Intensive care unit admission and survival among older patients with chronic obstructive pulmonary disease, heart failure, or myocardial infarction

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Abstract

Importance: Intensive care may be beneficial to pneumonia patients with uncertain ICU needs; however, evidence about the association between intensive care unit (ICU) admission and mortality for other common conditions is largely unknown.

Objective: To estimate the relationship between ICU admission and outcomes for patients with exacerbation of chronic obstructive pulmonary disease (COPD), exacerbation of heart failure (HF), or acute myocardial infarction (AMI).

Design: Retrospective cohort study with multivariable adjustment and instrumental variable analysis assessing each condition separately. The instrumental variable analysis used differential distance to a high ICU use hospital (defined separately for each condition) as an instrument for ICU admission to examine marginal patients, whose likelihood of ICU admission depended on the hospital to which they were admitted.

Setting: U.S. hospitals

Participants: Fee-for-service Medicare beneficiaries admitted with COPD exacerbation, HF exacerbation, or AMI from 2010 to 2012.

Exposure: ICU or general ward admission

Outcomes: The primary outcome was 30-day mortality. Secondary outcome included hospital costs.

Results: Among 1,555,798 Medicare beneficiaries with COPD exacerbation, HF exacerbation, or AMI, 486,272 (31%) were admitted to the ICU. The instrumental variable analysis found that ICU admission was not associated with significant differences in 30-day mortality for any condition. ICU admission was associated with significantly greater hospital costs for HF [$11,793 vs. $9,185, P<0.001; absolute increase, 2,608 (95% CI: 1377, 3840)] and AMI [$19,513 vs. $14,590, P<0.001; absolute increase, 4,922 (95% CI: 2665, 7180)], but not for COPD.

Conclusion: ICU admission did not confer a survival benefit for patients with uncertain ICU needs hospitalized with COPD exacerbation, HF exacerbation, or AMI—suggesting the ICU may be overused for some patients with these conditions. Identifying patients most likely to benefit from ICU admission may improve healthcare efficiency while reducing costs.

Introduction

Whether or not to admit a hospitalized patient to the intensive care unit (ICU) is a central question faced by clinicians caring for those with potentially severe illness. Hospitals vary widely and idiosyncratically in their rates of ICU use,[1] and there is little research to guide this decision. In fact, a large proportion of patients admitted to the ICU may not require ICU-level care.[2–5] While ICU admission can improve detection and rescue of patients likely to decompensate, the ICU may also lead to unnecessary and potentially harmful invasive monitoring and treatments.[6] Understanding which patients have the most to gain from ICU care is essential for optimizing the use of this costly resource.[7]

A recent analysis demonstrated that ICU admission conferred a mortality benefit for marginal patients with pneumonia, for whom ICU admission depended on the hospital to which they were admitted.[8] Since these patients might receive intensive care in some hospitals but general ward care in others, their need for the ICU may be considered uncertain, because clinicians might disagree about their indication for the ICU. These patients with pneumonia may benefit from the additional monitoring and resources that can be provided in an ICU setting, such as early, aggressive treatment[9–13] and greater attention from nurses.[14,15]

Like pneumonia, many elderly Americans are hospitalized with exacerbations of chronic obstructive pulmonary disease (COPD), heart failure (HF), or acute myocardial infarction (AMI).[16,17] While patients with these three conditions are frequently admitted to the ICU, there is great variability in the rates of ICU admission for these conditions across hospitals.[18,19] We sought to determine the association between ICU admission and patients' outcomes, including mortality and costs, for all three conditions individually. Because we believed these conditions, largely chronic in nature, would see less benefit from ICU admission than pneumonia, an acute illness, we hypothesized that ICU admission would not be associated with a survival benefit but would come with greater costs.

Methods

Data source

We performed a retrospective cohort study of all acute care hospitalizations from 2010 to 2012 among fee-for-service Medicare beneficiaries aged 65 and older. The Medicare Provider Analysis and Review file was linked to mortality data in the Medicare Beneficiary Summary File. Hospital characteristics were obtained from the 2010 to 2012 American Hospital Association's (AHA) Annual Surveys and the 2010 and 2011 Healthcare Cost Reporting Information Systems. Population and geographic information was obtained by linking the patient's ZIP code of residence to 2010 U.S. Census data.

Study cohort

Patients with COPD, HF, or AMI were analyzed separately. Patients with COPD were identified by *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) 1) primary diagnosis code for COPD exacerbation or 2) primary diagnosis code for acute respiratory failure and secondary diagnosis code for COPD exacerbation (**eTable 1**).[20,21] Patients with HF were identified by ICD-9-

CM primary diagnosis code for HF exacerbation (**eTable 1**).[22–24] Patients with AMI were identified by ICD-9-CM primary diagnosis code for acute MI (**eTable 1**).[22,25] Admissions to hospitals without ICU capabilities, transfers from other acute-care hospitals, patients admitted to intermediate ICU care, or patients with missing AHA data or ZIP codes were excluded. Each analysis was limited to the first hospitalization for individuals with multiple eligible hospitalizations in the same year (**eFigures 1-3**).

Treatment variable and covariate definitions

The treatment variable was ICU admission, defined as the presence of an ICU or coronary care unit revenue center code in the administrative billing record.[26] To account for differences between patients admitted to the ICU and those admitted to the wards, the multivariable and instrumental variable analyses adjusted for age, sex, race/ethnicity, median household income, comorbid illness, severity of illness, and year of admission. Median household income was defined by the patient's ZIP code of residence using 2010 U.S. Census data. Preexisting comorbid illness was measured according to Elixhauser et al,[27] and severity of illness was captured by using secondary ICD-9-CM diagnosis and procedural codes for acute organ dysfunction,[28] mechanical ventilation, respiratory failure, sepsis, shock, cardiac or respiratory arrest, and cardiopulmonary resuscitation (CPR). For the analyses of patients with acute exacerbation of COPD or HF, the model adjusted for a secondary diagnosis of pneumonia.[29]

The multivariable and instrumental variable analyses adjusted for hospital characteristics including hospital ownership (for-profit, not-for-profit, government), medical school affiliation, teaching hospital status (resident to hospital bed ratio), hospital size by number of beds, ICU size by proportion of total hospital beds, annual hospital case volume for each condition, nursing ratio (nursing FTE per 1,000 patient-days averaged over the entire hospital), proportion of Medicaid patients among all admitted patients, geographic region, and an index of a hospital's technological capacities (such as obstetrics, ICU care, emergency department, trauma center, open heart surgery, radiation therapy, computed tomography (CT), diagnostic radiology, magnetic resonance imaging, positron-emission tomography, single-photon emission CT, ultrasonography, and transplantation service).[30]

Outcome measures

The primary outcome was 30-day all-cause mortality measured from the time of hospital admission. Thirty-day mortality was chosen as the primary outcome, rather than in-hospital mortality, because it is less biased by hospital discharge practices.[31–33] The secondary outcome included hospital costs, calculated as the patient's hospital charges multiplied by the hospital-specific annual cost-to-charge ratio.[34]

Instrumental variable

To account for confounding by severity of illness, we used an instrumental variable analysis to test the effect of ICU admission on outcomes. An instrumental variable was necessary for the analysis because the decision for ICU admission is likely to be correlated with unmeasured severity of disease (i.e., sicker patients are more likely to be admitted to the ICU);[8] thus, standard multivariable regression results would produce biased estimates when compared to the instrumental variable model.[8,35]

The instrument aims to represent the probability that patients receive care in the ICU, unrelated to disease status or any other unmeasured factors related to the study outcomes. In this study, differential distance[8,36] was selected as the instrument. Differential distance was calculated as the difference between 1) the distance from a patient's residence to the nearest "high ICU use" hospital and 2) the distance from a patient's residence to the nearest hospital of any type. In other words, the differential distance is the extra distance, if any, beyond the closest hospital a patient would have to travel to arrive at a high ICU use hospital. High ICU use hospitals were determined separately for each condition. The distribution of ICU admission rates was examined across all hospitals, and consistent with prior work,[8] high ICU use hospitals were empirically defined as those with an ICU admission rate for each condition in the top 40 percent of the included hospitals in order to include a broad sample of hospitals with higher use of the ICU, including those known to provide higher quality of care and those known to provide lower quality of care to patients, based on previous research.[18,37] Distances were calculated using the linear arc distance function, which measures the number of miles between the centroids of two ZIP codes.

