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The Association of ICU with Outcomes of Patients at Low Risk of Dying

Kelly C. Vranas, MD^{1,2}, Jeffrey K. Jopling, MD, MSHS^{1,3}, Jennifer Y. Scott, MS¹, Omar Badawi, PharmD, MPH^{4,5,6}, Michael O. Harhay, PhD^{7,8}, Christopher G. Slatore, MD, MS^{9,2}, Meghan C. Ramsey, MD^{1,10}, Michael J. Breslow, MD⁴, Arnold S. Milstein, MD, MPH¹, and Meeta Prasad Kerlin, MD, MSCE¹¹

¹Clinical Excellence Research Center, Stanford University; Stanford, CA

²Division of Pulmonary and Critical Care, Oregon Health & Science University; Portland, OR

³Department of Surgery, Stanford University; Stanford, CA

⁴Department of Research and Development, Philips Healthcare; Baltimore, MD

⁵Department of Pharmacy Practice and Science, University of Maryland School of Pharmacy; Baltimore, MD

⁶Institute for Medical Engineering and Science; Massachusetts Institute of Technology; Cambridge, MA

⁷Department of Biostatistics, Epidemiology and Informatics; University of Pennsylvania; Philadelphia, PA

⁸Corporal Michael J. Crescenz VA Medical Center; Philadelphia, PA

⁹Health Services Research & Development, VA Portland Health Care System; Portland, OR

¹⁰Division of Pulmonary and Critical Care, Stanford University; Stanford, CA

¹¹Pulmonary, Allergy and Critical Care Division, University of Pennsylvania; Philadelphia, PA

Abstract

Corresponding Author: Kelly C. Vranas, MD, Oregon Health & Science University, 3181 SW Sam Jackson Park Road, Mail Code UHN67, Portland, OR, 97239, Telephone: 503-494-7680; Fax: 503-494-6670, vranas@ohsu.edu.

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KCV, KJ, MCR, OB, MOH, CGS, and MPK contributed to the conception and design of this study. OB, MJB, and ASM contributed to data acquisition. JYS and MOH contributed to the analysis of data. KCV, JYS, OB, MOH, CGS, and MPK contributed to interpretation of data. All authors have made substantial contributions to the conception and design, acquisition of data, or analysis and interpretation of data; have contributed to drafting the article for important intellectual content; and have provided final approval of the version to be published.

Note

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Objective—Many ICU patients do not require critical care interventions. Whether aggressive care environments increase risks to low-acuity patients is unknown. We evaluated whether ICU acuity was associated with outcomes of low mortality-risk patients. We hypothesized that admission to high-acuity ICUs would be associated with worse outcomes. This hypothesis was based on two possibilities: (1) high-acuity ICUs may have a culture of aggressive therapy that could lead to potentially avoidable complications, and (2) high-acuity ICUs may focus attention towards the many sicker patients and away from the fewer low-risk patients.

Design—Retrospective cohort study.

Setting—322 ICUs in 199 hospitals in the Philips eICU database between 2010–2015.

Patients—Adult ICU patients at low risk of dying, defined as an APACHE IVa-predicted mortality of 3%.

Exposure—ICU acuity, defined as the mean APACHE IVa score of all admitted patients in a calendar year, stratified into quartiles.

Measurements and Main Results—We used generalized estimating equations to test whether ICU acuity is independently associated with a primary outcome of ICU length of stay (LOS) and secondary outcomes of hospital LOS, hospital mortality, and discharge destination. The study included 381,997 low-risk patients. Mean ICU and hospital LOS were 1.8 ± 2.1 and 5.2 ± 5.0 days, respectively. Mean APACHE IVa-predicted hospital mortality was $1.6\% \pm 0.8\%$; actual hospital mortality was 0.7%. In adjusted analyses, admission to low-acuity ICUs was associated with worse outcomes compared to higher-acuity ICUs. Specifically, compared to the highest-acuity quartile, ICU LOS in low-acuity ICUs was increased by 0.24 days; in medium-acuity ICUs by 0.16 days; and in high-acuity ICUs by 0.09 days (all $p < 0.001$). Similar patterns existed for hospital LOS. Patients in lower-acuity ICUs had significantly higher hospital mortality (OR 1.28 [95% confidence interval (CI) 1.10 – 1.49] for low-, 1.24 [95% CI 1.07 – 1.42] for medium-, and 1.14 [95% CI 0.99 – 1.31] for high-acuity ICUs) and lower likelihood of discharge home (OR 0.86 [95% CI 0.82 – 0.90] for low-, 0.88 [95% CI 0.85 – 0.92] for medium-, and 0.95 [95% CI 0.92 – 0.99] for high-acuity ICUs).

