January 2014

Regional Density Of Cardiologists And Mortality For Acute Myocardial Infarction And Heart Failure

Vivek Kulkarni

Regional Density of Cardiologists and Mortality for Acute Myocardial Infarction and Heart Failure

A Thesis Submitted to the

Yale University School of Medicine

in Partial Fulfillment of the Requirements for the

Degree of Doctor of Medicine

by

Vivek Tammaji Kulkarni

2014

REGIONAL DENSITY OF CARDIOLOGISTS AND MORTALITY FOR ACUTE MYOCARDIAL INFARCTION AND HEART FAILURE

Vivek T. Kulkarni, Joseph S. Ross, Yongfei Wang, Brahmajee K. Nallamothu, John A. Spertus, Sharon-Lise T. Normand, Frederick A. Masoudi, and Harlan M. Krumholz.

Section of Cardiology, Department of Internal Medicine, Yale School of Medicine, New Haven, CT.

Cardiologists are distributed unevenly across regions of the United States. It is unknown whether patients in regions with fewer cardiologists have worse outcomes after hospitalization for acute myocardial infarction (AMI) or heart failure than patients in regions with more cardiologists. We hypothesized that patients hospitalized for AMI or heart failure in regions with lower density of cardiologists would have higher mortality than patients in regions with higher density.

Using Medicare administrative claims data from 2010, we examined the relationship between regional density of cardiologists and mortality after hospitalization for AMI and heart failure, using hospitalizations for pneumonia as a comparison. We defined density as the number of cardiologists divided by population aged ≥ 65 years within hospital referral regions, categorized into quintiles. We tested associations between density of cardiologists and 30-day and 1-year risk-standardized mortality for each condition. We used 2-level hierarchical logistic regression models that adjusted for characteristics of patients and hospital referral regions.

Our cohorts consisted of 171,126 admissions for AMI, 352,853 admissions for heart failure, and 343,053 admissions for pneumonia. Patients hospitalized for AMI (odds ratios [OR], 1.13; 95% confidence interval [CI], 1.06–1.21) and heart failure (OR, 1.19; 95% CI, 1.12–1.27) in the lowest quintile of density had modestly higher 30-day mortality risk compared with patients in the highest quintile, unlike patients hospitalized for pneumonia (OR, 1.02; 95% CI, 0.96–1.09). Patients hospitalized for AMI (OR, 1.06; 95% CI, 1.00–1.12) and heart failure (OR, 1.09; 95% CI, 1.04–1.13) in the lowest quintile had slightly higher 1-year mortality risk, unlike patients hospitalized for pneumonia (OR, 1.00; 95% CI, 0.95–1.05).

Patients hospitalized for AMI and heart failure in regions with lower density of cardiologists experienced modestly higher 30-day and 1-year mortality risk, unlike patients with pneumonia. These findings suggest that there is a relationship between regional density of cardiologists and mortality for AMI and heart failure, which is concentrated in the early period after these acute events.

Acknowledgements

I would like to thank my mentors, Dr. Harlan M. Krumholz and Dr. Joseph S. Ross. I greatly appreciate your dedication to my professional growth and development, and the skills you have taught will always stay with me. More importantly, you have been and continue to be my role models. I can only hope to have passion like yours in my career.

I would like to thank Mr. Yongfei Wang for his analytic contributions, as well as my other collaborators: Dr. Brahmajee K. Nallamothu, Dr. John A. Spertus, Dr. Sharon-Lise T. Normand, and Dr. Frederick A. Masoudi. I would also like to thank Dr. John Hwa for his guidance in preparing this thesis. Additionally, I would like to thank all the members of the Yale-New Haven Hospital Center for Outcomes Research and Evaluation.

Finally, I would like to thank my family and friends for their unlimited support, guidance, and love. You all help me become a better person each day.

This research was supported by a grant from the Doris Duke Charitable Foundation to Yale University for Clinical Research Fellow Vivek T. Kulkarni, and by a National Heart, Lung, and Blood Institute Cardiovascular Outcomes Center Award (1 U01 HL105270-03).

An article summarizing this work was previously published in Circulation: Cardiovascular Quality and Outcomes,[1] *Copyright © 2013 American Heart Association, Inc. Parts of that work are reproduced herein, according to permissions specified in the American Heart Association's Copyright Transfer Agreement and in the United States Code regarding Fair Use of Copyrighted Materials (17 U.S.C. § 107*).

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INTRODUCTION

Heart Disease in the United States

Heart disease poses a high burden on the health care system in the United States. Coronary heart disease alone affects an estimated 15.4 million Americans aged 20 or older.[2] This year, an estimated 720,000 patients will suffer from an acute myocardial infarction (AMI) – 515,000 new events and 205,000 recurrent events – and approximately 15% of these patients, or 108,000 Americans, will likely die from the event. Additionally, heart failure affects an estimated 5.1 million Americans aged 20 or older,[2] accounts for roughly 1 million hospital discharges annually,[3] and is the underlying cause of roughly 59,000 deaths annually.[4]

Distribution of Cardiologists in the United States

In 2011, Aneja and colleagues characterized the distribution of cardiologists across regions of the United States.[5] Their work demonstrated a total of 21,854 cardiologists nationwide. After accounting for the size of the elderly population, this number corresponds to a rate of approximately 48.4 cardiologists per 100,000 elderly people, or 1 cardiologist for roughly every 2066 elderly people.

However, Aneja and colleagues found that this figure varied substantially across the United States. Approximately 10% of regions in the country had 25 or fewer cardiologists per 100,000 elderly people. Nearly 50% of cardiologists were concentrated in regions that contain only 25% of the elderly population, and about 60% of the elderly population had access to only about 38% of cardiologists. In fact, this study demonstrated

that the distribution of cardiologists across the United States was less equal than the distribution of primary care physicians.

Aneja and colleagues also showed that, geographically, rural regions, regions in the Midwest, and regions with lower socioeconomic status have a lower density of cardiologists. When looking at population factors associated with density of cardiologists, the authors found that regions with higher median household income tended to have more cardiologists, while regions with higher unemployment rate or higher percentage of white persons tended to have fewer cardiologists.

Aneja and colleagues' findings raise concern about whether the observed unevenness in the distribution of cardiologists might impact health outcomes, and in particular, mortality. Do patients who have cardiovascular diseases such as AMI and heart failure in regions of the United States with fewer cardiologists fare worse than similar patients with the same diseases in other regions?

To address this question, we first conducted a thorough review of existing literature. No prior studies have directly investigated the relationship between regional density of cardiologists and mortality in AMI or heart failure. However, numerous prior studies have examined whether patients with cardiovascular diseases have different outcomes when treated by cardiologists, and studies in other medical specialties have investigated the relationship between regional density of healthcare providers and specialty-specific outcomes.

Treatment by Cardiologists and Mortality in Cardiovascular Diseases

AMI

In 1996, Jollis and colleagues published a study investigating whether patients admitted to the hospital for AMI have different outcomes depending on the specialty of the admitting physician.[6] They examined mortality up to 1 year after hospitalizations for AMI among 8241 Medicare beneficiaries in 1992. After adjusting for differences in patient and hospital characteristics, these authors found that, relative to patients admitted by internists, patients admitted by cardiologists had 12% lower risk of mortality within 1 year (hazard ratio, 0.88; $p<0.001$). Their work also demonstrated that patients admitted by cardiologists underwent more coronary revascularization procedures than patients admitted by internists. Jollis and colleagues speculated that differences in the use of these procedures (and other specialized treatments) might have accounted for the observed survival difference.

