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An Empirical Comparison of Key Statistical Attributes Among Potential ICU Quality Indicators*

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Abstract

Objective—Good quality indicators should have face validity, relevance to patients, and be able to be measured reliably. Beyond these general requirements, good quality indicators should also have certain statistical properties, including sufficient variability to identify poor performers, relative insensitivity to severity adjustment, and the ability to capture what providers do rather than patients' characteristics. We assessed the performance of candidate indicators of ICU quality on these criteria. Indicators included ICU readmission, mortality, several length of stay outcomes, and the processes of venous-thromboembolism and stress ulcer prophylaxis provision.

Design—Retrospective cohort study

Setting—One hundred thirty-eight U.S. ICUs from 2001–2008 in the Project IMPACT database.

Patients—Two hundred sixty-eight thousand eight hundred twenty-four patients discharged from U.S. ICUs.

Interventions—None.

Measurements and Main Results—We assessed indicators' (1) variability across ICU-years; (2) degree of influence by patient vs. ICU and hospital characteristics using the Omega statistic; (3) sensitivity to severity adjustment by comparing the area under the receiver operating characteristic curve (AUC) between models including vs. excluding patient variables, and (4) correlation between risk adjusted quality indicators using a Spearman correlation. Large ranges of among-ICU variability were noted for all quality indicators, particularly for prolonged length of

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All coauthors had access to the study data, take responsibility for the analysis, and had authority over manuscript preparation and the decision to submit for publication.

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stay (4.7–71.3%) and the proportion of patients discharged home (30.6–82.0%), and ICU and hospital characteristics outweighed patient characteristics for stress ulcer prophylaxis (ω , 0.43; 95% CI, 0.34–0.54), venous thromboembolism prophylaxis (ω , 0.57; 95% CI, 0.53–0.61), and ICU readmissions (ω , 0.69; 95% CI, 0.52–0.90). Mortality measures were the most sensitive to severity adjustment (area under the receiver operating characteristic curve % difference, 29.6%); process measures were the least sensitive (area under the receiver operating characteristic curve % differences: venous thromboembolism prophylaxis, 3.4%; stress ulcer prophylaxis, 2.1%). None of the 10 indicators was clearly and consistently correlated with a majority of the other nine indicators.

Conclusions—No indicator performed optimally across assessments. Future research should seek to define and operationalize quality in a way that is relevant to both patients and providers.

Keywords

critical care; ICU quality indicators; outcome measures; process measures; quality and patient safety; quality improvement

Quality indicators are screening tools used to identify potential areas for improvement in the quality of clinical care (1). Indicators reflecting hospital structure and processes of care should be associated with better outcomes, and measured outcomes should be causally linked to the care provided (2–6). They also must be reliably and objectively measured and reflect quality in both the opinion of providers and patients. In addition, quality indicators should have sufficient variability among ICUs to both differentiate good and poor performers and permit improvement (7, 8), be relatively insensitive to severity adjustment (3, 9, 10), perform as expected compared to a gold standard, should reflect consequences of the care delivered in the healthcare setting being assessed (10, 11), and should avoid inducing adverse incentives.

No study has empirically assessed how well currently used and potential ICU quality indicators meet these criteria. In general, more useful quality indicators would satisfy more criteria. In this study, we empirically examine 10 reliably measured current and potential quality indicators that are thought to have face validity according the criteria: 1) extent of impact of ICU rather than patient characteristics (12, 13), 2) sensitivity to severity adjustment (3, 9, 10), 3) variability (7, 14), and 4) correlation with other quality indicators (15). Quality indicators that are influenced more by ICU than patient characteristics and which display greater inter-ICU variability are more actionable (12). Indicators that are relatively insensitive to severity adjustment by known confounders are less likely to be influenced by unmeasured confounding (14, 16). Indicators that exhibit variability among ICUs more easily identify good and bad performers and identify domains for further improvement, enhancing their utility (7, 17). Finally, indicators that are uncorrelated with others may erroneously ascribe good performance to bad ICUs and vice versa.

Methods

Data Source

We performed a retrospective cohort study using Project IMPACT (Cerner Corporation, Kansas City, MO), a nationally representative, voluntary, fee-based ICU clinical information system used for benchmarking and research (18–20). Each ICU employs a trained data collector and a standardized web-based instrument to collect data regarding individual patients, care processes, and ICU characteristics (19, 21). In this database, ICU and hospital admission and discharge dates and times are collected on all patients, whereas complete clinical data on patient physiology, comorbidities, demographics, and procedures received during the ICU stay are collected on a random sample of between 50% and 100% of ICU patients. Detailed data regarding ICU and hospital characteristics, including staffing during day and nighttime hours and the provision of various clinical services such as transplant or cardiothoracic surgery, are also available. These data have been used to answer many questions related to the provision of critical care (18–20).