Conclusions—Admission to high-acuity ICUs is associated with better outcomes among low mortality-risk patients. Future research should aim to understand factors that confer benefit to patients with different risk profiles.

Key MeSH Terms

critical care; intensive care units; patient acuity; APACHE; resource allocation

Introduction

Every year, more than 5 million patients are admitted to intensive care units (ICUs) across the United States (US), with costs of roughly \$82 billion, or 0.66% of the gross domestic product.[1, 2] Such spending is driven largely by the number of ICU beds and their utilization.[3] The number of ICU beds in the US steadily increased by 26% from 1985 to 2000, despite a concurrent decrease in the total number of hospital beds.[4] The increased

supply of ICU beds in the US is associated with increased ICU utilization,[5, 6] even by patients unlikely to benefit from critical care.[7]

Patients at low risk of dying comprise a substantial proportion of ICU admissions in the US. Multiple studies in different healthcare settings have shown that up to 50% of patients admitted to ICUs are unlikely to require or benefit from critical care interventions, or could have received equivalent care in non-ICU settings.[8–10] These data highlight the potential opportunity to improve the efficiency and value of critical care in the US. Furthermore, there is an additional concern that ICU admission could actually expose such patients to undue risks. For example, hospitals that use ICU care more frequently for certain low-risk conditions are more likely to perform invasive procedures and incur higher costs, but without an associated improvement in hospital mortality.[11] In addition, ICU patients at low risk of dying who experience longer than expected ICU lengths of stay (LOS) have significantly higher mortality and increased resource consumption compared to patients of similar acuity with lengths of stay in the expected range, suggesting these outcomes may be in part due to complications suffered while in the ICU.[12]

Characterizing the treatment environment associated with improved outcomes for patients at low risk of dying will inform efforts to improve the efficiency, value and quality of ICU-based care. We sought to evaluate whether there is an association of admission to ICUs with higher average patient severity (defined as high-acuity ICUs) compared to ICUs with lower average patient severity (defined as low-acuity ICUs) with outcomes of patients at low risk of dying. We hypothesized that admission to high-acuity ICUs would be associated with worse outcomes among low mortality-risk patients. This hypothesis was based on two possibilities: (1) that high-acuity ICUs may have a culture of aggressive therapy that could lead to potentially avoidable complications, and (2) that high-acuity ICUs may focus attention towards the many sicker patients and away from the fewer low-risk patients.

Methods

Study Design and Data Source

We conducted a retrospective cohort study using the Philips eICU Research Institute Database, which aggregates granular clinical and administrative data from an organizationally and geographically diverse mix of over 320 participating hospitals in the United States.[13–15] Further details are available in the Supplemental Digital Content.

Patients and Variables

The cohort included patients 18 years old admitted to 322 ICUs between 2010 and 2015 who were at low risk of in-hospital mortality, defined as Acute Physiology and Chronic Health Evaluation (APACHE) IVa-predicted hospital mortality of $\leq 3\%$. APACHE IVa is a validated ICU severity-of-illness adjustment system which uses physiologic variables to predict ICU and hospital mortality and LOS.[16] This definition of low-risk patients was chosen *a priori* based on both expert consensus and prior literature demonstrating a hospital mortality of 2.5% for ICU patients admitted primarily for monitoring purposes, who were otherwise at low risk of requiring active ICU therapies.[10] It was also in line with results of

a study performed in the VA Healthcare System that demonstrated low (< 2%) 30-day predicted mortality for patients admitted to the ICU.[9]

Figure 1 summarizes patient selection. We excluded admissions to ICUs during years with less than 100 total admissions and/or less than 95% valid APACHE IVa data in a calendar year. We also excluded patients with invalid or incomplete data to calculate an APACHE IVa score; patients with unknown or “other” sex; and patients transferred to or from other facilities. For patients with multiple ICU admissions, we excluded all subsequent readmissions.