This study was followed in 1997 by a perspective piece written by Nash and colleagues.[7] They describe and interpret findings of a study conducted by the Pennsylvania Health Care Cost Containment Council that analyzed data from over 40,000 admissions for AMI in 1993. The authors report that patients admitted for AMI with an internist as the attending physician had a 26% higher risk-adjusted in-hospital mortality rate relative to patients admitted with a cardiologist as attending physician (risk ratio, 1.26; 95% confidence interval, 1.17-1.35). However, Nash and colleagues were cautious in their interpretation of these findings, stating that differences in patient volume alone may have accounted for the observed difference in mortality.

Casale and colleagues published a more extensive investigation into in-hospital mortality after AMI by physician specialty in 1998.[8] This study's sample consisted of approximately 30,000 patients directly admitted (not transferred) to the hospital for AMI. These authors included patient characteristics, physician characteristics, and hospital characteristics in their statistical analyses. Using multivariable logistic regression, they found that, relative to patients admitted with an attending primary care physician, patients admitted with a cardiologist as the attending physician had 17% lower risk-adjusted odds of in-hospital mortality (odds ratio, 0.83; $p < 0.003$). Subgroup analysis also demonstrated that, among patients who underwent procedural treatment (either percutaneous coronary intervention or coronary artery bypass graft surgery), patients admitted with a cardiologist as the attending physician had shorter length of stay by about 1 day.

These 3 studies established a relationship between inpatient treatment by cardiologists and improved outcomes in the United States. Several similar studies were subsequently conducted and published in the United Kingdom, suggesting that the existence of this relationship may be universal and not dependent on only the American health care system. In 2004, Abubakar and colleagues published a study examining 18-month survival in 476 patients hospitalized for AMI in 2 hospitals in the United Kingdom.[9] After controlling for patient and hospital characteristics, these authors found that patients seen by a cardiologist had an adjusted risk of mortality that was 78% lower than patients who were not seen by a cardiologist (adjusted hazard ratio, 0.22; 95% confidence interval, 0.14-0.38). However, the sample size of this study was relatively small, and the mortality benefit of seeing a cardiologist did not persist after adjusting for

access to effective post-infarction medications such as aspirin and appropriate thrombolysis (adjusted hazard ratio, 0.70; 95% confidence interval, 0.33-1.46). Birkhead and colleagues published a much larger study in 2006 that studied 88,782 patients admitted across 230 hospitals in England and Wales with AMI from 2004 to 2005.[10] These authors characterized whether each patient was admitted "under the direct responsibility of a cardiologist" and examined 90-day all cause mortality after admission. Using binary regression models adjusting for patient covariates as well as hospital covariates, this study found that patients admitted under cardiologists had a 14% lower risk-adjusted 90-day mortality relative to patients admitted under non-cardiologists (risk ratio, 0.86; 95% confidence interval, 0.81-0.91). This study along with the aforementioned studies provide strong support that inpatient treatment by a cardiologist confers a benefit to patients admitted with AMI that manifests as an improvement in mortality, both in-hospital and long-term.

In 2002, Ayanian and colleagues published a study that extended this relationship between cardiologists and mortality in AMI to ambulatory care.[11] These authors studied 35,520 Medicare beneficiaries who were hospitalized for AMI during 1994 and 1995 and subsequently survived at least 3 months after discharge from the hospital. Using propensity score matching, they compared the 2-year mortality rate among patients who saw a cardiologist within the first 3 months after hospital discharge to the rate among patients who saw only an internist or family physician in that time period. In a propensity score-matched cohort of 10,199 patients, the 2-year mortality rate among patients who saw a cardiologist was 14.6% compared with 18.3% among patients who did not see a cardiologist ($p<0.0001$). In the same cohort, these authors found that, compared with

patients who did not see a cardiologist within 3 months of hospital discharge, patients who saw a cardiologist were significantly more likely to undergo coronary procedures (angiography, angioplasty, or bypass graft surgery) within 3 months of hospital discharge and were significantly more likely to undergo exercise stress testing and/or cardiac rehabilitation within 18 months of hospital discharge – factors that may potentially mediate the observed differences in mortality.

When considered together, these studies strongly support that access to cardiology care, both in an inpatient setting and in an ambulatory setting, improves short-term and long-term mortality after hospitalization for AMI.

Heart Failure

In 2003, Jong and colleagues published a study investigating health outcomes among patients newly hospitalized for heart failure.[12] They analyzed data on 38,702 patients who were hospitalized between 1994 and 1996 in Ontario, Canada, and determined the specialty of the physician who provided the most days of inpatient care. Using multivariable logistic regression to adjust for patient-level characteristics, they found that patients managed primarily by cardiologists had lower risk-adjusted mortality rates than patients managed primarily by general internists. This relationship held for in-hospital mortality (6.5% v. 8.9%, $p<0.001$), 1-month mortality (8.5% v. 11.1%, $p<0.001$), and 1-year mortality (28.5% v. 31.7%, $p<0.001$). Additionally, using a Cox proportional hazards model, these authors found that patients primarily managed by internists had 44% higher risk of mortality in-hospital (odds ratio, 1.44; $p<0.001$), 30% higher risk of mortality within 1 month (odds ratio, 1.30; $p=0.001$), and 16% higher risk of mortality

within 1 year (odds ratio, 1.16; p=0.002) compared with patients primarily managed by cardiologists. Jong and colleagues' findings suggest that the mortality benefit conferred by inpatient cardiology care in patients admitted with heart failure is most pronounced early in the course of illness, but a difference persists for at least 1 year.

A subsequent study published by Boom and colleagues in 2012 further elucidated this relationship.[13] These authors analyzed data from approximately 7,600 patients newly hospitalized for heart failure from 2004 to 2005 in Ontario, Canada. Using a similar method to that used by Jong and colleagues, this study found that patients managed primarily by a general internist without cardiology consultation had a 50% higher risk of 30-day mortality (odds ratio, 1.50; p=0.001) and a 29% higher risk of 1-year mortality (odds ratio, 1.29; p=0.001) compared with patients managed primarily by a cardiologist, supporting the existence of a relationship that diminishes but still persists after 1 year. Interestingly, Boom and colleagues also found that patients primarily managed by a general internist with cardiology consultation had similar mortality risk to patients managed primarily by a cardiologist—findings that emphasize the importance of improved communication as a mediator of improved outcomes.

While these studies emphasize the relationship between access to cardiology care in an inpatient setting and heart failure mortality, Indridason and colleagues published a study in 2003 examining the importance of access to cardiology care in an ambulatory setting.[14] They studied a cohort of over 10,000 male veterans admitted to Veterans Affairs hospitals nationwide for heart failure between 1994 and 1995 and determined whether they received outpatient follow-up after discharge in a general medicine clinic, a cardiology clinic, or both. After adjusting for patient characteristics using a Cox

proportional hazards model, they found that, relative to patients who followed up in both clinics, patients who only followed up in a general medicine clinic had a 25% higher risk of 1-year mortality (risk ratio, 1.25; 95% confidence interval, 1.14-1.37), whereas patients who only followed up in a cardiology clinic did not have a higher risk of mortality (risk ratio, 0.98; 95% confidence interval, 0.85-1.14).

