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ICU Occupancy and mechanical ventilator use in the United States

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Abstract

Objectives—Detailed data on occupancy and use of mechanical ventilators in United States intensive care units (ICU) over time and across unit types, are lacking. We sought to describe the hourly bed occupancy and use of ventilators in US ICUs to improve future planning of both the routine and disaster provision of intensive care.

Design—Retrospective cohort study. We calculated mean hourly bed occupancy in each ICU and hourly bed occupancy for patients on mechanical ventilators. We assessed trends in overall occupancy over the three years. We also assessed occupancy and mechanical ventilation rates across different types and sizes of ICUs.

Setting—97 US ICUs participating in Project IMPACT from 2005–07.

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Patients—226,942 consecutive admissions to ICUs.

Interventions—None.

Measurements and Main Results—Over the three years studied, total ICU occupancy ranged from 57.4% to 82.1% and the number of beds filled with mechanically ventilated patients ranged from 20.7% to 38.9%. There was no change in occupancy across years and no increase in occupancy during influenza seasons. Mean hourly occupancy across ICUs was 68.2% SD ± 21.3, and was substantially higher in ICUs with fewer beds (mean 75.8% (± 16.5) for 5–14 beds versus 60.9% (± 22.1) for 20+ beds, $P = 0.001$), and in academic hospitals (78.7% (± 15.9) versus 65.3% (± 21.3) for community not-for profit hospitals, $P < 0.001$). More than half (53.6%) of ICUs had 4+ beds available more than half the time. The mean percentage of ICU patients receiving mechanical ventilation in any given hour was 39.5% (± 15.2), and a mean of 29.0% (± 15.9) of ICU beds were filled with a patient on a ventilator.

Conclusions—Occupancy of US ICUs was stable over time, but there is uneven distribution across different types and sizes of units. Only three out of ten beds were filled at any time with mechanically ventilated patients, suggesting substantial surge capacity throughout the system to care for acutely critically ill patients.

Keywords

Intensive Care Unit; Bed Occupancy; Mechanical Ventilation; United States

Introduction

The occupancy of US intensive care units (ICUs) dictates care decisions for patients under routine circumstances and also has implications for disaster planning (1, 2). The United States has more intensive care unit (ICU) beds – approximately 20 per 100,000 population – than most other nations (3), and the number of ICU beds in the country has steadily increased over time (4, 5). Despite an overall occupancy estimated at 68% in 2005, many clinicians and policymakers, and perhaps even patients, perceive that the supply of US ICU beds is still insufficient to meet normal temporal variation in critical care demand (6). Such views are bolstered by reports of how limited bed availability may influence care decisions and concern regarding the associated outcomes (7–9).

The apparent need to triage patients under “routine” conditions suggests that a large increase in ICU beds and mechanical ventilators may be needed to accommodate surges in critical care demand brought on by mass casualties or epidemics. However, specific data to guide disaster planning have been limited. A recent taskforce on disaster planning estimated that fewer than 70% of occupied ICU beds were filled by patients requiring mechanical ventilation at any one time, but more precise estimates were not available (10, 11). Furthermore, it is unknown what proportion of admitted patients in US ICUs need ICU beds immediately (e.g., patients with respiratory failure) or might have their admissions deferred (e.g., planned admissions for patients following elective surgeries) under situations of unexpected need.

Current estimates of occupancy are also limited in that they do not consider potential variation in utilization patterns across ICUs of different type or size. Perhaps most importantly, robust data are lacking regarding the utilization of mechanical ventilators in the US. All of these details are essential to understanding the flexibility of a system composed of many ICUs. Therefore, to inform decisions on how best to plan for normal variation in critical care demand and to guide regional and national disaster planning (12), we sought to provide estimates of ICU bed occupancy across ICU types, use of mechanical ventilators, and to determine the proportion of ICU beds used for elective surgical admissions across a representative sample of US ICUs.

Methods

Study Design & Data Source

We designed a cohort study in a large national sample of US ICUs to determine, (1) the proportion of ICU beds in use during each hour (2) the proportion of patients and beds requiring mechanical ventilators during each hour, and (3) the number and proportion of ICU admissions in a given 24-hour period that might be defered in the event of a mass casualty or other surge in demand. The study used a specially prepared version of the Project IMPACT database (Cerner Corporation, Kansas City Missouri) that included date and time stamps for admission and discharge information. Project IMPACT is a registry of patients admitted to US ICUs that contains detailed clinical and process-of-care data (13).

Patient Selection

We included patients admitted to participating US ICUs that contributed data for at least three consecutive months from January, 2005 through December, 2007, the latest three full years for which data were available. Admission and discharge data were collected for all patients admitted during the study period to all ICUs. This information included ICU admission and discharge dates/times for every ICU admission. For more detailed clinical data on patients, some ICUs chose to collect these additional clinical data on a randomly selected (50% or 75%) sample of patients. Severity of illness was measured using the Mortality Probability Model on ICU admission (MPM_0-III) (14).

Analysis of bed use

We calculated occupancy/available beds for each hour of each day in the ICU by counting patients who were in the ICU on the first minute of each hour. For the 9.8% of patients who were missing a date or time of ICU discharge, we imputed these values based on the mean length of stay of patients in that individual ICU. We defined bed use (occupancy) as the percentage of beds in use out of the total number of “operational beds” as reported by each ICU. Operational beds are defined in Project IMPACT as “the total number of licensed ICU beds in your unit for which you maintain nursing staff and which are considered operational.”