Primary Exposure—The primary exposure was ICU acuity, defined by the mean APACHE IVa score for all patients admitted during a calendar year regardless of their risk profile. After confirming a near normal distribution, we categorized ICU acuity into quartiles of low-, medium-, high-, and highest-acuity per ICU-year, to facilitate comparison of ICUs and interpretability of the results. ICUs could change categories of acuity across individual years of the study period, depending on the relative mean APACHE IVa score in a given year. The mean range of annual APACHE IVa scores for lowest-acuity ICUs was 34.4 to < 50.0; medium-acuity was 50.0 to < 54.0; high-acuity was 54.0 to < 58.0, and highest-acuity was 58.0 to 78.4.

Outcomes—The primary outcome variable was ICU LOS. Secondary outcomes were hospital LOS, ICU and hospital mortality, and likelihood of discharge to home. For the outcome of likelihood of discharge to home, decedents were included in the analysis as not being discharged to home.

Other Variables—Potential confounders chosen *a priori* included patient demographics, location prior to ICU admission, admitting diagnosis, ICU type, hospital teaching status and number of beds, and patient APACHE IVa score. Further details of potential confounders are available in the Supplemental Digital Content.

Analysis

We summarized all variables using standard descriptive statistics. We estimated unadjusted differences between ICU acuity levels using chi-squared tests and Wilcoxon rank sum tests, as appropriate.

We performed patient-level multivariable analyses using generalized estimating equations (GEE) to test for adjusted differences in ICU and hospital LOS. We built three models for the primary outcome of ICU LOS: 1) a simple model including only the exposure variable of ICU acuity; 2) a model including the exposure variable and patient APACHE IVa scores; 3) a fully adjusted model, including all covariates identified *a priori*. There was no difference in effect size or statistical significance for the exposure variable between the second and third models for the primary outcome. Therefore, we used the model adjusted for patient APACHE IVa scores for both primary and secondary analyses in order to optimize computational efficiency, and because APACHE IVa scores are based on several of the covariates we had included in the fully adjusted model.

Next, we fit logit models on the secondary outcomes of ICU and hospital mortality, and hospital discharge to home. We also conducted two sensitivity analyses using: 1) ICU acuity as a continuous variable, and 2) a broadened definition of low-risk patients defined as APACHE IVa-predicted hospital mortality of <5%, which represents the median mortality of all patients in the cohort regardless of risk profile. Full details of our model-building strategies are available in the Supplemental Digital Content.

Finally, we performed several restricted analyses to explore possible mechanisms for our findings. First, we excluded trauma patients and patients admitted for coronary bypass graft (CABG) surgery, since these patients represented the majority of LOS outliers (defined as LOS > 99th percentile). Patients undergoing CABG surgery also represented the majority of patients with APACHE IVa scores greater than 70. Second, we evaluated the role of total annual ICU patient volume by adding it to the model. Third, we excluded patients admitted with diabetic ketoacidosis (DKA) and neurologic diagnoses, since the prevalence of these diagnoses differed substantially between low- versus highest-acuity ICUs (Table 1). All analyses utilized a p-value of 0.05 as a threshold for significance, and were completed using Stata version 14 (StataCorp, LLC; College Station, Texas). All data were de-identified, and the study was considered exempt from human subjects review by both the Stanford University and Veteran Affairs Portland Health Care System Institutional Review Boards.

Results

Characteristics of Patients

The final analysis included 381,997 low mortality-risk patients admitted to 322 ICUs in 199 hospitals. Mean ICU and hospital LOS were 1.8 ± 2.1 and 5.2 ± 5.0 days, respectively. Mean APACHE IVa-predicted hospital mortality was $1.6\% \pm 0.8\%$; actual hospital mortality was 0.7% (Supplemental Table 1). Slightly more than half of the ICUs (52.2%) were mixed medical/surgical ICUs, and the rest were specialty ICUs. The average annual patient volume was 990 ± 569 , with a minimum of 112 and maximum of 2,964 patients. Hospitals varied widely in their number of hospital beds, and 80% of the ICUs were non-teaching (i.e., not members of Council of Teaching Hospitals and Health Systems (Supplemental Table 2)).[17] Additional data including characteristics of *all* patients in the study cohort (regardless of risk profile) and stratified by ICU acuity are available in Supplemental Table 3.

