Patient Outcomes and Unit Composition with Transition to a High-intensity ICU Staffing Model: A Before-and-After Study

Jennifer Proper, BS, David A. Wacker MD, PhD, Salma Shaker MD, Jamie Heisdorffer MS, Rami Shaker MHI, Larissa T Shiue MD, Kathryn M. Pendelton, Lianne K. Siegel, PhD, Ronald A. Reilkoff MD

Supplemental Digital Content

Supplemental Methods

Study design and setting

A prospective observational before-and-after study of consecutive patients admitted to a community-based ICU was conducted under two distinct staffing paradigms to evaluate their effect on patient outcomes as well as unit composition and turnover. The study was conducted in a 334-bed regional referral community hospital affiliated with a major medical academic center but without the presence of residents or fellows. The intensive care unit was a 24-bed combined (medical, surgical, cardiovascular, and neurosurgical), open ICU with greater than 1300 ICU admissions annually.

Study population and timeframe

Admission data was collected prospectively from October 2016 to November 2017. All patients (adults > 18 years of age) admitted to the ICU over the study period, regardless of admitting provider specialty, were included in this study (Figure 1). Data was collected prospectively upon admission to the ICU during the study time frame. This timeframe encompassed an 8-month period before and 6-month period after an administratively planned transition in ICU staffing from a low-intensity to high-intensity model (June 2017).

Low-intensity and high-intensity staffing models

Prior definitions of ICU structure describe “low-intensity” models as having an open admission policy in which providers of any specialty can manage patients, possibly with a non-mandatory intensivist consult if available. In contrast, “high-intensity” models traditionally involve a closed unit in which critical care specialty-trained providers are required to either assume primary responsibility of or at least consult on all patients admitted to the ICU(1, 2). In this study, the low-intensity staffing model (November 2016 - May 2017 time period) employed an open admission policy with elective intensivist consultation at the discretion of the admitting provider, though primary management of patients requiring mechanical ventilation or invasive hemodynamic support (e.g., vasopressors, intra-aortic balloon pump, or other advanced cardiac support devices) by intensivists was mandatory. The ICU was covered by two in-house board-certified intensivists (anesthesia, internal medicine, or surgical critical care trained physician) from 7:00 AM until 9:00 PM (14 hours) with staffing staggered to provide 4 hours of scheduled overlap at midday (Provider 1, 7:00AM - 2:00 PM; Provider 2, 10:00 AM - 9:00 PM). Overnight coverage was provided with as-needed tele-ICU MD support with an additional on-call provider available to return to the hospital if needed for bedside management at the discretion of the tele-ICU provider. The tele-ICU physician's workspace was located off-site at another hospital within the same healthcare system and utilized the same electronic medical record with visualization of patients obtained with high resolution cameras. Many of the intensivists who worked on-site at the study ICU also regularly rotated through the tele-ICU as part of their regular clinical activities.

The transition to a high-intensity staffing model occurred six months into the study period on June 1, 2017. The high-intensity model (June-November 2017) implemented three major staffing changes. First, a third daytime provider was added to the staffing complement in the form of a critical care advanced practice provider (APP) working from 7 AM to 5 PM, in addition to the two existing critical care physicians. The APP responsibilities included managing a share of admissions and consults and assisting with cross cover. Physician oversight was provided, but most APPs functioned largely independently. Second, unlike the low-intensity model in which intensivist consultation was optional except in the case of invasive mechanical ventilation and vasopressor use, all patients admitted to the ICU under the high-intensity model were either primarily admitted and managed by the intensivist team or co-managed by the non-intensivist admitting team and the intensivist team via mandatory consultation. Third, overnight coverage was changed from remote to in-house coverage by one intensivist who was responsible for ICU admissions, cross covering on all ICU patients, and covering tele-ICU responsibilities for four other community hospital ICUs in the area.

When making ICU triage decisions for a patient, calls were sent directly to the intensivist for any patient who was on vasopressors or mechanically ventilated. For patients not meeting these criteria, the admitting physician (usually hospitalist) determined the level of care necessary, including need for ICU cares. Under the low-intensity model, hospitalists contacted the intensivist for triage decisions only if they felt uncomfortable managing the patient without intensivist support. Under the high-intensity model, hospitalists were encouraged, though not required, to contact the intensivist for any question about ICU care needs.

