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Effects of Changes in ICU Bed Supply on ICU Utilization

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Abstract

Background: The availability of intensive care unit (ICU) beds may influence demand for critical care. Although small studies support a model of supply-induced demand in the ICU, there is a paucity of system-wide data.

Objective: To determine the relationship between ICU bed supply and ICU admission in United States hospitals.

Research Design: Retrospective cohort study using all-payer inpatient records from Florida, Massachusetts, New Jersey, New York, and Washington from 2010–2012, linked to hospital data from Medicare's Healthcare Cost Reporting Information System.

Subjects: Three patient groups with a low likelihood of benefiting from ICU admission—low severity patients with acute myocardial infarction (AMI) and pulmonary embolism (PE); and high severity patients with metastatic cancer at the end of life.

Measures: We compared the risk-adjusted probability of ICU admission at hospitals that increased their ICU bed supply over time to matched hospitals that did not, using a difference-in-differences approach.

Results: For patients with AMI, ICU supply increases were associated with an increase in the probability of ICU admission that diminished over time. For patients with PE, there was a trend toward an association between change in ICU supply and ICU admission that did not meet

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statistical significance. For patients with metastatic cancer, admission to hospitals with an increasing ICU supply was not associated with changes in the probability of ICU admission.

Conclusions: Increases in ICU bed supply were associated with inconsistent changes in the probability of ICU admission that varied across patient subgroups.

Keywords

critical care; demand; utilization

INTRODUCTION

Health care spending consumes nearly one-fifth of the annual United States Gross Domestic Product (GDP).¹ Patients admitted to the intensive care unit (ICU) contribute substantially to this spending, with attributable costs exceeding \$100 billion.² Moreover, the number of ICU admissions is rising, creating an urgent need to constrain spending on ICU services while preserving quality.³ Reducing the number of ICU admissions is one way to reduce spending. Some hospitals admit many more patients to the ICU than others, without accompanying differences in risk-adjusted mortality,^{4–9} suggesting the potential to reduce ICU admission rates without harming patients. The use of explicit ICU triage rules to identify patients who are either too well or too sick to benefit is a conceptually appealing solution but is but difficult to do in practice, creating a need for alternative strategies.^{10–13}

An alternative paradigm for reducing ICU admissions is to reduce the availability of ICU beds, relying on a conceptual model of *demand elasticity* in which the ICU bed supply is itself a driver of ICU admission, a concept also known as supply-induced demand.¹⁴ Under demand elasticity, a hospital that builds more ICU beds may see an increase in ICU admission rates but with less efficient use of the ICU. Such a scenario should predictably occur for patients at extremes of the illness severity spectrum (Figure 1) in that patients at very low risk of adverse events are likely to survive regardless of ICU admission while patients with very high illness severity are likely to die regardless of ICU admission.¹⁴ To the extent that ICU admission rates in these patient populations rise following an increase in ICU supply, spending will rise without a concomitant increase in survival, decreasing the value of hospital care.

There is some evidence for demand elasticity in ICU services. Several single-center studies show that, during times of ICU bed scarcity, both low risk and high risk patients are denied ICU admission without a change in overall mortality.^{15–17} Other studies show that increases in ICU bed supply lead to more ICU admissions for less severely ill patients – again without changing outcomes.¹⁸ However, at the system level, there is conflicting evidence for supply-driven ICU admissions, with some studies supporting demand elasticity in neonates and elderly patients with advanced dementia, at least one study showing no association between supply and utilization for Medicare.^{19–21} In concert, these studies suggest that increased availability of ICU beds may drive inefficient use of ICU resources at a local level, although the reproducibility of this finding at the health system level remain unknown.

Determining the extent of demand elasticity in ICU admissions at the system level is essential to predict the potential effects of supply side efforts to reduce health care spending. If demand elasticity is common, policies designed to limit the supply of ICU beds might contain cost growth without harming patients. Such policies might include of certificate-of-need (CON) laws, in which hospitals desiring to expand infrastructure must first seek government permission and demonstrate need. Although there are not currently any CON regulations for the adult ICU bed supply, the absence of CON legislation is associated with expansion and less efficient use of neonatal ICUs.¹⁹ Conversely, if ICU demand is inelastic to supply changes, efforts that constrain the supply of ICU beds could harm patients and fail to control costs.

