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Hospital Variation In The Use Of High Intensity Healthcare Resources And Its Association With Patient Outcomes

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Hospital variation in the use of high intensity healthcare resources and its association with patient outcomes

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By

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INTRODUCTION

Hospitals exert significant influence on the quality of care that patients receive, even after controlling for patient-level differences. Substantial variation exists among U.S. hospitals in terms of patient mortality rates at 30 days after admission for acute myocardial infarction (AMI), heart failure (HF), and stroke.[1-3] These results persist after adjustment for patient-level clinical risk factors and demographics, including co-morbidities, age, and gender. Risk-adjusted readmission rates demonstrate even more dramatic variation across hospitals. In addition to differences in their performance on outcomes, hospitals have demonstrated a varying ability to follow guideline-based processes of care in the treatment of some of the most common conditions that require in-patient hospital admission, including HF and AMI.[4, 5]

The hospital is becoming a focal point in the effort to increase quality in the healthcare system. The federal government has recognized that engaging hospitals in quality improvement initiatives may make a significant impact in patient care across the United States. The Center for Medicare and Medicaid Services (CMS) now penalizes hospitals with a reduction in reimbursement rates if they do not report their performance on a wide range of quality measures, which are then publically reported on CMS' Hospital Compare website.[6] Beginning in 2013, CMS will go further by reducing reimbursements to hospitals if they do not meet certain performance benchmarks.[7] In order to meet goals of quality improvement, studies are attempting to identify and characterize clinical practice patterns at the hospital level in order to determine whether they are associated with better or worse patient outcomes.

Beyond quality, hospital practice patterns deeply affect the healthcare system because they have enormous cost implications, as hospitals account for a disproportionately large percentage of healthcare costs in the U.S. In 2010, almost one-third of overall healthcare spending occurred because of hospitals.[8] Yet there is no clear relationship between hospital cost and the quality of care delivered to the patient, such that higher cost care does not necessarily translate into better quality care. The unclear association between cost and quality has been demonstrated in a number of common and diverse diagnoses, ranging from sepsis to trauma.[9-12] In a healthcare system facing increasingly limited resources, providers, payors, and policy makers are seeking to increase the value of care delivered to patients by identifying expensive, resource-intensive hospital practice patterns that are not associated with improved outcomes for the patient. Once practice patterns that increase cost but do not improve quality have been identified reform efforts have been directed to the hospital level successfully in the past.[13-18]

Yet we remain ignorant of which hospital care patterns are useful versus wasteful. Thus, we sought to illustrate practice patterns across a large, diverse sample of U.S. hospitals in areas of care that are expensive, resource intensive, and potentially impactful on patient outcomes. We then sought to determine whether these distinct patterns of hospital care were associated with improved patient outcomes. What follows are two studies that examine this question. The first study characterizes hospital admission practices to the ICU for patients admitted with heart failure and their association with risk-standardized in-hospital mortality rates. The second study describes patterns of hospital utilization of myocardial imaging for patients presenting with suspected ischemia and their association with downstream resource use and readmission outcomes. We hope that our findings may serve as a basis for healthcare reform to engage hospitals in improving the value of care delivered to their patients.

CHAPTER 1

Variation exists in rates of admission to intensive care units for heart failure patients across hospitals in the United States

1.1 Abstract

Background. Despite increasing attention on reducing relatively costly hospital practices while maintaining the quality of care, few studies have examined how hospitals use the intensive care unit (ICU), a high-cost setting, for patients admitted with heart failure (HF). We characterized hospital patterns of ICU admission for patients with HF and determined their association with the use of ICU-level therapies and patient outcomes.

Methods and Results. We identified 166,224 HF discharges from 341 hospitals in the 2009-10 Premier Perspective® database. We excluded hospitals with <25 HF admissions, patients <18 years old, and transfers. We defined ICU as including medical ICU, coronary ICU, and surgical ICU. We calculated the percent of patients admitted directly to an ICU. We compared hospitals in the top-quartile (high ICU admission) with the remaining quartiles. The median percentage of ICU admission was 10% (Interquartile Range 6% to 16%; range 0% to 88%). In top-quartile hospitals, treatments requiring an ICU were used less often: percentage of ICU days receiving mechanical ventilation (6% top quartile versus 15% others), non-invasive positive pressure ventilation (8% versus 19%), vasopressors and/or inotropes (9% versus 16%), vasodilators (6% versus 12%), and any of these interventions (26% versus 51%). Overall HF in-hospital risk standardized mortality was similar (3.4% versus 3.5%; P = 0.2).

Conclusion. ICU admission rates for HF varied markedly across hospitals and lacked association with in-hospital risk-standardized mortality. Greater ICU use correlated with fewer patients receiving ICU interventions. Judicious ICU use could reduce resource consumption without diminishing patient outcomes.

Keywords. congestive heart failure, mortality

1.2 Introduction

One in 5 patients hospitalized with heart failure (HF) in the U.S. is admitted to an intensive care unit (ICU), a resource-intense setting that accounts for 20-35% of total hospital costs.[19-21] Despite the high cost of ICU admission, there are no standard, evidence-based guidelines for ICU triage of patients with HF.[22] The decision to admit patients to an ICU, therefore, may be a result of multiple factors, including the patients' clinical status, practitioner discretion, institutional policies and procedures, and hospital capacity.[23] Several patient-level studies conducted more than a decade ago demonstrated that patients are frequently admitted to the ICU who never receive ICU-level therapies during their hospitalization.[24, 25] However, we lack information about contemporary practice for patients with heart failure and hospital-level variation.

The primary aim of this study is to describe patterns of ICU use for patients with HF among a diverse group of U.S. hospitals. Once we observed the variation in the use of ICUs, we compared groups of hospitals with distinct patterns of ICU use in terms of their management of HF within the ICU. We hypothesized that hospitals that more frequently triage patients with HF to the ICU admit, on average, lower-risk patients to the ICU and therefore provide fewer ICU-level therapies and have lower risk-adjusted mortality rates for these patients compared with hospitals that have lower rates of ICU triage. Because we did not expect higher ICU triage to be associated with better patient outcomes, we expected that overall in-hospital risk-standardized mortality rates (RSMRs) for all patients with HF would be similar across hospitals regardless of triage patterns.

1.3 Methods

Data Source

We conducted a cross-sectional study using data from Perspective®, a voluntary, fee-supported database developed by Premier, Inc. for measuring quality and healthcare utilization. Premier is a private consortium of hospitals that pools finances and a limited set of clinical data from hundreds of U.S. hospitals into a common database.[26] As of 2010, Perspective® contained data from more than 130 million cumulative hospital discharges. These inpatient discharges represent about 20% of all acute care inpatient hospitalizations nationwide. In addition to the information available in the standard hospital discharge file, Perspective® contains a date-stamped log of all billed items at the individual patient level including medications and laboratory, diagnostic, and therapeutic services, as well as limited clinical data about each patient. For this study, patient data were de-identified in accordance with the Health Insurance Portability and Accountability Act and a random hospital identifier assigned by Premier was used to identify the hospitals. The Yale University Human Investigation Committee reviewed the protocol for this study and determined that it is not considered to be Human Subjects Research as defined by the Office of Human Research Protections.

Study Cohort

We included hospitalizations from January 1, 2009 to December 31, 2010. To qualify for inclusion in the study cohort, patients must have had a principal discharge diagnosis of HF (International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) code 402.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 428.xx).[27] This code captures the reason, in retrospect, for the admission and is determined after discharge. Patients could contribute more than 1 hospitalization to the study cohort. Only hospitals that participated in Premier's research program in 2009-2010 and had at least 25 cases of HF during that period were considered for inclusion in the study. Hospitalizations were excluded if patients were less than 18 years of age at the time of admission, assigned a pediatrician as the attending of record, transferred in from another hospital, or received cardiac surgery during their stay. Excluded cardiac surgeries were coronary artery bypass grafting, valvular surgery, peripheral vascular surgery, ventricular assist device placement, and heart transplantation.

Outcomes

We first conducted an exploratory analysis on the variation in admission rates to the ICU across hospitals within our cohort. The primary outcome for each hospital was the proportion of its HF hospitalizations that were admitted to an ICU. Admission to an ICU was defined as having a room and board charge for an ICU bed on the first day of the hospitalization. ICU beds included those located in the medical ICU, coronary care unit, or surgical ICU.

We calculated the use of ICU-level therapies among patients with HF admitted to the ICU. ICU-level therapies were defined as commonly used therapies for acute decompensated HF typically only available in a critical-care setting. These included mechanical ventilation, intravenous (IV) vasopressors, IV inotropes, IV vasodilators, intra-aortic balloon pumps (IABPs), and/or pulmonary artery catheters. We also measured the use of non-invasive positive pressure ventilation (NPPV), including continuous positive airway pressure and bi-level positive airway pressure, which requires an ICU setting in many institutions.

We compared hospitals in terms of in-hospital all-cause mortality for patients with HF triaged to an ICU. Finally, we compared hospitals by in-hospital all-cause RSMRs for all patients admitted to the hospital with HF.