Variables

To identify potential quality indicators, we examined recommendations from United States and international critical care organizations (10, 22–24) and supplemented recommended indicators with others found during a PubMed literature search which intersected the keywords “ICU” or “intensive care unit,” and “quality indicator,” or “outcome measure.” We also searched the literature for indicators used in other care settings (25, 26). In picking process measures, we additionally selected measures shown to improve patient outcomes in clinical trials. All chosen indicators had clinical relevance and could be reliably measured in Project IMPACT. This selection process yielded two process and eight outcome measures (Table 1). We were not able to assess indicators such as rates of hospital-acquired infections due to lack of gold standard criteria in this dataset, complications due to an inability to distinguish complications from comorbidities in this dataset, and posthospital discharge outcomes such as 30-day mortality due to a lack of availability of posthospital discharge data.

Venous Thromboembolism Prophylaxis and Stress Ulcer Prophylaxis in Mechanically Ventilated Patients

We defined patients as having received venous thromboembolism (VTE) prophylaxis if they were given pharmacologic or mechanical prophylaxis at least once by the second day of the ICU admission. Patients with bleeding contraindications and those who received a lumbar puncture were considered ineligible to receive such prophylaxis. Stress ulcer prophylaxis against peptic ulcers using histamine-2 receptor blockers or proton pump inhibitors was indicated for patients receiving mechanical ventilation for at least 48 of 60 hours (27–29). Patients with indicated prophylaxis received at least one dose within a day of becoming eligible.

ICU Readmissions

ICU readmissions are often considered quality indicators because they are easily measured and associated with increased mortality, cost, and length of stay (15, 24, 30, 31). We examined readmissions to any ICU in the same hospital within two calendar days following first ICU discharge, which has been advocated based on typical patient flow patterns into and out of ICUs (32). Because hospitals vary in how they handle patients who deteriorate following ICU discharge (33, 34), we included, in a sensitivity analysis of ICU readmissions, all in-hospital death and ICU transfers within two calendar days of ICU discharge.

Risk-Adjusted Mortality Measures

We examined both ICU and in-hospital deaths, acknowledging that some but not all in-hospital deaths that occur following an ICU stay will be related to ICU activities (11, 22, 24, 35, 36). We were not able to assess mortality following hospital discharge.

ICU Length of Stay

ICU length of stay is the time between ICU admission and discharge (11, 24, 35, 37). We also examined 1) prolonged and 2) conditional length of stay. An ICU stay becomes “prolonged” on the day that the daily probability of being discharged first declines (Supplemental Fig. 1, Supplemental Digital Content 1, <http://links.lww.com/CCM/A925>) (25, 26). Prolonged length of stay is thought to reflect the ICU's ability to treat and discharge low-acuity patients quickly (25, 26). Conditional length of stay measures the length of stay past the prolongation point and describes the ICU's efficiency in treating more complicated patients (25, 26). For these analyses, we graphically identified the prolongation points, yielding definitions of prolonged stays as after 1 and 2 days for surgical and nonsurgical patients, respectively.

To estimate lengths of stay for patients who die or are transferred, we utilized interval-censored regression (38–40). Specifically, length of stay for such patients was defined as being at least as long as the time until death or transfer, and additional duration of stay was estimated from similar patients who did not die or transfer. We also examined more traditional linear models with log-transformed outcomes terminating length of stay for deaths and transfers on the day of death or transfer in a sensitivity analysis, as this is the definition currently used by the National Quality Forum.

Discharge Home

Discharge home following a hospitalization may represent a patient-centered outcome because it reflects the extent to which the ICU and hospital were able to restore functional capacity. Unlike in-hospital mortality and length of stay, it cannot be manipulated by institutions that differ in their propensities to send patients to long-term acute care and other facilities (33, 34). Our definition included patients discharged home with nursing care.

Inclusion/Exclusion Criteria

Adult patients were admitted to U.S. ICUs between April 1, 2001, and December 31, 2008 (Supplemental Fig. 2, Supplemental Digital Content 2, <http://links.lww.com/CCM/A926>). We included only first admissions to ICUs to preserve independence between observations. We excluded patients who 1) were ineligible to receive a Mortality Prediction Model (MPM₀-III) severity-of-illness score (i.e., cardiac surgery, coronary, and burn patients for whom MPM₀-III has not been validated) (41), 2) were less than 18 years, 3) were in an ICU that provided data for less than 12 months or with less than 10 admissions in a year, 4) had no events for any outcome or process measure across all years assessed, or 5) were missing data for one of our covariates.

