JAMA Internal Medicine | Original Investigation

Association of Intensive Care Unit Patient-to-Intensivist Ratios With Hospital Mortality

Hayley B. Gershengorn, MD; David A. Harrison, PhD; Allan Garland, MD, MA; M. Elizabeth Wilcox, MD, MPH; Kathryn M. Rowan, DPhil; Hannah Wunsch, MD, MSc

IMPORTANCE The patient-to-intensivist ratio (PIR) across intensive care units (ICUs) is not standardized and the association of PIR with patient outcome is not well established. Understanding the impact of PIR on outcomes is necessary to optimize senior medical staffing and deliver high-quality care.

OBJECTIVE To test the hypotheses that: (1) there is significant variation in the PIR across ICUs and (2) higher PIRs are associated with higher hospital mortality for ICU patients.

DESIGN, SETTING, AND PARTICIPANTS Retrospective cohort analysis of patients (≥16 years) admitted to ICUs staffed by a single intensivist during daytime hours in the United Kingdom from 2010 to 2013.

EXPOSURES Patient-to-intensivist ratios, which we defined for each patient as the number of patients cared for by the intensivist each day averaged over the patient's stay.

MAIN OUTCOMES AND MEASURES Using standard summary statistics, we evaluated PIR variation across ICUs. We used multivariable, mixed-effect, logistic regression analysis to evaluate the association between PIR and hospital mortality at ultimate discharge from acute hospital (primary outcome) and at ICU discharge.

FINDING Among 49 686 adults in 94 ICUs, median age was 66 (interquartile range [IQR], 52-76) years, and 45.1% were women. The ultimate hospital mortality was 25.7%. The median PIR for patients was 8.5 (IQR, 6.9-10.8; full range, 1.0-23.5), and varied substantially among individual ICUs. The association between PIR and ultimate hospital mortality was U-shaped; there was a reduction in the odds of mortality associated with an increasing PIR up to 7.5 after which the odds of mortality increased again significantly (average patient mortality for lowest PIR, 22%; PIR of 7.5, 15%; highest PIR, 19%; $P = .003$). A similar U-shaped association was seen for PIR and mortality in the ICU (nadir of mortality at a PIR of 7.8, $P < .001$).

CONCLUSIONS AND RELEVANCE PIR varied across UK ICUs. The optimal PIR in this cohort of UK ICU patients was 7.5, with significantly increased ICU and hospital mortality above and below this ratio. The number of patients cared for by 1 intensivist may impact patient outcomes.

JAMA Intern Med. 2017;177(3):388-396. doi:10.1001/jamainternmed.2016.8457
Published online January 24, 2017.

Invited Commentary page 396

Supplemental content at jamainternalmedicine.com

Author Affiliations: Author affiliations are listed at the end of this article.

Corresponding Author: Kathryn M. Rowan, DPhil, Intensive Care National Audit & Research Centre (ICNARC), Napier House, 24 High Holborn, London, WC1V 6AZ England (kathy.rowan@icnarc.org).

Critically ill patients require complex care and most studies indicate that senior critical care doctors (intensivists) improve intensive care unit (ICU) patient outcomes.[1,2] For this reason, recommendations from the Intensive Care Society in the United Kingdom (UK),[3] as well as the Society for Critical Care Medicine[4] and external bodies[5] in the US, call for higher intensity intensivist staffing. In addition, the number of ICU beds in the UK and US has been increasing.[6] Without increased intensivist supply, these trends require increasing patient-to-intensivist ratios (PIRs). While we know critical care is best delivered by a multidisciplinary team,[7] it is unclear how many patients may be appropriately cared for by a single intensivist.