The decision to transition to the higher intensity staffing model was driven by multiple factors, but the most prominent was requests from the hospital's surgical services to have expanded intensivist coverage for post-operative patients. The authors are not aware of any other major process or administrative changes that occurred at the hospital over this timeframe.

Data collection

Patient-to-provider ratios were calculated at the time of admission for each patient by dividing the ICU census at time of admission by the scheduled daytime provider coverage regardless of time of provider overlap. For example, in the low-intensity model, which had 24 beds and 2 daytime providers with 14 hours of continuous provider in-house daytime coverage, the maximum daytime provider-to-patient ratio was 1:12. Conversely, the maximum daytime provider-to-patient ratio in the high-intensity model was 1:8 (24 beds/3 daytime providers). Select patient and census-specific data were collected by the unit clerk using a data collection tool and additional variables were extracted from the electronic medical record by research coordinators and medical students trained to abstract data according to study protocol. For data collection training, investigators (RR, DW) reviewed random sample data from 10+ charts per reviewer to ensure the consistency and accuracy of the data abstracted. Data collection included ICU census at the time of admission, physician and nursing staffing ratios, the number of ICU discharges on the day of admission, and the number of patients on life support, defined as need for vasopressors, mechanical ventilation, or both. Patient acuity on admission was calculated using the sequential organ failure assessment (SOFA) score(3). Administrative data was collected to supplement the admission data and included the case mix index (CMI), daily average census, and distinct patient averages for each study month. The primary outcome of this study was 30-day all-cause mortality. Secondary outcomes included in-hospital mortality, ICU length of stay (LOS), and unit composition, defined as patients admitted to the ICU for a specific intervention versus observation.

Statistical Analysis

Patient characteristics and ICU staffing, census, and turnover were summarized by staffing model using standard descriptive statistics. Normally distributed variables were compared using Student’s t-test with unequal variances, skewed variables were compared using the Wilcoxon rank sum test, and categorical variables were compared using Fisher’s exact test. Thirty-day and in-hospital all-cause mortality were compared between staffing models using Fisher’s exact test. ICU LOS was compared between staffing models while treating in-hospital mortality as a competing risk using Aalen-Johansen cumulative incidence plots and Gray’s test(4), the competing risks analog to the log-rank test. Importantly, differences in patient outcomes were susceptible to bias from seasonal variation and other temporal trends as the staffing models were implemented over different time periods. To visually assess whether any underlying trends in patient outcomes were present over the course of the study period, 30-day mortality, in-hospital mortality, and ICU LOS by month of hospital admission were plotted. Additional adjusted analyses were similarly conducted to limit the chance of a biased association due to potential confounding. The association between staffing model and 30-day and in-hospital mortality were re-evaluated using multiple logistic regression models that accounted for patient age, race, ethnicity, gender, admission type (medical, surgical, etc), severity of comorbidities (Charlson comorbidity index), time of admission (day vs. night), and severity of illness (SOFA score and nurse-patient ratio on admission), as well as the overall acuity of the ICU (number of patients on pressors and number on mechanical ventilation). The association between staffing model and ICU LOS was similarly re-evaluated using a Fine-Gray competing risk regression model(5) accounting for the aforementioned factors. The adjusted models were then refit using an interaction term between staffing model and SOFA score to determine whether the association between each patient outcome and staffing model differed by patient acuity. All analyses were conducted using R version 4.1.1 and two-sided p-values <0.05 were considered statistically significant. This study was approved by the University of Minnesota Institutional Review Board (STUDY # 1606M89741).