These findings suggest that access to ambulatory cardiology care after hospitalization for heart failure, either alone or in conjunction with general medical follow-up, may also be important in improving long-term mortality.

Limitations of Prior Studies

Each of these studies has several important limitations. As with all observational studies, unobserved confounding is the primary limitation of all these studies, although the authors addressed this issue using various statistical methods (Cox proportional hazards models,[6,9] multivariable logistic regression,[7,8,12,14] propensity score matching,[11] binary regression,[10] and hierarchical logistic regression[13]). Additionally, each of these study populations may not be generalizable to large populations within the United States; some consist of patients from only a small number of states,[6-8,11] some consist of patients in other countries,[9,10,12,13] and 1 consists of only male veterans.[14] Finally, none of these studies include a non-cardiac comparison condition in order to assess whether the mortality benefit associated with access to cardiologists was specific to cardiovascular conditions.

Regional Density of Health Care Providers and Mortality

In 2011, Chang and colleagues published a study examining the relationship between the regional density of primary care physicians and mortality (along with other health outcomes) among 5 million Medicare beneficiaries nationwide.[15] These authors divided the country into regions known as Primary Care Service Areas and then quantified the total amount of primary care services provided in each region in terms of primary care full-time equivalents (FTEs). They then separated regions into quintiles by primary care FTEs and compared risk-adjusted mortality rates across quintiles. The authors found that patients in the highest quintile of primary care FTEs had 5% lower rate of mortality compared with patients in the lowest quintile of primary care FTEs (risk ratio, 0.95; 95% confidence, 0.93-0.96).

Additionally, a study published by Desai and colleagues in 2012 investigated the relationship between regional density of neuroscience providers and stroke mortality.[16] The authors examined the number of stroke deaths per million in the population and the density of neurologist and neurosurgeons across 3141 counties nationwide. After adjusting for various county-level characteristics using multivariate linear regression, these authors found that counties with more neuroscience providers had lower stroke mortality rates: each increase of 1 neuroscience provider per million in the population corresponded to 0.4 fewer stroke deaths ($p<0.001$).

Taken together, these 2 studies suggest that the relationship between regional density of health care providers and mortality may exist across medical and surgical specialties.

Conceptual Framework

As we have reviewed, a multitude of studies[6-14] has established an association between treatment by cardiologists and improved mortality in patients hospitalized with AMI and heart failure. Accordingly, one might suspect that regional density of cardiologists may relate to mortality for AMI and heart failure simply because patients in regions with high density of cardiologists have greater access to cardiologists compared with patients in other regions. Although access to cardiologists likely does play an important role, we devised a conceptual framework wherein high regional density of cardiologists can also affect mortality by improving quality of care delivered by each practitioner. In short, higher regional density of cardiologists results not just in greater access to cardiology care, but also in better quality of care delivered by cardiologists and non-cardiologists alike.

Better Quality of Cardiologists – Cardiologists in regions with higher density of cardiologists may provide better quality care than cardiologists in other regions for several reasons. Cardiologists in high-density regions may more easily share skills and knowledge with other cardiologists, via professional meetings, conferences, informal social gatherings, etc. This rapid dissemination of information may help to improve the overall quality of cardiology care delivered in those regions. Similarly, with an appropriately high density of cardiologists, cardiologists may be able to direct resources toward establishing better infrastructure for cardiac care. For example, large academic centers may develop specialized cardiology wards, high-volume catheterization labs, or even dedicated cardiovascular hospitals. Additionally, cardiologists practicing in high-density regions may be more likely to super-specialize within cardiology (e.g.

electrophysiology, interventional cardiology, echocardiography, etc.), thus enabling different providers to complement one another and deliver better care overall.

Alternatively, cardiologists in high-density regions necessarily have more competition amongst themselves for patients. Cardiologists who provide low quality care would have more difficulty in sustaining a practice, such that the increased competition in high-density regions may lead to higher overall quality throughout these regions.

Better Quality of Non-Cardiologists – Non-cardiologists, such as general internists and primary care physicians, may also provide better quality care for cardiac conditions in regions with high density of cardiologists. In these regions, primary care physicians and general internists may have more interactions with cardiologists (more shared patients, more consultations, more overlapping inpatient practices, etc.), which would allow cardiologists to more easily share specialized knowledge with general practitioners. This may help to improve the quality of inpatient and outpatient care delivered by non-cardiologists for cardiovascular conditions, even though the care delivered by those providers for non-cardiovascular conditions may not be affected.

Research Objectives

With this conceptual model in mind, we sought to assess the relationship between regional density of cardiologists across the United States and 30-day and 1-year mortality after hospitalization for AMI and heart failure. We hypothesized that patients who are hospitalized for AMI and heart failure in regions with higher density of cardiologists would have substantially lower mortality than patients in regions with lower density.

Identifying a systematic difference in regional health outcomes would support efforts to develop interventions to resolve the disparity in access to cardiology care.

In order to provide a basis of comparison for our results, we also examined the risk of mortality in patients hospitalized for pneumonia. Our conceptual framework suggested that patients with non-cardiovascular conditions would not necessarily benefit from being treated in regions with greater density of cardiologists. Accordingly, we chose pneumonia as a comparison condition because it is not primarily cardiovascular, but like AMI and heart failure, it is common, presents acutely, and has a high mortality rate. In line with our conceptual framework, we did not hypothesize mortality in patients hospitalized for pneumonia to have any relationship with regional density of cardiologists.

HYPOTHESIS AND SPECIFIC AIMS

Hypothesis

Patients hospitalized for AMI and heart failure in regions with a lower density of cardiologists have higher mortality.

Specific Aims

- To assess the relationship between regional density of cardiologists and 30-day and 1-year mortality among patients hospitalized with AMI or heart failure; and
- To assess the relationship between regional density of cardiologists and 30-day and 1-year mortality among patients hospitalized with pneumonia, as a comparison condition.

METHODS

Data Sources

We used the Medicare Standard Analytic and Denominator files to identify 3 cohorts of hospital admissions in 2010 based upon a principal discharge diagnosis of AMI, heart failure, or pneumonia. The Medicare Standard Analytic file contains administrative data about all hospitalizations of Medicare beneficiaries nationwide, and the Medicare Denominator file contains administrative data about all Medicare beneficiaries nationwide. Each cohort was defined with *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) codes identical to those used in the mortality measures that are publicly reported by the Centers for Medicare & Medicaid Services.[17-19] We excluded patients who were younger than 65 years of age at the time of admission, transferred to another acute care facility, not enrolled in Medicare fee-for-service for the prior year, or discharged against medical advice. These exclusion criteria are consistent with the methodology used in the aforementioned publicly reported mortality measures. For patients with multiple hospitalizations meeting these criteria, we included a randomly selected single admission. For each admission, we assembled information on patient age, sex, and condition-specific comorbidities. We used comorbidities that were identical to those used in the publicly reported mortality measures.[17-19]

We used the 2010 Bureau of Health Professionals' Area Resource File,[20] published by the Health Resources and Services Administration of the Department of Health and Human Services, to obtain data on the distribution of cardiologists in each county as derived from the American Medical Association's Physician Masterfile. We

also obtained demographic and socioeconomic data in each county (population aged 65 years or older, total population, number of white persons, number of unemployed persons, civilian workforce, and median household income).