To date, little is known about whether ICU patient outcomes are affected by the PIR. The only research study[8] directly evaluating this relationship—in which ICU bed-to-intensivist ratios (whether or not the bed was occupied) ranged from 7.5 to 15—found that higher ratios were associated with longer ICU length of stay (LOS) for patients but there was no association with ICU or hospital mortality. This study, however, was conducted in a single center using historical controls. Using data from UK ICUs, we performed a multicenter, retrospective analysis to test the hypotheses that: (1) there is significant variation in the PIR across ICUs and (2) higher PIRs are associated with higher hospital mortality for ICU patients.

Key Points

Question What is the association of patient-to-intensivist ratio with hospital mortality for intensive care unit patients?

Findings In this retrospective cohort analysis including 49 686 adults in 94 United Kingdom intensive care units, a patient-to-intensivist ratio of 7.5 was associated with the lowest risk adjusted hospital mortality, with higher mortality at both higher and lower patient-to-intensivist ratios.

Meaning Intensivist staffing should ensure that patient volume is sufficient for proficiency in care, but allows for sufficient time and care to be taken with each patient to minimize harm.

Methods

We conducted a retrospective cohort study using data on admissions to adult general critical care units in the United Kingdom participating in the Intensive Care National Audit and Research Centre (ICNARC) Case Mix Programme (CMP), linked with data from 2 staffing surveys. We used answers to 2 different questions, 1 from each staffing survey. The first was the United Kingdom Consultant Cover Census study (UK-3Cs),[9] conducted in 2011, in which was asked "open vs closed ICU?" and the second was a single question survey to ICUs in the CMP, conducted in 2013, in which was asked, "On weekdays, during daytime hours, is 1 or more intensive care consultants responsible for all patients in the unit?" Daytime hours were defined as 8:00 AM to 3:59 PM purposely to include hours in which primary intensivists are most likely to be physically present in the ICU. The answers from both surveys were assumed to apply for the full duration of this study, when more than 1 intensivist was responsible for daytime weekday care of ICU patients, the exact number was queried.

Institutional review board exemption was obtained from Albert Einstein College of Medicine. Approval for the collection and use of patient identifiable data in the CMP was obtained under Section 251 of the National Health Service Act of 2006.

Cohort

The cohort included participating ICUs from January 1, 2010, through December 31, 2013. We excluded ICUs with incomplete staffing survey responses, those reporting more than 1 intensivist during daytime hours, and those that did not have a closed-model of intensivist staffing (because accurate PIRs could not be assessed). Patients in included ICUs were those admitted during daytime hours because: (1) primary intensivists may not be actively involved in after-hours admissions and (2) daytime workload is unlikely to impact intensivists' ability to care for a new admission presenting after-hours. Patients were excluded if they were younger than 16 years (because adult and pediatric critical illnesses differ and may be differently affected by PIR). Only the first ICU admission in the hospital stay was included (to avoid double counting of hospital deaths).

Exposure of Interest: PIR

For the primary analysis, we calculated the PIR for a given patient as the total number of patients cared for by the intensivist for all or any portion of daytime hours, averaged over the patient's ICU stay. For example, if 10 patients were in the ICU at 8:00 AM, of whom 2 were discharged prior to 3:59 PM and 3 new patients were admitted during the daytime (8:00 AM-3:59 PM), the PIR would be 13 (the initial 10 plus the 3 admitted) for that day. All patients, including readmissions, were included for this calculation. This definition aimed to reflect the average overall patient workload for the intensivist, during daytime hours, over the duration of stay for a given patient.

In sensitivity analyses, we used 9 alternative calculations of PIR because it was not apparent which ones may affect patient outcome: (1) total number of patients in the ICU during daytime hours on the day of admission; number of new patients during daytime hours (2) averaged over the ICU stay and (3) on the day of admission; average level of care for all patients in the ICU (4) averaged over the ICU stay and (5) on the day of admission; average severity of illness for all patients in the ICU (6) averaged over the ICU stay and (7) on the day of admission; and the number of patients cared for during the daily rounding period of 8:00 AM to 10:59 AM (8) averaged over the ICU stay and (9) on the day of admission. Level of care was defined by the Critical Care Minimum Data Set and recorded as: 0, needs normal ward care; 1, needs acute ward care with support from a critical care team; 2, needs more detailed observation and/or intervention; and 3, needs advanced respiratory support and/or 2 or more organs supported.[10] Severity of illness was estimated as the probability of hospital mortality derived from the ICNARC risk prediction model (2013 recalibration).[11]