We sought to examine this issue by evaluating the longitudinal relationship between changes in the ICU supply and the probability of ICU admission for adults with conditions for which ICU admission may not be necessary. Because most of the decreases in ICU supply are due to hospital closures rather than downsizing within hospitals, and because the ICU supply is growing overall, we focused our analysis on the effects of ICU expansion.³ Our approach addresses several limitations in the existing literature. First, many studies examining ICU triage use data from one or only a few hospitals,^{15–17} potentially limiting their generalizability. We used data from multiple hospitals and health systems across different geographic regions, increasing the generalizability of our findings. Second, much of the existing literature is cross-sectional,^{6,7,19} whereas we used a longitudinal approach that enhances our ability to draw inferences about the causal link between supply changes and subsequent changes in utilization.

METHODS

Analytic framework

Using a sample of patients and hospitals from five states, we evaluated the relationship between an increase in the supply of ICU beds and ICU admission rates for different patient populations. We identified cohorts of patients at low risk and high risk of mortality, for whom outcomes were likely to be similar with or without ICU admission. Using propensity scores, we matched hospitals with an increasing ICU supply to similar hospitals with a stable ICU supply. We used a difference-in-differences analysis to evaluate the longitudinal association between an increase in a hospital's ICU bed supply and a change in the probability of ICU admission for these archetypal low and high risk patients. This approach allowed us to directly estimate the degree to which increasing ICU supply contributes to increasing ICU admission rates.

Data sources

We used 2010, 2011, and 2012 patient-level administrative discharge data from the Healthcare Cost and Utilization Project (HCUP), a data warehouse maintained by the United States Agency for Healthcare Research and Quality (AHRQ). We used the all-payer State Inpatient Databases (SID) of Florida, Massachusetts, New Jersey, New York, and Washington. We linked these patient-level data to hospital-level data from Medicare's

Healthcare Cost Report Information System (HCRIS) in order to obtain hospital characteristics in 2010, 2011, and 2012.

Patients

For our archetypal low severity patients we identified patients with a primary discharge diagnosis of acute myocardial infarction (AMI) and pulmonary embolism (PE).^{6,22} Existing data demonstrate variation in ICU admission practices for these patients without associated differences in outcomes, even after adjusting for case mix differences.^{6,7,9} For our archetypal high severity patients, we identified individuals with metastatic cancer who either died in the hospital or were discharged to hospice, using a combination of diagnosis codes²³ and discharge disposition variables. We therefore created three separate patient cohorts and conducted analyses in parallel. Full details of the ICD-9-CM codes used to define patient cohorts and derived variables are available in the Supplemental Digital Content.

In the event of multiple claims in the study period, we randomly selected a single hospitalization to preserve the independence of observations. No patients were excluded for missing data.

Hospitals

We included general, short-stay, acute care hospitals. We excluded hospitals that did not have data in all three years from 2010–2012. We excluded hospitals with fewer than 15 annual admissions for each condition, because ICU admission practices for patients with these conditions in these hospitals were unlikely to be representative of the nation as a whole. For similar reasons, we also excluded hospitals with condition-specific ICU admission rates of less than 5 percent or greater than 95 percent, because such extreme rates indicated that ICU admission decisions for our conditions of interest in these hospitals were not likely to be discretionary.

We used HCRIS data from 2010 and 2011 to define hospital-level changes in the ICU bed supply. We defined hospitals as having an increasing ICU supply if there was both an increase in the absolute number of ICU beds and an increase of at least 1 percent in the proportion of hospital beds that were ICU beds, accounting for the fact that the absolute increase in ICU beds has different supply implications in hospitals of different sizes. We defined hospitals as having stable ICU supply if they had no change in the absolute number or proportion of ICU beds in 2010 and 2011. We excluded hospitals that did not fall into the increasing or stable categories—i.e. those with a very small increase in ICU supply, or those with a decrease in ICU supply.