Statistical Analysis

Hospitals were divided into quartiles based on the proportion of patients admitted to the ICU, with the top quartile having the highest admission rates. The bottom 3 quartiles of hospitals had similar rates of ICU admission while the top-quartile hospitals had distinctly higher rates of ICU admission. Thus, we defined the top quartile as a group of hospitals with high ICU admission rates and compared them with the rest of the hospitals in our cohort (hospitals in the bottom 3 quartiles) for the remainder of the analysis. Hospital characteristics for the top quartile of hospitals were compared with the hospital characteristics for all other hospitals using chi-square tests to assess statistical differences. The top quartile of hospitals was compared with all other hospitals using chi-square tests to assess statistical differences for ICU-level therapies and ICU in-hospital mortality. A p-value <0.05 was considered statistically significant in all cases. Continuous variables are reported with medians and interquartile ranges (IQR).

Next, we calculated the proportion of days in the ICU in which the patient received mechanical ventilation, NPPV, IV vasopressors, IV inotropes, and/or IV vasodilator drugs. Among all hospitalizations occurring at hospitals in the top quartile of ICU admission rates, we calculated the proportion of days that each therapy was given and compared this to the average among all hospitalizations occurring at other hospitals. Similarly, we calculated the frequency with which pulmonary artery catheters and IABPs were administered during each hospitalization and compared the frequency across all hospitalizations occurring at top-quartile hospitals versus other hospitals. The proportion of days without any intervention (mechanical ventilation, NPPV, vasopressors and/or inotropes, vasodilators, pulmonary artery catheters, IABP and dialysis) was also calculated and compared between top-quartile hospitals and other hospitals.

In addition, we calculated the in-hospital all-cause mortality rate for patients triaged to top-quartile hospitals and compared it with the in-hospital all-cause mortality rate at other hospitals. We calculated RSMRs for each hospital using a hierarchical logistic regression, employing methods that are used in the outcomes measures that are publicly reported by the Centers for Medicare & Medicaid Services.[28-32] Adjustment was done for patient characteristics including age, gender and Elixhauser comorbidities (Supplemental Table 1) classified using the software (version 3.4, 3.5, and 3.6 for Federal fiscal years 2009, 2010, and 2011, respectively) provided by the Healthcare Costs and Utilization Project of the Agency for Healthcare Research and Quality.[33] The RSMRs for top-quartile hospitals were compared with RSMRs for the other hospitals using a Wilcoxon Rank Sum test. A p-value <0.05 was considered statistically significant. All analyses were conducted with SAS version 9.2 (SAS Institute Inc., Cary, NC). Procedure GLIMMIX was used to estimate the hierarchical logistic models. The figure was generated using R (R Development Core Team, Vienna, Austria).[34]

1.4 Results

Hospital Characteristics

Our cohort included 166,224 patients treated at 341 hospitals from across the U.S. Of these, 19,169 patients were admitted directly to the ICU and accrued a total of 59,709 ICU days. The median hospital bed size was 265 (131, 402), volume of patients with HF was 407 (193, 709), and volume of patients with HF admitted to the ICU was 34 (20, 69). Hospitals tended to be located in the South (41%), serve an urban population (78%), and identify as non-teaching (72%; Table 1). Hospitals in the top-quartile of ICU admission rates and those in other quartiles tended to have similar characteristics in terms of geographic location and population served; however, they varied in terms of bed size ($p<0.0001$), ICU HF volume ($p<0.0001$), and teaching status ($p=0.0108$) (Table 1). We observed that hospitals in the bottom 3 quartiles were slightly larger (31% had more than 400 beds), had a lower number of ICU HF patients during the study period, and more teaching hospitals (32% vs. 17%). In addition, we examined hospital characteristics within each of the 4 quartiles of ICU admission rates (Supplemental Table 2). We observed similar trends across the four quartiles with hospitals that have higher ICU admission rates being larger, having a lower number of ICU HF patients, and being designated as teaching.

ICU Admission Rates

Of the 341 hospitals we analyzed, 328 admitted patients with HF directly to an ICU during the study period. Figure 1 shows the ICU admission rate for each of the 328 hospitals, ranked from lowest rate of admission to highest. The range of ICU admission rates was from 0% to 88% (median 10%, IQR: 6, 16%). Among hospitalizations at hospitals in the top quartile of ICU admissions, 32% of patients on average were admitted directly to the ICU compared with only 8% of patients at hospitals in the other quartiles ($p<0.0001$). Supplemental Figure 1 demonstrates the number of hospitals with the indicated ICU admission rates.

ICU-Level Therapy Use

We compared the percentage of ICU days in which patients received critical care interventions between top-quartile hospitals and other hospitals (Table 2). Patients at top-quartile hospitals spent less than half as many ICU days on mechanical ventilation compared with other hospitals (6% versus 15%, $p<0.0001$). Similarly, vasopressors and/or inotropes, vasodilators and NPPV were administered during a smaller percentage of ICU days at top-quartile hospitals versus other hospitals (9% versus 16% for vasopressors and/or inotropes, $p<0.0001$, 6% versus 12% for vasodilators, $p<0.0001$, and 8% versus 19% for NPPV, $p<0.0001$). Overall, top-quartile hospitals had a lower percentage of ICU days in which any intervention was administered (26% versus 51%, $p<0.0001$). In addition, we observed similar trends when comparing all 4 quartiles of hospitals with higher admission quartiles having a lower percentage of ICU days in which patients received critical care interventions (Supplemental Table 3).

Furthermore, the proportion of patients receiving critical care interventions was compared between hospitals in the top quartile of ICU admission and other hospitals (Table 3). The proportion of patients receiving mechanical ventilation (7% versus 14%), NPPV (14% versus 31%), vasopressors and/or inotropes (9% versus 18%), vasodilators (16% versus 25%), IABP (0.2% versus 0.5%), and dialysis (0.01% versus 0.1%) was lower at top-quartile hospitals compared with other hospitals ($p<0.0001$, $p<0.0001$, $p<0.0001$, $p<0.0001$, $p=0.0016$, and $p=0.0139$, respectively). The difference among hospital groups in the proportion of patients receiving pulmonary artery catheters was not statistically significant. We also compared all 4 quartiles of hospitals in terms of the proportion of patients receiving critical care interventions and observed similar trends (Supplemental Table 4).

Mortality

The in-hospital mortality rate for patients with HF triaged to the ICU at top-quartile hospitals was 4% compared with 8% at other hospitals (Table 4). The overall RSMR for all patients with HF was not significantly different between top-quartile and other hospitals (3.4% versus 3.5%, p-value 0.2; Table 4). The median length of stay for patients with HF was 4 days at top-quartile as well as at all other hospitals. In addition, we compared all 4 quartiles of hospitals in terms of the in-hospital mortality rate for patients with HF triaged to the ICU and the overall RSMR for all patients with HF. Similarly, quartiles with higher admission rates had lower in-hospital ICU mortality and similar RSMR for all patients admitted with HF (Supplemental Table 5).

When comparing larger hospitals (>265 beds) with each other and smaller hospitals (<265 beds) with each other in terms of ICU admission rate, we found similar trends as in the primary analysis. Higher ICU admission hospitals had fewer ICU-level interventions, lower ICU mortality, and similar RSMRs compared with lower ICU admission hospitals.

1.5 Discussion

In a large study of more than 300 hospitals in the U.S., we observed remarkable variation in the rates at which the hospitals triage patients with HF to the ICU. This variation in the rate of ICU admission was accompanied by variation in the use of ICU-level therapies for acute decompensated HF, such as mechanical ventilation and IV vasopressors and inotropic medications. Patients triaged to the ICU at hospitals that admitted a high percentage of patients with HF to the ICU were less likely to have these treatments compared with those admitted to hospitals with lower rates of ICU admission. This finding suggests that the former may be admitting relatively healthier patients to their ICUs. Consistent with this hypothesis, we found that patients with HF triaged to the ICUs of hospitals with high rates of ICU admission had lower mortality compared with patients with HF in the ICUs of hospitals that less frequently triaged to the ICU. While it is plausible that closer monitoring in the ICU without any HF-related critical care intervention may reduce ICU mortality, our data showed that overall in-hospital RSMRs for all patients admitted with HF did not differ by ICU admission patterns. Thus, hospitals that most frequently triage patients with HF to the ICU may be engaging in a high-cost behavior that does not improve patient outcomes.

We could not directly determine whether an individual patient required ICU admission because our data source lacked acute clinical information such as patient vital signs and the results of diagnostic tests. Moreover, there are no clear standards for ICU admission. We sought, however, to characterize hospital-level patterns of ICU admission rather than determine the appropriateness of individual triage decisions and it is unlikely that patient case mix would account for the wide variation in admission rates among hospitals that we observed. Furthermore, the association of high ICU admission rates with less frequent use of ICU-level therapies suggests that higher admission rates were due to different admission thresholds rather than a more severe patient mix.