Statistical Analysis

ICU and patient variables were measured on the first day of a patient's first admission to the ICU during a hospitalization. Covariates were included in final models based on prespecified scientific plausibility or associations with any outcome of an odds ratio of more than 1.2 or less than 0.8 accompanied by a *p* value of less than 0.0001, chosen because of large sample size (3, 14, 21, 42–50). All covariates were included in each model to permit comparability across quality indicators. Patient covariates included the MPM₀-III, reflecting severity of illness at ICU admission, functional status (independent, partially dependent, and fully dependent), demographic variables (age, race, sex, and insurance), and comorbidities (described in Supplemental Table 1, Supplemental Digital Content 3, <http://links.lww.com/CCM/A927>). ICU covariates included ICU model (closed, open with mandatory consult, and open with optional consult), hospital type (academic, community, and city/state/county), and nighttime staffing (critical care attending, other attending, fellow, resident, and no physician available) (41, 51, 52).

We assessed the 10 potential quality indicators using four separate analyses. First, we assessed whether patient factors were relatively more important than institutional characteristics in predicting outcomes or whether a process measure was performed. Quality indicators that are determined more by patient characteristics may be less actionable than those determined more by ICU characteristics. We used the Omega statistic (ω) (12, 13), a ratio which measures the relative contribution of different sets of variables to the variance of a model. In this case, it weighs the variance contributed by patient relative to ICU characteristics across different quality indicators. With patient variables in the numerator and ICU and hospital variables in the denominator, $\omega = 0$ would mean that all the variation in the candidate indicator is predicted by ICU characteristics; if $\omega = 1$, ICU and patient characteristics predict equivalent amounts of variability. Omega is useful in comparing quality indicators relative to each other, but raw values associated with individual quality indicators cannot be interpreted in isolation. In our main analysis, we included all patient, ICU, and hospital variables. To determine the extent to which unmeasured ICU characteristics affected the results, we examined ω in models that treated ICU as a fixed effect instead of including variables representing ICU and hospital characteristics (53, 54).

Second, because the foregoing ω analyses measure the relative importance of ICU to patient characteristics, we also assessed how well our models predicted each outcome or process

measure in absolute terms using patient-level models in which we included all patient variables, including demographic variables, comorbidities, functional status, and severity of illness, and treated ICU as a fixed effect. From these models, we calculated the area under the receiver operating characteristic curve (AUC) and R^2 to assess 1) model discrimination and 2) sensitivity to severity adjustment (55–57). We assessed percent differences in AUCs or R^2 s between fully adjusted models and models containing only fixed effects for ICU and year of admission (57). We did not perform statistical comparisons of AUC because clinically irrelevant differences might be statistically significant due to large sample sizes.

Third, we assessed the variability of unadjusted quality indicators across ICU years. Although targeted rates for different quality indicators will necessarily differ (e.g., a good ICU should have low mortality but high compliance with process measures), a minimum amount of variability must exist to differentiate good and bad performance and to illustrate that it is possible for ICUs to improve (7, 8, 17). We compared the unadjusted variability of each quality indicator across ICUs using interquartile and full ranges and by graphically identifying ICUs with higher rates than others using box plots.

Finally, we assessed how correlated each quality indicator was with all others assessed. We calculated risk-adjusted rates for each indicator in each ICU using the following formula (15):

$$\text{Severity-adjusted rate} = (\text{observed hospital rate} / \text{hospital rate}) \times \text{predicted hospital rate} \times \text{overall rate in the study sample}$$

We then assessed correlation between indicators using a Spearman correlation (58).

All analyses were performed using STATA 12.1 (StataCorp, College Station, TX). This study was deemed exempt from review by the University of Pennsylvania Institutional Review Board. Neither the funding sources nor Cerner Corporation had a role in the design of this study or in the decision to submit it for publication.

Results

From an initial dataset of 381,582 admissions in 186 ICUs, we identified 268,824 eligible patients admitted to 138 ICUs in 99 hospitals (Supplemental Fig. 2, Supplemental Digital Content 2, <http://links.lww.com/CCM/A926>). Most patients (41.8%) were admitted from an emergency department, 55% were less than 65 years, and 31% required mechanical ventilation during the ICU stay. Among the 138 ICUs, the median predicted probability of death on ICU admission, as determined by the MPM-III (41), was 7.8% (interquartile range, 3.3, 16.7). A large proportion of ICUs had less than 12 beds (40.6%), were located in community ICUs (76.1%), and had an open staffing model with optional intensivist consult (75.4%) (Table 2).