Variables

The primary dependent variable of interest was a binary indicator of patient-level ICU admission using validated ICU-specific revenue codes.²⁴ We excluded step-down unit codes from this definition (with the exception of Florida, in which the SID data do not distinguish ICUs from step-down units). Patient-level covariates included age, sex, primary insurance payer, race, Elixhauser comorbidities,²⁵ and acute organ failures present on admission.²⁶ For AMI patients, we also included cardiac arrest present on admission,²² presence of

arrhythmias on admission, anterior MI,²² placement of an intra-aortic balloon pump,²⁷ and coronary artery bypass graft (CABG) surgery,²⁷ because we expected that these variables could confound the relationship between changes in the ICU supply and the probability of ICU admission and could reasonably vary over time with changes in case mix. Hospital-level covariates included annual ICU occupancy (ratio of annual ICU bed days to annual available ICU bed days),³ total hospital beds, total ICU beds, teaching status (based on resident-to-bed ratio), ownership, and annual condition-specific hospital case volume.

Analysis

Descriptive Analyses—We characterized differences between hospitals with stable vs. increasing ICU supply, and patients admitted to those hospitals, using standard summary statistics. To reduce the influence of sample size with propensity matching, we compared hospital characteristics using standardized differences.

Creating comparator groups of hospitals—To minimize the influence of differences between hospitals with increasing vs. stable ICU supply, we matched hospitals with an increase in the ICU supply to hospitals with a stable ICU supply using a 1:2 greedy nearest-neighbor propensity score matching algorithm, without replacement. We chose this approach over one using calipers in order to preserve the sample size. We conducted matching separately for each condition of interest, generating three sets of matched hospitals. The dependent variable in the propensity score logistic regression model was an increase in the ICU supply (as defined above), and independent variables included teaching status, ownership, baseline ICU occupancy, hospital size,³ baseline condition-specific hospital volume, and baseline condition-specific ICU admission rate. We excluded hospitals that did not match.

Modeling the Effect of Change in ICU Bed Supply on ICU Admission—We used a difference-in-differences approach to compare the change in probability of ICU admission over time between hospitals with an increasing versus stable ICU supply. We fit a logistic regression model with ICU admission as the dependent variable, and admission year, supply category (stable or increasing), and the interaction between admission year and supply as the independent variables of interest, accounting for clustering within hospitals and matching groups. Next, we fit a similar model including patient- and hospital-level covariates to account for the possibility that variation in case mix and hospital characteristics could confound the relationship between a change in ICU supply and the probability of ICU admission. Patient-level covariates included age, sex, race, primary payer, admission source, comorbidities, and organ failures at admission. For patients with AMI, we also included indicators for cardiac arrest, IABP insertion, anterior MI, arrhythmias, and CABG. Hospital-level covariates included baseline ICU occupancy, baseline total hospital beds, baseline total ICU beds, annual condition-specific hospital volume, and hospital teaching status, because these variables remained imbalanced after matching.

In these models, the coefficient for the interaction term between admission year and supply is the “difference-in-differences” estimator (λ) and is the test of significance for the association between an increase in the ICU supply and change in ICU admission over time.

Graphical Representation of Changes in Probability of ICU Admission—To

visualize trends in the predicted probability of ICU admission over time across the hospitals with increasing and stable ICU supply, we graphed the hierarchical logistic regression marginal predicted probabilities of ICU admission from 2010 to 2012.

Sensitivity Analyses—We performed several sensitivity analyses to evaluate assumptions in our approach; details of the methods for the sensitivity analyses are available in the Supplemental Digital Content.

We performed all analyses using Stata version 15.0 (College Station, TX). The use of de-identified patient-data for this study was reviewed and approved by the Office of Human Research Protections (PRO11060584).

RESULTS

We identified 577 short-stay acute care hospitals with HCRIS data from 2010–2012. Of these, 49 met our definition of an increase in ICU supply from 2010 to 2011, and 295 met our definition of a stable ICU supply from 2010 to 2011 (see sFigure 1 in Supplemental Digital Content, which provides detail of hospital selection). Of the 49 hospitals with an increase in ICU supply, 18 were excluded for low case volumes and aberrantly high or low ICU admission rates, leaving 31 hospitals with increasing supply. Hospitals with an increase in the ICU supply were larger, with more ICU beds and higher case volumes, compared to hospitals with a stable ICU supply (see sTable 1 in the Supplemental Digital Content). After matching, these differences were smaller but still present (Table 1).

