Published in final edited form as:

Med Care. 2016 October ; 54(10): 929–936. doi:10.1097/MLR.0000000000000571.

Hospital Phenotypes in the Management of Patients Admitted for Acute Myocardial Infarction

Xiao Xu, PhD^{*,†}, Shu-Xia Li, PhD[†], Haiqun Lin, MD, PhD[‡], Sharon-Lise T. Normand, PhD[§], Tara Lagu, MD, MPH^{||}, Nihar Desai, MD, MPH^{¶,†}, Michael Duan, MS[#], Eugene A. Kroch, PhD^{**,††}, and Harlan M. Krumholz, MD, SM^{†,¶,‡,§,||}

* Department of Obstetrics, Gynecology and Reproductive Sciences, Yale School of Medicine, New Haven, CT

† Center for Outcomes Research and Evaluation, Yale-New Haven Hospital, New Haven, CT

‡ Department of Biostatistics, Yale School of Public Health, New Haven, CT

§ Department of Health Care Policy, Harvard Medical School and Department of Biostatistics, Harvard T.H. Chan School of Public Health, Boston, MA

|| Division of General Medicine, Tufts University School of Medicine, Boston, MA and Baystate Medical Center, Springfield, MA

¶ Section of Cardiovascular Medicine, Department of Internal Medicine, Yale School of Medicine, New Haven, CT

Premier, Inc., Charlotte, NC

** Leonard Davis Institute of Health Economics, University of Pennsylvania, Philadelphia, PA

†† Booz Allen Hamilton Inc., McLean, VA

Address for Correspondence: Harlan M. Krumholz, 1 Church St., Suite #200, New Haven, CT 06510; Phone: (203) 764-5885; Fax: (203) 764-5653; harlan.krumholz@yale.edu.
xiao.xu@yale.edu; shu-xia.li@yale.edu; haiqun.lin@yale.edu; sharon@hcp.med.harvard.edu; lagutc@gmail.com; nihar.desai@yale.edu; michael_duan@premierinc.com; ekroch@wharton.upenn.edu

Conflict of Interest Disclosures: Dr. Krumholz is the recipient of research agreements from Medtronic and from Johnson & Johnson (Janssen), through Yale University, to develop methods of clinical trial data sharing; chairs a cardiac scientific advisory board for UnitedHealth; and has served as a subject matter expert for Premier. Dr. Lagu has received consulting fees from the Institute for Healthcare Improvement for her input on a project to help health systems achieve disability competence. The other authors report no potential conflicts.

Conference Presentation: This study was presented at the Yale Day of Data conference in New Haven, CT on September 26, 2014.

Authorship Statement: All authors made substantial contributions to the conception and design of the work, or acquisition of data, or analysis and interpretation of data; all have participated in drafting the article or revising it critically for important intellectual content; and all have read and approved the final submitted version.

List of Supplemental Digital Content

Supplemental Digital Content 1.docx (additional text regarding research methodology)

Supplemental Digital Content 2.docx (tables reporting results from the risk-adjustment models for receipt of percutaneous coronary intervention, receipt of coronary artery bypass grafting procedure, and admission to intensive care unit)

Supplemental Digital Content 3.docx (tables reporting results from the risk-adjustment model for in-hospital cost and in-hospital mortality)

Supplemental Digital Content 4.docx (figure illustrating variation in risk-standardized percutaneous coronary intervention rate, coronary artery bypass grafting procedure rate, and intensive care unit admission rate among hospitals, by year)

Supplemental Digital Content 5.docx (table reporting results from multinomial logistic regression regarding adjusted association of hospital characteristics with the phenotypes)

Supplemental Digital Content 6.docx (table reporting summary statistics of costs and patient outcomes by hospital phenotypes)

‡ Robert Wood Johnson Foundation Clinical Scholars Program, Department of Internal Medicine, Yale School of Medicine, New Haven, CT

§§ Department of Health Policy and Management, Yale School of Public Health, New Haven, CT

Abstract

Objectives—To characterize hospital phenotypes by their combined utilization pattern of percutaneous coronary interventions (PCI), coronary artery bypass grafting (CABG) procedures, and intensive care unit (ICU) admissions for patients hospitalized for acute myocardial infarction (AMI).

Research Design—Using the Premier Analytical Database, we identified 129,138 hospitalizations for AMI from 246 hospitals with the capacity for performing open-heart surgery during 2010–2013. We calculated year-specific, risk-standardized estimates of PCI procedure rates, CABG procedure rates, and ICU admission rates for each hospital, adjusting for patient clinical characteristics and within-hospital correlation of patients. We used a mixture modeling approach to identify groups of hospitals (i.e., hospital phenotypes) that exhibit distinct longitudinal patterns of risk-standardized PCI, CABG, and ICU admission rates.