We assessed the use of ICU beds across ICUs in three different ways. First, we examined occupancy in terms of the total “system” of ICUs by calculating percent occupancy as the total number of occupied ICU patients in the cohort in a given hour divided by the total number of operational ICU beds that hour. We used this approach to assess temporal trends in overall ICU occupancy during the three years of the study. We show this graphically with plots of all hourly data (Figure 1), accompanied by the moving weekly averages over the study period. To test for significant differences in occupancy over time, we created linear regression models clustered on ICU using the sandwich variance estimator and regressed hourly occupancy data on calendar year, which was modeled as a continuous variable. We also assessed differences in occupancy by day of the week (weekday versus weekend), and examined occupancy during days within the probable influenza seasons (December 1–March 31 of each year).

Second we calculated the mean hourly occupancy for each ICU, and summarized these data by presenting the mean (standard deviation (± SD)) and median (with interquartile range (IQR)) of these ICU-specific means across all ICUs. We explored variation in mean and median occupancy among hospital types (grouped as university affiliated, community not-

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for profit, community for-profit, or government), ICU types (grouped as medical, surgical, mixed, or cardio-thoracic), and ICU size (grouped as 5–14, 15–19, and 20+ beds, with groupings based on inspection of the distribution of ICU sizes and occupancies). To assess statistical differences between ICU and hospital types, we used linear regression clustered on ICU using the sandwich variance estimator, with ICU and hospital types and size as categorical variables. Third, we examined individual ICUs to determine the percentage of hours each ICU had 0, 1, 2, 3 or 4+ open beds, and the percentage of hours with different rates of occupancy (e.g., < 50% or > 90%). For units that reported periods of > 100% occupancy, we assigned zero available beds for those hours.

Mechanical ventilation

We used start and stop times as well as dates for invasive mechanical ventilation to calculate whether each patient was mechanically ventilated each hour of their stay in the ICU. As for the proportion of beds occupied by a mechanically ventilated patient, we counted patients who were mechanically ventilated on the first minute of each hour. We then determined the percentage of mechanically ventilated patients in each ICU for each hour. We calculated the percentage of operational ICU beds occupied by patients requiring mechanical ventilation each hour and calculated the mean (± SD) and median (IQR) hourly proportions. When randomly selected samples were used for data collection of clinical data (including mechanical ventilation information), we generated ICU-level estimates by multiplying the percentages generated using only the sampled patients by the total number of patients (with or without clinical data) present during that hour.

Frequency and type of admissions to ICU

We examined the daily frequency and type of admissions for all ICUs as well as stratified by ICU and hospital characteristics. We specifically sought to determine how many patients admitted to the ICU might be considered “discretionary” admissions where the patient could be taken care of as well outside of the ICU, or the need for an ICU bed could be avoided by appropriate upstream planning, as opposed to patients who would clearly require ICU admission regardless of bed availability. We explored two potential groups: (1) patients admitted with comfort care or withdrawal of care orders in place at the time of admission, who were therefore unlikely to require the level of organ support available in the ICU or (2) patients designated as “elective” surgical admissions where the surgery itself could be cancelled in the face of increased demand for ICU beds. Project IMPACT defines admitted with comfort care or withdrawal of care orders in place at the time of admission as the following: “this applies to situations in which therapy already in place is being withdrawn or removed. This may include any OR all of the following: removal from vent support, removal of pressors, stopping of dialysis and/or stopping of other therapeutic measures. This does not mean that the patient will have died, but that therapies were terminated. Frequently this may be indicated by the Comfort Measures Only designation”. We defined elective surgical patients as those patients designated as having elective surgery and *also* were directly admitted to the ICU from either an operating room or recovery room. In a secondary analysis, we also examined medical patients initially admitted for purposes of observation rather than treatment. (15, 16) Patients in each of these categories were identified based on variables in the Project IMPACT database that were collected for each patient on admission to ICU.

Supplemental Analyses

We performed three supplemental analyses (eTable 2). First, to test the possibility that imputing missing discharge dates or times could introduce bias, we excluded any ICU with missing ICU discharge date and time for > 1% of admissions. This resulted in exclusion of 27 ICUs (28%).

Second, to validate the number of operational beds, we sent emails, followed up by phone calls, to ICU site administrators. We received confirmation from 49 of the 97 ICUs (51%). Of these, 11 (22.4% of the confirmed group) reported a different number of beds than was reported in the dataset. These were evenly split between updating reports to higher (n = 6) and lower (n = 5) bed numbers. Updated bed numbers were used in primary analyses, and we performed a secondary analysis restricted to the 49 ICUs with confirmed bed numbers. Finally, we repeated the occupancy analysis by defining a bed as occupied for an hour after a patient's discharge to account for the possibility that a bed would not immediately be available for use by another patient. Database management and statistical analyses were performed using Excel (Microsoft, Redmond, WA), Stata 12 (StataCorp LP, College Station, Texas, USA), and SAS 9.1.3 (SAS Institute, Carey, NC, USA). This study was considered exempt from review by the University of Pennsylvania Institutional Review Board.

Results

The cohort consisted of 226,942 patients admitted to 97 ICUs from January 1, 2005 through December 31, 2007 (Table 1). Majorities of patients were male, Caucasian, and were admitted for medical rather than post-surgical reasons. The mean age was 59.8 (± 18.3). Patients' average MPM_0-III predicted probability of death was 13.9%, their observed hospital mortality was 14.1%, and they had a median ICU length of stay of 2.0 days (IQR 1.0–3.9).