Table 1 summarizes characteristics and unadjusted outcomes of the low-risk patients based on admission to ICUs of variable acuity levels. The Emergency Department was the most common admission source across all quartiles of ICU acuity, followed by the operating room. Cardiac diagnoses represented the most common reason for admission. Unadjusted analyses revealed a slight increase in ICU LOS (1.8 ± 2.1 versus 1.7 ± 2.2 days, $p < 0.001$) and decrease in hospital LOS (4.7 ± 4.7 versus 5.5 ± 5.3 days, $p < 0.001$) for low-risk patients admitted to low-acuity ICUs compared to highest-acuity, respectively. There were no significant differences in unadjusted ICU mortality (0.3% versus 0.2%, $p = 0.742$) or hospital mortality (0.6% versus 0.6%, $p = 0.986$).

Comparison by ICU Acuity

Results of the log-gamma and linear multivariable models were comparable and demonstrated a significant association of increasing average ICU acuity with decreased ICU LOS in a dose-dependent fashion (Table 2). Specifically, admission of low mortality-risk patients to low-acuity ICUs was associated with longer ICU LOS (difference of 0.24 days, $p < 0.001$) compared to admission to the highest-acuity ICUs. Similarly, admission to low-acuity ICUs was associated with longer hospital LOS (difference of 0.37 days, $p < 0.001$). These findings were consistent across all levels of patient APACHE score (Figure 2). Increasing average ICU acuity was also associated with decreased hospital mortality, and increased odds of discharge home from the hospital (Table 3). Admission to the highest-acuity ICUs was associated with decreased ICU mortality compared to any other category of ICU acuity.

Additional Analyses

For the primary outcome of ICU LOS, a sensitivity analysis using ICU acuity as a continuous variable again demonstrated that higher ICU acuity was associated with decreased ICU LOS. Our findings were also robust in a sensitivity analysis defining low-risk patients as those with an APACHE IVa-predicted mortality of $<5\%$. In a restricted analysis excluding CABG and trauma patients (who comprised the majority of LOS outliers within the study cohort), the overall pattern of results was the same and statistically significant, though the effect size decreased. The addition of annual ICU volume for patients across all illness severities as a fixed effect in the model resulted in no change in effect size. Finally, in a restricted analysis excluding patients admitted with DKA or neurologic diagnoses, the association between ICU acuity and ICU LOS was essentially unchanged (Supplemental Table 4).

Discussion

We found that admission of low mortality-risk patients to low-acuity ICUs was associated with longer ICU and hospital LOS, higher hospital mortality, and lower likelihood of discharge home from the hospital than those admitted to higher-acuity ICUs. These results are contrary to our hypothesis that admission to high-acuity ICUs would be associated with worse outcomes among patients at low risk of dying. Instead, our findings suggest that ICUs that routinely care for severely ill patients may perform better in the care of less sick ICU patients, and that these outcomes are robust in nonsurgical patients and independent of overall annual ICU volume.

There are several possible explanations for our findings. First, high-acuity ICUs may be more frequently located within larger, tertiary or quaternary care hospitals that provide a broader range of specialty services and tend to be busier than smaller hospitals. As such, high-acuity ICUs may experience more external pressure to discharge less sick patients earlier, in order to accommodate more severely ill patients who could derive greater benefit from ICU care, thus leading to shorter ICU LOS. Wagner and colleagues recently demonstrated that increases in ICU strain (measured as average ICU acuity, census, and admissions) on the days of ICU discharge were associated with significantly shorter ICU

LOS without any association with subsequent death, hospital LOS, or likelihood of being discharged home from the hospital.[18] These findings suggest that ICUs under pressure, as is common in high-acuity ICUs, may safely discharge low mortality-risk ICU patients earlier. Taken together, these findings also highlight the potential opportunity to safely reduce the provision of high-cost, low-value ICU care for this group of patients, particularly in low-acuity ICUs within the US.

Second, at the ICU level, high-acuity ICUs may more effectively implement and standardize evidence-based organizational structures and processes of care. For example, the use of daily checklists and interprofessional rounds have been associated with improved ICU mortality and LOS.[19, 20] Staffing models that include ready availability of critical care specialists and low patient-to-nurse ratios have been also associated with improved patient outcomes. [21, 22] In addition, clinical protocols for sedation management, adherence to low tidal volume mechanical ventilation approaches for patients with acute respiratory distress syndrome, and ventilator liberation strategies, have demonstrated mortality benefit in randomized clinical trials.[23–27] Future research investigating whether high-acuity ICUs are more adherent than low-acuity ICUs to such evidence-based practices is warranted and could be particularly useful in understanding possible mechanisms for our findings. Moreover, qualitative methods including medical ethnography could offer additional insights into the relationship between ICU culture, available resources, adherence to evidence-based practices, and patient outcomes. Such research may enable the identification of previously unmeasured and potentially modifiable features of critical care delivery systems that are associated with improved outcomes for patients with different risk profiles across a variety of healthcare settings.