References

1. Garland A, Gershengorn HB: Staffing in ICUs: physicians and alternative staffing models. *Chest* 2013; 143(1):214-221

2. Pronovost PJ, Angus DC, Dorman T, Robinson KA, et al: Physician staffing patterns and clinical outcomes in critically ill patients: a systematic review. *JAMA* 2002; 288(17):2151-2162

3. Ferreira FL, Bota DP, Bross A, Melot C, et al: Serial evaluation of the SOFA score to predict outcome in critically ill patients. *JAMA* 2001; 286(14):1754-1758

4. Gray RJ: A Class of K-Sample Tests for Comparing the Cumulative Incidence of a Competing Risk. *Ann Stat* 1988; 16(3):1141-1154

5. Fine JP, Gray RJ: A Proportional Hazards Model for the Subdistribution of a Competing Risk. *J Am Stat Assoc* 1999; 94(446):496-509

eTABLE 1: Multivariable model of in-hospital mortality with interaction term for staffing model and SOFA score

Covariate	Odds Ratio (95% CI)	P value
(Intercept)[a]	-6.73 (-8.26, -5.31)	<0.001
High-intensity staffing model	0.97 (0.38, 2.34)	0.94
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	1.12 (0.62, 1.97)	0.72
2 RN: 1 Pt	0.33 (0.02, 2.12)	0.32
Age	1.04 (1.03, 1.06)	<0.001
Female sex assigned at birth	0.78 (0.51, 1.17)	0.23
Race identified as White/Caucasian	1.43 (0.79, 2.69)	0.25
Charlson Comorbidity Index	1.06 (0.97, 1.16)	0.19
Sofa Score	1.42 (1.32, 1.54)	<0.001
Night admission (7 pm – 7 am)	0.98 (0.63, 1.51)	0.92
Weekend admission	0.73 (0.43, 1.20)	0.22
Number of ventilated patients on unit at time of admission	0.95 (0.88, 1.04)	0.27
Number of patients requiring pressors on unit at time of admission	1.06 (0.93, 1.20)	0.38
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	0.18 (0.08, 0.37)	<0.001
Neurologic	0.80 (0.43, 1.48)	0.49
Surgical (Post-operative)	0.23 (0.08, 0.58)	<0.001
High-intensity staffing model * SOFA score interaction term	0.99 (0.87, 1.13)	0.83

[a] Presented on the log (odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt

[c] Odds ratio relative to medical admission. Odd ratio for admission type “Other” was inestimable due to quasi-complete separation.

eTABLE 2: Multivariable model of 30-day mortality with interaction term for staffing model and SOFA score

Covariate	**Odds Ratio (95% CI)**	**P value**
(Intercept)[a]	-5.98 (-7.29, -4.75)	<0.001
High-intensity staffing model	0.88 (0.41, 1.82)	0.73
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	0.95 (0.57, 1.60)	0.86
2 RN: 1 Pt	0.21 (0.01, 1.32)	0.17
Age	1.04 (1.03, 1.06)	<0.001
Female sex assigned at birth	0.78 (0.54, 1.12)	0.18
Race identified as White/Caucasian	1.13 (0.68, 1.92)	0.64
Charlson Comorbidity Index	1.09 (1.01, 1.19)	0.03
Sofa Score	1.35 (1.26, 1.45)	<0.001
Night admission (7 pm – 7 am)	0.97 (0.65, 1.42)	0.87
Weekend admission	0.72 (0.45, 1.12)	0.15
Number of ventilated patients on unit at time of admission	0.97 (0.90, 1.04)	0.38
Number of patients requiring pressors on unit at time of admission	1.02 (0.91, 1.14)	0.74
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	0.23 (0.11, 0.41)	<0.001
Neurologic	0.90 (0.53, 1.52)	0.71
Surgical (Post-operative)	0.38 (0.16, 0.81)	0.02
High-intensity staffing model * SOFA score interaction term	1.01 (0.9, 1.13)	0.92

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt

[c] Odds ratio relative to medical admission. Odd ratio for admission type “Other” was inestimable due to quasi-complete separation.

eTABLE 3: Multivariable model of in-hospital mortality for subjects with intensivist initial ICU primary service (subgroup analysis)

Covariate	Odds Ratio (95% CI)	P value
(Intercept)[a]	-6.26 (-8.73, -4.11)	<0.001
High-intensity staffing model	0.98 (0.48, 1.99)	0.96
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	1.97 (0.87, 4.57)	0.11
2 RN: 1 Pt	0.52 (0.02, 6.11)	0.62
Age	1.03 (1.00, 1.07)	0.04
Female sex assigned at birth	0.909 (0.45, 1.80)	0.77
Race identified as White/Caucasian	0.96 (0.39, 2.48)	0.94
Charlson Comorbidity Index	1.11 (0.95, 1.30)	0.20
Sofa Score	1.40 (1.27, 1.57)	<0.001
Night admission (7 pm – 7 am)	0.44 (0.21, 0.90)	0.03
Weekend admission	0.73 (0.33, 1.57)	0.43
Number of ventilated patients on unit at time of admission	0.97 (0.85, 1.11)	0.66
Number of patients requiring pressors on unit at time of admission	1.20 (0.98, 1.48)	0.07
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	0.72 (0.19, 2.56)	0.62