Contribution of ICU Characteristics

Three quality indicators (Table 3) had ω less than 1, indicating that ICU and hospital characteristics contributed more to the variance of our models than patient characteristics: stress ulcer prophylaxis (ω , 0.43; 95% CI, 0.34–0.54), VTE prophylaxis (ω , 0.57; 95% CI,

0.53–0.61), and ICU readmissions (ω , 0.69; 95% CI, 0.52–0.90). All length-of-stay measures, ICU and in-hospital mortality, and discharge home had a ω scores greater than 20, indicating that patient characteristics were at least 20 times more important than ICU characteristics in determining whether a patient experienced these outcomes. Traditional definitions of ICU length of stay utilizing linear regression had higher ω values but ranked similarly relative to other measures (Supplemental Table 2, Supplemental Digital Content 4, <http://links.lww.com/CCM/A928>).

When ICU was modeled as a fixed effect (Table 3), all ω values were smaller because unmeasured ICU characteristics were now included in the denominator. However, the same three measures remained the only ones with ω less than 1.

Sensitivity to Severity Adjustment

Mortality measures were the most sensitive to severity adjustment, with percent differences in AUC between fully adjusted and base models at 29.6% for ICU mortality and 28.5% for in-hospital mortality (Table 4). Discharge home was also highly sensitive (26.3% change). The least sensitive measures were ICU readmission (3.7% change), VTE (3.4% change), and stress ulcer prophylaxis (2.1% change).

Variability

In unadjusted models (Fig. 1), all potential outcome measures had at least one outlier. The dichotomous outcomes with the widest ranges included prolonged length of stay (4.7–71.3%) and discharge home (30.6–82.0%). The outcomes with the smallest ranges were ICU readmissions (0.1–19.2%) and ICU mortality (0–20.6%).

Correlation

Improved performance on one measure was not clearly and consistently correlated with improved performance on a majority of the other nine measures for any of the 10 quality indicators assessed. (Table 5). ICU readmission was positively correlated with ICU mortality ($r_s = 0.1859$, $p = 0.0290$) and ICU length of stay ($r_s = -0.2260$, $p = 0.0077$) and negatively correlated with stress ulcer prophylaxis ($r_s = -0.1831$, $p = 0.0316$) (Table 5). ICU mortality was correlated with prolonged ($r_s = 0.2103$, $p = 0.0133$) and conditional ($r_s = -0.2787$, $p = < 0.0001$) lengths of stay. Stress ulcer prophylaxis was uncorrelated with most measures; VTE prophylaxis was positively correlated with in-hospital mortality ($r_s = 0.2181$, $p = 0.0101$).

Discussion

This study provides evidence of how ICU quality indicators that have been proposed based on their face validity, relevance, and ease of measurement actually perform across a set of criteria that characterize good quality indicators. No measure performed best across all metrics; however, some indicators—particularly the two process measures (VTE and stress ulcer disease prophylaxis)—performed better on balance than others. Measures such as ICU readmissions and prolonged length of stay exhibited intermediate performance, and rates of ICU mortality and discharge home performed least well, as these were strongly determined

by patient characteristics, and may not be as actionable by ICUs. No quality indicator, including the process measures, was consistently correlated with most other indicators, supporting the idea that there is no gold standard ICU quality indicator.

The process measures examined here were largely determined by ICU characteristics, supporting the idea that process measures reflect what providers do (3, 7), and were, perhaps unsurprisingly, least sensitive to severity adjustment. Although the attributable risks of noncompliance with these process measures may be more modest than those of more “downstream” clinical events, these data regarding the methodological attributes of different ICU quality indicators support the use of process measures over outcome measures (3, 59, 60). Furthermore, the observation that many ICUs performed below full compliance for these process measures suggests that promoting them as quality indicators could lead to improvements in healthcare as well (3, 59, 60). Indeed, a recent observational study demonstrated that hospitals performing well on a panel of process measures had lower observed mortality than would be expected simply due only to the direct effects of delivering the measured care (2, 7). Thus, although future research should confirm that compliance with these processes leads to better outcomes, measuring success on these measures may also help identify other unmeasured aspects of high-quality care (2, 7).