Interestingly, our results were independent of overall ICU volume. Prior studies have demonstrated a significant association of higher ICU admission volume with improved outcomes among critically ill adult patients.[28–32] In the largest systematic review and meta-analysis published on this topic to date, patients at the highest risk of death were most likely to benefit from admission to a high-volume center. However, ICU and/or hospital-level organizational factors were found to be major determinants of the observed volume-outcome relationship.[30] Our study adds to the literature by focusing on ICU acuity rather than volume as the primary exposure. Our results may also inform debates regarding regionalization of critical care by offering additional insight into potential ICU- and hospital-level factors that enable certain ICUs to perform better than others, specifically in the care of low-risk ICU patients who represent an important target in efforts to improve the overall value of critical care.

Our study has several limitations. First, there is a lack of consensus regarding the definition of low-risk patients. Although the definition used for this study was chosen *a priori* based on both expert consensus and literature review, the threshold of 3% predicted mortality is somewhat subjective. Second, ICUs include a diverse mix that vary in size, location, teaching status, and ICU type across the US, but are all participants in a tele-ICU program, which is in itself an ICU-level intervention. Third, our study could not measure the association of ICU acuity with outcomes of low-risk patients after discharge from the hospital, since the Philips eICU dataset does not collect post-hospital discharge data.

However, we would expect any adverse effects to be apparent closer to the time of ICU discharge. Fourth, we did not have access to data on other hospital characteristics such as ICU staffing models. Although we cannot exclude the influence of staffing patterns on outcomes in our study, recent literature has demonstrated that high-intensity daytime staffing may not be associated with improved mortality after accounting for interprofessional rounds, protocols and other organizational factors.[33] We also were not able to assess the availability of hospital beds downstream of the ICU, which may contribute to ICU LOS. However, the finding that average ICU acuity had similar relationships with both ICU and hospital LOS suggests that hospital bed availability was unlikely to be a major factor.

There is also risk of misclassification of ICU acuity. It is possible that some ICUs in our cohort may appear to be higher acuity units due to faulty recording of Glasgow Coma Scale (GCS). GCS is an important component of the APACHE IVa score that is subject to potentially inaccurate assessment in the setting of sedative medications, which are commonly administered to critically ill patients.[34] However, this issue is common across all studies that use APACHE IVa scoring for severity adjustment. In addition, our study focuses on comparisons between the low-acuity and highest-acuity ICUs, therefore maximizing the differences between the exposure variables. Finally, as an observational study, we cannot rule out the possibility that there is unmeasured confounding, such as patient characteristics, rather than ICU factors, that may drive the observed associations.