Results—We identified 3 distinct phenotypes among the 246 hospitals: 1) high PCI - low CABG - high ICU admission (39.2% of the hospitals), 2) high PCI - low CABG - low ICU admission (30.5%), and 3) low PCI - high CABG - moderate ICU admission (30.4%). Hospitals in the high PCI - low CABG - high ICU admission phenotype had significantly higher risk-standardized in-hospital costs and 30-day risk-standardized payment yet similar risk-standardized mortality and readmission rates compared with hospitals in the low PCI - high CABG - moderate ICU admission phenotype. Hospitals in these phenotypes differed by geographic region.

Conclusions—Hospitals differ in how they manage patients hospitalized for AMI. Their distinctive practice patterns suggest that some hospital phenotypes may be more successful in producing good outcomes at lower cost.

Keywords

Acute myocardial infarction; hospital variation; utilization; cost; outcome

INTRODUCTION

Using advanced analytics of pattern recognition, recent big data research revealed important similarities and differences among hospitals in provision of care (1–3). In contrast with conventional studies that analyze how hospitals deviate from an average tendency in care, the approach of pattern recognition explores whether there are distinct “phenotypes” among hospitals, representing fundamentally different patterns of care (4). By characterizing hospital practice phenotypes and comparing their financial and patient outcomes, we can inform strategies to improve the value of hospital care.

Acute myocardial infarction (AMI) is an ideal condition to study hospital practice patterns. AMI is among the most common and expensive conditions requiring hospitalization in the U.S., with 612,000 admissions and an average hospital cost of \$18,900 in 2011 (5, 6).

Underneath the average hospitalization cost, there was substantial variation among hospitals - after adjustment for patient case-mix, costs of a 30-day episode of care following an AMI admission ranged from \$13,909 to \$28,979 across 2,382 hospitals nationwide in 2008-2009 (7). Likewise, risk-standardized 30-day mortality rate for Medicare fee-for-service beneficiaries with AMI varied from 10.9% to 24.9% among 2,908 hospitals in the U.S. in 2005-2008 (8). These data suggest potentially large difference in how hospitals manage patients hospitalized for AMI.

Moreover, prior research suggests that determinants of cost for AMI hospitalizations are multifactorial, highlighting the need to study practice patterns across multiple aspects of care. Different procedure use, such as percutaneous coronary intervention (PCI) versus coronary artery bypass grafting (CABG), entails different levels of resource intensity, which has been shown to contribute importantly to cross-country differences in cost of AMI hospitalizations (9). Other studies also found that the proportion of patients receiving PCI influences hospitalization costs more than other treatment strategies (10), while changes in the costs of intensive care unit (ICU) contributed substantially to the growth of hospitalization costs in the U.S. (11). Therefore, practices related to PCI, CABG, and ICU use may be important indicators of care patterns and may present opportunities to optimize utilization.

Surprisingly, little is known about how hospitals differ in their practice of care for AMI. The purpose of this study was to assess whether distinct phenotypes of PCI, CABG and ICU use are present among hospitals for patients hospitalized for AMI. To capture evolving practice in AMI care, such as increasing use of PCI over time (12), our classification of hospital phenotypes also accounted for temporal changes in utilization measures. We compared costs, mortality, and readmission outcomes between hospital phenotypes to identify practice patterns providing the best value of care, and examined which hospital characteristics were associated with specific phenotypes. Findings from this study can inform subsequent hypothesis development, testing, and prediction to elucidate important contributors to hospital variation in practices.

METHODS

Data Source and Patient Population

We used the Premier Analytical Database maintained by Premier, Inc., Charlotte, NC. This database includes administrative and operational data from a large network of hospitals in the U.S. and ancillary providers nationwide. It contains a date-stamped log of all billed items and resource utilization during hospitalizations (e.g., blood, medications, and laboratory, diagnostic, and therapeutic services), diagnosis and procedure codes, and patient and hospital characteristics. Patient-level data were de-identified in accordance with the Health Insurance Portability and Accountability Act.

The study cohort included all hospitalizations with a principal diagnosis of new AMI, i.e., International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes 410.xx (except for 410.x2 (AMI, subsequent episode of care)), discharged from hospitals capable of performing open-heart surgery during January 2010-December 2013.

Whether a hospital had the capacity to perform open-heart surgery was determined based on its response to this question in the American Hospital Association annual survey.

We excluded hospitalizations attended by pediatricians, hospitalizations that were transferred from or to another acute care facility (because we could not link hospitalizations across hospitals), hospitalizations that involved a heart transplant or left ventricular assist device (LVAD) implantation (because such patients were not representative of the general AMI population), and hospitalizations with a length of stay of 1 day or less in which the patient was discharged alive, to eliminate unlikely AMIs. In addition, we excluded hospitalizations for patients younger than 65 years to be consistent with the age criterion for the Centers for Medicare & Medicaid Services (CMS) publicly reported mortality, readmission, and payment measures, which we used to measure longer-term outcomes.

This study is under a collaborative contract with Premier, Inc. regarding protection of privacy of hospitals and other providers. The Yale University Human Investigation Committee exempted this study protocol as defined by the Office of Human Research Protections.