Neurologic	1.36 (0.40, 4.31)	0.60
Surgical (Post-operative)	0.12 (0.01, 0.61)	0.02

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt

[c] Odds ratio relative to medical admission. Odd ratio for admission type “Other” was inestimable due to quasi-complete separation.

eTABLE 4: Multivariable model of 30-day mortality for subjects with intensivist initial ICU primary service (subgroup analysis)

Covariate	Odds Ratio (95% CI)	P value
(Intercept)[a]	-5.55 (-7.76, -3.59)	<0.001
High-intensity staffing model	1.03 (0.53, 2.01)	0.93
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	2.03 (0.93, 4.53)	0.08
2 RN: 1 Pt	0.34 (0.01, 3.86)	0.41
Age	1.03 (1.00, 1.07)	0.03
Female sex assigned at birth	1.14 (0.59, 2.18)	0.70
Race identified as White/Caucasian	0.66 (0.28, 1.54)	0.33
Charlson Comorbidity Index	1.13 (0.97, 1.31)	0.11
Sofa Score	1.35 (1.22, 1.49)	<0.001
Night admission (7 pm – 7 am)	0.53 (0.27, 1.03)	0.06
Weekend admission	0.76 (0.36, 1.54)	0.44
Number of ventilated patients on unit at time of admission	0.97 (0.86, 1.09)	0.66
Number of patients requiring pressors on unit at time of admission	1.13 (0.93, 1.36)	0.20
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	0.54 (0.14, 1.86)	0.34

Neurologic	1.16 (0.37, 3.35)	0.79
Surgical (Post-operative)	0.19 (0.03, 0.77)	0.03

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt

[c] Odds ratio relative to medical admission. Odd ratio for admission type “Other” was inestimable due to quasi-complete separation.

eTABLE 5: Multivariable model of in-hospital mortality for subjects with non-intensivist initial ICU primary service (subgroup analysis)

Covariate	**Odds Ratio (95% CI)**	**P value**
(Intercept)[a]	-7.31 (-9.48, -5.35)	<0.001
High-intensity staffing model	0.73 (0.38, 1.34)	0.32
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	0.66 (0.26, 1.52)	0.34
Age	1.05 (1.03, 1.08)	<0.001
Female sex assigned at birth	0.66 (0.38, 1.13)	0.13
Race identified as White/Caucasian	2.12 (0.90, 5.87)	0.11
Charlson Comorbidity Index	1.06 (0.94, 1.19)	0.34
Sofa Score	1.40 (1.27, 1.55)	<0.001
Night admission (7 pm – 7 am)	1.40 (0.77, 2.48)	0.26
Weekend admission	0.61 (0.29, 1.21)	0.17
Number of ventilated patients on unit at time of admission	0.92 (0.82, 1.03)	0.15
Number of patients requiring pressors on unit at time of admission	1.01 (0.84, 1.20)	0.91
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	0.21 (0.07, 0.61)	<0.001
Neurologic	0.70 (0.32, 1.49)	0.37

Surgical (Post-operative)	0.34 (0.10, 0.98)	0.06

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt. Odd ratio for ratio 2 RN: 1 Pt was inestimable due to quasi-complete separation.