Differential distance was highly correlated with ICU admission (partial $F_{1,2681} = 330$, $P < 0.001$) (**eTable 2**); instruments with F statistics higher than 10 are considered strong.[38] As further evidence of the instrument's strength, when the overall median differential distance (4.1 miles [interquartile range 0-18.4]) was used to stratify all patients, ICU admission was much more likely among patients living near a hospital with high ICU admission than those living farther away (40% for patients living closer vs. 23% for patients living farther away). The instrument's validity was supported by tests showing a balancing of patient characteristics across the distribution of the instrument (**eTables 3-5**), other than expected differences when using a distance instrument such as race and urbanicity.[39] The recommended approach to address these differences is to adjust for them in the instrumental variable model.[39,40] The validity of the instrument for intensive care has also been demonstrated elsewhere.[8]

Interpreting the instrumental variable results

While the results of standard multivariable regression represent the adjusted treatment effect for the *average* patient, the results of the instrumental variable analysis represent the adjusted treatment effect for the so-called *marginal* patient. The instrumental variable analysis relies on the fact that patients reside randomly around hospitals, independent of their specific clinical characteristics. In this analysis, marginal patients are those that are admitted to the ICU only because they live closer to a hospital with high ICU use.[8,41] Marginal patients might receive care in an ICU at one hospital or a general ward at another because ICU admission may be of uncertain benefit for these patients.[8,41] Therefore, marginal patients may be interpreted clinically as those whose need for ICU admission is borderline, discretionary, or of uncertain benefit.

Statistical analysis

Chi-square and t-tests were used to evaluate associations between ICU admission and patient characteristics. Unadjusted analyses without covariates were performed using logistic regression for 30-day mortality and linear regression for hospital costs. To adjust for patient and hospital characteristics, multivariable logistic and linear regression models were used adjusting for all above-mentioned covariates. Continuous variables were included by linear association. All regression models estimated robust standard errors with clustering at the hospital level.

In the instrumental variable analyses, we examined the association between ICU admission, 30-day mortality and hospital costs using two-stage least squares regression[8,42] after adjusting for the same patient and hospital characteristics and estimating robust standard errors with clustering at the hospital level. The adjusted outcomes from the instrumental variable model represent the mean predicted difference in the probability of death at 30 days or hospital costs. Adjusted absolute differences in outcomes were estimated using predictive margins.

The method of Newhouse et al. was used to estimate the proportion of patients hospitalized who were admitted to the ICU solely because they presented to a high ICU use hospital.[40] In this approach, the percentage of patients for which the instrumental variable analysis applies can be estimated by stratifying patients by median differential distance and subtracting the average rate of ICU admission between the two groups.

Sensitivity analysis

To test whether our results for HF may be impacted by temporal changes in coding,[43] we performed an instrumental variable analysis in which we included all patients with ICD-9-CM 1) primary diagnosis code for HF or 2) primary diagnosis code for acute respiratory failure and secondary diagnosis code for HF.

Data management and analysis was performed using SAS 9.3 (Cary, NC) and Stata 14.1 (College Station, TX). All tests were two-sided with a P value < 0.05 considered significant. The Institutional Review Board for the University of Michigan approved the study and provided a waiver of consent (HUM00053488).

Results

We identified 604,894 patients with COPD exacerbation admitted to 2,693 hospitals, 626,174 patients with HF exacerbation admitted to 2,691 hospitals, and 324,729 patients with acute MI admitted to 2,673 hospitals from 2010 to 2012 (**eFigures 1-3**). Among these patients, 121,209 with COPD (20.0%), 154,445 with HF (24.7%), and 210,618 with AMI (64.9%) were admitted to the ICU. Among clinically meaningful differences between ICU and ward patients from **Table 1**, patients admitted to the ICU were more likely to be aged between 65 and 75 years, male, and be sicker by the number of failed organs. ICU patients were more likely to receive mechanical ventilation or cardiac catheterization, regardless of the condition. High-ICU use hospitals were more likely to be for-profit, larger, and with a higher proportion of ICU beds. High-ICU use hospitals had lower average case volume for each condition than low-ICU use hospitals (**Table 2**).

In unadjusted analyses, individuals with COPD, HF, and AMI admitted to the ICU had greater 30-day mortality and hospital costs compared to ward patients (**Tables 3 and 4**). Differences between ICU and ward patients remained in regression models after adjusting for patient and hospital characteristics. In these models, ICU admission was associated with higher 30-day mortality for patients with COPD and HF (11.5% vs. 7.8%, 95% CI of absolute difference: 3.4, 4.1 for COPD and 12.6% vs. 10.8%, 95% CI of absolute difference: 1.5, 2.1 for HF) and lower mortality for patients admitted with AMI (15.4% vs. 17.2%, 95% CI of absolute difference: -2.1, -1.5) (**eTable 9**). ICU admission was associated with higher hospital costs for COPD, HF, and AMI (**eTable 9**).

We estimated that approximately 17% of analyzed patients were admitted to the ICU solely because of their proximity to a high ICU hospital—that is, met our definition of marginal—as approximately 40% of patients (308,869 of 778,144) living near a high ICU use hospital were admitted to the ICU compared to 23% of patients (177,403 of 777,654) living near a low ICU use hospital (**eTables 3-5**). These numbers were 26% vs. 15%, 34% vs. 15%, and 77% vs. 53% for COPD, HF, and AMI, respectively (**Figure 1**).

There were no significant differences in 30-day mortality associated with ICU admission for any of the 3 conditions in the instrumental variable analyses. For

COPD, 30-day mortality for marginal patients admitted to the ICU was 8.3% compared to 8.6% for patients admitted to the general ward (95% CI of absolute difference: -3.5, 2.8, *P*=0.84) (**Table 3**). For HF, 30-day mortality for marginal patients admitted to the ICU was 12.1% compared to 11.0% for patients admitted to the general ward (95% CI of absolute difference: -0.4, 2.6, *P*=0.14) (**Table 3**). For AMI, 30-day mortality for marginal patients admitted to the ICU was 15.9% compared to 16.3% for patients admitted to the general ward (95% CI of absolute difference: -2.2, 1.4, *P*=0.65) (**Table 3**).

ICU admission was associated with significantly greater hospital costs in the instrumental variable analyses for patients with HF ($11,793 vs. $9,185, 95% CI of absolute difference: 1377, 3840, *P*<0.001) and AMI ($19,513 vs. $14,590, 95% CI of absolute difference: 2665, 7180, *P*<0.001), although there were no significant differences for patients with COPD (95% CI of absolute difference: -1750, 2304, *P*=0.79) (**Table 4**).

In our sensitivity analysis assessing whether temporal changes in coding may affect the HF results, we identified 720,141 patients of which 219,633 (30.5%) were admitted to the ICU. Instrumental variable results demonstrated no significant difference in 30-day mortality and greater hospital costs associated with ICU admission, consistent with our primary results (**eTable 10**).

Discussion

ICU admission was not significantly associated with a survival advantage at 30 days for marginal patients hospitalized with COPD exacerbation, HF exacerbation, or acute MI (those for whom ICU admission depended on the hospital to which they presented). Hospital costs were substantially higher among patients with HF and AMI admitted to the ICU compared to those admitted to the general ward, though healthcare costs varied depending on the condition. These findings suggest that the ICU may be overused for some COPD, HF, or AMI patients with an uncertain indication for intensive care, and opportunities exist to decrease healthcare costs by reducing ICU admissions for certain patients.

The concept of "intensive care" differs from hospital to hospital and patient to patient. For instance, some patients may be admitted to the ICU for close monitoring while others may be admitted for life support. For this reason, many may consider intensive care a heterogeneous treatment and may question how an instrumental variable analysis accounts for such a mixed exposure. While individual treatments may differ between patients and between hospitals,[1] the ultimate goal for all clinicians in admitting a patient to the ICU is to reduce their likelihood of death. Other well-designed instrumental variable analyses in critical care were performed with heterogeneous exposures such as hospital admission volume,[44] hospital transfer,[45] and stroke center admission.[46] This heterogeneity only highlights the need to further understand the mechanism underlying the benefit of the ICU, and this work underscores that the benefit of the ICU may depend on the condition.