The decision to triage to an ICU comes at a high cost to both the patient and the healthcare system. Hospitalization in the ICU has been shown to hold inherent risks for the patient, including increased risk of medication errors, delirium, hospital-acquired infection with multidrug resistant pathogens, and post-traumatic stress disorder.[35-40] Furthermore, although ICU beds represent only 5-10% of total hospital capacity, ICU utilization accounts for as much as 20-35% of hospital cost.[20] The average daily cost to occupy an ICU bed is approximately $2,573.[41-44] This amount does not include the opportunity cost of delaying or denying use of that bed to a patient with critical care needs because it is occupied by a patient who could be safely managed in another setting.

Despite these costs, there may be clinical reasons that such behavior persists among hospitals. We hypothesized that small hospitals may not have telemetry capabilities outside of the ICU and may admit patients with HF to the ICU for telemetry until myocardial infarction can be ruled out. Table 1, however, demonstrates that there is not a statistically significant difference in telemetry capability in beds outside of the ICU among hospitals in the top quartile compared with hospitals in other quartiles.

Another clinical reason that differences in ICU triage exist may be related to the lack of guidelines that specify clinical criteria for ICU triage. The inconsistency in ICU resource utilization among hospitals underscores a need for improved HF triage guidelines for practitioners and adoption of HF risk-stratification models by hospitals.[22] Triage decision-making, which the American Heart Association recognizes as having a "crucial bearing on resource utilization," is not explicitly addressed in the most recent HF management guidelines.[45] General critical care guidelines from the Society of Critical Care Medicine suggest that efficient ICU use requires that patients who do not immediately need intensive care treatments should be triaged to an ICU only if there is a high likelihood that they will subsequently need ICU-level therapies.[46] Yet our findings add to other studies that have demonstrated that relatively healthy patients with HF may be frequently triaged to an ICU and often never receive critical care therapies associated with HF.[24, 25, 47] In response to this trend, several validated risk-assessment models have been developed to aid in ICU triage decision-making, but have yet to be widely adopted by hospitals.[47-49] These models have shown significant gains in improving the appropriateness of ICU triage both in the general medical population and specifically for patients with HF. Our data imply that these efforts might lead to significant savings in resources.

In addition, hospital ICU utilization may be driven by economic considerations. Hospitals that frequently triage to the ICU may do so in an effort to recuperate the high fixed cost of maintaining an ICU bed in terms of staffing, equipment and space. If hospitals have ICU capacity beyond patient need for ICU beds and services, they have the opportunity to reduce fixed costs by eliminating or repurposing resources. Studies have shown, however, that hospitals have been slow to address excess fixed costs.[50-52] This reluctance has significant implications for healthcare expenditures in the U.S., as more than 85% of hospital costs are fixed.

Despite these drivers of ICU bed use, reports of individual hospitals in the U.S. championing ICU triage reform have shown that ICU utilization can be more rationally guided. Unnecessary ICU admissions can be reduced and the value of care provided increased with the commitment of hospital leadership to changing institutional policies and attitudes through locally derived data.[23] For example, an 18-hospital system implemented an ICU quality and efficiency improvement initiative that resulted in a reduction of the proportion of ICU admissions deemed "low-risk" from 42% to 22%. The hospitals identified inefficient triage practices by collecting data using risk scoring models that predict hospital mortality rates and comparing them with triage destinations. The hospitals used these data to assess ICU triage policies and win institution-wide acceptance of the need for better practices and accountability at all levels within the hospital. Their quality management team rewrote hospital triage guidelines and moved from a subjective triage culture based almost totally on the discretion of the ICU director to a collaborative, data-driven approach involving emergency physicians, critical care physicians, nurse managers, and others. Institutional policy changed from a "next available bed" admission strategy, in which patients were admitted to beds based on availability, to one centered on patient needs. New policies received continual reinforcement by nurse and physician champions as well as top administrators. Thus, institution-level reforms to entrenched policy and culture may successfully improve hospital ICU triage practices.

Our study should be interpreted with the following caveats. The hospital risk adjustment was limited to age, sex, race, and comorbidities because our data source lacked acute clinical information. However, risk adjustment for patients with HF based on those characteristics has been validated in other studies.[53-55] Because of the lack of acute clinical data, we cannot comment on the appropriateness of ICU triage strategies. In addition, our dataset does not longitudinally track patient outcomes and we could not calculate long-term patient mortality, which could have been altered by ICU triage strategies even though in-hospital mortality was not. Moreover, although our cohort included more than 340 hospitals with diverse characteristics, all of them voluntarily participate in a consortium that gathers and shares data with the aim of improving hospital practices. This suggests that our cohort may be more sensitive to establishing efficient care practices than other hospitals, which may provide an underestimate of ICU triage rates nationally. Furthermore, our dataset does not contain information that would allow us to characterize ICUs to better understand the type of care offered, such as nursing ratios or levels of ICU care. Finally, our dataset does not contain information regarding the provider type or physician reimbursement, which may explain some of the variation in clinical triage patterns.

Identifying opportunities to improve the value of care provided to patients is especially important for hospitals and clinicians operating in an increasingly costly healthcare environment with greater resource constraints.[12, 56, 57] Our findings demonstrate that a significant number of hospitals in the U.S. triage many more patients with HF to their ICUs relative to other hospitals, without achieving better in-hospital RSMRs. Given the high price of ICU admission, it is plausible that some hospitals may be engaging in a low-value, high-cost behavior.

1.6 Tables and Figures

Figure 1. Hospital ICU admission rates. (Each data point shown represents a hospital.)

ICU, intensive care unit

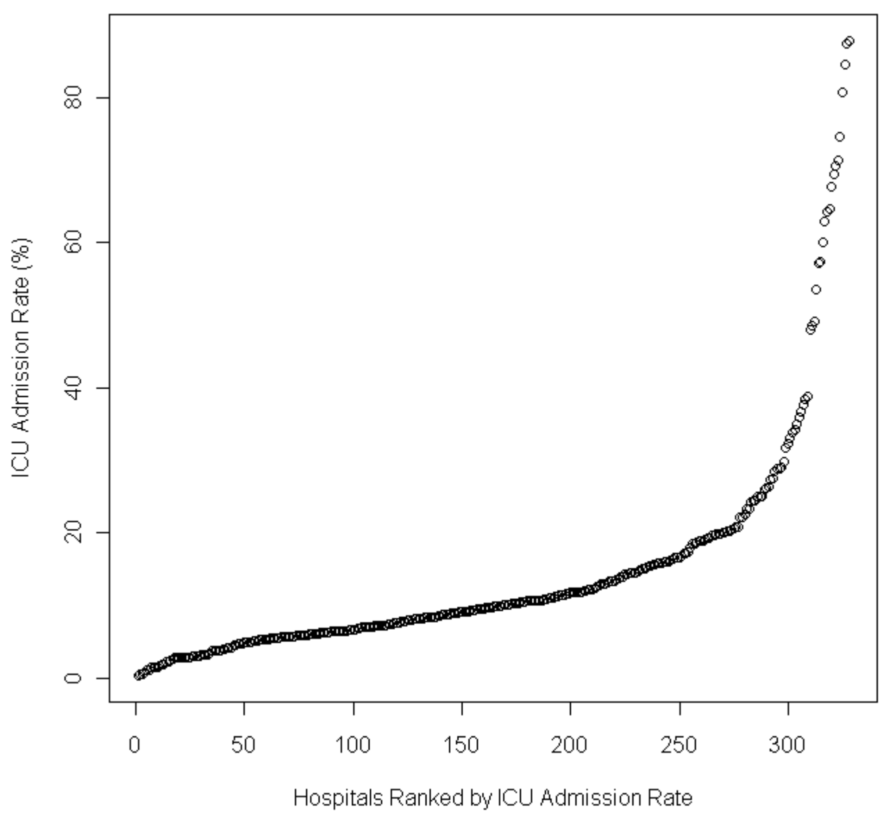


Table 1. Hospital cohort characteristics.

	All hospitals (n=341) n(%)	Top-quartile hospitals (n=86) n(%)	Other hospitals (n=242) n(%)	P-value
Number of beds				
1-200	125 (37)	48 (56)	69 (29)	
201 – 400	129 (38)	26 (30)	98 (40)	<0.0001
401 – 600	60 (17)	10 (12)	50 (21)	
>600	27 (8)	2 (2)	25 (10)	
ICU HF volume				
1 - 50	226 (66)	39 (45)	174 (72)	
51-200	104 (31)	36 (42)	68 (28)	
201 - 400	8 (2)	8 (9)	0 (0)	<0.0001
>400	3 (1)	3 (4)	0 (0)	
Geographic region				
Midwest	82 (24)	27 (31)	53 (22)	
Northeast	54 (16)	9 (11)	43 (18)	0.2
South	140 (41)	32 (37)	103 (42)	

West	65 (19)	18 (21)	43 (18)	
Population served				
Urban	267 (78)	63 (73)	197 (81)	0.1
Rural	74 (22)	23 (27)	45 (19)	
Teaching status				
Non-teaching	247 (72)	71 (83)	165 (68)	0.01
Teaching	94 (28)	15 (17)	77 (32)	
Telemetry available outside of ICU				
Yes	57 (17)	16 (19)	41 (17)	0.6
No	284 (83)	70 (81)	201 (83)	

HF, heart failure; ICU, intensive care unit

Table 2. Proportion of ICU days receiving ICU-level therapy.