Regional Analysis

We used HRRs as the unit of regional analysis. HRRs were devised based on historical patterns of referral for complex cardiologic-surgical and neurosurgical procedures, and they represent large areas with substantial population.[21] HRRs are commonly used to examine variation in health care.[22-24] We further explore the strengths and limitations of our choice to use HRRs in the Discussion.

Each county-level variable was aggregated to HRRs using geographically-based methodology that has been previously published.[25] In brief, we used geographic information software (ArcGIS, version 9.3.1, ESRI, Redlands, CA) to determine the overlap between counties and HRRs. More specifically, we overlaid a map of the United States by county on a map of the United States by HRR and then allocated each county to an HRR. If a county was contained entirely within a single HRR, we allocated that county to that HRR only. If a county was contained within multiple HRRs, we allocated that county to HRRs in proportion to its fractional area contained within each of the HRRs. We assumed a proportional distribution of each variable within each county, and we defined HRR-level variables as the sum of these proportional allocations from all component counties. We merged patient-level data into the HRR-level through patient ZIP code.

Outcomes

The primary outcomes for each condition were death within 30 days and 1 year of admission. The standard outcome used in the publicly reported hospital outcome measures is 30-day mortality. While this time window may be adequate in order to characterize hospital performance, we were also interested in capturing a range of possible effects not directly related to hospitalization, including follow-up treatment and long-term outpatient follow-up. Accordingly, we used both 30-day and 1-year mortality to help capture a range of possible effects.

Independent Variables

At the patient level, independent variables were age, sex, and the condition-specific comorbidities. These variables parallel those used in the hospital mortality measures that are publicly reported by the Centers for Medicare & Medicaid Services.[17-19] This approach has been previously validated against medical records-based models to assess hospital performance.

At the HRR level, the main independent variable was density of cardiologists, defined as the number of cardiologists divided by the population aged 65 or older, expressed per 100,000 older adults. We included regional socioeconomic and demographic variables previously shown[5] to relate to density of cardiologists as HRR-level covariates (unemployment rate (the number of unemployed persons divided by the civilian workforce), percentage of white race (number of white persons divided by the total population), and median household income).

Statistical Analyses

Primary Analyses

We categorized HRRs into quintiles by density of cardiologists, ranging from quintile 1 (lowest density) to quintile 5 (highest density), and examined the patient characteristics and regional characteristics among the 5 quintiles. We then used 2-level hierarchical logistic regression models (HLRMs) to assess the relationship between each mortality outcome and density of cardiologists by comparing across quintiles.

Logistic regression is a method of statistical analysis that models the natural logarithm of a continuous outcome variable as a linear combination of independent variables. Since mortality is a discrete variable, we first used a logit transformation to model the odds of mortality as a continuous variable, and we then used logistic regression to model the log-odds of mortality as a linear combination of our independent variables.

Hierarchical logistic regression, also known as multi-level logistic regression, modifies standard logistic regression in order to help account for the clustering of outcomes. For example, patients within the same HRR are more likely to have similar outcomes than patients randomly selected from a nationwide sample. Hierarchical logistic regression accounts for such clustering of outcomes by using multiple levels of analysis and distinguishing variation within a single level from variation across levels.[26] In our case, our HLRMs had 2 levels: patient and HRR. We included patient-level variables, HRR-level variables, and an HRR-level random effect.

For each outcome and condition, we used 2 separate hierarchical models. Model A adjusted for patient age, sex, and condition-specific comorbidities, as well as an HRR-level random effect. Model B added the 3 HRR-level covariates (unemployment rate,

percentage of white race, and median household income) to Model A. Only Model B accounted for HRR-level variables. We further consider the differences between these models in the Discussion section.

We reported odds ratios (ORs) for each quintile, with 95% confidence intervals (CIs), relative to quintile 5 in each model. We also used F-tests to assess linear trends across quintiles in model B.

Secondary Analysis

Prior to selecting the variables that we included in our final models, we initially considered density of primary care physicians as an HRR-level covariate. Due to concerns about colinearity, we ultimately decided to omit this variable from our final models (we further address the issue of colinearity in the Discussion section). Nevertheless, we conducted a secondary analysis in order to address potential confounding between density of primary care physicians and density of cardiologists.

Analogous to our primary analysis, we defined density of primary care physicians at the HRR level as the number of primary care physicians divided by the population aged 65 or older, expressed per 100,000 older adults. We then categorized HRRs into quintiles of density of primary care physicians. For each outcome and condition, we used a single 2-level hierarchical model, adjusting for patient age, sex, and condition-specific comorbidities, as well as the 3 HRR-level covariates and an HRR-level random effect – analogous to Model A in our primary analyses. We conducted all analyses with SAS version 9.1.3 (SAS Institute Inc., Cary, North Carolina).

Statement of Student Contributions

Mr. Kulkarni, with guidance from Dr. Krumholz and Dr. Ross, conceived and designed this study, conducted an extensive review of the literature, reviewed analytic results, and drafted the manuscript. Mr. Kulkarni, Dr. Krumholz, Dr. Ross, and Mr. Wang collaborated in designing and refining the analytic approach. Mr. Wang conducted all analyses.

RESULTS

Among eligible Medicare beneficiaries in 2010, there were 171,126 admissions for AMI, 352,853 for heart failure, and 343,053 for pneumonia. Overall, the 30-day mortality rates were 15.4%, 11.7%, and 11.9%, and 1-year mortality rates were 32.3%, 40.4%, and 35.2%, respectively (Table 1). Mean age and percentage male in each cohort were similar across quintiles.

Table 1. Patient Admission Cohorts and Unadjusted Outcomes Across Quintiles of Density

	Overall	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Acute Myocardial Infarction Cohort						
N	171,126	17,776	22,846	29,096	45,179	56,229
Mean (SD) Age, y	79.3 (8.3)	79.2 (8.3)	78.8 (8.2)	78.7 (8.2)	79.2 (8.3)	79.9 (8.4)
Males (%)	86,626 (50.6)	9,325 (52.5)	11,846 (51.9)	15,095 (51.9)	22,927 (50.8)	27,433 (48.8)
30-day deaths (%)	26,290 (15.4)	2,862 (16.1)	3,525 (15.4)	4,396 (15.1)	6,951 (15.4)	8,556 (15.2)
1-year deaths (%)	55,292 (32.3)	5,690 (32.0)	7,158 (31.3)	9,131 (31.4)	14,619 (32.3)	18,694 (33.3)
Heart Failure Cohort						
N	352,853	32,977	44,764	56,670	92,356	126,086
Mean (SD) Age, y	81.2 (8.1)	81.2 (8.1)	80.9 (8.1)	80.6 (8.1)	81.0 (8.1)	81.6 (8.1)
Males (%)	158,631 (45.0)	15,066 (45.7)	20,412 (45.6)	25,800 (45.5)	41,603 (45.1)	55,750 (44.2)
30-day deaths (%)	41,121 (11.7)	4,240 (12.9)	5,542 (12.4)	6,612 (11.7)	10,942 (11.9)	13,785 (10.9)
1-year deaths (%)	142,612 (40.4)	13,582 (41.2)	18,344 (41.0)	22,892 (40.4)	37,463 (40.6)	50,331 (39.9)
Pneumonia Cohort						
N	343,053	38,923	48,889	55,676	92,481	107,084
Mean (SD) Age, y	80.4 (8.2)	80.5 (8.2)	80.1 (8.2)	80.0 (8.2)	80.2 (8.2)	80.9 (8.3)
Males (%)	158,183 (46.1)	18,598 (47.8)	22,553 (46.1)	25,998 (46.7)	42,786 (46.3)	48,248 (45.1)
30-day deaths (%)	40,906 (11.9)	4,585 (11.8)	5,801 (11.9)	6,718 (12.1)	11,245 (12.2)	12,557 (11.7)
1-year deaths (%)	120,666 (35.2)	13,331 (34.3)	16,941 (34.7)	19,548 (35.1)	32,660 (35.3)	38,185 (35.7)