PCI Procedure, CABG Procedure, and ICU Admission

For each hospitalization, we measured whether the patient received a PCI or CABG procedure, and whether the patient was admitted to an ICU. Receipt of PCI and CABG procedures was determined based on ICD-9-CM procedure codes (PCI: 00.66, 36.01, 36.02, and 36.05-36.07; CABG: 36.1, 36.10-36.17 and 36.19) and hospital charge codes for PCI and CABG services, respectively. ICU admission was identified based on hospital charge codes for ICU services.

Cost, Mortality and Readmission Outcomes

We measured in-hospital cost and in-hospital mortality for each AMI hospitalization. Methods for estimating in-hospital cost are detailed elsewhere (3, 13). Briefly, we used accounting cost data available in the Premier database and removed geographic variation in input prices by applying average unit cost across all hospitals for each service item by year. All cost estimates were adjusted to 2013 U.S. dollars (14). We Winsorized cost data within each year at the 0.5th and 99.5th percentiles to reduce the influence of outliers (15-17). Because patients were de-identified, we were unable to track their outcomes post-discharge and hence measured in-hospital mortality for each hospitalization.

To assess longer-term financial and health outcomes at the hospital level, we linked hospitals in our sample to CMS public reporting data on 2010-2013 hospital-specific 30-day risk-standardized mortality rate (RSMR), 30-day risk-standardized readmission rate (RSRR), and 30-day risk-standardized payment (RSP) (18-20). Although RSP did not directly measure costs, it can serve as an approximation for resource utilization over the 30-day episode of care (20).

Hospital Characteristics

Hospital structural, financial, and capacity characteristics were available from the Premier Analytical Database with some of the measures obtained from the American Hospital Association annual survey. We constructed additional measures based on each hospital's AMI hospitalizations in pooled 2010-2013 data (regardless of aforementioned exclusion criteria), including average annual volume of AMI hospitalizations, proportions of AMI hospitalizations covered by Medicare or Medicaid, proportion of AMI patients who were African American, proportion of AMI hospitalizations with a cardiologist as the attending physician, proportion of AMI hospitalizations that were transferred from or to another acute care facility, and whether the hospital performed any LVAD implantation or heart transplant.

Statistical Analysis

We assigned each hospitalization to a year based on its discharge date. For each hospital-year, we estimated risk-standardized measures of PCI procedure rate, CABG procedure rate, and ICU admission rate, as well as risk-standardized in-hospital cost and in-hospital mortality rate, by adjusting for patient case-mix using hierarchical generalized linear models. Candidate risk-adjustors included patient age, an indicator for ST-segment-elevation myocardial infarction (STEMI) (versus non ST-segment-elevation myocardial infarction (NSTEMI)) (21), comorbidities (22, 23), prior PCI and CABG history, and proportion of the corresponding hospital-year's AMI patients who were transferred from another acute care facility, were transferred to another acute care facility, or received a heart transplant or LVAD implantation. The latter 3 variables acted as markers for expected patient severity in a given hospital-year. We used stepwise selection to determine risk-adjustors in the final model. Hereafter all measures refer to their risk-standardized estimates unless otherwise specified.

To identify distinct hospital phenotypes, we analyzed hospital-level, risk-standardized estimates of PCI procedure rate, CABG procedure rate, and ICU admission rate using a group-based growth-mixture modeling approach (4, 24). Because hospitals had multiple years of data, each utilization measure was characterized by a trajectory. The model simultaneously analyzed trajectories of all 3 measures and assumed that there were distinct hospital groups (i.e., phenotypes) based on the joint pattern of these trajectories. Shapes of the trajectories and size of each group were estimated via maximum likelihood estimation. Trajectories of hospital PCI and CABG rates were best modeled as a linear function of time, where time reflected the number of years since 2010. The trajectory of ICU admission rate was best modeled as a cubic function of time. We determined the optimal number of phenotypes based on several criteria by comparing alternative models with different numbers of groups: the Bayesian Information Criteria (BIC) index, average posterior probability of phenotype membership, 95% confidence intervals of adjacent trajectories, size of the smallest phenotype, and whether additional phenotypes identified in successive models represented substantially distinct phenotypes or mere subdivisions of major phenotypes already identified (4). Posterior probability of phenotype membership was calculated based on Bayes' theorem, reflecting each hospital's probability of belonging to a particular phenotype given its observed utilization measures (with higher posterior probability indicating better model performance) (4). We included all eligible hospitalizations in the

risk-adjustment models. However, to provide reliable estimates of hospitals' longitudinal trajectories, we limited the phenotype analysis to hospitals with 25 AMI hospitalizations in at least one year.