Therapy	Usage of therapy (Proportion of bed-days) High ICU admissions (N=31,066)	Low ICU admissions (N=28,643)	P-value
Mechanical ventilation	6	15	<0.0001
NPPV	8	19	<0.0001
Vasopressors and/or inotropes	9	16	<0.0001
Vasodilators	6	12	<0.0001
Pulmonary artery catheter	0.7	0.5	0.04
None of these interventions*	74	49	<0.0001

*No intervention includes mechanical ventilation, NPPV, vasopressors and/or inotropes, vasodilators, pulmonary artery catheter, dialysis, and intra-aortic balloon pump

ICU, intensive care unit; NPPV, non-invasive positive pressure ventilation

Table 3. Proportion of patients receiving ICU-level therapy.

	Usage of therapy (Proportion of patients receiving therapy)		
Therapy	High ICU admissions (N=8,830)	Low ICU admissions (N=10,339)	P-value
Mechanical ventilation	7	14	<0.0001
NPPV	14	31	<0.0001
Dialysis	0.01	0.10	0.01
Vasopressors and/or inotropes	9	18	<0.0001
Vasodilators	16	25	<0.0001
Intra-aortic balloon pump	0.2	0.5	0.0016
Pulmonary artery catheter	1	1	0.1

ICU, intensive care unit; NPPV, non-invasive positive pressure ventilation

Table 4. Patient mortality.

Outcome	**Category**	**N**	**Mortality rate (%)**	**P-value**
In-hospital mortality for heart failure patients triaged to ICU	High ICU admission group	8,830	4%	<0.0001
	Low ICU admission group	10,339	8%	
Risk-standardized in-hospital mortality*	High ICU admission group	86	3.4 (3.0, 3.9)	0.2†
	Low ICU admission group	242	3.5 (3.0, 4.2)	

*Includes entire patient cohort (ICU and non-ICU)

†Calculated using a 2-sided Wilcoxon Rank Sum test

ICU, intensive care unit

Supplemental Table 1. Selected comorbidities.

Valvular disease

Pulmonary circulation disease

Peripheral vascular disease

Paralysis

Other neurological disorders

Chronic pulmonary disease

Diabetes without chronic complications

Diabetes with chronic complications

Hypothyroidism

Renal failure

Liver disease

Acquired immune deficiency syndrome

Lymphoma

Metastatic cancer

Solid tumor without metastasis

Rheumatoid arthritis/collagen vascular disease

Coagulopathy

Obesity

Weight loss

Fluid and electrolyte disorders

Chronic blood loss anemia

Deficiency anemias

Alcohol abuse

Drug abuse

Psychoses

Depression

Hypertension

Disorders of lipid metabolism

Coronary atherosclerosis and other heart disease

Acute myocardial infarction

Peripheral and visceral atherosclerosis

Aortic, peripheral and visceral artery aneurysms

Aortic and peripheral arterial embolism or thrombosis

Transient cerebral ischemia

Cardiac dysrhythmias

Cardiac arrest and ventricular fibrillation

Supplemental Table 2. Hospital cohort characteristics.

	All hospitals (n=341) n(%)	Top-quartile (n=86) n(%)	Quartile 3 (n=84) n(%)	Quartile 2 (n=85) n(%)	Bottom Quartile (n=86) n(%)
Number of beds					
1-200	125 (37)	48 (56)	26 (31)	28 (33)	23 (27)
201 – 400	129 (38)	26 (30)	37 (44)	32 (38)	34 (40)
401 – 600	60 (17)	10 (12)	14 (17)	16 (18)	20 (23)
>600	27 (8)	2 (2)	7 (8)	9 (11)	9 (10)
ICU HF volume					
1 - 50	226 (66)	39 (45)	40 (48)	64 (75)	83 (97)
51-200	104 (31)	36 (42)	44 (52)	21 (25)	3 (3)
201 - 400	8 (2)	8 (9)	0	0	0
>400	3 (1)	3 (4)	0	0	0
Geographic region					
Midwest	82 (24)	27 (31)	18 (21)	22 (26)	15 (17)
Northeast	54 (16)	9 (11)	12 (14)	16 (19)	17 (20)
South	140 (41)	32 (37)	43 (51)	33 (39)	32 (37)
West	65 (19)	18 (21)	11 (14)	14 (16)	22 (26)
Population served					
Urban	267 (78)	63 (73)	70 (83)	70 (82)	64 (74)
Rural	74 (22)	23 (27)	14 (17)	15 (18)	22 (26)
Teaching status					
Non-teaching	247 (72)	71 (83)	59 (70)	62 (73)	55 (64)
Teaching	94 (28)	15 (17)	25 (30)	23 (27)	31 (36)
Telemetry available outside of ICU					

Yes	57 (17)	17 (20)	18 (21)	12 (14)	13 (15)
No	284 (83)	69 (80)	66 (79)	73 (86)	73 (85)

HF, heart failure; ICU, intensive care unit

Supplemental Table 3. Proportion of ICU days receiving ICU-level therapy.

Therapy	Usage of therapy (Proportion of bed-days) Top Quartile (N=31,066)	Quartile 3 (N=15,396)	Quartile 2 (N=8,795)	Bottom Quartile (N=4,452)	P-value
Mechanical ventilation	6	15	14	19	<0.0001
NPPV	8	17	22	23	<0.0001
Vasopressors and/or inotropes	9	15	16	19	<0.0001
Vasodilators	6	12	13	13	<0.0001
Pulmonary artery catheter	0.7	0.4	0.6	0.7	0.02
None of these interventions*	74	52	47	42	<0.0001

*No intervention includes mechanical ventilation, NPPV, vasopressors and/or inotropes, vasodilators, pulmonary artery catheter, dialysis, and intra-aortic balloon pump

ICU, intensive care unit; NPPV, non-invasive positive pressure ventilation

Supplemental Table 4. Proportion of patients receiving ICU-level therapy.

	Usage of therapy (Proportion of patients receiving therapy)				
Therapy	**Top Quartile (N=8,830)**	**Quartile 3 (N=5,273)**	**Quartile 2 (N=3,383)**	**Bottom Quartile (N=1,683)**	**P-value**
Mechanical ventilation	7	15	13	16	<0.0001
NPPV	14	28	33	36	<0.0001
Dialysis	0.01	0.08	0.03	0.30	0.0006
Vasopressors and/or inotropes	9	16	17	22	<0.0001
Vasodilators	16	25	25	25	<0.0001
Intra-aortic balloon pump	0.2	0.3	0.4	1	<0.0001
Pulmonary artery catheter	1	1	2	2	0.08

ICU, intensive care unit; NPPV, non-invasive positive pressure ventilation

Supplemental Table 5. Patient mortality.

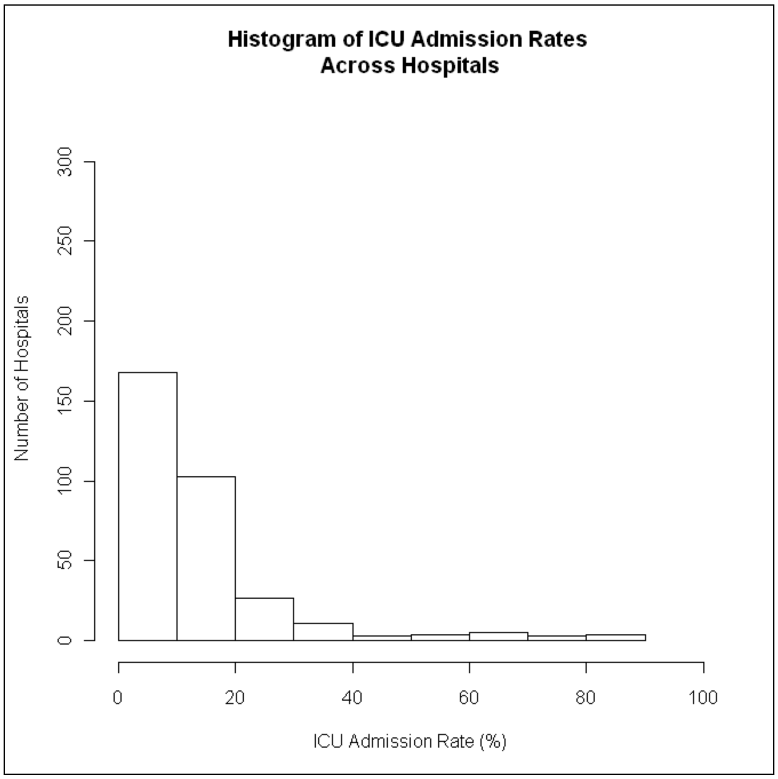
Outcome	Category	N	Mortality rate (%)	P-value
In-hospital mortality for heart failure patients triaged to ICU	Top Quartile	8,830	4%	<0.0001
	Quartile 3	5,273	7%	
	Quartile 2	3,383	8%	
	Bottom Quartile	1,683	11%	
Risk-standardized in-hospital mortality*	Top Quartile	86	3.4 (3.0, 3.9)	0.41
	Quartile 3	84	3.3 (3.1, 4.2)	
	Quartile 2	85	3.4 (3.0, 4.3)	
	Bottom Quartile	73	3.6 (3.2, 4.1)	

*Includes entire patient cohort (ICU and non-ICU)

†Calculated using a 2-sided Kruskal-Wallis test

ICU, intensive care unit

Supplemental Figure 1. Histogram of ICU Admission Rates Across Hospitals (N=328)



CHAPTER 2

Hospital patterns of myocardial imaging and their association with downstream testing, interventions and outcomes in the evaluation of suspected ischemia

2.1 Abstract

Background. Once acute myocardial infarction (AMI) has been ruled out among patients presenting to the hospital with possible cardiac ischemia, current guidelines allow substantial discretion in the use of cardiac imaging in the initial evaluation. Despite the cost implications, few studies have compared how the use of these modalities varies among hospitals and their implications on downstream testing, interventions, and patient outcomes.