In summary, we found that admission to high-acuity ICUs is associated with better outcomes for ICU patients at low risk of dying. These results improve our understanding of factors that may influence outcomes for low-risk ICU patients, and highlight the potential opportunity to improve the value and efficiency of care for this important and substantial patient population.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. Guidelines for intensive care unit admission, discharge and triage. Task Force of the American College of Critical Care Medicine, Society of Critical Care Medicine. *Crit Care Med.* 1999; 27(3): 633–638. [PubMed: 10199547]
2. Halpern NA, Pastores SM. Critical Care Medicine Beds, Use, Occupancy, and Costs in the United States: A Methodological Review. *Crit Care Med.* 2015; 43(11):2452–2459. [PubMed: 26308432]
3. Pastores SM, Dakwar J, Halpern NA. Costs of critical care medicine. *Crit Care Clin.* 2012; 28(1):1–10. [PubMed: 22123095]
4. 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(1):65–71. [PubMed: 19730257]
5. Wunsch H, Angus DC, Harrison DA, et al. Variation in critical care services across North America and Western Europe. *Crit Care Med.* 2008; 36(10):2787–2793. e2781–2789. [PubMed: 18766102]
6. Wunsch H, Wagner J, Herlim M, et al. ICU occupancy and mechanical ventilator use in the United States. *Crit Care Med.* 2013; 41(12):2712–2719. [PubMed: 23963122]
7. Gooch RA, Kahn JM. ICU bed supply, utilization, and health care spending: an example of demand elasticity. *JAMA.* 2014; 311(6):567–568. [PubMed: 24408679]
8. Chang DW, Dacosta D, Shapiro MF. Priority Levels in Medical Intensive Care at an Academic Public Hospital. *JAMA internal medicine.* 2017; 177(2):280–281.
9. Chen LM, Render M, Sales A, et al. Intensive care unit admitting patterns in the Veterans Affairs health care system. *Arch Intern Med.* 2012; 172(16):1220–1226. [PubMed: 22825806]
10. Zimmerman JE, Kramer AA. A model for identifying patients who may not need intensive care unit admission. *J Crit Care.* 2010; 25(2):205–213. [PubMed: 19682848]
11. Chang DW, Shapiro MF. Association Between Intensive Care Unit Utilization During Hospitalization and Costs, Use of Invasive Procedures, and Mortality. *JAMA internal medicine.* 2016; 176(10):1492–1499. [PubMed: 27532500]
12. Dahl D, Wojtal GG, Breslow MJ, et al. The high cost of low-acuity ICU outliers. *J Healthc Manag.* 2012; 57(6):421–433. discussion 434. [PubMed: 23297608]
13. Lilly CM, Zuckerman IH, Badawi O, et al. Benchmark data from more than 240,000 adults that reflect the current practice of critical care in the United States. *Chest.* 2011; 140(5):1232–1242. [PubMed: 21868469]
14. McShea M, Holl R, Badawi O, et al. The eICU research institute - a collaboration between industry, health-care providers, and academia. *IEEE Eng Med Biol Mag.* 2010; 29(2):18–25. [PubMed: 20659837]
15. <https://eicu-crd.mit.edu/>
16. Zimmerman JE, Kramer AA, McNair DS, et al. Acute Physiology and Chronic Health Evaluation (APACHE) IV: hospital mortality assessment for today's critically ill patients. *Crit Care Med.* 2006; 34(5):1297–1310. [PubMed: 16540951]
17. <https://www.aamc.org/members/coth/>
18. Wagner J, Gabler NB, Ratcliffe SJ, et al. Outcomes among patients discharged from busy intensive care units. *Ann Intern Med.* 2013; 159(7):447–455. [PubMed: 24081285]
19. Weiss CH, Moazed F, McEvoy CA, et al. Prompting physicians to address a daily checklist and process of care and clinical outcomes: a single-site study. *Am J Respir Crit Care Med.* 2011; 184(6):680–686. [PubMed: 21616996]
20. Checkley W, Martin GS, Brown SM, et al. Structure, process, and annual ICU mortality across 69 centers: United States Critical Illness and Injury Trials Group Critical Illness Outcomes Study. *Crit Care Med.* 2014; 42(2):344–356. [PubMed: 24145833]
21. Amaravadi RK, Dimick JB, Pronovost PJ, et al. ICU nurse-to-patient ratio is associated with complications and resource use after esophagectomy. *Intensive Care Med.* 2000; 26(12):1857–1862. [PubMed: 11271096]