This study contrasts a recently published analysis in which ICU admission for marginal patients with pneumonia was associated with six percentage point lower 30-day mortality compared to general ward admission, without significant differences in costs.[8] There may be several possibilities that account for the discrepant findings between these studies. Ultimately, the benefit of the ICU may depend on the condition. Pneumonia is the most common cause of sepsis,[47] and evidence suggests that early and aggressive resuscitation for sepsis, often begun in the emergency department and continued in the hospital, may reduce mortality.[48] This type of care may be more readily provided in an ICU than a general ward.[9–12] Timely interventions and catheterization most certainly reduce mortality for AMI; however, these treatments are typically performed prior to ICU or general ward admission.[49] The ICU has the capability to provide closer monitoring to patients,[14] and perhaps, patients with pneumonia are at greater risk of decompensation than patients with COPD, HF, or AMI. Late admission to an ICU for pneumonia has been associated with worse outcomes;[11] however, this relationship has not been studied in COPD, HF, or AMI.

Prior studies evaluating the association between ICU admission and outcomes for patients with COPD, HF, or AMI used traditional risk adjustment and demonstrated that ICU admission was associated with increased mortality.[50–54] However, traditional risk adjustment techniques fail to fully address confounding in scenarios where treatment administration is strongly associated with severity of illness.[55] This study addresses the potential for unmeasured confounding by using instrumental variable analyses and focuses on the marginal population, who are patients with an uncertain indication for ICU admission. In our study, there were notable differences between the effects measured for average patients using traditional regression and for marginal patients using instrumental variable analyses.

In the instrumental variable analysis, hospital costs for HF and AMI were one-third times greater with ICU admission than with general ward admission. We estimated that approximately 20-25 percent of patients hospitalized with HF or AMI might be considered marginal. Combined with the lack of mortality benefit seen in patients with these conditions, these findings suggest that there is a substantial population of patients who are admitted to the ICU but could potentially be cared for in the general wards, resulting in higher healthcare costs.

It is important to note that the findings of this study apply only to marginal patients, for whom the likelihood of ICU admission depended solely on the hospital to which they presented. While these patients cannot be distinctly identified from the instrumental variable analysis, these are likely to be patients with a moderate risk of death. Our results suggest that nearly one out of five hospitalized Medicare patients with COPD, HF, or AMI would be considered marginal, receiving different levels of care based solely on the hospital. The specific characteristics of these patients could not be identified in this analysis, and further research is necessary to assist clinicians in identifying these patients. These results should not, however, be applied to patients with obvious needs for the ICU, such as those requiring mechanical ventilation or vasopressor support, or to patients for whom ICU admission is clearly not indicated, such as low risk admissions.[41]

This study should be interpreted in the context of several limitations. First, administrative data were used, which may under-identify or improperly identify patients.[26] However, patients were selected using well-established definitions from epidemiologic research.[24,25,56] Second, it cannot be proven that the instrument fully addresses unmeasured confounding;[27,28] however, the instrument has been previously used[8] and demonstrated covariate balance, with differences that would be expected for a distance instrument, such as with race and urbanicity.[39] Third, because the analysis includes only Medicare beneficiaries, it may not generalize to a younger population of patients. Fourth, the reason for ICU admission and timing of ICU admission within a hospitalization was not available. In addition, clinical variables useful to understanding triage decisions were not present. Furthermore, due to limitations of the instrumental variable analysis, we cannot currently identify the specific characteristics of marginal patients objectively, in a way suitable for bedside use. Finally, the costs examined in this study are related to hospital charges and do not include physician, facility, or outpatient payments related to the hospitalization.

These results may have important implications for health system leaders and policymakers. Improving the efficiency of intensive care is vital to any restructuring of the American healthcare system, given the substantial resources associated with its use.[57,58] Attempts to constrain national ICU capacity, however, must be preceded by evidence that withholding ICU care will actually reduce costs without worsening outcomes for vulnerable patients. While pneumonia patients with uncertain ICU needs may obtain a survival advantage with ICU admission, this pattern appears to be condition-specific, as it does not extend to patients with COPD, HF, or AMI. These findings suggest that some COPD, HF, or AMI patients without obvious ICU indications may be reasonably cared for in either the ICU or the general ward. Identifying these patients who do not benefit from ICU admission could reduce costs while improving healthcare efficiency.

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Study concept and design: Valley, Cooke

Acquisition of data: Valley, Cooke

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Figure Legend

Figure 1: Estimation of the marginal patient population

For each condition, the marginal patient population was estimated by the method of Newhouse et al.[40] Marginal patients were admitted to the ICU solely because they lived proximally to a high ICU use hospital. After stratifying patients by each condition's median differential distance, patients who were admitted to the general ward, despite living close to a high ICU use hospital, were considered patients who would always be admitted to the general ward, regardless of hospital. Patients who were admitted to the ICU, despite living far from a high ICU use hospital, were considered patients who would always be admitted to the ICU, regardless of hospital. The difference between these two groups provides the estimated marginal patient population, those who might be admitted to the ICU or to the general ward depending on the hospital.

Figure 1: Estimation of the marginal patient population

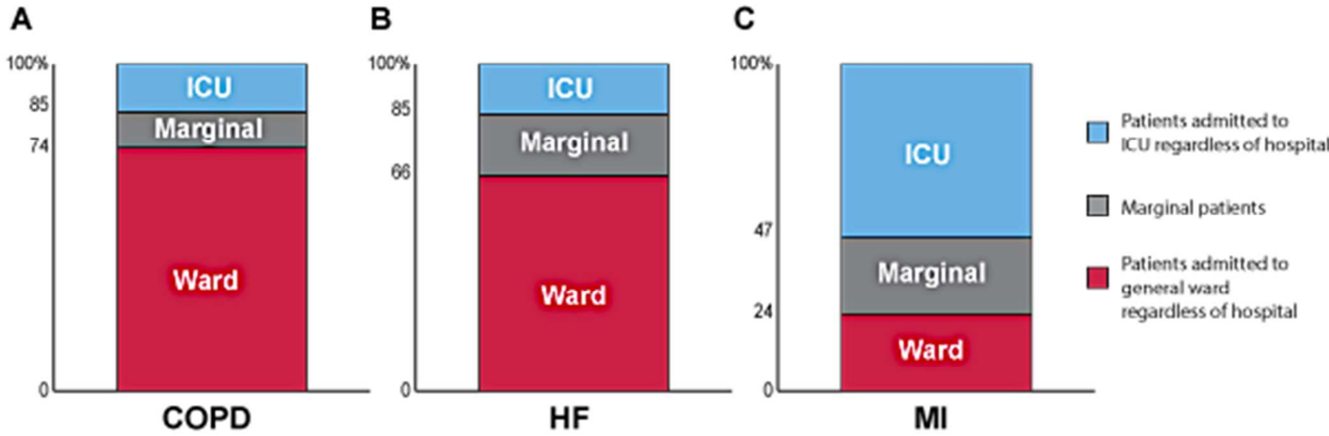


Table 1: Patient characteristics by condition and ICU admission

Characteristics[a]	**COPD**		**HF**		**AMI**	
	ICU	**Ward**	**ICU**	**Ward**	**ICU**	**Ward**
No. Patients (%)	121,209 (20.0)	483,686 (80.0)	154,445 (24.7)	471,729 (75.3)	210,618 (64.9)	114,111 (35.1)
Age, mean (SD)	76 (7)	77 (8)	79 (8)	81 (8)	77 (8)	80 (9)
65-74 years	47.2	41.1	32.2	25.7	41.5	30.1
75-84 years	37.3	38.3	36.3	34.5	35.3	32.6
≥ 85 years	15.5	20.6	31.5	39.8	23.2	37.4
Female	55.3	59.4	53.1	56.4	45.7	53.1
Race/Ethnicity						
White	86.2	88.3	82.8	84.1	86.8	87.4
Black	9.8	8.4	12.1	12.3	8.2	9.1
Other	4.0	3.3	5.1	3.7	5.1	3.4
Urbanicity						
Large Central Metro	21.0	17.6	23.2	19.0	21.9	17.2
Suburban Metro	23.1	24.3	23.2	24.2	23.2	23.4
Medium Metro	21.3	21.4	20.4	23.1	21.3	24.6
Small Metro	12.2	13.7	11.8	12.7	12.6	14.3
Micro	13.2	14.0	12.8	12.9	12.1	12.6
Noncore	9.3	9.0	8.5	8.1	8.8	8.0
Median Household Income by Zip Code						
< $40,000	29.9	28.8	28.1	27.1	25.9	24.6
$40,000-$100,000	65.7	66.7	66.6	67.6	68.6	70.1
> $100,000	4.4	4.5	5.4	5.2	5.5	5.3
Elixhauser Comorbid., mean (SD)	3.1 (1.4)	2.6 (1.4)	3.3 (1.4)	3.5 (1.4)	2.5 (1.4)	2.8 (1.4)
Hospital Diagnoses						
Respiratory Failure	72.8	16.5	35.7	9.4	18.0	5.1
Sepsis	4.5	0.3	3.8	0.5	3.3	1.0
Shock	3.8	0.1	5.2	0.2	11.1	1.6
Cardiac or Respiratory Arrest	2.8	0.1	1.7	0.2	4.8	1.0
Procedures Performed during Hospitalization						
Invasive Ventilation	39.0	0.4	8.0	0.2	8.7	0.9
Non-invasive Ventilation	21.0	3.6	12.9	2.9	3.2	1.7
CPR[b]	1.9	0.1	1.6	0.2	2.2	0.7
Cardiac Cath	2.7	0.6	9.7	3.9	57.9	36.7
Angus Organ Failures[c]						
0	47.5	88.3	57.9	76.2	60.5	76.3
1	34.1	11.0	30.8	21.8	25.9	20.5
≥ 2	18.4	0.8	11.3	2.0	13.6	3.2
Year of Admission						
2010	20.2	79.8	35.5	35.1	35.3	33.4
2011	19.8	80.2	33.5	33.8	33.1	33.6
2012	20.2	79.8	31.0	31.1	31.6	33.1