Within the 31 hospitals with an increase in ICU supply, there were 32,450 admissions for AMI, 8,058 admissions for PE, and 11,728 admissions for patients with metastatic cancer that died or were discharged to hospice across the entire study period. We matched the 31 hospitals with an increase in ICU supply to three sets of 62 control hospitals with a stable ICU supply from 2010 to 2011; within these control hospitals there were 48,724 admissions for AMI, 12,685 admissions for PE, and 18,569 admissions for patients with metastatic cancer that died or were discharged to hospice. With few exceptions, the case mix of patients within each condition was similar across both sets of hospitals (see sTables 5–10 in the Supplemental Digital Content). Most notably, patients with AMI admitted to hospitals with an increasing ICU supply were more likely to be transferred in from outside hospitals (20.0% vs. 13.9%, $p<0.001$), and to undergo CABG (8.3% vs. 6.5%, $p<0.001$).

The pattern of changes in the probability of ICU admission associated with changes in the ICU supply differed across the three conditions (Table 2, Figure 2). For patients with AMI, an increase in the ICU supply was associated with an increase in the probability of ICU admission in 2011, followed by a return toward the control trend in 2012. For patients with PE, there were increases in the probability of ICU admission in both 2011 and 2012 in unadjusted analyses (see sTable 11 in Supplemental Digital Content), though these coefficients were not statistically significant in adjusted analyses. Among patients with metastatic cancer who either died in the hospital or were discharged to hospice, changes in ICU supply were not associated with changes in the probability of ICU admission over time.

Detailed results of sensitivity analyses are available in the Supplemental Digital Content. Quarterly trends in ICU admission during 2010 were similar in hospitals with stable vs. increasing supply (sTable 12 and sFigure 2). Results of the primary analysis were similar after excluding patients receiving mechanical ventilation (sTable 13) or excluding baseline occupancy from the covariates (sTable 14). Matching hospitals within calipers resulted in lower standardized differences (see sTables 2–4). In this smaller subset of hospitals, the increase in ICU admissions for patients with AMI was no longer significant in 2011, and the rate fell below control trend in 2012; results for PE and cancer were similar to the primary analysis (sTables 15–17).

DISCUSSION

Using a difference-in-differences approach comparing hospitals with increasing ICU supply to hospitals with a stable ICU supply, we found that an increase in the ICU supply is associated with longitudinal changes in the probability of ICU admission that vary by patient population.

In patients with AMI, we found an association between an expansion of the ICU supply and a transient increase in the probability of ICU admission, followed by a return toward baseline ICU admission rates. These findings are consistent with a model of supply-induced demand, at least in the first year. The attenuation in the relationship between ICU supply and ICU admission rates seen in the second year, and the shift in results in a sensitivity analysis, suggest that demand elasticity in critical care services may not be permanent, even when it does occur. It is possible that over time, the same factors that contribute to a hospital's decision to expand the ICU lead to "crowding out" of discretionary AMI admissions by patients with other diagnoses and higher priority indications for ICU admission.

We found a trend toward an association between changes in the ICU supply and ICU admission rates for patients admitted with PE. There is wide variation in the use of ICU resources for patients with PE,⁶ and our results suggest that this variation may be due both to the availability of ICU beds and to local practice patterns that are independent of the availability of ICU beds—for example, the local use of catheter-directed thrombolytic interventions.²⁸ Clinical guidelines do not make strong recommendations regarding the use of thrombolytic therapy in intermediate-risk PE patients (for whom mortality is generally <5%).²⁹ In the absence of strong guideline recommendations for use of an invasive procedure, triage and treatment decisions may result in significant variation in ICU admission rates that are independent of the ICU supply.