We then examined whether the identified hospital phenotypes differed significantly in in-hospital cost, in-hospital mortality rate, and 30-day RSMR, RSRR and RSP. Because in-hospital cost and in-hospital mortality rates were assessed annually, we modeled each measure as a function of hospital phenotype and year using a generalized estimation equation model to control for hospital correlation over time. We used statistical significance level of coefficient estimates on the hospital phenotype indicators as the p values for the association between phenotype and treatment outcomes. Because 30-day RSMR, RSRR, and RSP were cross-sectional measures for the 2010-2013 public report period, we used the Wilcoxon rank sum test to compare their differences across hospital phenotypes.

We also assessed the association of hospital phenotype with various hospital characteristics via bivariate analyses and a multinomial logistic regression model (dependent variable = hospital phenotype). Hospital characteristics that differed significantly across phenotypes in bivariate analyses were included as candidate explanatory variables in the regression model and stepwise selection was used to determine variables for the final model.

P values less than 0.05 were considered statistically significant. When conducting pairwise comparisons between the phenotypes, we used the Bonferroni method to calculate adjusted p values to account for multiple comparisons. More details regarding our analytical methods are in Supplemental Digital Contents 1-3. All analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC). Graphs were generated using R (25).

RESULTS

Hospital Variation in PCI, CABG, and ICU Use

We identified 129,262 hospitalizations for AMI from 248 hospitals that were capable of performing open-heart surgery. Of these, 246 (99.2%) hospitals had 25 or more hospitalizations for at least one year and were included in our analysis of hospital phenotypes. They contributed 129,138 (99.9%) AMI hospitalizations, with 237 hospitals (96.3%) having at least 2 years of data and 167 (67.8%) having all 4 years of data. These hospitals were mostly non-teaching, medium to large size, and served urban populations (Table 1).

Among the 246 hospitals, after adjustment for patient case-mix, PCI, CABG, and ICU use all varied widely across hospitals in any given year (see Figure, Supplemental Digital Content 4, which illustrates variation in these three measures by year). For example, in 2013, PCI procedure rates, CABG procedure rates, and ICU admission rates ranged from 22.5% to 64.0%, 5.6% to 22.1%, and 0.7% to 93.5%, respectively, across hospitals. The hospital-level rates of PCI and CABG remained relatively stable during 2010-2013, while ICU admission rates slightly declined in 2011 but returned to their initial levels afterwards.

Hospital Phenotypes

We selected a 3-phenotype model because the BIC score plateaued after 3 groups and a model with 3 phenotypes achieved better average posterior probability of phenotype membership (greater than 0.89 for all 3 phenotypes) than models with more phenotypes. The 3 phenotypes exhibited different patterns of care for patients hospitalized for AMI (Figure 1):

Phenotype 1: High PCI - low CABG - high ICU admission (39.2% of hospitals)

—Hospitals in this phenotype had high rates of PCI procedures and ICU admissions (45.3% and 65.4%, respectively, in 2010). However, they had low CABG rates (9.4% in 2010).

Phenotype 2: High PCI - low CABG - low ICU admission (30.5% of hospitals)—

Compared with hospitals in phenotype 1, those in phenotype 2 had similar rates of PCI and CABG procedures (45.5% and 9.1%, respectively, in 2010), but much lower ICU admission rates (38.8% in 2010).

Phenotype 3 - Low PCI - high CABG - moderate ICU admission (30.4% of hospitals)—

Hospitals in this phenotype had moderate rates of ICU admission (48.6% in 2010). Their rates of PCI procedures were much lower than other phenotypes (36.3% in 2010) yet their rates of CABG procedures were higher than the other phenotypes (10.9%).

Although the absolute difference in CABG procedure rate between phenotypes is modest, it reflects a meaningful, relative difference in practice given the generally low rate of CABG. The CABG rate of 10.9% in phenotype 3 is nearly 20% higher than the rate in phenotype 2 (i.e., 9.1%). The difference in PCI, CABG, and ICU use among the phenotypes remained stable over time.

Hospital Characteristics Associated with Phenotypes

Hospitals in the 3 phenotypes are largely similar in the characteristics assessed (see Table 2). Only geographic region was significantly associated with a hospital's phenotype membership ($p=0.03$). This was confirmed in multivariable regression analysis, where we assessed adjusted association of hospital characteristics with the phenotypes. Only geographic region remained statistically significant in this model (see Table, Supplemental Digital Content 5, which reports results from multinomial logistic regression regarding adjusted association of hospital characteristics with the phenotypes). Compared with hospitals in the South, those in the Midwest were more likely to have high PCI - low CABG - high ICU admission (odds ratio (OR) = 2.83, $p=0.005$) or high PCI - low CABG - low ICU admission (OR = 4.08, $p=0.001$) than low PCI - high CABG - moderate ICU admission.

Cost, Mortality and Readmission Outcomes Associated with Phenotypes—

After adjusting for patient case-mix, high PCI - low CABG - high ICU hospitals had higher in-hospital cost than the other two phenotypes ($p<0.001$ for both), averaging \$21,139 per patient (Figure 2; also see Table, Supplemental Digital Content 6: summary statistics of costs and patient outcomes). Likewise, these hospitals also had higher 30-day RSP than

hospitals in low PCI - high CABG - moderate ICU admission phenotype (\$22,266 versus \$21,566, $p=0.005$).

