  COUNT(&unit) AS VOLUME&time
            FROM &ds
            GROUP BY &unit;
      QUIT;
%mend;

%macro get all RSMR(dsout);
      %do i=1 %to 12;
            data ds&i;
                  set go1.glimmix_outpred_&i;
            run;

            %calculate_RSMR(ds&i, prov_num_en, obs30, %eval(&i));
      %end;

      data &dsout(drop=i);
            merge dsout1 - dsout12;
            array ts(12) t1 - t12;
            by prov num en;
            do i = 1 to 12;
                  ts(i) = i;
            end;
      run;

      proc datasets lib=work nolist;
            delete ds1 - ds12 dsout1 - dsout12 ;
      quit;
%mend;

%get_all_RSMR(hq.RSMR_by_6m);

%macro group_vote_prb(grps, grp_prbs, tempds);

      data temp;
            set &tempds;
            array grp prb (&grps) &grp_prbs;
            do i = 1 to &grps;
                  if i = group then
                  prb = grp_prb(i);
            end;
      run;

      proc means data=temp mean median std;
            class group;
            var prb;
      run;
%mend;
```

```
/***Growth Mixture Modeling***/

%macro gmm(i);
      proc traj data=hq.RSMR_by_6m outplot=gs.op&i outstat=gs.os&i
out=gs.of&i outest=gs.oe&i;
            id prov num en;
            var rsmr1 - rsmr12;
            indep t1 - t12;
            model cnorm;
            min 0;
            max 100;
            ngroups &i;
      run;
      %traiplot (gs.op&i, gs.os&i, "AMI Mortality Rate, 2005-2010",
"Cnorm Model - &i group", "Mortality Rate(%)", "Time(6-month)");
%mend;

%macro run all gmm;
      %do numgrp=5 %to 5;
            %gmm(&numgrp);
      %end;
%mend;