The lack of an association between the expansion of the ICU supply and reduction in ICU admission for patients with metastatic cancer at the end of life is inconsistent with a model of supply-induced demand. This finding does not prove that supply-induced demand does not exist, but instead shows that regardless of whether it exists, competing factors may overshadow it at least in high-illness severity patients. One possibility is that hospitals facing ICU capacity constraints not only expanded their ICU bed supply but also undertook other efforts to keep patients with end-stage malignancy out of the ICU. For example, more comprehensive palliative care programs that proactively elicit patient preferences and

anticipate treatment options in advance of clinical deterioration may allow patients who are at the end of life to remain outside the ICU when that is most consistent with their wishes.³⁰ To the extent that such an approach achieves better alignment of patient preferences and treatment received, hospitals and health systems could realize both cost savings and higher quality end-of-life care.³¹

The inconsistency of demand elasticity in our results is important in light of recent observational data suggesting that increased ICU utilization may confer a clinical benefit in certain patient populations but not in others.^{9,21,32} If demand elasticity operated consistently across patient populations, then constraining the growth of the ICU supply could create a tradeoff involving overall reductions in inefficient ICU admissions along with some reduction in potentially beneficial ICU admissions. However, inconsistent demand elasticity could create mismatched changes in utilization that lead to continued inefficient admissions and reductions in beneficial admissions, or vice versa—making it difficult to predict the impact of supply constraints on overall cost growth and patient outcomes. Consequently, health policy makers seeking to constrain ICU spending while preserving quality may need to seek alternatives to broad-based regulation of the construction of ICU beds.

Our results should be interpreted in the context of several potential limitations. First, we used administrative data that are subject to potential coding error, although the outcome of interest, ICU admission, is well validated in administrative data.²⁴ Second, because of our strict definition of an expansion in the ICU supply, we analyzed a relatively small number of hospitals. We explicitly designed our study to detect the “efficacy” of hospital-level changes in the ICU supply and felt this tradeoff was necessary in order to reduce the chances that negative findings simply represented an insufficient “dose” of ICU expansion. Despite the small sample size, we found statistically significant associations between ICU supply changes and ICU admission practices, and the confidence intervals were relatively narrow, meaning that a larger sample would likely only increase power to detect small changes of uncertain clinical significance. Third, we did not explicitly analyze intermediate care or “step-down” unit supply or admissions; these are heterogeneous entities with complex interactions with the ICU, and a full analysis of this issue is beyond the scope of our work.^{33,34} Fourth, we analyzed three medical conditions; for some other conditions, such as pneumonia, increases in ICU admission are associated with better outcomes,³² such that changes in utilization may not represent demand elasticity, making it difficult to interpret either positive or negative findings in our study. Ultimately, including additional cohorts would not likely change the conclusion that demand elasticity operates inconsistently across the health system. Fifth, we focused on the relationship between ICU supply changes and ICU admission practices rather than patient outcomes, and a true analysis of whether our observed ICU use represents appropriate use^{9,32} is outside the scope of this study. Finally, while we used propensity scores and multivariable risk adjustment, some differences in hospitals persisted, making it possible that residual confounding by unobserved differences between hospitals that did and did not expand their ICU supply contributed to observed changes in the probability of ICU admission.

CONCLUSIONS

Using a difference-in-differences approach comparing hospitals that did and did not expand their ICU supply, we found mixed effects of an increase in the ICU supply on the probability of ICU admission for patients at low risk and high risk of mortality. Our findings do not support a model of widespread and persistent demand elasticity in hospitals that build new ICU beds. Policymakers seeking to reduce inefficient ICU utilization and rising costs may need to identify alternatives to simply constraining the construction of new ICU beds.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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		Survival	
		Yes	No
Illness severity	High	<p>Target ICU population</p>	<p>HIGH BED AVAILABILITY</p> <p>Increased ICU admissions</p> <hr/> <p>LOW BED AVAILABILITY</p> <p>Decreased ICU admissions</p>
	Low	<p>HIGH BED AVAILABILITY</p> <p>Increased ICU admissions</p> <hr/> <p>LOW BED AVAILABILITY</p> <p>Decreased ICU admissions</p>	<p>Rare occurrence</p>

Figure 1. Conceptual model of demand elasticity in the ICU.

The target population for the ICU is patients with relatively high severity of illness who will survive with appropriate ICU interventions. Less efficient use of the ICU occurs for patients in the lower left quadrant, who are less ill and likely to survive regardless of ICU admission; and for patients in the upper right quadrant, who are severely ill at the end of life and likely to die regardless of ICU admission. Reproduced with permission from Gooch and Kahn, JAMA 2014.