In terms of patient outcomes, there was no statistically significant difference in in-hospital RSMR among the 3 hospital phenotypes nor did the 3 phenotypes differ in 30-day RSMR or 30-day RSRR.

DISCUSSION

In a large sample of U.S. hospitals, we identified 3 distinct phenotypes of hospital practice for AMI hospitalizations after adjusting for patient case-mix. These phenotypes were associated with different cost profiles yet similar patient outcomes. Hospitals in these phenotypes differed by geographic region.

Our study extends prior research by classifying distinct hospital groups according to the combined pattern of 3 practice indicators – PCI procedure rate, CABG procedure rate, and ICU admission rate. Based on observed data pattern, the group-based growth-mixture model used in our analysis empirically determined the optimal number of distinct hospital groups and the shape of each group (i.e., level of care and rate of change in care over time for each practice indicator). Moreover, by modeling multiple practice indicators, our approach informs how hospitals deploy multiple resources in different compositions (e.g., procedures, ICU admission). We found that 1 hospital phenotype used more CABG procedures but fewer PCI procedures and had moderate ICU admission rates. In contrast, the remaining two phenotypes both had high PCI procedure rates and low CABG rates, but one had high ICU admission rates while the other had low ICU admission rates. Although variation in CABG rates was modest across the phenotypes, PCI procedure rates and ICU admission rates differed substantially, ranging from 36.3% to 45.5%, and from 38.8% to 65.4%, respectively. These phenotypes were identified after adjustment for patient case-mix, indicating that they did not emerge because of patient differences and there may be opportunities to improve efficiency.

Our assessment of a wide range of hospital characteristics only identified geographic region as a factor associated with the phenotypes. This is consistent with earlier research showing regional variation in other AMI-related care such as utilization of coronary angiography (26, 27). Our findings extend this literature by depicting the relationship of geographic region with multi-dimensional practice patterns. More in-depth investigation of hospital attributes (e.g., qualitative assessment of institutional policies and protocols regarding patient selection for revascularization procedures and ICU admissions at hospitals in different phenotypes) will further inform the underlying reasons for the variation (28). Moreover, some factors that influence practice patterns may be at the physician level, calling for more research on physician-hospital dynamics (e.g., engagement of physicians by hospitals in quality, safety, and cost containment initiatives) (29, 30).

Another contribution of this study is our comparison of “value”, i.e., the combination of cost and patient outcomes (mortality and readmission), associated with the different hospital phenotypes. Care patterns that produce good outcomes at lower costs signal higher value

care, and hospitals with such patterns warrant closer investigation in order to fully understand their exemplary experience. Costs should not be evaluated in isolation from patient outcomes. In our analysis, average in-hospital cost and 30-day episode of care payment for an AMI patient hospitalized in high PCI - low CABG - high ICU admission hospitals were \$1,456 and \$700, respectively, higher than low PCI - high CABG - moderate ICU hospitals. Yet these hospitals achieved similar mortality and readmission rates, suggesting no obvious gains in health outcomes. **With** the large number of AMI hospitalizations each year, the overall financial impact of the different care patterns can be substantial. Moreover, given that the high PCI - low CABG - high ICU admission hospitals had similar mortality and readmission outcomes as high PCI - low CABG - low ICU admission hospitals, there may be opportunities to reduce ICU utilization without comprising quality of care. While we recognize that our analysis only assessed associations and cannot infer causal relationships, this approach offers a novel and useful tool for classifying hospital performance. Further investigation is needed to extend our understanding of financial and health consequences of the different hospital phenotypes and the possibility of safely shifting lower-value hospitals to a higher-value profile. For example, additional research incorporating data on post-discharge care is needed, as such care might differ across the phenotypes and contribute to 30-day outcomes as well.

Several limitations of our study should be acknowledged. First, the Premier database included a voluntary network of hospitals. Although it consisted of a large sample of hospitals with diverse characteristics, our findings may not be generalizable to other hospitals in the U.S. Second, our **measurement of risk factors** relied on information available in administrative data. We also had limited information on physicians' characteristics (e.g., skills) and patients' coronary anatomy (e.g., multi-vessel or left main stem disease), which may influence clinical decisions regarding the choice between PCI and CABG for revascularization (31). However, earlier work on AMI demonstrated that administrative data can provide estimates of hospital performance similar to models that employ richer clinical data (32). Third, due to the de-identified nature of the data, we measured PCI and CABG history based on records within the same hospital, which might underestimate prior revascularization in risk-adjustment. However, we found no systematic difference in documentation of prior PCI/CABG across hospitals. The influence on our estimated hospital variation in revascularization rate is likely small. Finally, even 30-day outcomes may not fully capture the benefit of revascularization procedures. Future studies with longer-term follow-up will provide additional insights.