[a] %
[b] Cardiopulmonary resusciation
[c] Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six. Higher scores indicate more organ failures.

Table 2: Comparison of hospitals with high and low ICU utilization for each condition

	COPD		HF		AMI	
Characteristic	**High ICU Hospitals**[a]	**Low ICU Hospitals**	**High ICU Hospitals**	**Low ICU Hospitals**	**High ICU Hospitals**	**Low ICU Hospitals**
No. Hospitals	1077 (40.0)	1616 (60.0)	1076 (40.0)	1615 (60.0)	1,063 (39.8)	1,610 (60.2)
Hospital Ownership						
For-profit	22.3	18.1	23.5	17.2	22.3	17.8
Not-for-profit	61.1	67.8	62.1	67.1	64.3	66.0
Government	16.7	14.1	14.4	15.7	13.4	16.2
Medical School Affiliation	38.0	32.2	35.6	33.	38.7	31.7
Teaching Status						
No Residents	79.8	80.3	80.2	80.0	77.2	81.5
Minor Teaching Program (< 0.25 residents/bed)	12.5	13.0	13.5	12.3	15.1	11.6
Major Teaching Program (≥ 0.25 residents/bed)	7.7	6.8	6.3	7.7	7.6	6.9
Hospital Beds						
< 100	22.2	26.9	21.8	27.1	15.9	30.6
100-199	29.3	28.8	30.4	28.0	30.8	27.8
≥ 200	48.5	44.3	47.8	44.9	53.3	41.6
Percent of Total that are ICU Beds						
≤ 5%	4.5	7.7	4.6	7.6	4.3	7.6
5-10%	35.4	49.7	39.0	47.4	39.9	46.9
> 10%	60.2	42.5	56.4	45.0	55.8	45.4
Hospital Annual Case Volume, Mean (SD)						
COPD	76 (61)	120 (94)				
HF			62 (70)	132 (122)		
AMI					39 (36)	51 (53)
Nursing FTE[b] per 1000 Patient-Days, Mean (SD)	4.1 (1.7)	3.7 (1.5)	4.0 (1.5)	3.8 (1.6)	4.1 (1.5)	3.7 (1.6)
Technology Index, Mean (SD)[c]	25.4 (12.6)	11.6	25.0 (12.2)	24.1 (11.9)	26.6 (12.1)	23.2 (11.8)
Medicaid Patients						
< 7%	31.1	40.3	32.9	39.1	30.9	40.2
7-11%	30.6	32.6	29.0	33.8	29.2	33.9
> 11%	38.3	27.1	38.1	27.1	40.0	26.0
Census Regions						
Northeast	11.6	20.1	13.5	18.8	14.3	18.4
Midwest	32.8	36.0	34.1	35.1	33.1	36.0
South	30.7	30.2	29.6	31.0	27.4	32.1
West	25.0	13.7	22.8	15.2	25.2	13.5

[a] High ICU use hospitals were defined as hospitals with an ICU admission rate for each condition in the top 40% of all hospitals over the three year period.

[b] Full-time equivalents over the entire hospital

[c] Weighted sum of hospital capabilities, including obstetrics, ICU care, emergency department, trauma center, open heart surgery, radiation therapy, CT, diagnostic radiology, magnetic resonance imaging, positron-emission tomography, single-photon emission CT, ultrasonography, and transplantation service

Table 3: Association of ICU admission on 30-Day mortality for COPD, HF, and AMI

Model	ICU Patients	Ward Patients	Absolute Difference (95% CI)	*P* value
COPD (n=604,894)				
Model	**ICU Patients**	**Ward Patients**	**Absolute Difference (95% CI)**	***P* value**
Unadjusted regression	22.2%	5.1%	17.1% (16.6, 17.5)	< 0.001
Instrumental variable[a,b]	8.3%	8.6%	-0.3% (-3.5, 2.8)	0.84
HF (n=626,174)				
Model	**ICU Patients**	**Ward Patients**	**Absolute Difference (95% CI)**	***P* value**
Unadjusted regression	18.2%	9.1%	9.1% (8.6, 9.7)	< 0.001
Instrumental variable	12.1%	11.0%	1.1% (-0.4, 2.6)	0.14
AMI (n=324,729)				
Model	**ICU Patients**	**Ward Patients**	**Absolute Difference (95% CI)**	***P* value**
Unadjusted regression	17.3%	13.8%	3.5% (3.0, 4.0)	< 0.001
Instrumental variable	15.9%	16.3%	-0.4% (-2.2, 1.4)	0.65

[a] Model adjusted for all variables in tables 1 and 2 in addition to all 29 individual Elixhauser comorbidities. Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six, was defined to include all organ failures numbered 0 to ≥ 5. Higher scores indicate more organ failures. Hospital region included the nine U.S. census defined regions. All standard errors for models were adjusted for clustering of patients within hospitals.
[b] 2-stage least squared regression of all patients using differential distance to nearest high-ICU use hospital as instrumental variable, adjusted for all variables in tables 1 and 2, and for clustering of patients within hospitals

Table 4: Association of ICU admission on hospital costs for COPD, HF, and AMI

COPD (n=604,894)		
Model	**Absolute Difference (95% CI)**	***P* value**
Unadjusted regression	$11,136 (10790, 11482)	< 0.001
Instrumental variable[a,b]	$277 (-1750, 2304)	0.79
HF (n=626,174)		
Model	**Absolute Difference (95% CI)**	***P* value**
Unadjusted regression	$9,383 (8826, 9940)	< 0.001
Instrumental variable	$2,608 (1377, 3840)	< 0.001
AMI (n=324,729)		
Model	**Absolute Difference (95% CI)**	***P* value**
Unadjusted regression	$12,037 (11636, 12438)	< 0.001
Instrumental variable	$4,922 (2665, 7180)	< 0.001

[a] Model adjusted for all variables in tables 1 and 2 in addition to all 29 individual Elixhauser comorbidities. Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six, was defined to include all organ failures numbered 0 to $\geq$ 5. Higher scores indicate more organ failures. Hospital region included the nine U.S. census defined regions. All standard errors for models were adjusted for clustering of patients within hospitals.

[b] 2-stage least squared regression of all patients using differential distance to nearest high-ICU use hospital as instrumental variable, adjusted for all variables in tables 1 and 2, and for clustering of patients within hospitals

eTable 1: International Classification of Disease, Ninth Revision, Clinical Modification (ICD-9-CM) Codes

Diagnosis	**ICD-9-CM Codes**
COPD	491.21, 491.22, 491.8, 491.9, 492.8, 493.20, 493.21, 493.22, 496
HF	401.01, 402.11, 402.91, 404.01, 404.03, 404.11, 404.13, 404.91, 404.93, 428.xx
AMI	410.xx
Pneumonia	480.0-480.3, 480.8, 480.9, 481, 482.0, 482.1, 482.2, 482.30-482.32, 482.39-482.41, 482.49, 482.81-482.84, 482.89, 482.9, 483.0, 483.1, 483.8, 485, 486, 487.0
Acute respiratory failure	518.81, 518.82, 518.84, 799.1
Sepsis	038.xx, 785.52, 790.7, 995.91, 995.92
Shock	458, 785.5- 785.59, 958.4, 998.0
Respiratory or cardiac arrest	427.5, 799.1
Procedures	
Invasive mechanical ventilation	96.7, 96.70, 96.71, 96.72, 93.90
Non-invasive mechanical ventilation	93.90
Cardiac catheterization	37.21, 37.22, 37.23
Cardiopulmonary resuscitation	99.60, 99.63

eTable 2: Instrument analysis

Differential distance is highly correlated with ICU admission, conditional on other covariates.