Mortality measures were primarily determined by patient characteristics and were highly sensitive to severity adjustment, suggesting that ICUs have less control over whether a patient dies than they have over other measures. Evidence that ICUs can “game the system” and artificially improve their mortality statistics by discharging more patients to other facilities (33) illustrates additional problems with using such measures as quality indicators. Furthermore, the relative lack of variability of in-hospital deaths may make it difficult for ICUs to improve their mortality rates. Thus, although risk-adjusted mortality has long been considered the gold standard for assessing ICU performance (15), it does not possess any of the desirable characteristics of a good quality indicator examined in this study.

Discharge home occurred more commonly than death but was similarly sensitive to severity adjustment and not driven by ICU characteristics. Rates of discharge home could also reflect regional differences in the availability of long-term acute care facilities rather than quality of care provided in ICUs. Because this may affect ICU patients' admission sources and discharge destinations, future studies should seek to evaluate a more nuanced measure than we had access to, namely the proportion of patients discharged to their place of residence immediately prior to ICU admission. Although our measure of discharge home adjusted for ICU admission source, many patients admitted most proximately from the emergency department or floor may have originated in skilled nursing or other facilities.

ICU readmissions and length-of-stay measures had intermediate performance across the metrics assessed. Although ICU readmission rate was primarily determined by ICU characteristics and was insensitive to severity adjustment, both of these observations may be attributable to the fact that patient characteristics were calculated on the day patients were admitted to the ICU. If a severity-of-illness score was available at ICU discharge, we speculate that ICU readmission rate would have been considerably more sensitive to severity adjustment and may have been influenced more prominently by patient rather than ICU

characteristics. This speculation is supported by the low AUC observed for the ICU readmission rate, indicating that neither patient nor ICU characteristics are especially good predictors of ICU readmission. Unlike previous studies, we found that ICU readmissions were correlated with ICU mortality and ICU length of stay, which may reflect changes in bed triage practices over recent years (15). If ICU readmissions are to be used as a quality indicator for ICUs, at a minimum, a day of ICU discharge severity score that can be used for severity adjustment must be developed.

Length-of-stay measures (traditional, conditional, and prolonged) also had intermediate performance according to our measures of sensitivity to severity adjustment and determination by ICU characteristics. Continuous length-of-stay measures have promise because they have greater power to detect differences between ICUs and because they are closely associated with cost. Prolonged and conditional lengths of stay may reflect how well ICUs care for less complicated and more complicated patients, respectively. However, length of stay may be influenced by bed availability on the wards rather than ICU care (26, 61), there exist considerable challenges in analyzing length-of-stay data, and clinically significant differences are not well defined.

This study has several limitations. First, we could not assess posthospital discharge outcomes such as long-term mortality or hospital readmissions. However, ICU care is merely one of many contributors to these more distant measures, reducing the likelihood that they would serve as useful ICU quality indicators. We also could not assess complications in this dataset because of difficulty distinguishing complications from comorbidities, determining which complications were caused by negligent care versus underlying illness (62), and the lack of availability of gold standard data such as culture data for hospital-acquired infections. Complications would be better assessed using alternative data sources in which methods for overcoming these problems have been validated. We similarly could not assess process measures such as prophylaxis against ventilator-associated pneumonia because of a lack of detailed data on these processes.

Second, Project IMPACT includes data collected through 2008. Since 2008, nurse practitioners and physician assistants have become more involved in patient management, and there has been increased interest in early identification of patients who need ICU-level care. However, similar analyses using more recent data would likely yield similar results because the analyses focus on the relative performance of groups of variables rather than on specific point estimates for individual factors. Additionally, the quality indicators we examined could behave differently in other settings, such as ICUs in other countries, or among types of patients we excluded because they lacked an MPM-III score (41) preventing valid severity-of-illness adjustment. However, with 76% of ICUs in Project IMPACT residing in community hospitals, this data source is largely representative of critical care provision across the United States.

Third, we have not determined the clinical significance of the magnitude of differences across ICUs in the variability of these quality indicators or the degree to which a measure can be attributable to patient characteristics and still remain useful. It is possible that as more ICUs adopt specific process measures, variability will decrease over time. Such

progress would not decrease the importance of measuring and following the indicator, although it would become less able to differentiate good and poor performers.

Fourth, it is possible that inclusion of unmeasured patient-level variables in our models could change the results. However, the variables included in these models were as comprehensive as in any ICU study we are aware of, and unmeasured variables are unlikely to meaningfully change our results given that the MPM-III severity-of-illness adjustment score was developed in this database.