Methods. Using the 2010 Premier Perspective® database, we defined patients suspected of myocardial ischemia on their initial evaluation as those seen in the emergency department, in observation status, or during inpatient hospitalization, who received at least one cardiac biomarker test ordered on day 0 or 1 of their hospital visit. We selected patients with a principal discharge codes consistent with myocardial ischemia and specifically excluded AMI. The primary outcome was the percentage of patients at each hospital who received myocardial imaging designed to evaluate for ischemia, including stress nuclear myocardial perfusion imaging (MPI), stress echocardiography, cardiac positron emission tomography, cardiac magnetic resonance imaging, and cardiac computed tomography with coronary angiography with or without calcium scoring. We compared hospitals above the median rate of imaging (high imaging) with hospitals below the median (low imaging) using Chi-square tests. We used hierarchical logistic regressions to identify predictors of imaging use as well as interclass correlation coefficients (ICC).

Results. We identified 549,078 patients at 224 hospitals. The median hospital imaging rate was 19.8% of patients (interquartile range 10.9% to 27.7%; range 0.2% to 55.7%). High imaging hospitals were associated with higher rates of catheterization for coronary angiogram (4.1% versus 1.7%) and more revascularization procedures (1.5% versus 0.7%). Readmission rates to the same hospital for AMI within the same or subsequent month were not different (0.3% versus 0.3%). Almost 23% of variation in imaging use among hospitals was attributable to individual hospital-level factors.

Conclusions. Substantial variation exists among hospitals in their use of myocardial imaging in the initial work-up of patients with suspected ischemia that is not AMI and much of this variation is explained by hospital-level factors. Despite much higher rates of imaging and associated higher rates of downstream invasive testing, high imaging hospitals perform only slightly more revascularization procedures and do not achieve better readmission rates for AMI.

2.2 Introduction

Introduction

Chest pain is the second most common cause of emergency department visits and accounts for over $3.7 billion in hospital costs.[58, 59] The vast majority of patients presenting with chest pain do not have acute myocardial infarction (AMI).[60] Clinicians have many options during the initial evaluation of these patients in seeking to determine the patient's risk for a cardiovascular event, and the information that they glean often guide decisions about hospitalization as well as the need for further testing and treatment.

There are few studies that have compared the hospitals' approach to the evaluation of patients presenting acutely for ischemic work-up who do not have AMI. In particular, physicians face a decision about the use of imaging in stress testing. Imaging imposes significant healthcare costs and, except for echocardiography, radiation exposure.[61] These considerations must be weighed against the possibility that imaging increases the sensitivity and specificity of stress testing, leading to better decisions and possibly better patient outcomes.[62] Unfortunately, clinical guidelines do not provide strong recommendations about which patients should undergo specific testing strategies, leaving considerable discretion to the practitioner.[6, 63] Without well established guidelines, hospitals have developed several different diagnostic approaches to these patients with some creating units dedicated to assessing suspected myocardial ischemia with either mandatory or optional myocardial imaging.[62, 64-67]

We currently have little information about how hospitals vary in their patterns of myocardial imaging use among patients being evaluated for ischemia who do not have AMI. The implications of variation in myocardial imaging use among hospitals may be far-reaching as previous patient-level studies have shown that frequent use of myocardial imaging is associated with a greater likelihood to perform more invasive and expensive downstream tests, such as catheterization for coronary angiography, without clear improvements in outcomes.[68, 69] Evidence of marked variation in practice that is associated with the hospital more than the patient would highlight an urgent need to clarify the marginal benefit of more expensive strategies and those that expose patients to radiation.

Our aim is to describe variation among hospitals in the use of myocardial imaging in patients who initially were evaluated for myocardial ischemia but who did not have AMI. We sought to determine whether the hospital's use of myocardial imaging was associated with patterns of downstream resource utilization, including inpatient hospitalization and catheterization for coronary angiography. Furthermore, we sought to determine if hospitals that frequently used myocardial imaging in their initial assessment subsequently performed revascularization procedures such as percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG) at a substantially higher rate. Finally, we aimed to determine whether more frequent use of myocardial imaging among hospitals was associated with fewer readmissions for AMI to the same hospital.

2.3 Methods

Data Source

We conducted a cross-sectional study of data using Perspective®, a voluntary, fee-supported database developed by Premier, Inc. for measuring quality and healthcare utilization. Premier is a private consortium of hospitals that pools finances and a subset of clinical data from hundreds of U.S. hospitals into a common database.[26] From 2005 to 2010, Perspective® accumulated data from over 130 million hospital discharges. These inpatient discharges represent about 20% of all acute care inpatient hospitalizations nationwide. In addition to the information available in the standard hospital discharge file, Perspective® contains a date-stamped log of all billed items at the individual patient level including medications and laboratory, diagnostic, and therapeutic services, as well as limited clinical data about each patient. For this study, patient data were de-identified in accordance with the Health Insurance Portability and Accountability Act and a random hospital identifier assigned by Premier was used to identify the hospitals. The Yale University Human Investigation Committee exempted this study protocol because it is not considered Human Subjects Research as defined by the Office of Human Research Protections.

Study Cohort

We included hospital visits that occurred during 2010, including those restricted to only the emergency department, those in which the patient stayed in a bed labeled with observation status, and those in which a patient was admitted to an inpatient bed. In order to include patients in whom cardiac ischemia was being considered as a primary diagnosis, we required that patients must have received at least one cardiac biomarker test to assess for myocardial necrosis, which was defined as either a serum cardiac troponin or creatine kinase-MB. Cardiac biomarkers had to be ordered on day 0 or day 1 of the patient's visit.

In addition, patients must have had one of the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) principal discharge diagnoses listed in Supplemental Table 1. These codes were selected based upon a review by three authors (KS, AV, KD) to determine whether they met any of the following criteria: (1) represents a common cause of chest discomfort; (2) represents a symptom or sign that can be associated with chest discomfort; or (3) represents a diagnosis that is often co-morbid with coronary artery disease. Patients with a primary discharge diagnosis of AMI were specifically excluded because well-established guidelines exist for myocardial testing in these patients.

In addition, diagnoses in which an acute, emergent non-cardiac disease may have warranted cardiac biomarker testing but not myocardial imaging were excluded because we sought to compare hospital myocardial imaging use in situations where it was likely to be realistically considered as an option in the patient's management. These excluded diagnoses were aortic dissection, pulmonary embolism, and gastrointestinal ulcers with hemorrhage or perforation. Hospital visits were excluded if patients were younger than 35 years of age at the time of admission, assigned a pediatrician as the attending of record, transferred in from another hospital, transferred out to another hospital, or received cardiac surgery during their stay, with the exception of coronary artery bypass grafting (CABG).

Excluded cardiac surgeries were valvular surgeries, vascular surgeries, ventricular assist device placement, and heart transplantation in which biomarkers may have been ordered for pre or peri-operative evaluation.

Only hospitals that participated in Premier's research program in 2010 and performed at least 5 revascularization procedures were considered for inclusion in the study. We set these minimum requirements in order to reliably assure that we were comparing hospitals capable of performing catheterization for coronary angiography and revascularization procedures. Revascularization procedures were defined as percutaneous coronary interventions (PCI) or CABG.

Outcomes

The primary outcome for each hospital was the proportion of its patients that received myocardial imaging testing out of all patients meeting inclusion criteria at the hospital. Myocardial imaging tests were defined as stress nuclear myocardial perfusion imaging (MPI), stress echocardiography, cardiac positron emission tomography (CPET), cardiac magnetic resonance imaging (MRI), and cardiac computed tomography with coronary angiography (CTCA) with or without calcium scoring.

In order to determine the association of imaging use with downstream resource utilization, we calculated for each hospital the proportion of patients meeting inclusion criteria who: (1) were discharged from an inpatient bed; (2) received catheterization for coronary angiogram downstream of imaging; and, (3) received revascularization (either PCI or CABG).

The hospital visit during which the patient received the cardiac biomarker test as well as a primary discharge diagnosis that met the inclusion criteria was defined as the index hospital visit. Myocardial imaging tests, catheterizations for coronary angiography, and revascularization procedures were counted if they occurred within the same month or in the month following the index hospital visit. Finally, we calculated readmissions for AMI as the proportion of patients who returned to the same hospital with a principal discharge diagnosis of AMI (410.x) within the same month or month following the index hospital visit.