Condition	Model	F-statistic	*P* value
COPD	Linear	191.3	< 0.001
HF	Linear	224.4	< 0.001
AMI	Linear	240.4	< 0.001
Total	Linear	330.2	< 0.001

Instrumental Variable – First Stage Results

Condition	Beta	95% CI	F-statistic (1, 2675)	*P* value	Adj. R-squared
COPD	-0.018 absolute change in ICU admission probability for every 10 mile increase in differential distance	(-0.02, -0.015)	191	< 0.001	0.44
HF	-0.04 absolute change in ICU admission probability for every 10 mile increase in differential distance	(-0.05, -0.04)	224	< 0.001	0.21
AMI	-0.05 absolute change in ICU admission probability for every 10 mile increase in differential distance	(-0.05, -0.04)	240	< 0.001	0.16
Total	-0.04 absolute change in ICU admission probability for every 10 mile increase in differential distance	(-0.04, -0.03)	330	< 0.001	0.21

eTable 3: Patient characteristics by median differential distance for COPD

Characteristic	< 3.7 miles No. (%)	≥ 3.7 miles No (%)
No. Patients	302,524 (50.0)	302,371 (50.0)
ICU Patients	77,480 (25.6)	43,729 (14.5)
Age, mean (SD)	77 (8)	77 (8)
65-74 years	127,489 (42.1)	128,552 (42.5)
75-84 years	114,750 (37.9)	115,597 (38.2)
≥ 85 years	60,285 (19.9)	58,222 (19.3)
Female	178,477 (59.0)	176,061 (58.2)
Race/Ethnicity		
White	254,753 (84.2)	276,956 (91.6)
Black	33,990 (11.2)	18,551 (6.1)
Other	13781 (4.6)	6864 (2.2)
Urbanicity		
Large Central Metropolitan	90,869 (30.0)	19,860 (6.6)
Large Suburban Metropolitan	70,578 (23.3)	74,738 (24.7)
Medium Metropolitan	64,558 (21.3)	64,550 (21.4)
Small Metropolitan	28,927 (9.6)	52,060 (17.2)
Micropolitan	28,111 (9.3)	55,681 (18.4)
Noncore	19,481 (6.4)	35,482 (11.7)
Median Household Income by Zip Code		
< $40,000	83,983 (27.8)	91,648 (30.3)
$40,000-$100,000	204,028 (67.4)	198,324 (65.6)
≥ $100,000	14,513 (4.8)	12,399 (4.1)
Elixhauser Comorbidities, mean (SD)	2.6 (1.2)	2.6 (1.2)
Admission Source		
Outpatient	17,154 (5.7)	20,850 (6.9)
Emergency Department	284,452 (94.3)	280,397 (93.1)
Angus Organ Failure Score[a]		
0	236,611 (78.2)	248,008 (82.0)
1	50,695 (16.8)	43,569 (14.4)
≥ 2	15218 (5)	10794 (3.6)
Year of Admission		
2010	105,365 (50.8)	102,188 (49.2)
2011	104,426 (50.0)	104,350 (50.0)
2012	92,733 (49.2)	95,833 (50.8)

[a] Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six. Higher scores indicate more organ failures.

eTable 4: Patient characteristics by median differential distance for HF

Characteristic	< 4.8 miles No. (%)	≥ 4.8 miles No (%)
No. Patients	313,075 (50.0)	313,099 (50.0)
ICU Patients	107,120 (34.2)	47,325 (15.1)
Age, mean (SD)	80 (8)	80 (8)
65-74 years	87,698 (28.0)	83,072 (26.5)
75-84 years	108,416 (34.6)	110,521 (35.3)
≥ 85 years	116,961 (37.4)	119,506 (38.2)
Female	173,391 (55.4)	174,558 (55.8)
Race/Ethnicity		
White	252,646 (80.7)	272,066 (86.9)
Black	44,549 (14.2)	32,196 (10.3)
Other	15,880 (5.1)	8,837 (2.8)
Urbanicity		
Large Central Metropolitan	98,701 (31.5)	26,728 (8.5)
Large Suburban Metropolitan	78,475 (25.1)	71,605 (22.9)
Medium Metropolitan	63,568 (20.3)	76,723 (24.5)
Small Metropolitan	27,319 (8.7)	50,957 (16.3)
Micropolitan	25,549 (8.2)	55,229 (17.6)
Noncore	19,463 (6.2)	31,857 (10.2)
Median Household Income by Zip Code		
< $40,000	81,549 (26.1)	89,818 (28.7)
$40,000-$100,000	211,627 (67.6)	210,204 (67.1)
≥ $100,000	19,899 (6.4)	13,077 (4.2)
Elixhauser Comorbidities, mean (SD)	3.1 (1.0)	3.2 (1.0)
Admission Source		
Outpatient	19,277 (6.2)	24,175 (7.8)
Emergency Department	292,906 (93.8)	287,698 (92.2)
Angus Organ Failure Score[a]		
0	218,743 (69.9)	230,060 (73.5)
1	78,595 (25.1)	71,825 (22.9)
≥ 2	15737 (4.9)	11214 (3.6)
Year of Admission		
2010	110,623 (50.2)	109,623 (49.8)
2011	105,651 (50.0)	105,738 (50.0)
2012	96,801 (49.8)	97,738 (50.2)

[a] Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six. Higher scores indicate more organ failures.

eTable 5: Patient characteristics by median differential distance for AMI

Characteristic	< 3.3 miles No. (%)	≥ 3.3 miles No (%)
No. Patients	162,545 (50.1)	162,184 (49.9)
ICU Patients	124,269 (76.5)	86,349 (53.2)
Age, mean (SD)	78 (8)	78 (8)
65-74 years	62,688 (38.6)	59,082 (36.4)
75-84 years	55,765 (34.3)	55,696 (34.3)
≥ 85 years	44,092 (27.1)	47,406 (29.2)
Female	77,847 (47.9)	78,865 (48.6)
Race/Ethnicity		
White	136,915 (84.2)	145,725 (89.9)
Black	16,277 (10.0)	11,298 (7.0)
Other	9,353 (5.8)	5,161 (3.2)
Urbanicity		
Large Central Metropolitan	51,011 (31.4)	14,850 (9.2)
Large Suburban Metropolitan	39,905 (24.6)	35,639 (22.0)
Medium Metropolitan	33,178 (20.4)	39,853 (24.6)
Small Metropolitan	16,750 (10.3)	26,180 (16.1)
Micropolitan	11,953 (7.4)	27,847 (17.2)
Noncore	9,748 (6.0)	17,815 (11.0)
Median Household Income by Zip Code		
< $40,000	38,482 (23.7)	44,237 (27.3)
$40,000-$100,000	113,919 (70.1)	110,561 (68.2)
≥ $100,000	10,144 (6.2)	7,386 (4.6)
Elixhauser Comorbidities, mean (SD)	2.5 (1.2)	2.5 (1.2)
Admission Source		
Outpatient	6,253 (3.9)	8,858 (5.5)
Emergency Department	155,621 (96.1)	152,420 (94.5)
Angus Organ Failure Score[a]		
0	103,392 (63.6)	111,149 (68.5)
1	40,576 (25.0)	37,313 (23.0)
≥ 2	18577 (11.5)	13722 (8.5)
Year of Admission		
2010	56,324 (50.1)	56,127 (49.9)
2011	54,082 (50.0)	53,965 (50.0)
2012	52,139 (50.0)	52,092 (50.0)

[a] Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six. Higher scores indicate more organ failures.