Overall Occupancy

The percentage of all ICU beds in the cohort occupied by ICU patients in any given hour ranged from 57.4% to 82.1%, and the percentage filled with mechanically ventilated patients ranged from 20.7% to 38.9% over the three years (Figure 1). Mean hourly occupancy did not change over the three years from 68.2% (± 21.3) in 2005 to 70.4% (± 22.8) in 2007 ($P = 0.25$) (eTable 1). There was small weekday/weekend variation (mean 69.1% (± 21.3) on weekdays versus 66.6% (± 21.4) on weekends, $P < 0.001$). We also examined overall occupancy during historical influenza seasons (1 December–March 31) versus non-influenza seasons (1 April – November 30), and contrary to our hypothesis, found slightly higher occupancy in non-influenza season (mean 69.6% (± 22.2)) than in influenza season (mean 67.2% (± 22.1)) ($P < 0.001$).

Individual ICU Occupancy

The mean hourly occupancy for ICUs was 68.2% ± 21.3, with a median of 74.6% (IQR 53.4–86.1%, and full range of 17.4% to 109.0%) (Figure 2; eTable 2). There was variation in mean hourly occupancy across ICU types, from 62.9% (± 21.9) among mixed medical-surgical ICUs to 74.0% (± 17.6) among surgical ICUs ($P = 0.036$). Smaller ICUs had higher mean occupancy (75.8 ± 16.5%) for ICUs with 5–14 beds, versus 60.9 ± 22.1% for ICUs with 20+ beds, $P < 0.001$). ICUs in academic hospitals had the highest mean occupancy (78.7% (± 15.9)). All supplemental analyses yielded similar estimates of overall occupancy (eTable 3).

There was considerable variation in hourly bed availability across ICUs (Figure 3). Most ICUs 52 (53.6%) had ≥ 4 beds available at least 50% of the hours (light yellow), whereas only 5 (5.2%) ICUs had no beds available more than half of the hours (dark grey). Comparable assessments of hourly occupancy rate (instead of open beds), yielded similar variations across ICUs (eFigure 1).

Use of mechanical ventilation

A mean of 39.5% (± 15.2) of ICU patients were mechanically ventilated in any given hour (eTable 4). Patients in mixed medical-surgical ICUs were the least likely to be receiving mechanical ventilation (36.4% (± 14.1)) and patients in surgical ICUs the most likely (46.7% (± 14.4), $P = 0.012$). ICUs in academic hospitals had the highest percentage of mechanically ventilated patients each hour (50.8% (± 13.5)).

At any time, 29.0% (± 15.9) of ICU beds were occupied by patients receiving mechanical ventilation (Figure 4; eTable 4). This ranged from a mean of 24.5% (± 15.3) in units with 20+ beds to 33.8% (± 15.7) of patients in units with 5–14 ICU beds, $P = 0.004$. ICUs in academic hospitals again had the highest percentage of beds filled with a patient requiring mechanical ventilation (mean 41.0% (± 15.3)).

Daily and potentially discretionary admissions

ICUs had a mean of 3.0 (± 1.5) admissions daily (Table 2). Smaller ICUs admitted fewer patients per day (mean 2.1 (± 1.3) admissions for ICUs with 5–14 beds versus 4.2 (± 1.6) admissions for ICUs with 20+ beds, $P < 0.001$) and there were otherwise no large differences between types of units regarding admissions. Very few patients (< 0.1%) were admitted to ICUs with orders already in place for withdrawal of care or comfort care. However, 18.1% were admitted directly to the ICU after elective surgery and an additional 34.5% were medical patients admitted for observation (eTable 5).

Discussion

In providing national estimates of real-time ICU occupancy and mechanical ventilator use in the US, this study yields four primary findings. First, at any given time, approximately two thirds of ICU beds are occupied, and approximately one third of these beds are occupied by patients requiring mechanical ventilation. These results suggest greater excess capacity in the US critical care supply than many have imagined. Second, this excess in critical care supply is increased if one considers the large proportion of potentially "discretionary admissions". Third, there appears to be little seasonal variation in critical care occupancy or mechanical ventilator use. This should facilitate local planning for the provision of routine critical care, and regional or national planning for mass casualties, by suggesting that seasonal contingencies need not be considered.

Finally, we found considerable variation in occupancy across ICUs. In particular, our data support many clinicians' perceptions that ICU bed allocation decisions are common in academic medical centers, where ICUs tend to operate at significantly higher occupancy rates. Although the high volume and expertise clustered in academic centers may be beneficial for patients on average (17), these units may be less able to safely accommodate sudden increases in critical care demand. This raises the possibility that when these units are near capacity, individual patients may be better served in one of the many available beds elsewhere.

The likelihood that a given patient will have a requested ICU admission delayed or refused is a function of both occupancy and the total number of beds in the system (18). One unexpected finding was that smaller ICUs in our cohort tended to have higher occupancy rates than did larger ICUs. Queuing theory suggests that ICUs with more beds can operate at higher occupancy than can ICUs with fewer beds while maintaining the same probability of a delayed admission (i.e., a bottleneck) (18, 19). However, we found that the opposite pattern occurs in US ICUs. These results suggest that regional reallocation of critical care beds, without increasing the total supply of beds, may reduce the odds of delayed or deferred ICU admissions in both surge and non-surge situations. Implementation of improved and formalized triage and transfer systems, such as are used in some other countries (20), might also promote efficiency.