Statistical Analysis

Hospitals were divided into two groups based on the proportion of patients who received myocardial imaging tests. In order to make the most conservative comparison, we compared hospitals above the median rate of myocardial imaging (high imaging hospitals) with hospital below the median rate of myocardial imaging (low imaging hospitals). Hospital characteristics of the high imaging hospitals were compared with the characteristics of the low imaging hospitals using chi-square tests to assess statistical differences. We also assessed the use of specific types of imaging modalities among the hospitals and compared high imaging hospitals with low imaging hospitals. Furthermore, we compared the two groups of hospitals to determine the association of imaging with downstream resource utilization by calculating the number of patients in the cohort who: (1) were admitted to an inpatient bed during their index hospital encounter; (2) received catheterization for coronary angiogram after having received imaging; and, (3) received a revascularization procedure. In order to determine the association of imaging with outcomes, we compared high versus low imaging hospitals in terms of the proportion of patients in the cohort who were readmitted with AMI to the same hospital as their index encounter during the same month or month following the index hospital visit. A p-value <0.05 was considered statistically significant in all cases. Continuous variables are reported with medians and interquartile ranges (IQR). Finally, we performed a sensitivity analysis by dividing the hospitals into quartiles based on the proportion of patients who received myocardial imaging test and repeated the above analyses comparing quartiles for differences in hospital characteristics, downstream angiogram use, revascularization, and readmissions for AMI.

In addition, we sought to understand the degree to which patient case-mix and hospital factors explained the variation. To do this, we fit three hierarchical logistic regression models. In the first model, we fit an empty model with only a hospital random intercept to determine whether any hospital-level variation existed. In the second model, we incorporated patient characteristics, including age and sex, in order to investigate the extent with which hospital differences in myocardial imaging were explained by the patient mix of the hospitals. Finally, in the third model we incorporated hospital characteristics to see how much of the variation could be explained by known hospital characteristics. For each of the models, we calculated the hospital-level variance and reported a C-statistic as a measure of model discrimination. We then derived the interclass correlation coefficient (ICC) to measure the proportion of variance attributable to the between hospital variation, and the median odds ratio (MOR) to quantify the variance between hospitals.

2.4 Results

Myocardial imaging rates and hospital characteristics

Our cohort included 549,078 patients treated at 224 hospitals from across the U.S. The median hospital bed size was 360 (IQR: 250, 462). Hospitals tended to be located in the South (41%), serve an urban population (88%), and identify as non-teaching (66%).

Figure 1 demonstrates the proportion of patients at each hospital who received myocardial imaging tests. The range of myocardial imaging rates for hospitals was from 0.2% to 55.7% (median 19.8%, IQR: 10.9, 27.7%). High imaging hospitals performed imaging in 29.1% of their patients, on average, compared with 10.9% of patients at low imaging hospitals ($p<0.0001$).

Hospitals with myocardial imaging rates above the median rate of imaging and hospitals below the median tended to have similar characteristics in terms of bed size ($p=0.08$), having beds with observation status ($p=0.87$), population served ($p=0.84$), and teaching status ($p=0.16$; Table 1). We observed that hospitals above the median were more likely to be located in the Midwest and Northeast ($p<0.0001$; Table 1).

Hospitals tended to use MPI and stress echocardiography most commonly when performing myocardial imaging (Figure 2). There were small, but statistically significant differences when comparing high imaging hospitals with low imaging hospitals in terms of the rates at which they used specific modalities when performing myocardial imaging (Table 2).

Catheterization for Coronary Angiogram

The range of hospital angiogram rates was from 0.0% to 16.9% (median 2.5%, IQR: 1.4, 4.1%). Among visits at high imaging hospitals, 4.1% received catheterization for coronary angiogram downstream of imaging compared with 1.7% at low imaging hospitals (p<0.0001; Table 3).

Revascularization procedures

The range of revascularization procedures performed was from 0.0% to 9.5% (median 0.8%, IQR: 0.4, 1.4%). Among visits at high imaging hospitals, slightly more revascularization procedures were performed compared with low imaging hospitals (1.5% versus 0.7%, p<0.0001; Table 3).

Readmission with AMI

High imaging hospitals had a similar proportion of patients who were readmitted for AMI within the same or subsequent month as the index hospital visit, compared with low imaging hospitals (0.3% versus 0.3%, p=0.3134; Table 3).

Sensitivity Analysis

The above comparisons were repeated for quartiles of hospitals stratified by myocardial imaging rates as opposed to comparing hospitals as above or below the median rate. In terms of hospital characteristics, only hospital geographic location seems related to rates of myocardial imaging when comparing each of the four quartiles of hospitals (Supplemental Table 2). Quartiles of hospitals with higher rates of myocardial imaging tended to have higher catheterization rates for coronary angiogram, similar rates of revascularization procedures overall, and the same readmission rates for AMI (Supplemental Table 3).

Institutional effects on myocardial imaging utilization

The interclass correlation coefficients (ICCs) (95% confidence interval) for the unadjusted model (empty model), the model adjusted for patients' age and sex, and the model further adjusted for hospital characteristics are 23.18 (19.54-26.52), 23.27 (19.61-26.61) , and 16.08 (8.64-22.40), respectively (Table 4). This demonstrates that about 23% of the variation in myocardial imaging rates is attributable to between hospital variation, and this variation is not affected by patient-mix. When known hospital characteristics are included, the ICC drops to 16%. The median odds ratio was 2.6 for the empty model and the age/sex-adjusted model, and 2.2 for the model with hospital characteristics. These results signify that a randomly selected patient receiving myocardial imaging at one hospital would have around 2-fold higher odds of receiving an imaging test than an identical patient at a different randomly selected hospital.

2.5 Discussion

Substantial hospital-level variation exists in the use of myocardial imaging in patients deemed not to have an AMI who are undergoing further work-up for coronary artery disease. Greater use of non-invasive myocardial imaging was associated with increased use of downstream invasive imaging with catheterization for coronary angiography. If a hospital more frequently uses imaging and subsequent coronary angiograms, it might be expected that the hospital will use that information to alter the patient's management in terms of revascularization interventions or to achieve better patient outcomes, given the expense of these tests and the patient's exposure to harmful radiation. Yet hospitals that more frequently engaged in testing did not have substantially higher rates of revascularization interventions. Furthermore, high imaging hospitals did not achieve lower rates of same hospital readmission with AMI. Thus, our study suggests that frequent use of myocardial imaging at a group of U.S. hospitals led to greater use of invasive downstream diagnostic tests without substantially affecting the use of therapeutic interventions or achieving better short-term outcomes.

The results of our study extend the prior literature demonstrating variation in the use of expensive diagnostic modalities in the evaluation of common acute clinical presentations.[70-72] Prior studies have shown that variation has particularly occurred in clinical scenarios in which guidelines are not well established, including neuroimaging in the evaluation of dizziness, headache, trauma and epilepsy. For subgroups of patients in which guidelines are more well-established, such as in the neuroimaging of children, variation was considerably less. In comparison, clinical guidelines do not clearly identify which patients who should receive cardiac imaging, out of the clinically heterogeneous group presenting with suspected myocardial ischemia.

Moreover, our findings are similar to other studies which have raised the question of whether increased use of an expensive diagnostic modality translated into improved patient outcomes. For example, despite high rates of imaging, such as head CT in patients presenting with symptoms of stroke or chest CT in patients presenting with chest symptoms, the rates at which stroke and pulmonary embolism have been diagnosed have not changed.[70, 72] One potential explanation for unchanged outcomes despite higher rates of myocardial imaging is that hospitals that use imaging more frequently are doing so in patients where the benefit is not clear. Again, without strong evidence upon which to develop clear recommendations in the guidelines it may not be readily apparent to clinicians which patients are likely to benefit from imaging.

Previous single center studies have shown that, regardless of pre-test probability, patients frequently received non-invasive myocardial imaging.[73] The trends that emerged in our study suggest similar findings as hospitals that more frequently used imaging performed revascularization procedures in only a slightly larger proportion of their patients. Thus, the rates at which high imaging hospitals found lesions on which they performed revascularization were lower compared with low imaging hospitals. In addition, studies have shown that frequent use of cardiac imaging is associated with a greater number of findings that are false positives or classified as having indeterminate significance.[74] These categories of findings can drive higher rates of coronary catheterization with angiogram for lesions that ultimately do not meet criteria for revascularization.

In an attempt to understand what may have driven the variation in imaging practices, a hierarchical logistical regression analysis showed that differences in patient case-mix between hospitals did not explain the majority of the variation, while hospital factors, such as geographic location, did explain a significant proportion of the variation. Our study adds to other studies on cardiac imaging use by demonstrating that the likelihood that a patient receives a given testing strategy in their work-up depends largely upon what hospital the patient receives his or her care.[67, 73]The finding that the geographic location of the hospital is associated with differences in the use of imaging tests is consistent with studies on imaging use in the outpatient setting, but further work is necessary to enrich our understanding of what aspects of hospital practice are driving the use of imaging and why.[67] For example, prior studies suggest that hospitals employ different protocols in the work-up of patients with suspected ischemia, with some reflexively ordering myocardial imaging as a rule out for coronary disease.[64-66] In addition, some hospitals may respond more to financial incentives to order imaging tests compared with others. Studies, for example, have demonstrated that if a physician practice purchases its imaging equipment, utilization and spending increase substantially.[75] It is plausible that hospitals may experience similar motivations once investing in expensive imaging equipment.