Median density of cardiologists per 100,000 elderly adults across the 306 HRRs was 38.6 (minimum 7.6, maximum 227.1). There was wide variation in density across HRRs; the median density per 100,000 was 23.7, 32.0, 38.6, 51.0, and 78.6 in quintiles 1 to 5, respectively (Table 2). Percentage of white race decreased from quintile 1 to quintile 5, whereas median household income increased. Unemployment rate did not vary uniformly across quintiles.

Table 2. Density of Cardiologists and Hospital Referral Region Covariates Across Quintiles

	Overall	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	p[A]
Median Density[B]	38.6	23.7	32.0	38.6	51.0	78.6	–
IQR[C]	29.9-54.4	20.4-25.8	29.9-33.3	37.6-41.5	48.4-54.4	66.0-94.9	
White Race (%)	77.2	84.6	80.3	75.5	75.9	69.7	<0.0001
Unemployment (%)	9.2	8.9	9.5	9.7	9.0	8.9	0.1811
Median Income[D] ($)	46,519	41,737	41,737	44,375	47,141	57,682	<0.0001

A: P value for trend, calculated using Cochrane-Armitage test. B: Density is expressed as number of cardiologists per 100,000. C: IQR denotes interquartile range. D: Median income among households.

Primary Analyses

Associations between Density Quintiles and 30-Day Mortality

At 30 days, when adjusting for patient characteristics only (model A), patients hospitalized for all 3 conditions in the lowest quintile had higher mortality risk compared with patients hospitalized in the highest quintile. ORs were 1.20 (95% CI, 1.13-1.27) for AMI, 1.26 (95% CI, 1.19-1.34) for heart failure, and 1.09 (95% CI, 1.03-1.16) for pneumonia (Table 3). These findings were consistent across all quintiles for each condition.

After adjusting for HRR covariates (model B), patients hospitalized for AMI (OR 1.13, 95% CI 1.06-1.21) and heart failure (OR 1.19, 95% CI 1.12-1.27) in the lowest quintile had higher 30-day mortality risk compared with patients hospitalized in the highest quintile, but patients hospitalized for pneumonia did not (OR 1.02, 95% CI, 0.96-1.09) (Table 3). These findings were broadly consistent across quintiles for all 3 conditions, with similar magnitudes of effect observed. Furthermore, there were significant linear trends between lower density of cardiologists and higher 30-day mortality risk for AMI ($p=0.0002$) and heart failure ($p<0.0001$), but not for pneumonia ($p=0.6465$) (Figure).

Associations between Density Quintiles and 1-Year Mortality

At 1 year, when adjusting for patient characteristics only (model A), patients hospitalized for AMI and heart failure in the lowest quintile had higher mortality risk compared with patients hospitalized in the highest quintile. The difference was borderline significant for pneumonia. ORs were 1.11 (95% CI, 1.05-1.17) for AMI, 1.13 (95% CI,

1.08-1.17) for heart failure, and 1.04 (95% CI, 1.00-1.09) for pneumonia (Table 3). These findings were consistent across all quintiles for AMI and for heart failure; however, for pneumonia, patients hospitalized in all other quintiles had higher mortality risk, with ORs ranging from 1.06 to 1.08.

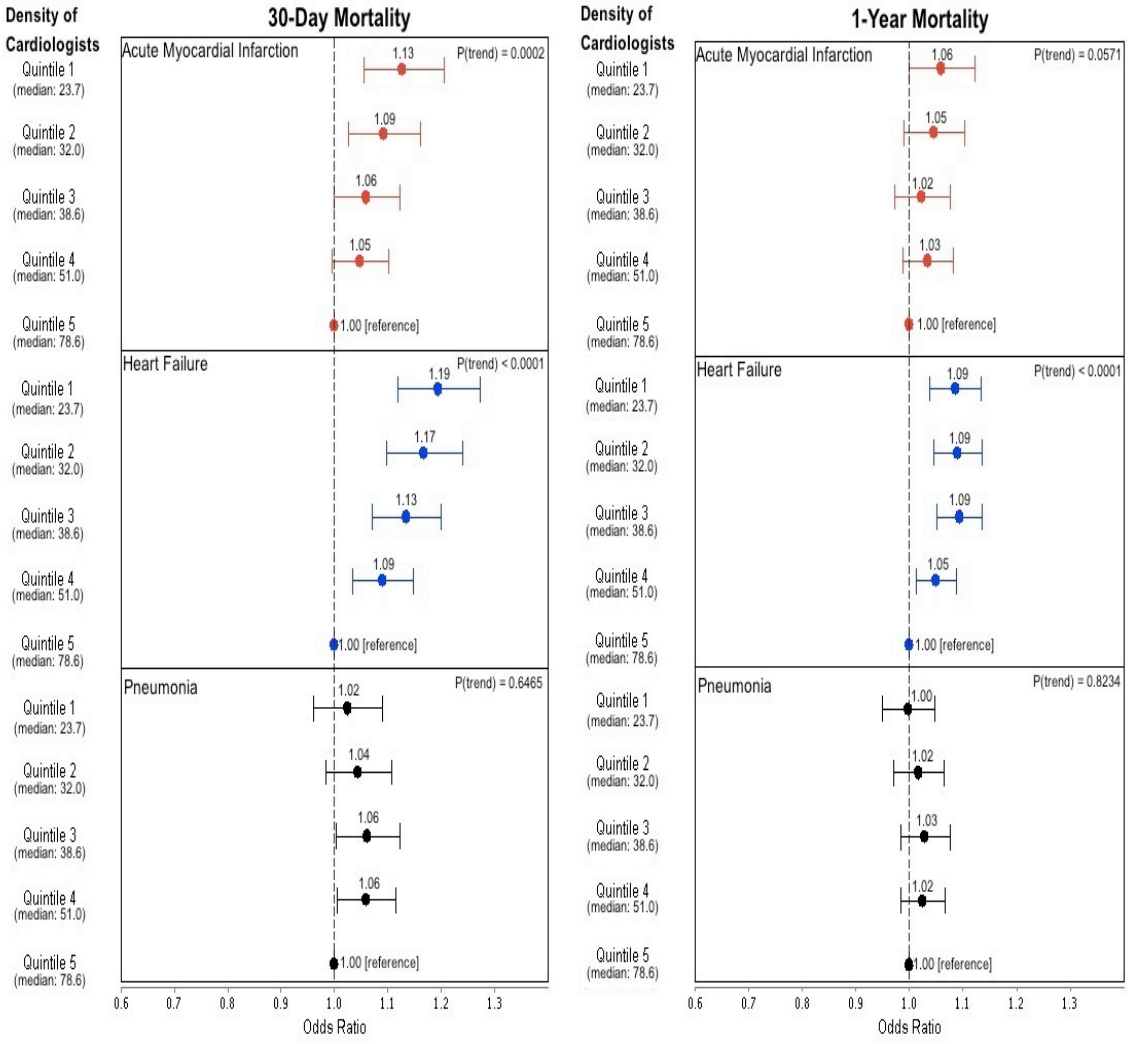
After adjusting for HRR covariates (model B), patients hospitalized for heart failure in the lowest quintile had higher 1-year mortality risk compared with patients hospitalized in the highest quintile (OR 1.09, 95% CI 1.04-1.13), unlike patients hospitalized with pneumonia (OR 1.00, 95% CI 0.95-1.05) (Table 3). For patients hospitalized for AMI in the lowest quintile, there was a borderline significantly higher 1-year mortality risk compared with patients hospitalized in the highest quintile (OR 1.06, 95% CI 1.00-1.12). These findings were consistent across all quintiles for each condition. Furthermore, there was a significant linear trend between lower density of cardiologists and higher 1-year mortality risk for heart failure ($p<0.0001$), and the linear trend for AMI was nearly significant ($p=0.0571$). For pneumonia, there was no significant trend ($p=0.82$) (Figure).