Prior studies have assessed daily occupancy using billing data, but with little distinction among types of ICUs, and without detailed information on the use of mechanical ventilation. For example, administrative data does not capture patients' exact duration of mechanical ventilation (21). This may account for the differences between our estimates of the use of mechanical ventilators in US ICUs in comparison to estimates that have guided disaster planning to date (10). Our data suggest that the number of appropriately trained staff to care for these patients and manage their ventilators is far more likely to be the limiting factor than is the availability of fixed resources such as ICU beds or ventilators in the provision of critical care in the US during mass casualties (22, 23).

Recent evidence from Canada showed that patients experiencing sudden clinical deterioration on a hospital floor when fewer (or no) ICU beds were available were more likely to receive palliation instead of ICU admission, but were not more likely to die (1). This suggests that some patients who are admitted to the ICU when beds are plentiful may be too sick to benefit from intensive care (24). There are also many patients admitted to ICUs in the US who may be too well to benefit (25), as evidenced by hospitals admitting many patients with a low predicted risk of death (≤ 2%) (26). Our study complements these findings in showing that up to a third of patients admitted to ICU beds might be considered discretionary admissions. Among these, elective surgical patients represent the clearest group for potential deferral or diversion during mass casualties. We also considered medical patients admitted for observation as a potentially discretionary group because only 10–15% of such patients eventually require active treatment (15, 16).

Our study has limitations. ICUs in this study did not cluster geographically in a way that permits determination of the slack present within a given local area or region. Thus, although Project IMPACT provides the best available data for estimating national ICU occupancy and ventilator use, we cannot assess how ICU occupancy is balanced across ICUs within a small geographic area. Moreover, data suggest that ICU beds are not distributed equally in the US based on the underlying population in a given region (27). Prudent use of inter-hospital transfers (28), and of ICU beds within a hospital or local area may promote more efficient use of the system's existing capacity (29).

Although Project IMPACT comprises a large and diverse sample of US ICUs – including ICUs in 35 states and the District of Columbia – it is not a random sample (30). In particular, the ICUs are skewed towards larger, academic ICUs compared with the country as a whole. (23) Given that academic ICUs were more likely to operate at higher occupancy, and with a greater proportion of patients mechanically ventilated, this means we have likely erred on the side of overestimating both occupancy and use of mechanical ventilators. The higher occupancy in academic ICUs compared with other types of ICUs also suggests that studies that solely involve academic ICUs may provide skewed estimates of use of mechanical ventilation and bed pressure.

A few ICUs reported very high occupancy rates, including rates greater than 100%. Although we cannot establish why these numbers arose, we speculate these are high-occupancy units that also commonly "board" patients in other parts of the hospital (31). We also cannot be certain that every ICU bed is equipped to support a patient requiring mechanical ventilation. However, a recent survey of ventilators available in US acute care hospitals found that approximately one (0.96) ventilator existed for every adult ICU bed in the country (32). Finally, the calculated occupancy rates depend on the number of "operational" beds available at any given time. In particular, we found some discrepancies;

for the units where we were able to confirm the number of operational beds, in a small proportion the correct bed numbers were different from the original data in Project IMPACT. Our sensitivity analysis using only ICUs with validated bed numbers yielded very similar calculations of overall occupancy, as well as reported ranges within ICUs, supporting the robustness of our estimates. We cannot rule out the possibility, however, that the units we were unable to contact had systematic errors in reported bed numbers.

Using our occupancy estimates in combination with data regarding the total number of US ICU beds (5), we estimate that there are approximately 20,000 adult ICU beds available at any given time. As this number represents 8.5 available ICU beds per 100,000 adult population, the excess capacity in the US system is greater than the total capacity in many developed countries (3). This study shows that this substantial excess in capacity is consistent over time, and provides explanations for why triage is nevertheless needed in certain institutions; redistributing existing beds from low to high occupancy units may alleviate critical care bottlenecks.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Stelfox HT, Hemmelgarn BR, Bagshaw SM, et al. Intensive care unit bed availability and outcomes for hospitalized patients with sudden clinical deterioration. Arch Intern Med. 2012; 172:467–474. [PubMed: 22412076]
2. Robert R, Reignier J, Tournoux-Facon C, et al. Refusal of ICU Admission Due to a Full Unit: Impact on Mortality. AJRCCM. 201210.1164/rccm.201104-200729OC
3. Wunsch H, Angus DC, Harrison DA, et al. Variation in critical care services across North America and Western Europe. Crit Care Med. 2008; 36:2787–2789. [PubMed: 18766102]
4. Halpern NA, Pastores SM, Thaler HT, et al. Changes in critical care beds and occupancy in the United States 1985–2000: Differences attributable to hospital size. Crit Care Med. 2006; 34:2105–2112. [PubMed: 16755256]
5. Halpern NA, Pastores SM. Critical care medicine in the United States 2000–2005 an analysis of bed numbers, occupancy rates, payer mix, and costs. Crit Care Med. 2010; 38:65–71. [PubMed: 19730257]
6. Truog RD, Brock DW, Cook DJ, et al. Rationing in the intensive care unit. Crit Care Med. 2006; 34:958–963. [PubMed: 16484912]
7. Strauss MJ, LoGerfo JP, Yeltatzie JA, et al. Rationing of intensive care unit services. An everyday occurrence. JAMA. 1986; 255:1143–1146. [PubMed: 3945032]
8. Baker DR, Pronovost PJ, Morlock LL, et al. Patient flow variability and unplanned readmissions to an intensive care unit. Crit Care Med. 2009; 37:2882–2887. [PubMed: 19866504]