eTable 6: Hospital characteristics by quintile of ICU admission rates for COPD

Characteristics	Quintile 1 (<12%)	Quintile 2 (12-17%)	Quintile 3 (18-23%)	Quintile 4 (24-32%)	Quintile 5 (>32%)
No. Hospitals	539 (20.0)	539 (20.0)	538 (20.0)	539 (20.0)	538 (20.0)
Hospital Ownership					
For-profit	89 (16.64)	103 (19.22)	105 (19.59)	106 (19.81)	125 (23.41)
Not-for-profit	378 (70.65)	363 (67.72)	347 (64.74)	331 (61.87)	324 (60.67)
Government	68 (12.71)	70 (13.06)	84 (15.67)	98 (18.32)	85 (15.92)
Medical School Affiliation	190 (35.25)	149 (27.64)	177 (32.9)	204 (37.85)	209 (38.85)
Teaching Status					
No Residents	428 (79.55)	437 (81.08)	432 (80.3)	425 (78.85)	433 (80.48)
Minor Teaching Program (< 0.25 residents/bed)	64 (11.9)	73 (13.54)	73 (13.57)	73 (13.54)	62 (11.52)
Major Teaching Program (≥ 0.25 residents/bed)	46 (8.55)	29 (5.38)	33 (6.13)	41 (7.61)	43 (7.99)
Hospital Beds					
< 100	144 (26.77)	157 (29.13)	130 (24.16)	127 (23.56)	115 (21.38)
100-199	167 (31.04)	135 (25.05)	164 (30.48)	154 (28.57)	161 (29.93)
≥ 200	227 (42.19)	247 (45.83)	244 (45.35)	258 (47.87)	262 (48.7)
Percent of ICU Beds					
≤ 5%	53 (9.85)	28 (5.19)	46 (8.55)	23 (4.27)	23 (4.28)
5-10%	299 (55.58)	276 (51.21)	221 (41.08)	203 (37.66)	185 (34.39)
> 10%	186 (34.57)	235 (43.6)	271 (50.37)	313 (58.07)	330 (61.34)
Hospital COPD Annual Case Volume, Mean (SD)	129 (111)	124 (82)	107 (84)	83 (63)	69 (59)
Nursing FTE[a] per 1000 Patient-Days, Mean (SD)	3.6 (1.6)	3.7 (1.3)	3.8 (1.7)	4.0 (1.7)	4.2 (1.7)
Technology Index, Mean (SD)[b]	23.4 (11.6)	23.7 (11.5)	24.3 (11.9)	25.4 (12.5)	25.6 (12.6)
Medicaid Patients					
< 7%	228 (42.38)	231 (42.86)	191 (35.5)	175 (32.47)	160 (29.74)
7-11%	183 (34.01)	172 (31.91)	185 (34.39)	162 (30.06)	155 (28.81)
> 11%	127 (23.61)	136 (25.23)	162 (30.11)	202 (37.48)	223 (41.45)
Census Regions					
Northeast	143 (27.24)	91 (16.88)	89 (16.54)	60 (11.15)	63 (11.75)
Midwest	187 (35.62)	197 (36.55)	190 (35.32)	185 (34.39)	169 (31.53)
South	131 (24.95)	179 (33.21)	173 (32.16)	180 (33.46)	151 (28.17)
West	64 (12.19)	72 (13.36)	86 (15.99)	113 (21)	153 (28.54)

[a] Full-time equivalents over the entire hospital

[b] Weighted sum of hospital capabilities, including obstetrics, ICU care, emergency department, trauma center, open heart surgery, radiation therapy, CT, diagnostic radiology, magnetic resonance imaging, positron-emission tomography, single-photon emission CT, ultrasonography, and transplantation service

eTable 7: Hospital characteristics by quintile of ICU admission rates for HF

Characteristics	Quintile 1 (<12%)	Quintile 2 (12-18%)	Quintile 3 (19-31%)	Quintile 4 (32-55%)	Quintile 5 (>55%)
No. Hospitals	538 (20.0)	538 (20.0)	538 (20.0)	538 (20.0)	538 (20.0)
Hospital Ownership					
For-profit	75 (13.99)	82 (15.36)	119 (22.16)	120 (22.51)	131 (24.49)
Not-for-profit	394 (73.51)	360 (67.42)	324 (60.34)	323 (60.6)	340 (63.55)
Government	67 (12.5)	92 (17.23)	94 (17.5)	90 (16.89)	64 (11.96)
Medical School Affiliation	223 (41.45)	173 (32.16)	147 (27.32)	190 (35.32)	193 (35.87)
Teaching Status					
No Residents	401 (74.67)	432 (80.3)	457 (84.94)	415 (77.14)	448 (83.27)
Minor Teaching Program (< 0.25 residents/bed)	82 (15.27)	67 (12.45)	50 (9.29)	82 (15.24)	63 (11.71)
Major Teaching Program (≥ 0.25 residents/bed)	54 (10.06)	39 (7.25)	31 (5.76)	41 (7.62)	27 (5.02)
Hospital Beds					
< 100	120 (22.35)	138 (25.65)	179 (33.27)	141 (26.21)	94 (17.47)
100-199	139 (25.88)	141 (26.21)	172 (31.97)	144 (26.77)	183 (34.01)
≥ 200	278 (51.77)	259 (48.14)	187 (34.76)	253 (47.03)	261 (48.51)
Percent of Total that are ICU Beds					
≤ 5%	39 (7.26)	44 (8.18)	40 (7.43)	25 (4.65)	24 (4.46)
5-10%	299 (55.68)	247 (45.91)	218 (40.52)	222 (41.26)	198 (36.8)
> 10%	199 (37.06)	247 (45.91)	280 (52.04)	291 (54.09)	316 (58.74)
Hospital HF Annual Case Volume, Mean (SD)	166 (149)	140 (107)	91 (89)	59 (64)	64 (75)
Nursing FTE[a] per 1000 Patient-Days, Mean (SD)	3.9 (1.9)	3.8 (1.6)	3.7 (1.4)	3.9 (1.5)	4.1 (1.5)
Technology Index, Mean (SD)[b]	25.2 (12.0)	24.2 (11.9)	23.1 (11.8)	25.0 (12.4)	25.0 (12.0)
Medicaid Patients					
< 7%	210 (39.11)	212 (39.41)	208 (38.66)	193 (35.87)	161 (29.93)
7-11%	198 (36.87)	177 (32.9)	170 (31.6)	151 (28.07)	161 (29.93)
> 11%	129 (24.02)	149 (27.7)	160 (29.74)	194 (36.06)	216 (40.15)
Census Regions					
Northeast	131 (24.76)	94 (17.47)	76 (14.15)	72 (13.38)	73 (13.7)
Midwest	187 (35.35)	192 (35.69)	184 (34.26)	190 (35.32)	175 (32.83)
South	129 (24.39)	183 (34.01)	185 (34.45)	183 (34.01)	134 (25.14)
West	82 (15.5)	69 (12.83)	92 (17.13)	93 (17.29)	151 (28.33)

[a] Full-time equivalents over the entire hospital

[b] Weighted sum of hospital capabilities, including obstetrics, ICU care, emergency department, trauma center, open heart surgery, radiation therapy, CT, diagnostic radiology, magnetic resonance imaging, positron-emission tomography, single-photon emission CT, ultrasonography, and transplantation service