The current U.S. health care system could benefit from innovative and rigorous research identifying treatment patterns that yield high-value care (i.e., good outcomes at lower cost). By examining the combined pattern of PCI procedure use, CABG procedure use, and ICU admission, we identified 3 distinct hospital phenotypes for the management of AMI hospitalizations that are not, to the extent possible, due to differences in patient clinical characteristics. These practice patterns were associated with similar patient outcomes but had very different cost implications, suggesting that some hospital phenotypes may be more successful in producing high-value care. The financial and health impact of moving hospitals from one phenotype to another warrants further investigation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

Funding: This work was supported by grant DF10-301 from the Patrick and Catherine Weldon Donaghue Medical Research Foundation, West Hartford, CT. Drs. Xu and Krumholz were supported by grant U01 HL105270-05 from National Heart, Lung, and Blood Institute, Bethesda, MD. Dr. Lagu is supported by grant K01HL114745 from the National Heart, Lung, and Blood Institute, Bethesda, MD.

REFERENCES

1. Krumholz HM. Big data and new knowledge in medicine: the thinking, training, and tools needed for a learning health system. *Health Aff (Millwood)*. 2014; 33:1163–1170. [PubMed: 25006142]
2. Partovian C, Li SX, Xu X, et al. Patterns of change in nesiritide use in patients with heart failure: how hospitals react to new information. *JACC Heart Fail*. 2013; 1:318–324. [PubMed: 24621935]
3. Xu X, Li SX, Lin H, et al. “Phenotyping” hospital value of care for patients with heart failure. *Health Serv Res*. 2014; 49:2000–16. [PubMed: 24974769]
4. Nagin, DS. Group-based modeling of development. Harvard University Press; Cambridge, MA: 2005.
5. Pfuntner, A., Wier, LM., Steiner, C. HCUP Statistical Brief #168. Agency for Healthcare Research and Quality; Rockville, MD: Dec. 2013 Costs for hospital stays in the United States, 2011.. <http://www.hcup-us.ahrq.gov/reports/statbriefs/sb168-Hospital-Costs-United-States-2011.pdf>
6. Torio, CM., Andrews, RM. HCUP Statistical Brief #160. Agency for Healthcare Research and Quality; Rockville, MD: Aug. 2013 National Inpatient Hospital Costs: The Most Expensive Conditions by Payer, 2011.. <http://www.hcup-us.ahrq.gov/reports/statbriefs/sb160.pdf>
7. Kim N, Bernheim SM, Ott LS, et al. An administrative claims measure of payments made for medicare patients for a 30-day episode of care for acute myocardial infarction. *Med Care*. 2015; 53:542–549. [PubMed: 25970575]
8. Bradley EH, Herrin J, Curry L, et al. Variation in hospital mortality rates for patients with acute myocardial infarction. *Am J Cardiol*. 2010; 106:1108–12. [PubMed: 20920648]
9. Kauf TL, Velazquez EJ, Crosslin DR, et al. The cost of acute myocardial infarction in the new millennium: evidence from a multinational registry. *Am Heart J*. 2006; 151:206–212. [PubMed: 16368320]
10. Tiemann O. Variations in hospitalisation costs for acute myocardial infarction - a comparison across Europe. *Health Econ*. 2008; 17:S33–45. [PubMed: 18186036]
11. Maeda JL, Raetzman SO, Friedman BS. What hospital inpatient services contributed the most to the 2001-2006 growth in the cost per case? *Health Serv Res*. 2012; 47:1814–1835. [PubMed: 22946883]
12. Tisminetzky M, Coukos JA, McManus DD, et al. Decade-long trends in the magnitude, treatment, and outcomes of patients aged 30 to 54 years hospitalized with ST-segment elevation and non-ST-segment elevation myocardial infarction. *Am J Cardiol*. 2014; 113:1606–10. [PubMed: 24666616]
13. Lagu T, Krumholz HM, Dharmarajan K, et al. Spending more, doing more, or both? An alternative method for quantifying utilization during hospitalizations. *J Hosp Med*. 2013; 8:373–379. [PubMed: 23757115]
14. Centers for Medicare and Medicaid Services. [April 11, 2015] Market basket data: actual regulation market basket change and Medicare payment updates as published in the “Federal Register”.. Current history and forecasts of the market baskets. Available at: <http://www.cms.gov/Research-Statistics-Data-and-Systems/Statistics-Trends-and-Reports/MedicareProgramRatesStats/MarketBasketData.html>.
15. Adams JL, Mehrotra A, Thomas JW, et al. Physician cost profiling--reliability and risk of misclassification. *N Engl J Med*. 2010; 362:1014–1021. [PubMed: 20237347]
16. Dixon WJ, Yuen KK. Trimming and winsorization: a review. *Statistische Hefte*. 1974; 15:157–170.