9. Sinuff T, Kahnamoui K, Cook DJ, et al. Rationing critical care beds: a systematic review. Crit Care Med. 2004; 32:1588–1597. [PubMed: 15241106]
10. Christian MD, Devereaux AV, Dichter JR, et al. Definitive care for the critically ill during a disaster: current capabilities and limitations: from a Task Force for Mass Critical Care summit meeting, January 26–27, 2007, Chicago, IL. Chest. 2008; 133:8S–17S. [PubMed: 18460503]
11. Devereaux AV, Dichter JR, Christian MD, et al. Definitive care for the critically ill during a disaster: a framework for allocation of scarce resources in mass critical care: from a Task Force for Mass Critical Care summit meeting, January 26–27, 2007, Chicago, IL. Chest. 2008; 133:51S–66S. [PubMed: 18460506]
12. Halpern SD. ICU capacity strain and the quality and allocation of critical care. Curr Opin Crit Care. 2011; 17:648–657. [PubMed: 21986461]
13. Cook SF, Visscher WA, Hobbs CL, et al. Project IMPACT: results from a pilot validity study of a new observational database. Crit Care Med. 2002; 30:2765–2770. [PubMed: 12483071]
14. Higgins TL, Teres D, Copes WS, et al. Assessing contemporary intensive care unit outcome: an updated Mortality Probability Admission Model (MPM0-III). Crit Care Med. 2007; 35:827–835. [PubMed: 17255863]
15. Wagner DP, Knaus WA, Draper EA, et al. Identification of low-risk monitor patients within a medical-surgical intensive care unit. Med Care. 1983; 21:425–434. [PubMed: 6843195]
16. Zimmerman JE, Kramer AA. A model for identifying patients who may not need intensive care unit admission. J Crit Care. 2010; 25:205–213. [PubMed: 19682848]
17. Kahn JM, Goss CH, Heagerty PJ, et al. Hospital volume and the outcomes of mechanical ventilation. N Engl J Med. 2006; 355:41–50. [PubMed: 16822995]
18. Green LV. How many hospital beds? Inquiry. 2002; 39:400–412. [PubMed: 12638714]
19. McManus ML, Long MC, Cooper A, et al. Queuing theory accurately models the need for critical care resources. Anesthesiology. 2004; 100:1271–1276. [PubMed: 15114227]
20. Aylwin CJ, Konig TC, Brennan NW, et al. Reduction in critical mortality in urban mass casualty incidents: analysis of triage, surge, and resource use after the London bombings on July 7, 2005. Lancet. 2006; 368:2219–2225. [PubMed: 17189033]
21. Wunsch H, Linde-Zwirble WT, Angus DC, et al. The epidemiology of mechanical ventilation use in the United States. Critical Care Medicine. 2010; 38:1947–1953. [PubMed: 20639743]
22. Rubinson L, Nuzzo JB, Talmor DS, et al. Augmentation of hospital critical care capacity after bioterrorist attacks or epidemics: recommendations of the Working Group on Emergency Mass Critical Care. Crit Care Med. 2005; 33:2393–2403. [PubMed: 16215397]
23. Angus DC, Shorr AF, White A, et al. Critical care delivery in the United States: distribution of services and compliance with Leapfrog recommendations. Crit Care Med. 2006; 34:1016–1024. [PubMed: 16505703]
24. Wagner J, Halpern SD. Deferred admission to the intensive care unit: rationing critical care or expediting care transitions? Arch Intern Med. 2012; 172:474–476. [PubMed: 22412077]
25. Singer DE, Carr PL, Mulley AG, et al. Rationing intensive care--physician responses to a resource shortage. N Engl J Med. 1983; 309:1155–1160. [PubMed: 6413862]
26. Chen LM, Render M, Sales A, et al. Intensive Care Unit Admitting Patterns in the Veterans Affairs Health Care System. Arch Intern Med. 2012:1–7. [PubMed: 22710831]
27. Carr BG, Addyson DK, Kahn JM. Variation in critical care beds per capita in the United States: implications for pandemic and disaster planning. JAMA. 2010; 303:1371–1372. [PubMed: 20388892]
28. Iwashyna TJ, Christie JD, Kahn JM, et al. Uncharted paths: hospital networks in critical care. Chest. 2009; 135:827–833. [PubMed: 19265091]
29. Gray A, Bush S, Whiteley S. Secondary transport of the critically ill and injured adult. Emerg Med J. 2004; 21:281–285. [PubMed: 15107363]
30. Wunsch H, Angus DC, Harrison DA, et al. Comparison of medical admissions to intensive care units in the United States and United Kingdom. Am J Respir Crit Care Med. 2011; 183:1666–1673. [PubMed: 21471089]

31. Lott JP, Iwashyna TJ, Christie JD, et al. Critical illness outcomes in specialty versus general intensive care units. Am J Respir Crit Care Med. 2009; 179:676–683. [PubMed: 19201923]

32. Rubinson L, Vaughn F, Nelson S, et al. Mechanical ventilators in US acute care hospitals. Disaster Med Public Health Prep. 2010; 4:199–206. [PubMed: 21149215]