Finally, it is possible that quality indicators that are more actionable are also more susceptible to “gaming” by hospitals in order to artificially improve their statistics.

Future work should explore whether other measures, such as mortality among patients who have suffered complications (or “failure to rescue”) (14), may serve as useful ICU quality indicators. Given the lack of a gold standard ICU quality indicator, future work should seek to define what quality in the ICU means to both physicians and patients. Studies investigating how the internal use of control charts by ICUs to track these measures can improve quality of care are also warranted.

Conclusions

This study provides the first empirical assessment of the statistical properties of a variety of ICU quality indicators that also have face validity and are easily measurable. If policy makers and payers adopt quality indicators lacking most of these attributes, they may penalize institutions for outcomes they cannot control, misidentify good and poor performers, and promote adverse incentives. We find that no measured quality indicator was adequate for all applications, nor does any one indicator outperform all others on all criteria. Although the process measures we evaluated performed the best across these statistical properties, no measure, including the process measures, performed clearly and consistently as a “good” quality indicator across all metrics. Future work should identify quality indicators that are important to patients as well as providers and work toward operationalizing them.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1. Variability of the eight dichotomous and two continuous quality indicators. VTE = venous thromboembolism.

Table 1
Description of Quality Potential Quality Indicators

Quality Indicator	Outcome or Process Measure	Definition	Eligible Patients
Stress ulcer prophylaxis	Process	Use of a histamine-2 receptor blocker or proton pump inhibitor	Patients receiving mechanical ventilation for at least 48 of 60 hr
Venous thromboembolism prophylaxis	Process	Mechanical or pharmacologic prophylaxis	Patients without bleeding admission diagnoses or complications
ICU readmission	Outcome	Readmission to any ICU in the same hospital within 2 calendar days of first ICU discharge	All patients
Potential post-ICU discharge adverse event	Outcome	Readmission, in-hospital death, or transfer to another hospital within 2 calendar days of first ICU discharge	All patients
ICU mortality	Outcome	Death in the ICU	All patients
In-hospital mortality	Outcome	Death in the hospital	All patients
ICU length of stay ^a	Outcome	Days from ICU admission to ICU discharge, length of stay for deaths, and transfers estimated using interval-censored regression	All patients
Prolonged length of stay	Outcome	Length of stay is “prolonged” when the probability of ICU discharge on a given day begins to decline	All patients
Conditional ICU length of stay ^a	Outcome	Length of stay past prolongation point, conditional length of stay for deaths, and transfers estimated using interval-censored regression	Patients incurring a prolonged length of stay
Discharge home	Outcome	Discharge to home from the hospital with or without skilled nursing care	All patients

^aUsed interval-censored regression to estimate length of stay for patients who died or who transferred to another hospital.

Table 2
Patient, ICU, and Hospital Characteristics

Variables	% or Median (IQR)
Patient variables	
Race	
Black	14.1
White	77.0
Other	8.9
Age (yr)	
< 65	54.6
65–74	19.6
75–84	18.9
85+	6.8
% Male	53.9
Insurance	
Medicare	50.0
Private	29.5
Self pay	8.9
Medicaid	8.6
Other	3.0
Source of ICU admission	
Emergency department	41.8
Operating room/procedure suite	32.3
General care floor or step-down	15.5
Another hospital	7.9
Other (includes skilled nursing facility, long term acute care facility, rehabilitation facility)	2.5
Patient type	
Medical	66.4
Scheduled surgical	21.5
Unscheduled surgical	12.2
Predicted probability of death (Mortality Prediction Model-III)	7.8 (3.3, 16.7)
Functional status	
Independent	77.0
Partially dependent	16.3
Completely dependent	6.7
Number of comorbidities	0 (0, 1)
Required mechanical ventilation on day of ICU admission	26.7
Required vasopressors on day of ICU admission	18.1
ICU and hospital variables	
ICU model	
Closed	4.4
Open, mandatory intensivist consult	20.3

Variables	% or Median (IQR)
Open, optional, or no intensivist consult	75.4
Night physician coverage	
Critical care attending	28.3
Other attending	28.3
Fellow	5.8
Resident	29.7
No physician coverage	8.0
Nursing education level	
LPN and above	10.1
Registered nurse and LPN	87
Critical care registered nurse required	2.9
Hospital organization	
Academic	19.6
Community	76.1
City/state/county	4.4

IQR = interquartile range, LPN = licensed practical nurse.