Our study, as well as those mentioned above, suggest that nationally endorsed quality measures on imaging use could have a positive impact by targeting imaging to patients who are more likely to benefit from it. In recent years, the American College of Cardiology has released consensus standards on the appropriate use criteria (AUC) for stress cardiac radionuclide imaging and echocardiography in patients presenting with suspected ischemia.[76-78] The AUC are designed to reduce wasteful utilization by targeting imaging to patients with higher pretest probability for occlusive coronary artery disease. The AUC continue to evolve as the threshold for appropriate testing continues to rise.[79, 80] Scenarios in which imaging would not be considered appropriate and which may have occurred in the hospitals in this study include patients presenting with acute chest pain who have low pre-test probability of coronary disease and are able to exercise.[76, 77] Another example scenario in which imaging would be inappropriate includes patients with stable symptoms and known coronary disease who have had a stress test within the prior two years. While we could not directly determine the appropriateness of imaging use in any given patient, we fail to produce evidence that hospitals that are performing more imaging are, at the margin, providing greater benefits to the patient. Future efforts should directly study the appropriateness of imaging use in patients. In the future, the AUC may provide a basis for monitoring the appropriateness of hospital testing practices and could be used to incentivize more efficient use if hospitals are held accountable or rewarded based on their record.

The cohort of hospitals in this study was diverse, but there may be some questions about the generalizability of our sample. In terms of size, rural or urban setting, geographic region, and teaching status, our cohort included a full spectrum of the types of hospitals in the U.S. In addition, the cohort of patients in this study is highly specific for individuals being evaluated for cardiac ischemia. Because our database indicates whether a cardiac troponin test was ordered for a patient, we were able to avoid the selection bias and misclassification that results from previous studies that attempted to identify patterns of care for patients with chest pain based solely on discharge diagnosis. In fact, we found that among patients who received a troponin test within the first day of their hospital encounter, over 3,600 primary discharge diagnosis codes were used and only 25% of these patients were coded with chest pain diagnoses. The remaining codes were included in our study if they represented common causes of chest pain, symptoms commonly associated with chest pain, and comorbidities that may cause concern for occlusive coronary disease.

Our study has several limitations. First, we were not able to track whether a hospital referred a patient for myocardial imaging to a different hospital. However, it is unlikely that hospitals with the capability to perform myocardial imaging (which all of our hospitals had) would refer patients to another hospital for an imaging study. Moreover, patients may seek care at multiple hospitals and we were not able to capture downstream testing and revascularization if it occurred at a hospital different from where the patient had his or her index encounter. In addition, although our cohort included more than 220 hospitals with diverse characteristics, all of them voluntarily participate in a consortium that gathers and shares data with the aim of improving hospital practices. This suggests that our cohort may be more sensitive to establishing efficient care practices than other hospitals, which may provide an underestimate of imaging rates nationally. In addition, our administrative database does not contain acute clinical data, patient socioeconomic information, or hospital or community level characteristics regarding provider access, which may influence hospital practice patterns. Finally, we could only capture readmissions for AMI if the patient was readmitted to the same hospital at which they received their initial evaluation. Though this may mean that readmission rates were in fact higher than what we report, it is unlikely that the relative readmission rates when comparing high versus low imaging hospitals would be any different

In a healthcare system facing greater resource constraints, it is increasingly important to identify opportunities to reduce healthcare utilization that is not associated with improved patient outcomes. With over 7.2 million emergency department visits annually in which chest pain is the primary diagnosis, the cost implications of myocardial testing practices are significant.[81] We identified substantial variation in the use of myocardial imaging in patients presenting for ischemia work-up, but much smaller differences in revascularization intervention rates and no difference in readmission outcomes. An important determinant of whether these expensive tests were used was the hospital at which the patient received care.

2.6 Tables and Figures

Figure 1. Rates of myocardial imaging, coronary angiogram, and revascularization

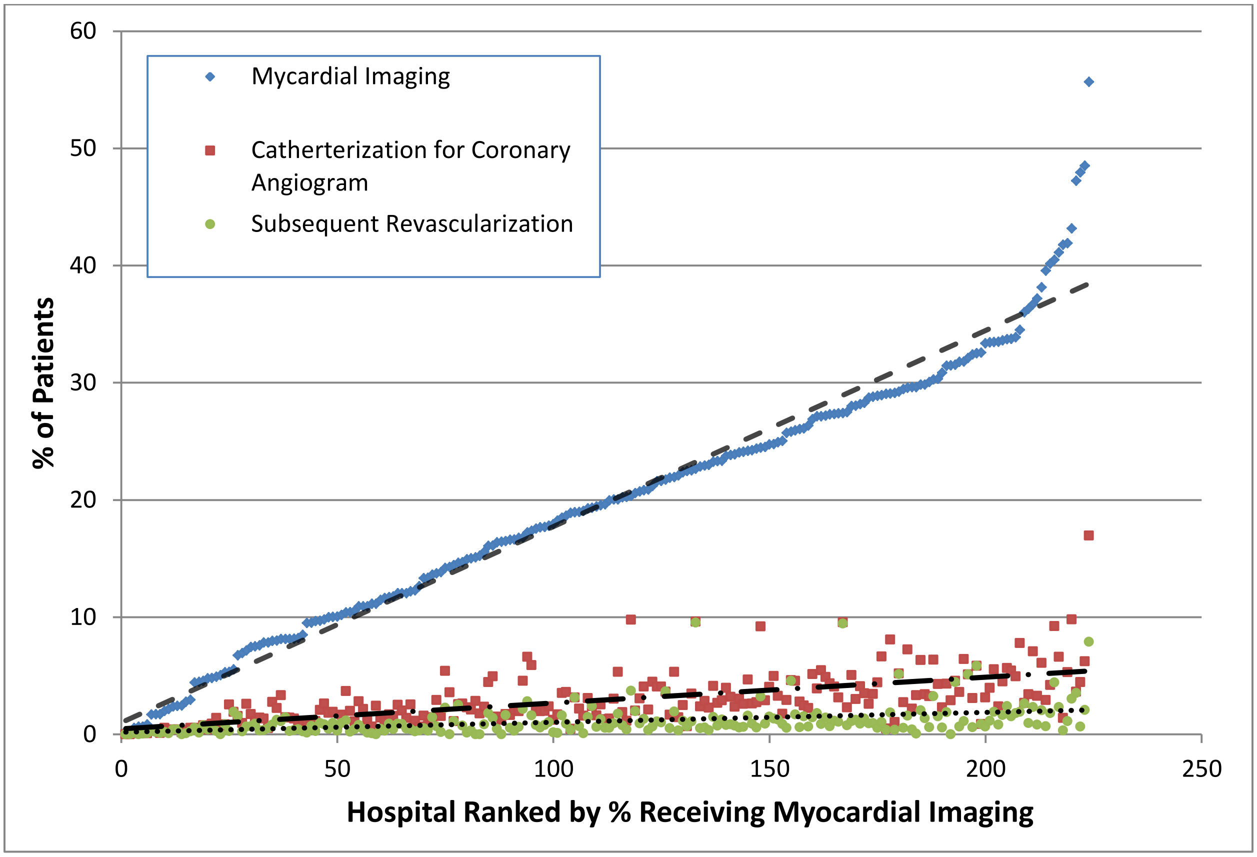


Table 1. Hospital characteristics compared by hospital imaging groups.