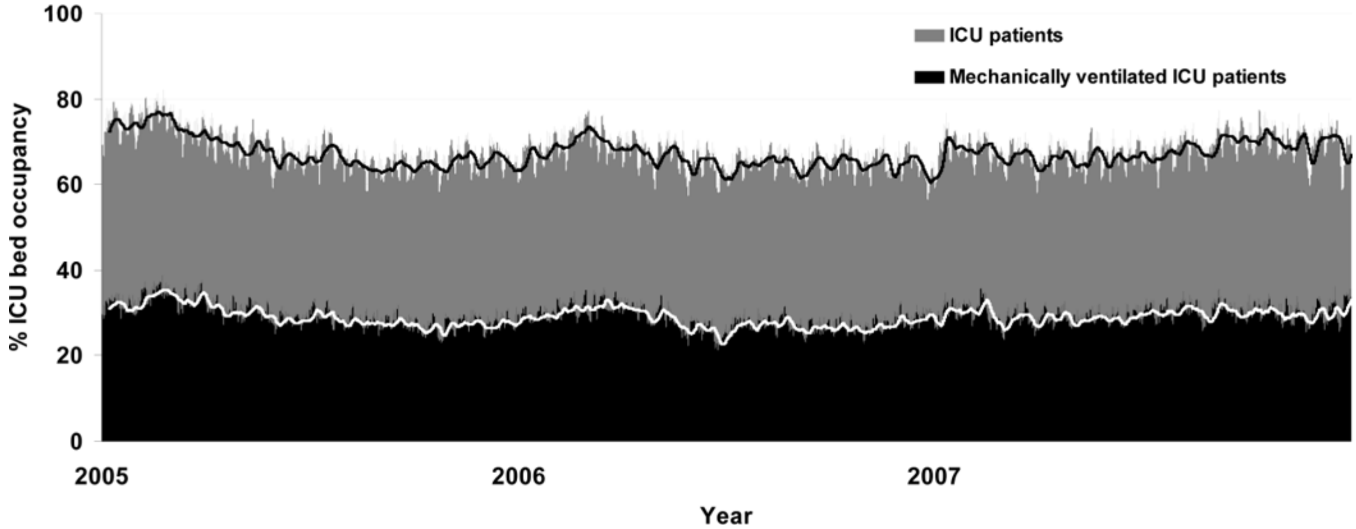
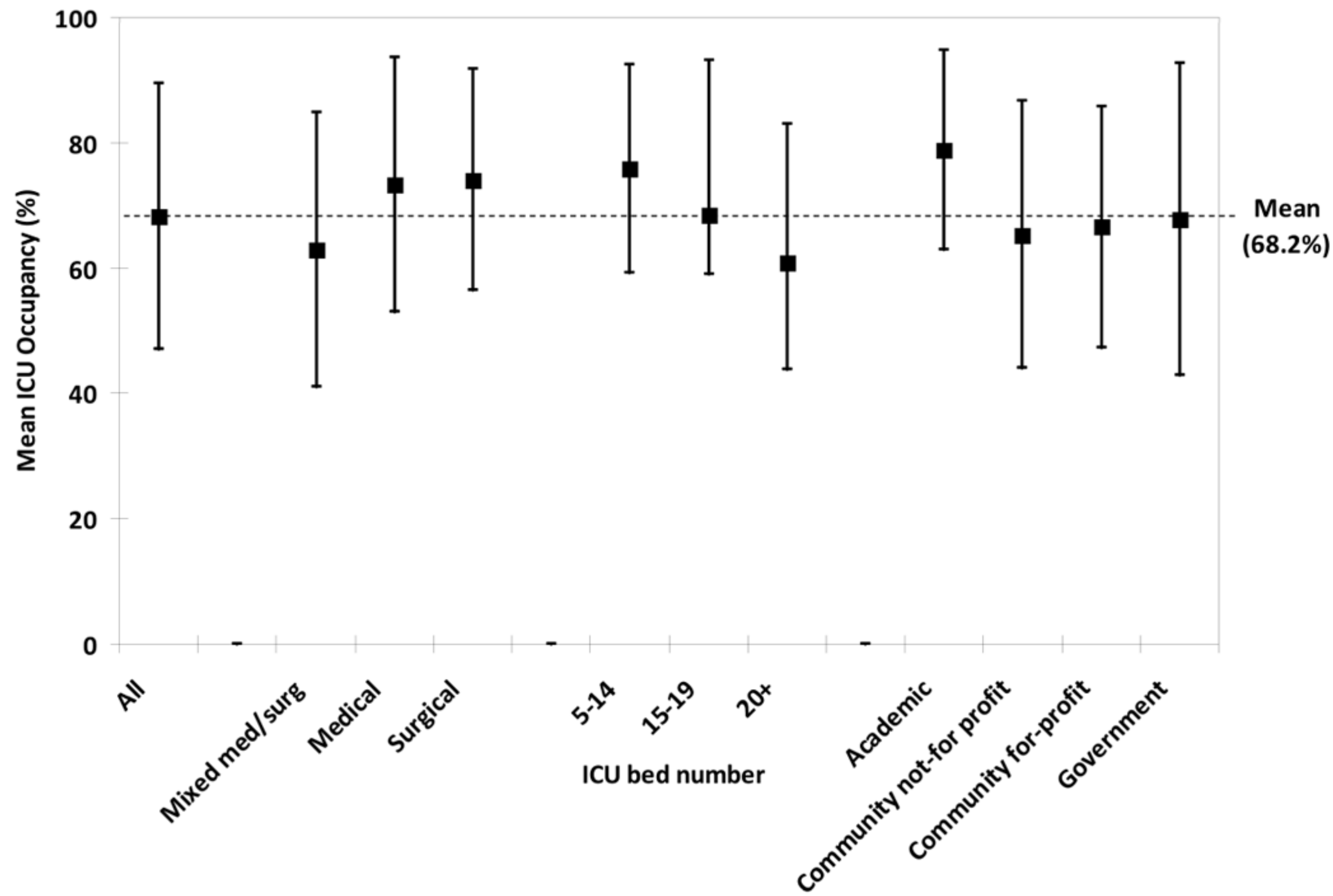


Figure 1.
Percentage of all ICU beds (pooled data from all ICUs) that were occupied each hour 2005–2007. Smoothed lines are one week moving averages.