Table 3
Contribution of ICU Relative to Patient Characteristics (Omega Statistic)

Quality Indicator	Patient Level					
	Hospital + ICU Characteristics			ICU as Fixed Effect		
	Rank	ω	95% CI	Rank	ω	95% CI
Stress ulcer prophylaxis ^a	1	0.43	0.34–0.54	1	0.15	0.12–0.20
Venous thromboembolism prophylaxis ^a	2	0.57	0.53–0.61	2	0.30	0.28–0.31
ICU readmission	3	0.69	0.52–0.90	3	0.34	0.28–0.42
Potential post-ICU discharge adverse event ^b	4	5.35	4.31–6.65	4	2.15	1.91–2.43
Prolonged length of stay	5	21.52	19.32–23.96	5	5.41	5.28–5.55
Conditional ICU length of stay ^a	6	22.41	19.88–25.27	6	7.61	7.35–7.89
ICU length of stay	7	27.28	25.35–29.36	7	8.73	8.56–8.91
In-hospital mortality	8	31.14	27.69–35.01	9	13.82	13.31–14.36
ICU mortality	9	33.14	28.71–38.26	8	11.59	11.19–11.99
Discharge home ^c	10	55.87	50.38–61.95	10	18.79	18.18–19.42

^aModels exclude ineligible patients.

^bIncludes ICU readmission, in-hospital mortality, and transfer to another hospital within 2 calendar days of ICU discharge.

^cDischarge home from the hospital with or without nursing care.

Patient variables included race (white, black, and other), age (< 65, 65–74, 75–84, and 85 yr), sex, insurance status (Medicare, private, Medicaid, self pay, and other), ICU admission source (emergency department, floor, step-down unit, other hospital, and other), patient type (medical, scheduled surgical, and unscheduled surgical), predicted probability of death (Mortality Prediction Model(I–III), functional status (independent, partially dependent, and fully dependent), number of comorbidities, required mechanical ventilation or vasopressors on ICU admission day, the presence of a baseline serum creatinine of > 2 mg/dL, a solid-organ tumor, chronic respiratory disease, chronic cardiac disease, chronic renal disease requiring dialysis, or cancer with proven metastasis.

ICU/hospital variables included ICU model (closed, open with mandatory intensivist consult, and open with optional intensivist consult), night provider coverage (critical care attending, any attending, fellow, resident, and no physician coverage), minimum nursing education level (licensed practical nurse, registered nurse, and critical care registered nurse), hospital organization (academic, community, and city/state/county), number of ICU and hospital beds, the presence of a critical care fellowship program, hospital location (urban, suburban, and rural), whether or not the hospital or ICU employs residents or hospitalists, the presence of transplant, cardiothoracic surgery, a burn unit, an interventional cardiac catheterization laboratory, or transplant surgery, and the presence of a step-down unit from the ICU to the floor.

Also included in model: year of first ICU admission.

Table 4
Sensitivity to Severity Adjustment

Dichotomous Quality Indicators	Area Under the Curve		
	(A) With Severity Adjustment	(B) Without Severity Adjustment	% Difference Between A and B
Stress ulcer prophylaxis ^a	0.7510	0.7349	2.1%
Venous thromboembolism prophylaxis ^a	0.7573	0.7314	3.4%
ICU readmission	0.6643	0.6399	3.7%
Potential post-ICU discharge adverse event ^b	0.6774	0.5929	12.5%
Prolonged length of stay	0.7219	0.6070	15.9%
Discharge home ^c	0.7986	0.5889	26.3%
In-hospital mortality	0.8606	0.6149	28.5%
ICU mortality	0.8833	0.6216	29.6%

Continuous Quality Indicators	Estimated R^2		
	(A) With Severity Adjustment	(B) Without Severity Adjustment	% Difference between A and B
ICU length of stay	0.2354	0.0468	80.1%
Conditional ICU length of stay ^a	0.1874	0.0432	76.9%

^aModels exclude ineligible patients.

^bIncludes ICU readmission, in-hospital mortality, and transfer to another hospital within 2 calendar days of ICU discharge.

^cDischarge home from the hospital with or without nursing care.

Patient variables included race (white, black, and other), age (< 65, 65–74, 75–84, and 85 yr), sex, insurance status (Medicare, private, Medicaid, self pay, and other), ICU admission source (emergency department, floor, step-down unit, other hospital, and other), patient type (medical, scheduled surgical, and unscheduled surgical), predicted probability of death (Mortality Prediction Model(I-III)), functional status (independent, partially dependent, and fully dependent), number of comorbidities, required mechanical ventilation or vasopressors on ICU admission day, the presence of a baseline serum creatinine of > 2 mg/dL, a solid-organ tumor, chronic respiratory disease, chronic cardiac disease, chronic renal disease requiring dialysis, or cancer with proven metastasis.