Table 3. Associations between Density of Cardiologists by Quintiles and Mortality

	30-day Mortality		1-year Mortality	
	Model A	**Model B**	**Model A**	**Model B**
		Acute Myocardial Infarction Cohort		
	OR[A] [95% CI[B]]	OR [95% CI]	OR [95% CI]	OR [95% CI]
Quintile 1	1.20 [1.13, 1.27]	1.13 [1.06, 1.21]	1.11 [1.05, 1.17]	1.06 [1.00, 1.12]
Quintile 2	1.16 [1.09, 1.22]	1.09 [1.03, 1.16]	1.10 [1.05, 1.15]	1.05 [0.99, 1.10]
Quintile 3	1.12 [1.06, 1.18]	1.06 [1.00, 1.13]	1.07 [1.02, 1.13]	1.02 [0.97, 1.08]
Quintile 4	1.10 [1.04, 1.15]	1.05 [0.99, 1.10]	1.07 [1.03, 1.12]	1.03 [0.99, 1.08]
Quintile 5	1.00 [reference]	1.00 [reference]	1.00 [reference]	1.00 [reference]
		Heart Failure Cohort		
	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
Quintile 1	1.26 [1.19, 1.34]	1.19 [1.12, 1.27]	1.13 [1.08, 1.17]	1.09 [1.04, 1.13]
Quintile 2	1.22 [1.15, 1.28]	1.17 [1.10, 1.24]	1.12 [1.08, 1.16]	1.09 [1.05, 1.14]
Quintile 3	1.16 [1.10, 1.22]	1.13 [1.07, 1.21]	1.11 [1.07, 1.15]	1.09 [1.05, 1.14]
Quintile 4	1.12 [1.07, 1.18]	1.09 [1.03, 1.15]	1.07 [1.04, 1.11]	1.05 [1.01, 1.09]
Quintile 5	1.00 [reference]	1.00 [reference]	1.00 [reference]	1.00 [reference]
		Pneumonia Cohort		
	OR [95% CI]	OR [95% CI]	OR [95% CI]	OR [95% CI]
Quintile 1	1.09 [1.03, 1.16]	1.02 [0.96, 1.09]	1.04 [1.00, 1.09]	1.00 [0.95, 1.05]
Quintile 2	1.12 [1.06, 1.18]	1.04 [0.98, 1.11]	1.07 [1.02, 1.11]	1.02 [0.97, 1.07]
Quintile 3	1.13 [1.07, 1.19]	1.06 [1.00, 1.12]	1.08 [1.03, 1.12]	1.03 [0.98, 1.07]
Quintile 4	1.11 [1.06, 1.17]	1.06 [1.01, 1.12]	1.06 [1.02, 1.11]	1.02 [0.98, 1.07]
Quintile 5	1.00 [reference]	1.00 [reference]	1.00 [reference]	1.00 [reference]

A: OR denotes odds ratio. B: CI denotes confidence interval.

Figure. Odds Ratios for 30-day and 1-year Mortality by Density of Cardiologists



Secondary Analysis

Associations between Density of Primary Care Physicians and Mortality

At 30 days, after adjusting for patient characteristics and HRR covariates, patients hospitalized for AMI (OR 1.04, 95% CI 0.97-1.11), heart failure (OR 1.05, 95% CI 0.98-1.13) and pneumonia (OR 1.03, 95% CI 0.97-1.10) in the lowest quintile of density of primary care physicians did not have higher mortality risk compared with patients hospitalized in the highest quintile (Table 4). These findings were consistent across all quintiles for AMI. For heart failure, patients hospitalized in quintiles 2 through 4 had higher 30-day mortality risk, with ORs ranging from 1.08 to 1.12, and for pneumonia, patients hospitalized in quintile 3 (OR 1.06) and quintile 4 had 30-day higher mortality risk (OR 1.07). Nevertheless, there was no significant linear trend between density of primary care physicians and 30-day mortality risk for any condition (p=0.14, 0.08, and 0.50 for AMI, heart failure, and pneumonia, respectively).

At 1 year, after adjusting for patient characteristics and HRR covariates, patients hospitalized for AMI in the lowest quintile of density of primary care physicians had higher mortality risk compared with patients hospitalized in the highest quintile (OR 1.07, 95% CI 1.00-1.13), unlike patients with heart failure (OR 1.01, 95% CI 0.97-1.06) and pneumonia (OR 1.04, 95% CI 0.99-1.10) (Table 4). For AMI, patients hospitalized in quintile 2 (OR 1.06) and quintile 3 (OR 1.07) had higher 1-year mortality risk; for heart failure, patients hospitalized in quintile 2 (OR 1.06) and quintile 3 (OR 1.06) had higher 1-year mortality risk; and for pneumonia, patients hospitalized in quintile 3 (OR 1.05) had higher 1-year mortality risk. Furthermore there was a significant linear trend between

lower density of primary care physicians and higher 1-year mortality risk for AMI (p=0.0360), but not for heart failure (p=0.36) or pneumonia (p=0.17).