Figure 2. Changes in ICU admission in association with increases in ICU supply.

Hospitals with an increase in ICU supply from 2010 to 2011 are represented by black solid circles and black solid lines. Comparison hospitals with a stable ICU supply from 2010 to 2011 are represented by grey open circles and grey lines. Vertical dashed black lines demarcate the baseline year (2010) from the first year with an increase in ICU supply (2011). Following an increase in the ICU supply, there was an increase in risk-adjusted ICU admissions for patients with acute myocardial infarction that attenuated over time (AMI, panel A), trend toward increases in risk-adjusted ICU admissions for patients with pulmonary embolism (PE, panel B), and no change in risk-adjusted ICU admissions for patients with metastatic cancer at the end of life (Panel C).

Table 1.

Hospital Characteristics in 2010, matched sample

N Hospitals	Case hospitals: increasing ICU supply 31	AMI 62	Control hospitals: stable ICU supply				Standard Difference
			Standard Difference	PE 62	Standard Difference	Cancer 62	
AMI propensity score	0.40 (0.22)	0.25 (0.17)	0.33				
AMI case volume 2010	353 (260)	268 (209)	5.7				
AMI ICU admission rate 2010	0.55 (0.17)	0.57 (0.18)	0.05				
PE propensity score	0.42 (0.25)			0.23 (0.16)	0.42		
PE case volume 2010	90 (60)			68 (41)	3.2		
PE ICU admission rate 2010	0.24 (0.14)			0.27 (0.18)	0.08		
Cancer propensity score	0.42 (0.22)					0.26 (0.16)	0.36
Cancer case volume 2010	124 (72)					99 (70)	3.0
Cancer ICU admission rate 2010	0.30 (0.10)					0.31 (0.11)	0.01
Total ICU beds 2010	70 (52)	40 (31)	4.6	40 (29)	4.7	37 (30)	5.1
Total hospital beds 2010	389 (197)	330 (186)	4.2	309 (161)	5.9	313 (191)	5.4
ICU proportion 2010	0.17 (.08)	0.12 (0.05)	0.19	0.12 (0.05)	0.17	0.11 (0.05)	0.21
ICU occupancy 2010	0.79 (0.18)	0.73 (0.14)	0.17	0.71 (0.15)	0.21	0.72 (0.15)	0.19
ICU beds 2010–11	13 (11)	0 (0)		0 (0)		0 (0)	
ICU proportion 2010–11	0.04 (0.03)	0 (0)		0 (0)		0 (0)	
Non-profit ownership	25 (81%)	48 (77%)	0.07	47 (76%)	0.10	50 (81%)	0
Large teaching hospital	15 (48%)	15 (24%)	0.41	17 (27%)	0.35	17 (27%)	0.35

Data are reported as mean (+/- standard deviation) for continuous variables and N (%) for categorical variables.

Standardized differences are for comparisons between hospitals with stable vs. increasing ICU supply for each condition.

Abbreviations: AMI acute myocardial infarction; PE pulmonary embolism; ICU intensive care unit.

Table 2.

Association between changes in ICU supply and risk-adjusted ICU admission rates

	Year	Case hospitals with increasing ICU supply	Control hospitals with stable ICU supply			
		Adjusted ICU Rate	Adjusted ICU Rate	aOR for DiD	95% CI	P
AMI	2010	0.555	0.557	--	--	--
	2011	0.567	0.534	1.20	1.10 – 1.31	<0.001
	2012	0.539	0.523	1.09	1.01 – 1.19	0.03
PE	2010	0.231	0.229	--	--	--
	2011	0.224	0.203	1.14	0.95 – 1.38	0.16
	2012	0.217	0.191	1.20	0.99 – 1.44	0.06
Cancer	2010	0.277	0.297	--	--	--
	2011	0.273	0.300	0.96	0.83 – 1.11	0.59
	2012	0.271	0.298	0.96	0.84 – 1.11	0.61

ICU: intensive care unit; DiD: difference-in-differences; aOR: adjusted odds ratio; AMI: acute myocardial infarction; PE: pulmonary embolism