Patient-, ICU-, and Hospital-Level Data

Patient data included demographics (age, sex); long-term health status (comorbidities—coded individually as severe dysfunction of each of 7 organ systems); functional status (determined by degree of assistance needed with activities of daily living); and details of the acute illness (medical—not admitted directly following surgery—vs surgical, first 24-hour probability of hospital mortality from the ICNARC model,[11] number of organ dysfunctions in the first 24 hours, highest level of care over the first 24 hours, use of advanced respiratory support [invasive mechanical ventilation and/or extracorporeal life support] during ICU stay, average level of care during ICU stay, and whether treatments were withheld or withdrawn during ICU stay). Intensive care unit and hospital data included number of ICU beds and reported hospital type (nonuniversity, university, university-affiliated). No information was available pertaining to nonintensivist physician or nonphysician staffing during daytime hours.

Outcomes

All patients were followed up to ultimate discharge from acute hospital whether this discharge was from the original ICU and acute hospital (housing the ICU) or from a subsequent ICU and/or acute hospital to which the patient was transferred. The primary outcome for this analysis was ultimate hospital mortality. Secondary outcomes included ultimate ICU mortality, original ICU mortality, and original hospital mortality (from original acute hospital housing original ICU).

Statistical Analyses

Baseline characteristics and unadjusted outcomes for the cohort were tabulated using standard summary statistics. PIRs across ICUs were evaluated using median, interquartile ranges (IQR), and full ranges. We compared PIRs across predefined subgroups (medical vs surgical, highest level of care over the first 24 hours, number of ICU beds, and hospital type) using the Kruskal-Wallis equality-of-populations rank test.

We used multivariable, mixed-effect logistic regression to assess the association of patient-level PIR and mortality. All listed patient, ICU, and hospital variables were included as covariates with clustering within ICUs, except ICU bed number owing to collinearity with PIR. The PIR was modeled using restricted cubic splines with 4 knots to allow for possible nonlinear associations.[12,13] Models were restricted to patients with data available for all covariates. To display model results, we plotted curves that depict the effect on mortality for an average patient—defined as having the average of all non-patient-to-intensivist ratio covariates—as a function of patient-to-intensivist ratio. To address the possibility of overfitting, we repeated our primary analyses across 20 bootstrapped samples with random sampling at the level of the individual ICU.[14]

As a first sensitivity analysis, we repeated modeling using the nine alternate definitions of PIR (described above). As a second sensitivity analysis, assessed post hoc because larger ICUs tended to have higher PIRs, we performed stratified analyses by ICU size using both tertiles of bed number and specific bed numbers to assess whether observed associations between PIR and hospital mortality were independent of ICU size. As a third post hoc sensitivity analysis, we analyzed (separately) the ICUs and patients excluded from our primary analysis where multiple intensivists cared for patients during daytime hours. The PIRs for these ICUs were calculated assuming patients were evenly divided among the daytime intensivists; this allowed us to evaluate PIRs similar to our primary analysis but for ICUs of larger size (thus, separating PIR from ICU size). We limited this sensitivity analysis, post hoc, to patients with a PIR of 10 or less to avoid skewing of the results by high PIR outliers. These latter 2 analyses were conducted to address possible confounding by ICU size given the tight correlation between PIR and ICU size.

Statistical analyses were performed using Stata statistical software (version 13, Statacorp) and Microsoft Excel (2013, Microsoft). P values less than .05 were considered significant.