Table 4. Associations between Density of Primary Care Physicians by Quintiles and Mortality

	30-day Mortality	1-year Mortality
	Acute Myocardial Infarction Cohort	
	OR[A] [95% CI[B]]	OR [95% CI]
Quintile 1	1.04 [0.97, 1.11]	1.07 [1.00, 1.13]
Quintile 2	1.05 [0.99, 1.12]	1.06 [1.00, 1.12]
Quintile 3	1.02 [0.95, 1.08]	1.07 [1.02, 1.13]
Quintile 4	1.01 [0.96, 1.07]	1.04 [0.99, 1.09]
Quintile 5	1.00 [reference]	1.00 [reference]
	Heart Failure Cohort	
	OR [95% CI]	OR [95% CI]
Quintile 1	1.05 [0.98, 1.13]	1.01 [0.97, 1.06]
Quintile 2	1.12 [1.05, 1.20]	1.06 [1.01, 1.11]
Quintile 3	1.08 [1.01, 1.15]	1.06 [1.01, 1.10]
Quintile 4	1.08 [1.02, 1.15]	1.04 [1.00, 1.08]
Quintile 5	1.00 [reference]	1.00 [reference]
	Pneumonia Cohort	
	OR [95% CI]	OR [95% CI]
Quintile 1	1.03 [0.97, 1.10]	1.04 [0.99, 1.10]
Quintile 2	1.06 [0.99, 1.12]	1.03 [0.99, 1.08]
Quintile 3	1.06 [1.00, 1.13]	1.05 [1.01, 1.10]
Quintile 4	1.07 [1.01, 1.13]	1.04 [1.00, 1.09]
Quintile 5	1.00 [reference]	1.00 [reference]

A: OR denotes odds ratio. B: CI denotes confidence interval.

DISCUSSION

We found that patients who were hospitalized for AMI and heart failure in regions with lower density of cardiologists had modestly higher 30-day and 1-year mortality risk compared with patients hospitalized in regions with higher density. At 30 days, compared with the highest quintile, the lowest quintile had 13% higher odds of mortality for AMI and 19% higher for heart failure. The risk was attenuated by 1 year, with 6% higher odds of mortality for AMI and 9% higher for heart failure. Furthermore, we found linear trends between higher density of cardiologists and lower mortality risk for AMI and heart failure, although the trend for 1-year mortality risk for AMI did not quite reach statistical significance. Moreover, we found no relationships between density of cardiologists and mortality among patients hospitalized for pneumonia.

These findings suggest that there is a relationship between regional density of cardiologists and mortality for AMI and heart failure, which is concentrated in the early period after these acute events. If all regions had the same mortality rates as those in the highest quintile of density of cardiologists, there would have been approximately 1,200 (95% CI: 200-2,100) fewer deaths within 30 days of AMI hospitalization and 3,200 (95% CI: 1,700-4,500) fewer deaths within 30 days of heart failure hospitalization. Lower density areas may need to develop new approaches to achieve results that are similar to those of higher density regions.

Interpretations

There are several possible explanations for our findings, as we outlined in our conceptual framework in the Introduction. Patients hospitalized in regions with high

density of cardiologists may be more likely to receive care from a cardiologist, either inpatient treatment or outpatient follow-up after discharge. As we reviewed, numerous studies have demonstrated that patients treated by cardiologists have better short-term and long-term outcomes,[6-14] and our results may simply reflect greater access to cardiologists. Additionally, density of cardiologists may correlate with quality of cardiology care—possibly due to increased sharing of skills and knowledge with other cardiologists, development of specialized cardiac care facilities, super-specialization within cardiologic subfields, or even increased competition among practitioners. Alternatively, the threshold for diagnosis of cardiac conditions or for admission to hospital for acute cardiac diseases may be lower in regions with high density of cardiologists, such that the average admitted patient is less severely ill.

On the other hand, despite more than 3-fold variation in median density between the lowest quintile of regions and the highest, the magnitudes of the observed associations were modest. We can speculate several reasons why we did not observe a larger effect. First, cardiologists in regions with low density may concentrate their efforts on patients with the most severe disease, for whom their specialized training is likely to have the greatest impact. Thus, scarce resources are allocated to the highest risk patients, whose care and outcomes do not reflect any effect of reduced access to cardiologists, and for lower risk patients, the specialty of their care provider has only a small impact on their care. Second, cardiologists in regions with low density may have found ways to circumvent their diminished workforce by facilitating efficient communication networks with one another and with other providers. Given that cardiologists treat as few as 35% of patients with AMI[27] and 36% of patients with heart failure,[13] and that treatment

guidelines for heart failure,[28] non-ST-elevation myocardial infarction,[29] and ST-elevation myocardial infarction[30] do not routinely recommend consultation with a cardiologist, this may explain how patients with AMI and heart failure can still receive some of the benefits of cardiology input even if they are not directly treated by a cardiologist. Third, cardiologists in regions with high density may practice primary care or spend their time treating cardiac conditions other than AMI or heart failure, resulting in diminishing marginal returns from additional cardiologists and a nonlinear relationship between density of cardiologists and mortality. Nevertheless, the difference in mortality between the highest and lowest quintiles of density of cardiologists, especially within the first 30 days, is not trivial and translates into many fewer deaths in the high-density regions.

Contribution to Existing Literature

Our study adds to the existing literature in several ways. Numerous studies have demonstrated the better outcomes achieved by patients with AMI and heart failure who are treated by cardiologists,[6-14] but ours is the first study to examine this relationship at the regional level. Additionally, our study consists of large national cohorts of elderly Medicare beneficiaries, which more readily allows for generalization than prior work. Also, in distinction to prior work, our study included pneumonia as a comparison condition. In the absence of a comparison condition, we might have suspected that the observed relationships for AMI and heart failure resulted from differences in density of physicians overall, especially in light of our preliminary analyses that demonstrated colinearity between density of cardiologists and that of primary care physicians. However, we found no relationships between density of cardiologists and mortality risk

among patients hospitalized for pneumonia. These findings help to allay concerns about confounding and provide an important contrast for the relationships that we observed for AMI and heart failure.

Directions for Further Work

Our work supports the existence of a relationship between regional density of cardiologists and mortality for AMI and heart failure whose magnitude appears to diminish over time. We speculate that access to care and quality of care likely both play a role in this relationship, and further work may attempt to investigate the nature of this interaction more carefully. Additionally, the attenuation in the observed effect from 30 days to 1 year for both conditions also remains an unanswered question. Perhaps increased communication among cardiologists, specialized cardiac facilities, and super-specialists matter more in the short-term because patients tend to have closer follow-up immediately following a cardiac hospitalization. Alternatively, perhaps the effect of increased access to cardiologists diminishes with time because patients have more opportunities to seek cardiac care. Nonetheless, given that Jong and colleagues found a similar attenuation in mortality benefit from 1 month to 1 year,[12] further work will be required to investigate this phenomenon.

Our findings also raise questions about the relationship between regional density of cardiologists and hospitalization rates for AMI and heart failure. Although our cohorts demonstrated that numbers of admissions for AMI and heart failure were higher in regions with higher density of cardiologists, we did not directly examine hospitalization rates. Prior studies have shown that both hospitalization rates and mortality rates have

declined nationwide for AMI and heart failure.[31,32] Our results might highlight the role of density of cardiologists as a mediator of this decline. For example, one possibility is that cardiologists may be attracted to regions with higher hospitalization rates for AMI and heart failure. Further work will be required to investigate this relationship.

Analytic Concerns

Choice of Unit of Regional Analysis

To calculate density of cardiologists for geographic areas, we used data from the Area Resource File,[20] which allows estimates at the county-level. Unfortunately, county-level data may not be the optimal means of assessing density of cardiologists. For example, New York County contains both Harlem and the Upper East Side of Manhattan, areas that likely have widely disparate density of cardiologists. However, more granular estimates of density of cardiologists could not be calculated because data were not available at a smaller geographic level.