ICU/hospital variables included ICU model (closed, open with mandatory intensivist consult, and open with optional intensivist consult), night provider coverage (critical care attending, any attending, fellow, resident, and no physician coverage), minimum nursing education level (licensed practical nurse, registered nurse, and critical care registered nurse), hospital organization (academic, community, and city/state/county), number of ICU and hospital beds, the presence of a critical care fellowship program, hospital location (urban, suburban, and rural), whether or not the hospital or ICU employs residents or hospitalists, the presence of transplant, cardiothoracic surgery, a burn unit, an interventional cardiac catheterization laboratory, or transplant surgery, and the presence of a step-down unit from the ICU to the floor.

Also included in model: year of first ICU admission.

Correlation Between Quality Indicators

Table 5

Variable	ICU Readmission	Post-ICU Discharge Adverse Events	ICU Mortality	In-Hospital Mortality	Discharge Home	Prolonged Length of Stay	ICU Length of Stay	Conditional Length of Stay	Stress Ulcer Prophylaxis
Post-ICU discharge adverse events ^a	0.7152 (< 0.0001)								
ICU mortality	0.1859 (0.0290)	0.4584 (< 0.0001)							
In-hospital mortality	0.1289 (0.1318)	0.4577 (< 0.0001)	0.8444 (< 0.0001)						
Discharge home ^b	0.1998 (0.0188)	0.1820 (0.0327)	-0.0172 (0.8412)	-0.1740 (0.0413)					
Prolonged length of stay	-0.0819 (0.3396)	-0.0335 (0.6965)	0.2103 (0.0133)	0.2243 (0.0082)	-0.1877 (0.0275)				
ICU length of stay	-0.2260 (0.0077)	-0.1556 (0.0684)	-0.1234 (0.1493)	0.1420 (0.0967)	-0.4934 (< 0.001)	0.0740 (0.3887)			
Conditional length of stay ^c	-0.1513 (0.0764)	-0.3066 (< 0.0001)	-0.2787 (0.0009)	-0.1695 (0.0469)	-0.1129 (0.1875)	0.0172 (0.8409)	0.4096 (< 0.0001)		
Stress ulcer prophylaxis ^c	-0.1831 (0.0316)	-0.2226 (0.0087)	-0.0782 (0.3620)	-0.1318 (0.1232)	-0.0027 (0.9750)	0.0378 (0.6600)	-0.0958 (0.2638)	0.0935 (0.2753)	
Venous thromboembolism prophylaxis ^c	-0.0947 (0.2691)	0.0513 (0.5503)	0.1398 (0.1021)	0.2184 (0.0101)	-0.1159 (0.1760)	0.3055 (< 0.0001)	0.2748 (0.0011)	0.1387 (0.1048)	0.1038 (0.2257)

^aIncludes ICU readmission, in-hospital mortality, and transfer to another hospital within 2 calendar days of ICU discharge.

^bDischarge home from the hospital with or without nursing care.

^cModels exclude ineligible patients.

Patient variables included race (white, black, and other), age (< 65, 65–74, 75–84, and 85 yr), sex, insurance status (Medicare, private, Medicaid, self pay, and other), ICU admission source (emergency department, floor, step-down unit, other hospital, and other), patient type (medical, scheduled surgical, and unscheduled surgical), predicted probability of death (Mortality Prediction Modelq-III), functional status (independent, partially dependent, and fully dependent), number of comorbidities, required mechanical ventilation or vasopressors on ICU admission day, the presence of a baseline serum creatinine of > 2 mg/dL, a solid-organ tumor, chronic respiratory disease, chronic cardiac disease, chronic renal disease requiring dialysis, or cancer with proven metastasis.

ICU/hospital variables included ICU model (closed, open with mandatory intensivist consult, and open with optional intensivist consult), night provider coverage (critical care attending, fellow, resident, and no physician coverage), minimum nursing education level (licensed practical nurse, registered nurse, and critical care registered nurse), hospital organization (academic, community, and city/state/county), number of ICU and hospital beds, the presence of a critical care fellowship program, hospital location (urban, suburban, and rural), whether or not the hospital or ICU employs residents or hospitalists, the presence of transplant, cardiothoracic surgery, a burn unit, an interventional cardiac catheterization laboratory, or transplant surgery, and the presence of a step-down unit from the ICU to the floor.

Also included in model: year of first ICU admission.