[c] Odds ratio relative to medical admission. Odd ratio for admission type "Other" was inestimable due to quasi-complete separation.

eTABLE 6: Multivariable model of 30-day mortality for subjects with non-intensivist initial ICU primary service (subgroup analysis)

Covariate	Odds Ratio (95% CI)	P value
(Intercept)[a]	-6.58 (-8.35, -4.95)	<0.001
High-intensity staffing model	0.79 (0.47, 1.31)	0.37
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	0.54 (0.25, 1.12)	0.10
Age	1.05 (1.03, 1.07)	<0.001
Female sex assigned at birth	0.61 (0.38, 0.96)	0.03
Race identified as White/Caucasian	1.72 (0.86, 3.71)	0.14
Charlson Comorbidity Index	1.09 (0.99, 1.21)	0.07
Sofa Score	1.32 (1.22, 1.45)	<0.001
Night admission (7 pm – 7 am)	1.21 (0.73, 1.99)	0.46
Weekend admission	0.60 (0.32, 1.09)	0.10
Number of ventilated patients on unit at time of admission	0.94 (0.86, 1.04)	0.24
Number of patients requiring pressors on unit at time of admission	1.00 (0.86, 1.15)	0.95
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	0.29 (0.12, 0.70)	0.01
Neurologic	0.84 (0.45, 1.57)	0.59

Surgical (Post-operative)	0.50 (0.19, 1.21)	0.14

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt. Odd ratio for ratio 2 RN: 1 Pt was inestimable due to quasi-complete separation.

[c] Odds ratio relative to medical admission. Odd ratio for admission type “Other” was inestimable due to quasi-complete separation.

eTABLE 7: Unadjusted analysis of staffing model and patient outcomes

Outcome	Low-intensity	High-intensity	Odds Ratio	95% CI	P-value
In-Hospital Mortality, n (%)	110 (14.1%) (N = 780)	43 (9.8%) (N = 440)	0.66	(0.44, 0.97)	0.03
30-Day Mortality, n (%)	139 (17.8%) (N = 779)	59 (13.4%) (N = 440)	0.71	(0.50, 1.00)	0.04
ICU length of stay (days), median [IQR]	1.0 [1.0, 3.0] (N=779)	1.0 [1.0,3.0] (N=440)	N/A	N/A	0.58

eTABLE 8: Multivariable model of ICU length of stay

Covariate	**Odds Ratio (95% CI)**	**P value**
High-intensity staffing model	0.99 (0.89, 1.09)	0.80
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	0.98 (0.86, 1.12)	0.78
2 RN: 1 Pt	1.28 (1.03, 1.61)	0.03
Age	0.99 (0.99, 1.00)	<0.001
Female sex assigned at birth	1.09 (0.99, 1.22)	0.07
Race identified as White/Caucasian	0.95 (0.84, 1.07)	0.42
Charlson Comorbidity Index	0.99 (0.96, 1.01)	0.36
Sofa Score	0.86 (0.84, 0.88)	<0.001
Night admission (7 pm – 7 am)	0.98 (0.88, 1.09)	0.68
Weekend admission	1.06 (0.94, 1.21)	0.33
Number of ventilated patients on unit at time of admission	1.01 (0.99, 1.03)	0.53
Number of patients requiring pressors on unit at time of admission	1.01 (0.97, 1.04)	0.75
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	1.60 (1.36, 1.87)	<0.001
Neurologic	0.92 (0.80, 1.06)	0.24
Surgical (Post-operative)	1.23 (1.06, 1.44)	0.01
Other	1.67 (0.90, 3.11)	0.11

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt

[c] Odds ratio relative to medical admission.

eTABLE 9: Multivariable model of ICU length of stay with interaction term for staffing model and SOFA score