Subgroup analysis of type of ICU excludes a single cardio-thoracic ICU for data protection

Figure 2.
Mean hourly occupancy of ICUs (bars represent the standard deviations for the means across ICUs).

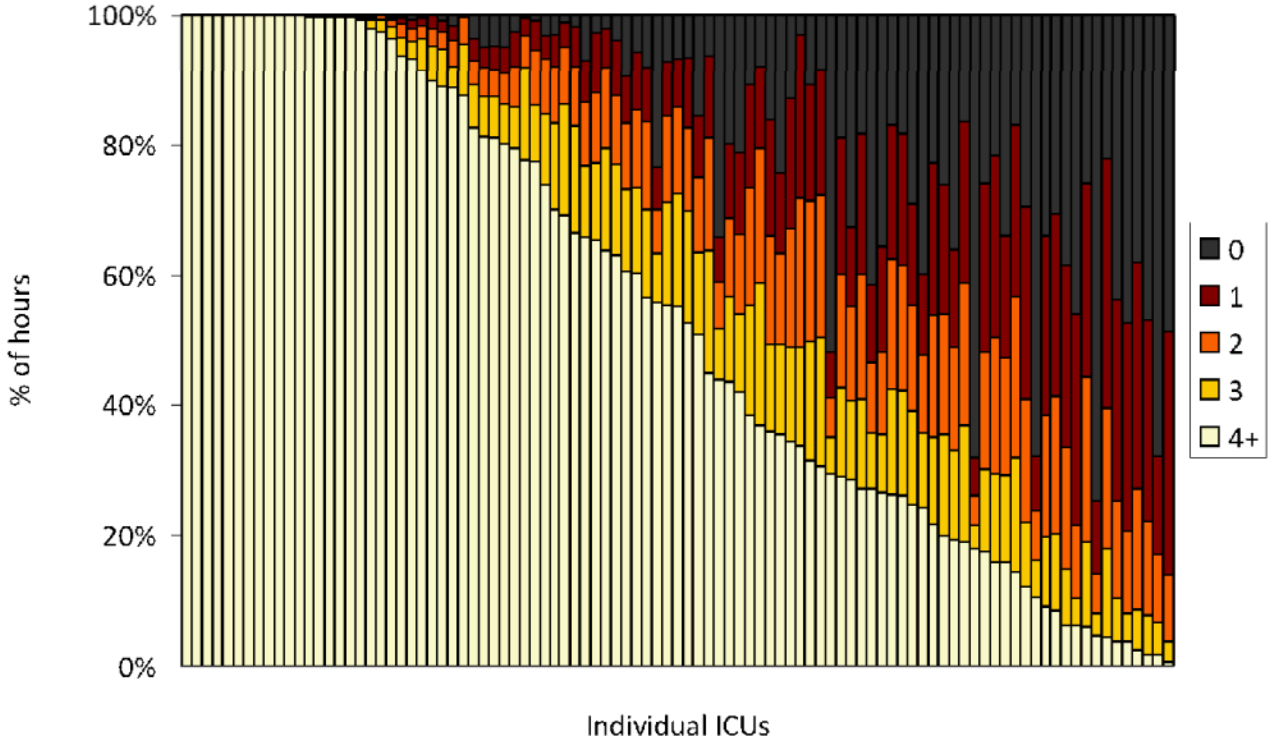


Figure 3.
Percentage of hours with available beds (0, 1, 2, 3, 4+) in each ICU. Each column represents a single ICU.