eTable 8: Hospital characteristics by quintile of ICU admission rates for AMI

Characteristics	Quintile 1 (<43%)	Quintile 2 (43-61%)	Quintile 3 (62-80%)	Quintile 4 (81-94%)	Quintile 5 (>94%)
No. Hospitals	535 (20.0)	536 (20.1)	532 (19.9)	534 (20.0)	534 (20.0)
Hospital Ownership					
For-profit	64 (12.01)	94 (17.64)	121 (23.05)	118 (22.14)	123 (23.12)
Not-for-profit	394 (73.92)	348 (65.29)	308 (58.67)	335 (62.85)	351 (65.98)
Government	75 (14.07)	91 (17.07)	96 (18.29)	80 (15.01)	58 (10.9)
Medical School Affiliation	169 (31.59)	174 (32.46)	165 (31.02)	201 (37.64)	212 (39.7)
Teaching Status					
No Residents	435 (81.46)	441 (82.28)	427 (80.26)	407 (76.22)	422 (79.03)
Minor Teaching Program (< 0.25 residents/bed)	57 (10.67)	63 (11.75)	66 (12.41)	81 (15.17)	79 (14.79)
Major Teaching Program (≥ 0.25 residents/bed)	42 (7.87)	32 (5.97)	39 (7.33)	46 (8.61)	33 (6.18)
Hospital Beds					
< 100	197 (36.89)	157 (29.29)	141 (26.5)	98 (18.35)	66 (12.36)
100-199	134 (25.09)	147 (27.43)	167 (31.39)	163 (30.52)	164 (30.71)
≥ 200	203 (38.01)	232 (43.28)	224 (42.11)	273 (51.12)	304 (56.93)
Percent of Total that are ICU Beds					
≤ 5%	51 (9.55)	37 (6.9)	38 (7.14)	21 (3.93)	22 (4.12)
5-10%	280 (52.43)	245 (45.71)	231 (43.42)	217 (40.64)	206 (38.58)
> 10%	203 (38.01)	254 (47.39)	263 (49.44)	296 (55.43)	306 (57.3)
Hospital MI Annual Case Volume, Mean (SD)	52 (58)	55 (55)	44 (46)	39 (35)	41 (37)
Nursing FTE[a] per 1000 Patient-Days, Mean (SD)	3.7 (1.6)	3.8 (1.7)	3.8 (1.5)	4.0 (1.4)	4.2 (1.6)
Technology Index, Mean (SD)[b]	21.7 (11.4)	23.9 (12.2)	23.5 (11.7)	26.6 (12.1)	27.0 (11.9)
Medicaid Patients					
< 7%	245 (45.88)	203 (37.87)	199 (37.41)	172 (32.21)	154 (28.84)
7-11%	187 (35.02)	177 (33.02)	178 (33.46)	163 (30.52)	150 (28.09)
> 11%	102 (19.1)	156 (29.1)	155 (29.14)	199 (37.27)	230 (43.07)
Census Regions					
Northeast	138 (26.04)	83 (15.6)	71 (13.4)	76 (14.23)	78 (14.72)
Midwest	192 (36.23)	187 (35.15)	187 (35.28)	203 (38.01)	157 (29.62)
South	122 (23.02)	199 (37.41)	194 (36.6)	154 (28.84)	135 (25.47)
West	78 (14.72)	63 (11.84)	78 (14.72)	101 (18.91)	160 (30.19)

[a] Full-time equivalents over the entire hospital

[b] Weighted sum of hospital capabilities, including obstetrics, ICU care, emergency department, trauma center, open heart surgery, radiation therapy, CT, diagnostic radiology, magnetic resonance imaging, positron-emission tomography, single-photon emission CT, ultrasonography, and transplantation service

eTable 9: Multivariable regression results[a]

COPD		
Model	**Absolute Difference (95% CI)**	***P* value**
30-day mortality	3.7% (3.4, 4.1)	< 0.001
Hospital costs	$5,020 (4741, 5298)	< 0.001
HF		
Model	**Absolute Difference (95% CI)**	***P* value**
30-day mortality	1.8% (1.5, 2.1)	< 0.001
Hospital costs	$5,764 (5373, 6156)	< 0.001
AMI		
Model	**Absolute Difference (95% CI)**	***P* value**
30-day mortality	-1.8% (-2.1, -1.5)	< 0.001
Hospital costs	$8,117 (7781, 8453)	< 0.001

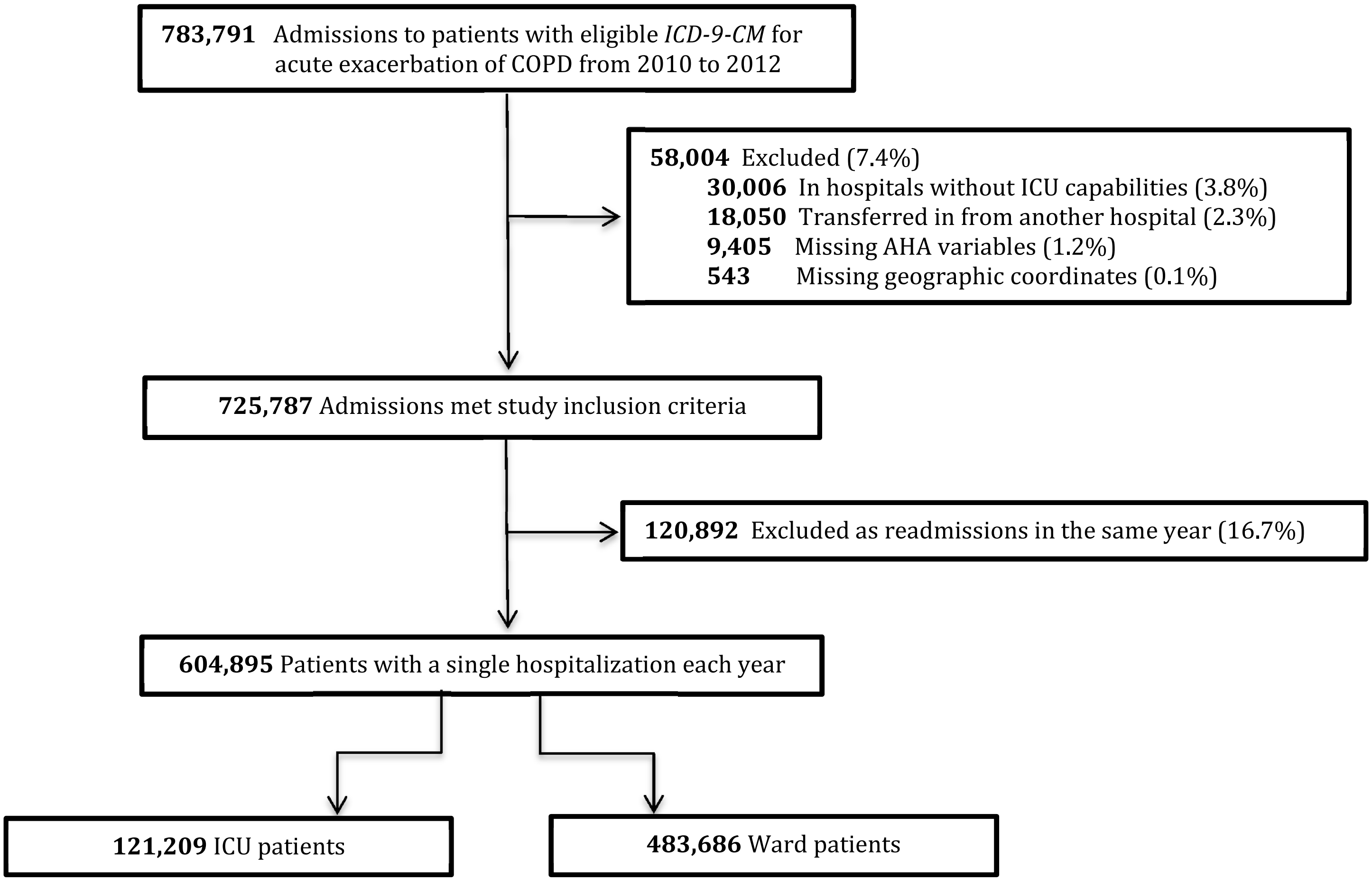
[a] Model adjusted for all variables in tables 1 and 2 in addition to all 29 individual Elixhauser comorbidities. Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six, was defined to include all organ failures numbered 0 to $\geq$ 5. Higher scores indicate more organ failures. Hospital region included the nine U.S. census defined regions. All standard errors for models were adjusted for clustering of patients within hospitals.

eTable 10: Sensitivity analysis[a,b]