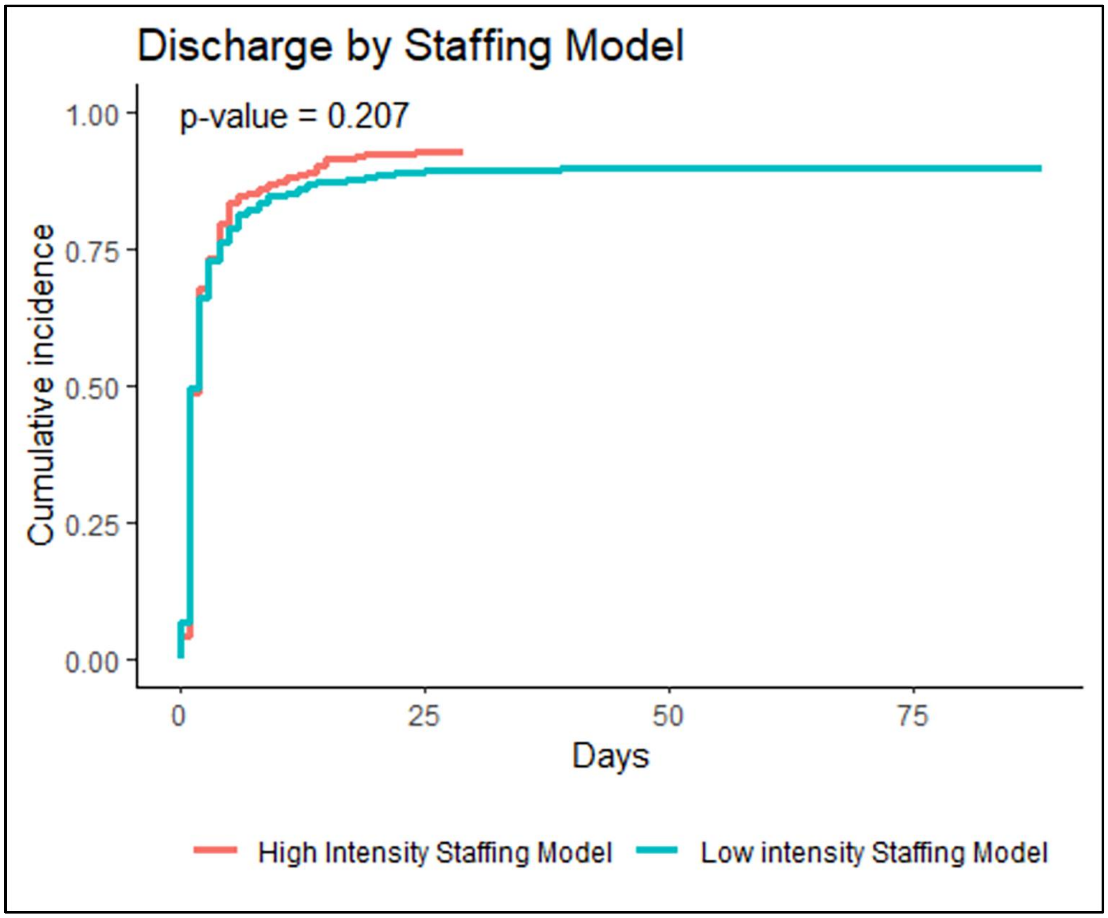
Covariate	Odds Ratio (95% CI)	P value
High-intensity staffing model	0.96 (0.81, 1.14)	0.67
Subject Nurse:Patient Ratio at time of admission[b]		
1 RN: 1 Pt	0.98 (0.86, 1.12)	0.79
2 RN: 1 Pt	1.28 (1.02, 1.60)	0.03
Age	0.99 (0.99, 1.00)	<0.001
Female sex assigned at birth	1.09 (0.99, 1.22)	0.07
Race identified as White/Caucasian	0.95 (0.84, 1.07)	0.42
Charlson Comorbidity Index	0.99 (0.96, 1.01)	0.36
Sofa Score	0.86 (0.84, 0.88)	<0.001
Night admission (7 pm – 7 am)	0.98 (0.88, 1.09)	0.67
Weekend admission	1.06 (0.94, 1.21)	0.33
Number of ventilated patients on unit at time of admission	1.01 (0.99, 1.03)	0.55
Number of patients requiring pressors on unit at time of admission	1.01 (0.97, 1.04)	0.74
Type of ICU admission[c]		
Cardiac/Cardiovascular surgery	1.60 (1.36, 1.87)	<0.001
Neurologic	0.92 (0.80, 1.06)	0.24
Surgical (Post-operative)	1.23 (1.06, 1.45)	0.01
Other	1.65 (0.88, 3.10)	0.12
High-intensity staffing model * SOFA score interaction term	1.01 (0.97, 1.04)	0.73

[a] Presented on the log(odds ratio) scale

[b] Odds ratio relative to nurse:patient ratio 1 RN: 2 Pt

[c] Odds ratio relative to medical admission.

eFigure 1: Cumulative incidence curve for ICU discharge by staffing model. Red curve: High-intensity staffing model. Blue curve: Low-intensity staffing model.



eFigure 2: Median ICU length of stay (in days) by month of admission for the full study population.