17. Jha AK, Orav EJ, Dobson A, et al. Measuring efficiency: the association of hospital costs and quality of care. *Health Aff (Millwood)*. 2009; 28:897–906. [PubMed: 19414903]
18. Dorsey, K., Grady, JN., Wang, C., et al. [May 15, 2015] 2014 measures updates and specifications report hospital-level 30-day risk-standardized readmission measures. Jul. 2014 Available at: http://www.qualitynet.org/dcs/BlobServer?blobkey=id&blobnocache=true&blobwhere=1228890360600&blobheader=multipart%2Foctet-stream&blobheadervalue1=attachment%3Bfilename%3D2014_Rdmsn_UpdtSpecsRpt.pdf&blobcol=urldata&blobtable=MungoBlobs.
19. Dorsey, K., Grady, JN., Wang, Y., et al. [May 15, 2015] 2014 measures updates and specifications report hospital-level 30-day risk-standardized mortality measures. Aug. 2014 Available at: http://www.qualitynet.org/dcs/BlobServer?blobkey=id&blobnocache=true&blobwhere=1228890360571&blobheader=multipart%2Foctet-stream&blobheadervalue1=attachment%3Bfilename%3D2014_Mortlty_MsrUpdtsRpt.pdf&blobcol=urldata&blobtable=MungoBlobs.
20. Kim, N., Ott, LS., Hsieh, A., et al. [October 27, 2015] 2015 condition-specific measure updates and specifications report hospital-level 30-day risk-standardized payment measures. Mar. 2015 Available at: http://www.qualitynet.org/dcs/BlobServer?blobkey=id&blobnocache=true&blobwhere=1228890435533&blobheader=multipart%2Foctet-stream&blobheadervalue1=attachment%3Bfilename%3DPymt_AMI_HFPN_Msr_Updt_Rprt_032715.pdf&blobcol=urldata&blobtable=MungoBlobs.
21. Cannon CP. Update to International Classification of Diseases, 9th Revision codes: distinguishes STEMI from NSTEMI. *Crit Pathw Cardiol*. 2005; 4:185–6. [PubMed: 18340207]
22. Elixhauser A, Steiner C, Harris DR, et al. Comorbidity measures for use with administrative data. *Med Care*. 1998; 36:8–27. [PubMed: 9431328]
23. HCUP comorbidity software. Healthcare Cost and Utilization Project (HCUP). 2005-2013 (v3.0 through v3.7). Agency for Healthcare Research and Quality; Rockville, MD.: www.hcup-us.ahrq.gov/toolssoftware/comorbidity/comorbidity.jsp
24. Jones BL, Nagin DS. Advances in group-based trajectory modeling and an SAS procedure for estimating them. *Sociol Method Res*. 2007; 35:542–571.
25. R Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing; Vienna, Austria: 2013. <http://www.R-project.org/>
26. Garg PP, Landrum MB, Normand SL, et al. Understanding individual and small area variation in the underuse of coronary angiography following acute myocardial infarction. *Med Care*. 2002; 40:614–626. [PubMed: 12142777]
27. Guadagnoli E, Landrum MB, Normand SL, et al. Impact of underuse, overuse, and discretionary use on geographic variation in the use of coronary angiography after acute myocardial infarction. *Med Care*. 2001; 39:446–458. [PubMed: 11317093]
28. Krumholz HM, Curry LA, Bradley EH. Survival after acute myocardial infarction (SAMI) study: the design and implementation of a positive deviance study. *Am Heart J*. 2011; 162:981–987. e989. [PubMed: 22137070]
29. Berenson RA, Ginsburg PB, May JH. Hospital-physicians relations: cooperation, competition, or separation? *Health Aff (Millwood)*. 2007; 26:w31–43. [PubMed: 17148489]
30. Jena AB, Prasad V, Goldman DP, et al. Mortality and treatment patterns among patients hospitalized with acute cardiovascular conditions during dates of national cardiology meetings. *JAMA Intern Med*. 2015; 175:237–244. [PubMed: 25531231]
31. Gunn J, Taggart DP. Revascularisation for acute coronary syndromes: PCI or CABG? *Heart*. 2003; 89:967–70. [PubMed: 12922989]
32. Krumholz HM, Wang Y, Mattera JA, et al. An administrative claims model suitable for profiling hospital performance based on 30-day mortality rates among patients with an acute myocardial infarction. *Circulation*. 2006; 113:1683–1692. [PubMed: 16549637]

Figure 1.

Distinct hospital phenotypes identified by jointly modeling the longitudinal trajectory of risk-standardized percutaneous coronary intervention (PCI) rate, coronary artery bypass grafting (CABG) procedure rate, and intensive care unit (ICU) admission rate.

Proportion of hospitals classified into each phenotype	39.2%	30.5%	30.4%
Number of hospitals in each phenotype	100	71	75

Dotted lines in the figure reflect confidence intervals for each trajectory, based on 95% confidence intervals of the point estimates in each year. Intercepts and slopes were measured as percentage points. * $P < 0.05$; [†] $P < 0.01$; [‡] $P < 0.001$.