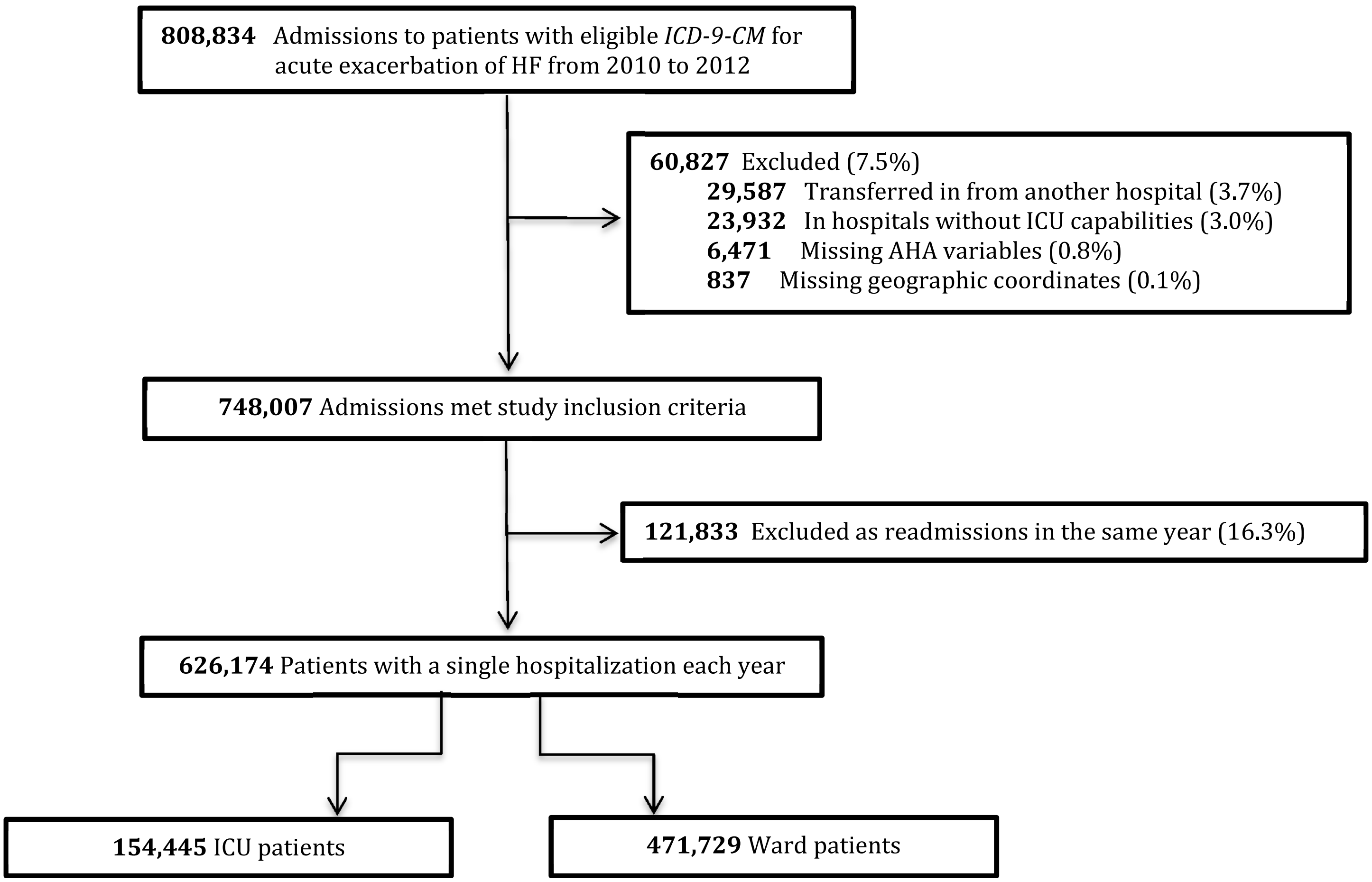
HF (n=708,758)		
Model	**Absolute Difference (95% CI)**	***P* value**
30-day mortality	1.3% (-0.4, 3.1)	0.14
Hospital costs	$2,537 (997,4076)	0.001

[a] Model adjusted for all variables in tables 1 and 2 in addition to all 29 individual Elixhauser comorbidities. Angus organ failure score, which identifies severity of illness by patient organ failures derived from the administrative record with a maximum score of six, was defined to include all organ failures numbered 0 to $\geq$ 5. Higher scores indicate more organ failures. Hospital region included the nine U.S. census defined regions. All standard errors for models were adjusted for clustering of patients within hospitals.
[b] 2-stage least squared regression of all patients using differential distance to nearest high-ICU use hospital as instrumental variable, adjusted for all variables in tables 1 and 2, and for clustering of patients within hospitals

eFigure 1: Study selection criteria/recruitment table for COPD



eFigure 2: Study selection criteria/recruitment table for HF



eFigure 3: Study selection criteria/recruitment table for AMI

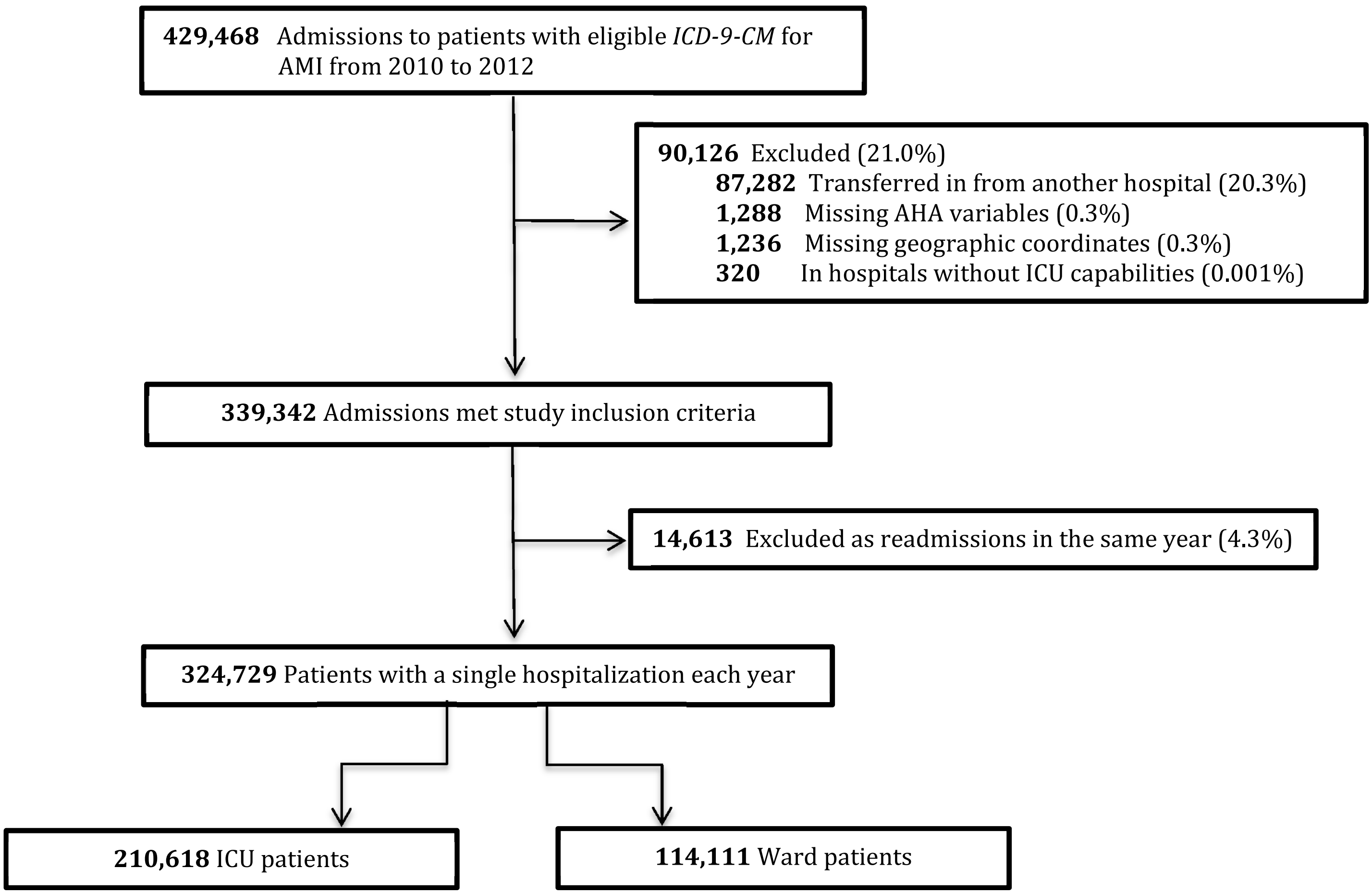


Figure Legend

Figure 1: Estimation of the marginal patient population

For each condition, the marginal patient population was estimated by the method of Newhouse et al.[42] Marginal patients were admitted to the ICU solely because they lived proximally to a high ICU use hospital. After stratifying patients by each condition's median differential distance, patients who were admitted to the general ward, despite living close to a high ICU use hospital, were considered patients who would always be admitted to the general ward, regardless of hospital. Patients who were admitted to the ICU, despite living far from a high ICU use hospital, were considered patients who would always be admitted to the ICU, regardless of hospital. The difference between these two groups provides the estimated marginal patient population, those who might be admitted to the ICU or to the general ward depending on the hospital.

Figure 1: Estimation of the marginal patient population