22. Wilcox ME, Chong CA, Niven DJ, et al. Do intensivist staffing patterns influence hospital mortality following ICU admission? A systematic review and meta-analyses. *Crit Care Med.* 2013; 41(10):2253–2274. [PubMed: 23921275]
23. Kohn R, Madden V, Kahn JM, et al. Diffusion of Evidence-based Intensive Care Unit Organizational Practices. A State-Wide Analysis. *Annals of the American Thoracic Society.* 2017; 14(2):254–261. [PubMed: 28076685]
24. Jakob SM, Lubszky S, Friolet R, et al. Sedation and weaning from mechanical ventilation: effects of process optimization outside a clinical trial. *J Crit Care.* 2007; 22(3):219–228. [PubMed: 17869972]
25. Dale CR, Kannas DA, Fan VS, et al. Improved analgesia, sedation, and delirium protocol associated with decreased duration of delirium and mechanical ventilation. *Annals of the American Thoracic Society.* 2014; 11(3):367–374. [PubMed: 24597599]
26. Needham DM, Colantuoni E, Mendez-Tellez PA, et al. Lung protective mechanical ventilation and two year survival in patients with acute lung injury: prospective cohort study. *BMJ.* 2012; 344:e2124. [PubMed: 22491953]
27. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network. *N Engl J Med.* 2000; 342(18):1301–1308. [PubMed: 10793162]
28. Kahn JM, Linde-Zwirble WT, Wunsch H, et al. Potential value of regionalized intensive care for mechanically ventilated medical patients. *Am J Respir Crit Care Med.* 2008; 177(3):285–291. [PubMed: 18006884]
29. Nguyen YL, Kahn JM, Angus DC. Reorganizing adult critical care delivery: the role of regionalization, telemedicine, and community outreach. *Am J Respir Crit Care Med.* 2010; 181(11):1164–1169. [PubMed: 20224067]
30. Nguyen YL, Wallace DJ, Yordanov Y, et al. The Volume-Outcome Relationship in Critical Care: A Systematic Review and Meta-analysis. *Chest.* 2015; 148(1):79–92. [PubMed: 25927593]
31. Gaieski DF, Edwards JM, Kallan MJ, et al. The relationship between hospital volume and mortality in severe sepsis. *Am J Respir Crit Care Med.* 2014; 190(6):665–674. [PubMed: 25117723]
32. Kahn JM, Goss CH, Heagerty PJ, et al. Hospital volume and the outcomes of mechanical ventilation. *N Engl J Med.* 2006; 355(1):41–50. [PubMed: 16822995]
33. Costa DK, Wallace DJ, Kahn JM. The Association Between Daytime Intensivist Physician Staffing and Mortality in the Context of Other ICU Organizational Practices: A Multicenter Cohort Study. *Crit Care Med.* 2015; 43(11):2275–2282. [PubMed: 26308426]
34. Livingston BM, Mackenzie SJ, MacKirdy FN, et al. Should the pre-sedation Glasgow Coma Scale value be used when calculating Acute Physiology and Chronic Health Evaluation scores for sedated patients? Scottish Intensive Care Society Audit Group. *Crit Care Med.* 2000; 28(2):389–394. [PubMed: 10708172]

Figure 1.

Combined ICU- and patient-level exclusion criteria.

eRI = eICU Research Institute. APACHE IVa= Acute Physiology and Chronic Health Evaluation. ICU = Intensive Care Unit.

Figure 2.

Expected ICU length of stay (panel A) and hospital length of stay (panel B) based on patient APACHE IVa score.^{a,b,c}

Each line represents the relationship between patient Acute Physiology and Chronic Health Evaluation^a IVa score and predicted ICU length of stay, stratified by quartiles of ICU acuity. APACHE IVa scores < 10 or > 70 were collapsed into two groups given the small number of patients in the study cohort with scores beyond these thresholds.

^bRepresents margins plot of log gamma model including interaction term between ICU acuity and APACHE IVa score.

^cchi-squared tests comparing the interactions between APACHE and ICU acuity in aggregate for ICU and hospital LOS were significant at $p < 0.001$ ($\chi^2 = 62.64$ and 47.63 , respectively).

Table 1

Characteristics and unadjusted outcomes of low-mortality risk^a patients based on admission to ICUs of variable acuity levels.