Phenotype 1: High PCI - low CABG - high ICU admission.

Phenotype 2: High PCI - low CABG - low ICU admission.

Phenotype 3: Low PCI - high CABG - moderate ICU admission.

Figure 2.

Comparison of costs and patient outcomes across hospital phenotypes.

Phenotype 1: High PCI - low CABG - high ICU admission.

Phenotype 2: High PCI - low CABG - low ICU admission.

Phenotype 3: Low PCI - high CABG - moderate ICU admission.

Phenotype 1 differed from phenotypes 2 and 3 in in-hospital risk-standardized cost ($p < 0.001$ for both). Phenotype 1 differed from phenotype 3 in Centers for Medicare & Medicaid Services (CMS) publicly reported 30-day risk-standardized episode of care payment ($p = 0.005$). There was no statistically significant difference in in-hospital risk-standardized mortality rate (RSMR) or CMS publicly reported 30-day RSMR or risk-standardized readmission rate (RSRR) between any phenotypes.

Table 1

Sample characteristics at the hospital and hospitalization level.

Characteristics	Hospital Level (N=246)	Hospitalization Level (N=129,138)
	n (%)	n (%)
Bed size		
<200	26 (10.6)	8,346 (6.5)
200-400	110 (44.7)	46,023 (35.6)
>400	110 (44.7)	74,769 (57.9)
Teaching hospital		
Yes	100 (40.7)	60,504 (46.9)
No	146 (59.3)	68,634 (53.1)
Census region		
Midwest	60 (24.4)	24,930 (19.3)
Northeast	34 (13.8)	23,000 (17.8)
South	101 (41.1)	58,069 (45.0)
West	51 (20.7)	23,139 (17.9)
Urban/Rural population served		
Urban	218 (88.6)	117,669 (91.1)
Rural	28 (11.4)	11,469 (8.9)

Table 2

Unadjusted association of hospital characteristics with the phenotypes.

Hospital characteristics	Phenotype 1 (high PCI - low CABG - high ICU admission)	Phenotype 2 (high PCI - low CABG - low ICU admission)	Phenotype 3 (low PCI - high CABG - moderate ICU admission)	P value
Number of hospitals	100	71	75	
Teaching hospital, n (%)	38 (38.0)	33 (46.5)	29 (38.7)	0.493
Urban, n (%)	91 (91.0)	62 (87.3)	65 (86.7)	0.618
Census region, n (%)				
Midwest	28 (28.0)	24 (33.8)	8 (10.7)	0.033
Northwest	14 (14.0)	7 (9.9)	13 (17.3)	
South	42 (42.0)	25 (35.2)	34 (45.3)	
West	16 (16.0)	15 (21.1)	20 (26.7)	
Bed size, mean $\pm$ SD	414 $\pm$ 203	409 $\pm$ 198	403 $\pm$ 193	0.172
Average annual volume of AMI hospitalizations, mean $\pm$ SD	135 $\pm$ 73	160 $\pm$ 106	160 $\pm$ 95	0.207
Proportion of AMI hospitalizations with Medicaid coverage, median (IQR)	0.6 (0-1.3)	0.3 (0-0.9)	0.3 (0-0.6)	0.176
Proportion of AMI hospitalizations with Medicare coverage, median (IQR)	71.6 (54.9-81.2)	71.6 (60.2-82.6)	65.2 (49.7-78.4)	0.141
Proportion of AMI hospitalizations that were African American patients, median (IQR)	6.1 (1.5-14.5)	3.5 (0.7-8.9)	4.4 (0.8-11.7)	0.083
Proportion of hospitals performing any LVAD implantation or heart transplant among patients admitted for AMI, n (%)	66 (66.0)	37 (52.1)	46 (61.3)	0.185
Proportion of AMI hospitalizations with a cardiologist as the attending physician, median (IQR)	38.4 (15.7-57.8)	35.4 (12.7-50.6)	29.0 (12.4-45.0)	0.130
Proportion of AMI patients transferred-in, median (IQR)	12.2 (3.5-27.6)	10.1 (4.6-27.5)	12.4 (3.2-28.1)	0.909
Proportion of AMI patients transferred-out, median (IQR)	1.1 (0.5-2.1)	1.1 (0.4-2.5)	1.1 (0.6-2.6)	0.943
Capacity of cardiac services				
Availability of adult ICU, n (%)	94 (94.0)	71 (100.0)	71 (94.7)	0.160
Adult ICU beds, median (IQR)	22 (14-34)	22 (15-28)	20 (14-31)	0.850
Availability of cardiac ICU, n (%)	64 (64.0)	43 (60.6)	46 (61.3)	0.489
Cardiac ICU beds, median (IQR)	10 (0-15)	8 (0-13)	8 (0-16)	0.562

AMI = acute myocardial infarction; ICU = intensive care unit; IQR = interquartile range; LVAD = left ventricular assist device; SD = standard deviation