In deciding how to minimize misclassification, we considered the option of calculating the density of cardiologists at the level of hospital service areas (HSAs). HSAs are more than 3,000 regions that were devised based on patterns of inpatient care/referral.[21] Each HSA corresponds to a hospital, and the patients within that HSA are likely to receive inpatient care at that hospital. However, although we were interested in inpatient care, we were also interested in outpatient follow-up, long-term care, and other regional factors unrelated to inpatient admission. We did not think it wise to have our regional unit center primarily around inpatient services, especially given that we included 1-year mortality as an outcome, since outpatient care may be more important than

inpatient care among hospital survivors, and since doctors' practices may easily cross boundaries defined by hospital care. For these reasons, we thought that HSAs would not be the ideal region for examining density of cardiologists.

Instead, we opted for HRRs. Because HRRs were devised based on patterns of referral for complex patients,[21] we felt that patients most likely remain within the boundaries of their HRR when seeking inpatient and outpatient care. Additionally, HRRs are relatively large compared with counties and HSAs, and thus likely encompass a well-defined care region. We believe that physicians likely practice within a single HRR, even if they have multiple practice locations.

Nevertheless, the choice of HRRs has limitations – most notably that HRRs are heterogeneous. In particular, HRRs include both urban and rural areas that may have substantial differences in their densities of cardiologists. For example, the Los Angeles HRR contains both Los Angeles County and southeastern Kern County, which are likely to have different densities of cardiologists. In fact, HRRs often encompass multiple urban areas and rural areas, and this heterogeneity may even relate to outcomes: prior work has shown that patients with AMI in urban areas have higher mortality than patients in non-urban areas.[33] This limitation is inherent to our choice of HRRs.

Still, our methodology ensured that each HRR's value for density of cardiologists represents a weighted average of the rates of its constituent counties by aggregating county-level data to the HRR-level using weights determined by geographic information software. We made an assumption that, if there were a relationship between regional density of cardiologists and mortality, it would be detectable based on average density, even if that density were not uniformly distributed within the geographic region. In other

words, populations in HRRs with higher density have, on average, greater access to cardiologists, even though this access may not be uniform and some subpopulations may have relatively limited access. However, analyses to quantify the degree of heterogeneity within each HRR were beyond the scope of our study. Thus, our results at the HRR level can only be interpreted as averages for the entire region.

Moreover, because our focus in this work was the density of cardiologists, we explicitly do not make any inferences about whether patients who receive care from a cardiologist have better or worse outcomes. Such an inference would be susceptible to an ecological fallacy. The ecological fallacy refers to making inferences about individuals based on analyses among groups. We believe that making inferences about access to cardiologists at the patient-level would risk incurring the ecological fallacy, and accordingly we do not make such inferences. Our results do not permit the conclusion that patients have lower risk of mortality when treated by a cardiologist. Rather, we make inferences only at the regional level, stating that patients hospitalized in regions with high density of cardiologists have lower mortality. We are determining whether regions with higher density of cardiologists tend to have better patient outcomes. Such an effect could be mediated in many different ways. The density of cardiologists could, for example, have an influence on the care by non-cardiologists. This interpretation of our results avoids the ecological fallacy.

Inclusion of Regional Variables

A central challenge in this work was accounting for differences among patients in different HRRs. In-depth clinical data were unavailable for our cohorts. Instead, we used

2 models to evaluate the relationship between density of cardiologists and mortality, each of which provided different insights. Our first model, Model A, adjusted only for patient characteristics, using an approach that mirrors publicly reported hospital mortality measures.[17-19] Among hospitals, this methodology has been validated against other methods based on clinical data. In this first model, we found that lower density of cardiologists was associated with higher rates of 30-day and 1-year mortality for all conditions, even for our comparison condition of pneumonia. These findings raised concerns that, when only adjusting for patient data, density of cardiologists might serve as a proxy for other regional factors that might influence health care outcomes, which are known to vary.[31,34,35]

To better address these concerns, our second model, Model B, also adjusted for regional socioeconomic status using HRR-level covariates—unemployment rate, percentage of white race, median household income—because these factors were known or expected to be associated with health care intensity and patient outcomes.[24,36-40] In this second model, we found no relationship between density of cardiologists and mortality for pneumonia, suggesting that the risk-adjustment adequately accounted for other regional differences that might have affected outcomes. The difference in our findings between these 2 models highlights the importance of accounting for regional characteristics when studying physician density.

Colinearity and Secondary Analysis

In preliminary analyses, we also included density of primary care physicians as an HRR-level covariate. However, because subsequent work showed that this variable was highly colinear with density of cardiologists, we omitted it from our final models.

Colinearity is a statistical phenomenon that can occur in regression models.[41] In brief, the most robust regression models have independent variables that each correlate strongly with the dependent variable but not with one another. When independent variables correlate with one another in a regression model, estimation of the regression coefficients becomes less precise, which results in a less generalizable model. Colinearity refers to the loss of precision and generalizability resulting from including correlated independent variables.

In order to ensure robust statistical models, we omitted density of primary care physicians as an HRR-level variable. However, the colinearity that we observed in our preliminary analyses raised concerns that any associations we might find could be related to primary care physicians rather than cardiologists. To address these concerns without risking the introduction of colinearity into our models, we conducted a secondary analysis using density of primary care physicians as the main independent variable. Although we found a significant linear trend between lower density of primary care physicians and higher 1-year mortality risk after hospitalization for AMI, we found no other linear trends for 30-day or 1-year mortality—in contrast to our findings of consistent linear trends between density of cardiologists and mortality risk. These results suggest that, despite the observed colinearity, density of cardiologists is not simply a marker for density of primary care physicians. Nevertheless, further studies may explore

the associations between regional densities of various physicians and their relationship with outcomes.

Limitations

Our study has several limitations. First, given our use of observational methods, there may be unobserved differences between areas of varying density of cardiologists, potentially confounding our analysis. Although we adjusted for HRR-level covariates to minimize confounding from socioeconomic status, our techniques may have been inadequate, or other confounders unrelated to socioeconomic status may account for the associations we observed. Second, we used county-level data to determine density of cardiologists. There may be variation in the density of cardiologists within each county, but we did not have information in smaller units. However, regardless of the geographic area that is used, the exact location of a physician's practice is difficult to determine, and when smaller areas are employed it may be more likely that the doctors' practices may cross boundaries. Third, our cohorts were limited to Medicare fee-for-service beneficiaries older than 65 years of age; the association between density of cardiologists and mortality risk in younger patients remains unexplored. Fourth, information about physician specialty was self-reported; however, prior work has demonstrated this information to be an accurate reflection of practice patterns.[42] Fifth, we accounted only for the number of cardiologists, which may overestimate the level of care provided in areas with large academic centers due to inability to account for the time some cardiologists spend performing research.[43] Finally, we only assessed mortality, and other outcomes such as readmission may also relate to density of providers.

Conclusion

In conclusion, patients hospitalized for AMI and heart failure in regions with lower density of cardiologists have modestly higher 30-day and 1-year mortality risk compared with patients hospitalized in regions with higher density. Deeper understanding of the causes of this observed difference in mortality may potentially reveal a target for interventions to improve outcomes.

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