	Low Imaging Hospitals, % (N=112)	High Imaging Hospitals, % (N=112)	p-value
Number of beds			0.08
1-200	15.2 (17)	14.3 (16)	
201 – 400	53.6 (60)	38.4 (43)	
401 – 600	22.3 (25)	31.3 (35)	
>600	8.9 (10)	16.1 (18)	
Hospital has patients with observation status (%)			0.87
Yes	78.6 (88)	79.5 (89)	
No	21.4 (24)	20.5 (23)	
Geographic region			<0.0001
Midwest	12.5 (14)	33.9 (38)	
Northeast	12.5 (14)	15.2 (17)	
South	42.9 (48)	39.3 (44)	
West	32.1 (36)	11.6 (13)	
Population served			0.84
Urban	88.4 (99)	87.5 (98)	
Rural	11.6 (13)	12.5 (14)	
Teaching status			0.16
Non-teaching	70.5 (79)	61.6 (69)	
Teaching	29.5 (33)	38.4 (43)	

Figure 2. Type of Imaging Modality Used Among Hospitals

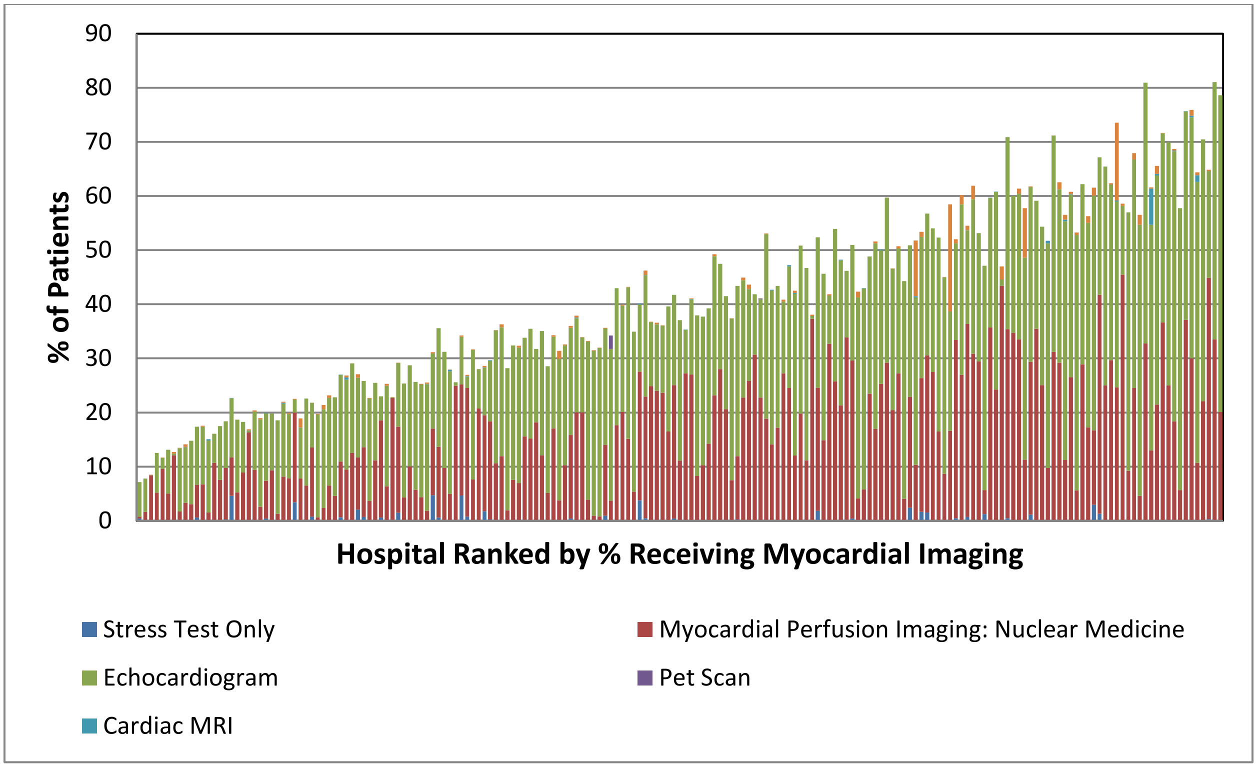


Table 2. Imaging type of low and high imaging group

Imaging Type	Total (N=113602), %	Low Imaging Group (N=27403), %	High Imaging Group (N=86199), %	p-value*
Myocardial Perfusion Imaging: Nuclear Medicine	80.4	85.1	79	<0.0001
Echocardiogram	16.6	13.5	17.5	
Coronary CT Angiogram with or without Calcium Score	1.2	0.8	1.3	
Cardiac MRI	0.1	<0.1	0.1	
PET Scan	<0.1	0.2	0	
More than one type	1.7	0.5	2.2	

*chi-square test

Table 3. Utilization and patient outcomes compared by hospital imaging groups

	Low Imaging Hospitals (N=252669)	**High Imaging Hospitals (N=296409)**	p-value
Imaging (%)	10.9	29.1	
Admission (%)			
Discharged from ED or observation bed	34.5	38.9	<.0001
Discharged from inpatient bed	65.5	61.2	
Received coronary angiogram (%)	1.7	4.1	<.0001
Received revascularization (%)	0.7	1.5	<.0001
Readmission with AMI (%)	0.3	0.3	0.3134

Table 4. Hospital effects on imaging utilization

	Empty model	Age/Sex Adjusted Model	Age/Sex and Hospital Factors Adjusted Model
C-statistics	0.69 (0.69-0.70)	0.70 (0.70-0.70)	0.70 (0.70-0.70)
Random effects hospital level variance (95% CI)*	0.99 (0.80-1.19)	1.00 (0.80-1.19)	0.63 (0.31-0.95)
Interclass correlations ICC, % (95% CI) *	23.18 (19.54- 26.52)	23.27 (19.61-26.61)	16.08 (8.64-22.40)
MOR†	2.58	2.58	2.13

$*ICC = \frac{\sigma^2}{\sigma^2+\left(\frac{\pi^2}{3}\right)}$

$\dagger MOR = \exp(0.95\sigma)$

Supplemental Table 1. ICD-9CM codes selected for inclusion.

Common causes of chest pain	Coronary atherosclerosis
	Coxsackie viral disease
	Acute pericarditis
	Acute myocarditis
	Anxiety states
	Pleurisy
	Tietze’s disease
	Mediastinitis
	Esophagitis (includes GERD)
	Acute Gastritis, acute duodenitis
	Gastric and duodenal ulcer disease
	Cholelithiasis, cholecystitis, choledocolithiasis
	Spondylosis (cervical and thoracic)
	Intervertebral disc disease (cervical and thoracic)
	Rotator cuff and shoulder disease
Signs and symptoms of cardiac chest pain	Angina (decubitis, pectoris, prinzmetal)
	Palpitations
	Cardiac dysrhythmias
	Abnormal heart sounds and murmurs
	Nausea
	Vomiting
	Abdominal bloating
	Abdominal pain
Comorbidities	Type 2 Diabetes (complicated and

commonly associated with coronary artery disease	uncomplicated) Disorders of lipid metabolism Hypertension (essential and secondary) Hypertensive heart and/or kidney disease Peripheral artery atherosclerosis and renal artery atherosclerosis Cardiomyopathies Coronary atherosclerosis Coxsackie viral disease Acute pericarditis Acute myocarditis Anxiety states Pleurisy

Supplemental Table 2. Hospital characteristics by hospital imaging quartiles.

	Q1: Lowest Imaging Hospitals, % (N=56)	Q2 (N=56)	Q3 (N=56)	Q4: Highest Imaging Hospitals, % (N=56)	p-value
Number of beds					0.13
1-200	12.5	17.9	14.3	14.3	
201 – 400	62.5	44.6	33.9	42.9	
401 – 600	14.3	30.4	32.1	30.4	
>600	10.7	7.1	19.6	12.5	
Have observation stay patients or not (%)					0.87
Yes	80.4	76.8	76.8	82.1	
No	19.6	23.2	23.2	17.9	
Geographic region					0.0002
Midwest	3.6	21.4	32.1	35.7	
Northeast	8.9	16.1	14.3	16.1	
South	46.4	39.3	41.1	37.5	
West	41.1	23.2	12.5	10.7	
Population served					0.93
Urban	87.5	89.3	89.3	85.7	
Rural	12.5	10.7	10.7	14.3	
Teaching status					0.44
Non-teaching	73.2	67.9	58.9	64.3	
Teaching	26.8	32.1	41.1	35.7	

Supplemental Table 3. Utilization and patient outcomes compared by hospital imaging quartiles

	Q1: lowest imaging Hospitals (N=129021)	Q2 (N=123648)	Q3 (N=149668)	Q4: Highest Imaging Hospitals (N=146741)	p-value
Imaging (%)	6.0	15.9	23.5	34.8	
Admission (%)					<0.0001
Discharged from ED or observation bed	67.9	63.0	62.3	60.0	
Discharged from inpatient bed	32.1	37.0	37.8	40.0	
Received coronary angiogram (%)	1.2	2.2	3.3	4.9	<0.0001
Received revascularization (%)	0.5	0.9	1.2	1.9	<0.0001
Readmission with AMI (%)	0.3	0.3	0.3	0.3	0.51

CONCLUSIONS

Our studies demonstrate two scenarios in which higher intensity patterns of hospital care are not associated with improved patient outcomes. In a healthcare system faced with increased resource constraints, it will be imperative to reduce expensive care patterns. Yet it is incumbent upon reformers to target not just any expensive care patterns, but particularly those that are not shown to be linked with better quality care for the patient. In each study, our findings suggest that a large subset of U.S. hospitals use expensive resources in a disproportionately higher percentage of patients as compared to other hospitals, but do not achieve improved mortality or readmission outcomes, respectively.

Moreover, our studies demonstrate that the hospital may be a useful entry-point for researchers, providers, payors, and policy makers to convene in order to reduce unnecessary healthcare utilization. In the second study, we performed an analysis that demonstrates that a significant proportion of the variation in myocardial imaging use was due to hospital-level factors and that patient-level factors account for very little of the observed differences in imaging rates. Bringing into focus the internal practices of the hospital—clinically, financially, and managerially—may elucidate numerous opportunities to improve the efficiency of care and to reduce waste in our healthcare system moving forward.

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