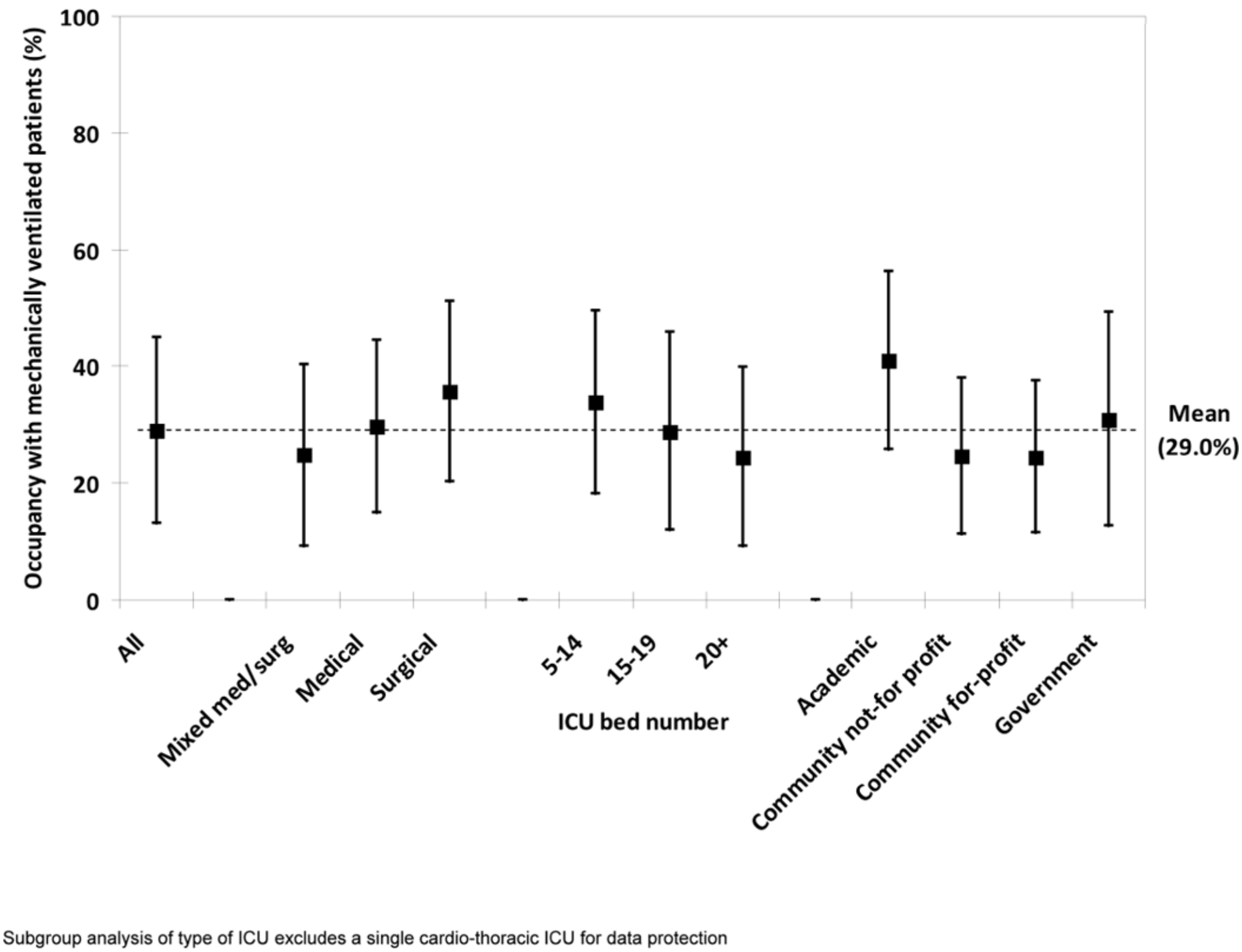


Figure 4.
Mean hourly occupancy of ICUs with mechanically ventilated patients (bars represent the standard deviations for the means across ICUs)

Table 1

Patient characteristics of admissions to ICUs in Project IMPACT

	Cohort
Total admissions, n	226,942
Total ICU beds, median (IQR)	19 (12–26)
Admissions with detailed ICU data, n	147,056
Age, mean ± sd	59.8 ± 18.3
Male, %	56.2
Race, %	
Caucasian	77.0
African-American	13.9
Hispanic	5.0
Other	2.0
Patient type, %	
Medical	65.9
Elective surgical	18.1
Emergent surgical	16.0
CPR in 24 hours prior to admission, %	3.4
APACHE II score, mean, ± sd*	15.8 ± 7.9
MPM_0-III mortality probability, mean % ± sd*	13.9 ± 16.5
ICU LOS (days), median (IQR)	
All	2.0 (1.0–4.0)
Survived	2.0 (1.1–3.9)
Died	2.2 (0.7–6.2)
Hospital LOS (days), median (IQR)	
All	7.0 (4.0–14.0)
Survived	7.0 (4.0–14.0)
Died	7.0 (2.0–17.0)
Hospital mortality, %	14.1

*The MPM0-III score is not calculated on patients missing one or more required variable, or on patients with burns, those who had an acute myocardial infarction, or post-cardiac surgery

SD = standard deviation, IQR = interquartile range

Table 2

Average (mean and median) daily number of admissions to each ICU

ICUs	Daily admissions per ICU (n)		% of all admissions	
	Mean (± sd)	Median (IQR)	Admitted with withdrawal/comfort care	Elective surgical
All	3.0 ± 1.5	2.7 (1.8–3.7)	0.03	18.1
Sub-type†				
Mixed med/surg	3.4 ± 1.7	3.2 (2.1–4.4)	0.04	16.2
Medical	2.8 ± 1.3	2.6 (2.0–3.1)	0.04	4.0
Surgical	2.5 ± 1.1**	2.2 (1.7–3.0)	0.02	30.2
ICU size (beds)				
5–14	2.1 ± 0.6	2.0 (1.5–2.6)	0.05	14.8
15–19	3.1 ± 1.1**	3.0 (2.2–4.1)	0.03	17.6
20+	4.2 ± 1.6**	4.1 (3.2–5.0)	0.02	20.9
Hospital type				
Academic	2.7 ± 1.4	2.2 (1.5–3.5)	0.02	21.3
Community not-for profit	3.2 ± 1.6	2.9 (2.1–4.1)	0.04	15.5
Community for-profit	3.3 ± 1.0	3.2 (2.5–4.2)	0.03	34.2
Government	2.1 ± 0.5**	2.0 (1.7–2.7)	0	16.2

** *P* Value < 0.05 for comparison with top group in each category using linear regression with clustering by ICU.

† Sub-group analysis excludes one cardio-thoracic ICU for data protection

ICU = intensive care unit SD = standard deviation, IQR = interquartile range, med/surg = combined medical and surgical