%run all gmm;
%group_vote_prb(5, grp1prb grp2prb grp3prb grp4prb grp5prb, gs.of5);
```

References

Krumholz, H. M., Y. Wang, J. Chen, E. E. Drye, J. A. Spertus, J. S. Ross, J. P. Curtis, B. K. Nallamothu, J. H. Lichtman, E. P. Havranek, F. A. Masoudi, M. J. Radford, L. F. Han, M. T. Rapp, B. M. Straube and S. L. Normand (2009). "Reduction in acute myocardial infarction mortality in the United States: risk-standardized mortality rates from 1995-2006." JAMA **302**(7): 767-773.

Andruff, H., N. Carraro, A. Thompson and P. Gaudreau (2009). "Latent Class Growth Modelling: A Tutorial." Tutorials in Quantitative Methods for Psychology **5**(1): 11-24.

Bernheim, S. M., Y. Wang, S. Spivack, K. Bartczak, K. R. Bhat, M. M. Desai, E. E. Drye, J. N. Grady, L. Grosso, H. Krumholz, Z. Lin, C. Parzynski, K. Strait and C. Wang (2012). 2012 Measures Maintenance Technical Report: Acute Myocardial Infarction, Heart Failure, and Pneumonia 30-Day Risk-Standardized Mortality Measures, Centers for Medicare & Medicaid Services / Yale New Haven Health Services Corporation/Center for Outcomes Research & Evaluation (YNHHSC/CORE).

Bielaszka-DuVernay, C. (2011). "Health Policy Brief: Improving Quality and Safety." Heatlth Affairs.

Go, A. S., D. Mozaffarian, V. L. Roger, E. J. Benjamin, J. D. Berry, W. B. Borden, D. M. Bravata, S. Dai, E. S. Ford, C. S. Fox, S. Franco, H. J. Fullerton, C. Gillespie, S. M. Hailpern, J. A. Heit, V. J. Howard, M. D. Huffman, B. M. Kissela, S. J. Kittner, D. T. Lackland, J. H. Lichtman, L. D. Lisabeth, D. Magid, G. M. Marcus, A. Marelli, D. B. Matchar, D. K. McGuire, E. R. Mohler, C. S. Moy, M. E. Mussolino, G. Nichol, N. P.

Paynter, P. J. Schreiner, P. D. Sorlie, J. Stein, T. N. Turan, S. S. Virani, N. D. Wong, D. Woo, M. B. Turner, C. American Heart Association Statistics and S. Stroke Statistics (2013). "Heart disease and stroke statistics--2013 update: a report from the American Heart Association." Circulation **127**(1): e6-e245.

Jones, B. L., D. S. Nagin and K. Roeder (2001). "A SAS procedure based on mixture models for estimating developmental trajectories." Sociological Methods & Research **29**(3): 374-393.

Jung, T. and K. A. S. Wickrama (2008). "An Introduction to Latent Class Growth Analysis and Growth Mixture Modeling." Social and Personality Psychology Compass **2**(1): 302-317.

Keenan, P. S., S. L. Normand, Z. Lin, E. E. Drye, K. R. Bhat, J. S. Ross, J. D. Schuur, B. D. Stauffer, S. M. Bernheim, A. J. Epstein, Y. Wang, J. Herrin, J. Chen, J. J. Federer, J. A. Mattera, Y. Wang and H. M. Krumholz (2008). "An administrative claims measure suitable for profiling hospital performance on the basis of 30-day all-cause readmission rates among patients with heart failure." Circ Cardiovasc Qual Outcomes **1**(1): 29-37.

Krumholz, H. M., Z. Lin, E. E. Drye, M. M. Desai, L. F. Han, M. T. Rapp, J. A. Mattera and S. L. Normand (2011). "An administrative claims measure suitable for profiling hospital performance based on 30-day all-cause readmission rates among patients with acute myocardial infarction." Circ Cardiovasc Qual Outcomes **4**(2): 243-252.

Krumholz, H. M., A. R. Merrill, E. M. Schone, G. C. Schreiner, J. Chen, E. H. Bradley, Y. Wang, Y. Wang, Z. Lin, B. M. Straube, M. T. Rapp, S. L. Normand and E. E. Drye (2009). "Patterns of hospital performance in acute myocardial infarction and heart failure 30-day mortality and readmission." Circ Cardiovasc Qual Outcomes **2**(5): 407-413.

Krumholz, H. M., S.-L. T. Normand, D. H. Galusha, J. A. Mattera, A. S. Rich, Y. Wang and Y. Wang (2005). Risk-Adjustment Models for AMI and HF 30-Day Mortality: Methodology, Yale University/Center for Medicare and Medicaid Services.

Krumholz, H. M., Y. Wang, J. Chen, E. E. Drye, J. A. Spertus, J. S. Ross, J. P. Curtis, B. K. Nallamothu, J. H. Lichtman, E. P. Havranek, F. A. Masoudi, M. J. Radford, L. F. Han, M. T. Rapp, B. M. Straube and S. L. Normand (2009). "Reduction in acute myocardial infarction mortality in the United States: risk-standardized mortality rates from 1995-2006." JAMA **302**(7): 767-773.

Mukamel, D. B., L. G. Glance, A. W. Dick and T. M. Osler (2010). "Measuring quality for public reporting of health provider quality: making it meaningful to patients." Am J Public Health **100**(2): 264-269.

Normand, S. L. T., M. E. Glickman and C. A. Gatsonis (1997). "Statistical methods for profiling providers of medical care: Issues and applications." Journal of the American Statistical Association **92**(439): 803-814.

Normand, S. L. T. and D. M. Shahian (2007). "Statistical and clinical aspects of hospital outcomes profilling." Statistical Science **22**(2): 206-226.

Ross, J. S., S. L. Normand, Y. Wang, D. T. Ko, J. Chen, E. E. Drye, P. S. Keenan, J. H. Lichtman, H. Bueno, G. C. Schreiner and H. M. Krumholz (2010). "Hospital volume and 30-day mortality for three common medical conditions." N Engl J Med **362**(12): 1110-1118.

Services, C. f. M. M. (2013, 01/09/2013). "Hospital Quality Initiative: Hospital Compare." Retrieved March 2013, from http://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/HospitalQualityInits/HospitalCompare.html.

Sloan, F. A., J. G. Trogdon, L. H. Curtis and K. A. Schulman (2003). "Does the ownership of the admitting hospital make a difference? Outcomes and process of care of Medicare beneficiaries admitted with acute myocardial infarction." Med Care **41**(10): 1193-1205.

Timbie, J. W. and S. L. Normand (2008). "A comparison of methods for combining quality and efficiency performance measures: profiling the value of hospital care following acute myocardial infarction." Stat Med **27**(9): 1351-1370.

Wennberg, J. E., M. M. Cooper, J. D. Birkmeyer, K. K. Bronner, T. A. Bubolz, D. E. Campbell, E. S. Fisher, G. T. O'Connor, J. F. Poage, S. M. Sharp, J. S. Skinner, T. A. Stukel and D. E. Wennberg (1999). "The Quality of Medical Care in the United States: A Report on the Medicare Program." The Dartmouth Atlas of Health Care 1999.