Characteristics	Low-Acuity ICUs (n=100,987)	Med-Acuity ICUS (n=98,309)	High-Acuity ICUs (n=90,392)	Highest-Acuity ICUs (n=92,309)
Age, Mean $\pm$ SD ^b	53.8 $\pm$ 16.4	54.8 $\pm$ 16.3	52.8 $\pm$ 16.5	52.2 $\pm$ 16.7
Male, No. (%)	56,926 (56.4)	57,227 (58.2)	51,758 (57.3)	53,092 (57.5)
Race, No. (%)				
White	75,419 (74.7)	73,697 (75.0)	68,952 (76.3)	66,816 (72.4)
Black	11,688 (11.6)	12,585 (12.8)	9,999 (11.1)	12,305 (13.3)
Other	13,880 (13.7)	12,027 (12.2)	11,441 (12.7)	13,188 (14.3)
APACHE ^c IVa Score, Mean $\pm$ SD ^b	31.9 $\pm$ 11.1	35.3 $\pm$ 11.9	35.5 $\pm$ 12.0	37.0 $\pm$ 12.5
APACHE IVa Predicted Hospital Mortality, Mean % $\pm$ SD ^b	1.6 $\pm$ 0.8	1.5 $\pm$ 0.8	1.6 $\pm$ 0.8	1.6 $\pm$ 0.8
Admission Source, No. (%)				
Emergency Department	49,491 (49.0)	46,865 (47.7)	46,666 (51.6)	47,876 (51.9)
Operating Room	24,432 (24.2)	30,570 (31.1)	23,486 (26.0)	21,196 (23.0)
Ward Transfer	6,104 (6.0)	5,954 (6.1)	6,498 (7.2)	6,627 (7.2)
Direct Admit	7,980 (7.9)	5,732 (5.8)	5,579 (6.2)	5,732 (6.2)
Other	12,980 (12.9)	9,188 (9.3)	8,163 (9.0)	10,878 (11.8)
Admitting Diagnosis, No. (%)				
Cardiac	29,051 (28.8)	35,838 (36.5)	26,074 (28.8)	22,834 (24.7)
Diabetic Ketoacidosis	5,787 (5.7)	6,950 (7.1)	7,876 (8.7)	9,702 (10.5)
Gastrointestinal Bleeding	3,941 (3.9)	4,150 (4.2)	4,241 (4.7)	5,132 (5.6)
Neurologic	13,168 (13.0)	7,480 (7.6)	7,508 (8.3)	6,985 (7.6)
Overdose	6,239 (6.2)	6,422 (6.5)	7,028 (7.8)	7,920 (8.6)
Respiratory	1,528 (1.5)	1,663 (1.7)	1,381 (1.5)	1,426 (1.5)
Sepsis	6,196 (6.1)	6,292 (6.4)	6,646 (7.4)	8,000 (8.7)
Trauma	6,946 (6.9)	3,599 (3.7)	3,983 (4.4)	3,857 (4.2)
Other	28,131 (27.9)	25,915 (26.4)	25,655 (28.4)	26,453 (28.7)
ICU LOS ^d , Mean days $\pm$ SD ^b	1.8 $\pm$ 2.1	1.8 $\pm$ 2.2	1.7 $\pm$ 2.1	1.7 $\pm$ 2.2
ICU Mortality, No. (%)	257 (0.3)	284 (0.3)	266 (0.3)	228 (0.2)
Hospital LOS ^d , Mean days $\pm$ SD ^b	4.7 $\pm$ 4.7	5.3 $\pm$ 5.1	5.2 $\pm$ 5.1	5.5 $\pm$ 5.3
Hospital Mortality, No. (%)	647 (0.6)	707 (0.7)	601 (0.7)	592 (0.6)

^aLow-mortality risk defined as APACHE IVa predicted hospital mortality between 0–3%.

^bStandard deviation

^cAcute Physiology and Chronic Health Evaluation

^dLength of stay

Table 2

Results of multivariable analyses demonstrating ICU and hospital length of stay (LOS) outcomes^a for low-mortality risk^b ICU patients based on ICU acuity.

ICU Acuity	Predicted Difference in Days (95% CI)^c	
	ICU LOS	Hospital LOS
Highest-acuity	1.64 days	4.81 days
High-acuity	+ 0.09 (0.07, 0.12)	+ 0.10 (0.04, 0.17)
Medium-acuity	+ 0.16 (0.13, 0.19)	+ 0.29 (0.21, 0.36)
Low-acuity	+ 0.24 (0.21, 0.28)	+ 0.37 (0.28, 0.46)

^a All p values < 0.001

^b Low-mortality risk defined as Acute Physiology and Chronic Health Evaluation IVa-predicted hospital mortality between 0–3%.

^c Confidence interval

Table 3

Results of multivariable analyses demonstrating the association of intensive care unit (ICU) acuity with ICU and hospital mortality, and odds of discharge home from hospital among low mortality-risk^a ICU patients.

ICU Acuity	ICU Mortality OR ^b (95% CI ^c)	Hospital Mortality OR ^b (95% CI ^c)	Discharge to Home OR ^b (95% CI ^c)
Highest-acuity	<i>Reference</i>	<i>Reference</i>	<i>Reference</i>
High-acuity	1.30 (1.07, 1.59)	1.14 (0.99, 1.31)	0.95 (0.92, 0.99)
Medium-acuity	1.29 (1.06, 1.58)	1.24 (1.07, 1.42)	0.88 (0.85, 0.92)
Low-acuity	1.32 (1.07, 1.64)	1.28 (1.10, 1.49)	0.86 (0.82, 0.90)

^aLow-mortality risk defined as Acute Physiology and Chronic Health Evaluation IVa-predicted hospital mortality between 0–3%.

^bOdds ratio

^cConfidence interval