Results

The primary cohort included 49 686 adults admitted between January 2010 and December 2013 to 94 ICUs (eFigure 1 in the Supplement). The 94 ICUs had a median of 10 (interquartile range [IQR], 8-13) beds (**Table**) (eTable 1 in the Supplement). Median age of patients was 66 (IQR, 52-76) years and 45.1% were women. A minority had a very severe comorbidity (19.3%) and/or reported requiring some functional assistance prior to hospitalization (25.0%). Most were admitted for medical reasons (62.1%), predominantly with conditions of the respiratory, gastrointestinal, or cardiovascular system. Mean (SD) predicted risk of hospital mortality was 24.1% (26.8%) and the median was 12.2% (IQR, 2.7%-39.1%). Of 49 686 patients, 46.2% received level 3 care within the first 24 hours in ICU and 43.8% received advanced respiratory support during their ICU stay. Median LOS in the original ICU was 2.2 (IQR, 1.1-5.0) days and ultimate hospital mortality was 25.7%.

PIRs

The median PIR for the primary cohort was 8.5 (IQR, 6.9-10.8; range, 1.0-23.5). Median PIRs varied substantially across individual ICUs (**Figure 1**). At the extremes, a 4-bedded ICU had a median PIR of 2.0 (IQR, 1.5-2.7) and a 20-bedded ICU had a median PIR of 19.0 (IQR, 18.0-19.9). Median PIRs were systematically higher in larger ICUs ($P < .001$) and differed significantly by type of hospital (**Figure 2**). Median PIR was lower for patients with lower levels of care at ICU admission ($P < .001$). Median PIR values for medical (8.5; IQR, 6.9-11.0) and surgical (8.5; IQR, 6.9-10.7) patients were similar ($P = .05$).

Association of PIR With Outcomes

After multivariable adjustment, the PIR for each patient was significantly associated with ultimate hospital mortality ($P = .003$) (**Figure 3**). This relationship was U-shaped with the lowest mortality at a nadir PIR of 7.5 and significantly higher

Table. Cohort Characteristics of 49 686 Patients

Patient Characteristics[a]	Value
Patients, No.	49 686
Age, median (IQR), y	66 (52-76)
Female, %	45.1
Comorbidities, %	
None	81.7
Liver disease	2.5
Cardiovascular disease	1.7
Respiratory disease	3.0
Renal disease	2.0
Hematologic malignant abnormality	2.2
Metastatic cancer	3.0
Immunocompromised state	7.4
Functional status prior to hospitalization, %	
No assistance needed	75.0
Assistance needed for some ADLs	19.2
Assistance needed for most ADLs	4.9
Assistance needed for all ADLs	0.9
Predicted mortality [IM2013], mean (SD), %	24.1 (26.8)
Medical patient, %	62.1
Admitting diagnosis, %	
Cardiovascular	17.9
Dermatologic	0.9
Endocrine/metabolic/poisoning	7.9
Gastrointestinal	23.4
Genitourinary	11.5
Hematologic/immunologic	1.4
Musculoskeletal	4.9
Neurologic	8.3
Respiratory	23.7
Organ failures in first 24 hours in the ICU, %	
0	15.0
1	31.8
2	28.0
3	15.8
4	7.8
5	1.6
Advanced respiratory support during ICU stay, %[b]	43.8
Level of care required[c]	
Highest in the first 24 h, %	
1	1.1
2	52.7
3	46.2
Average over ICU stay, median (IQR)	2.0 (2.0-2.7)
Treatment withheld/withdrawn, %	12.9
Hospital type, %	
Nonuniversity	57.3
University	22.4
University-affiliated	20.3
ICU beds, median (IQR)	10 (8-13)

(continued)

Table. Cohort Characteristics of 49 686 Patients (continued)

Patient Characteristics[a]	Value
Patients-to-intensivist ratio, median (IQR)	
Daytime (8:00 AM to 3:59 PM)	
Total patients daily averaged over ICU stay	8.5 (6.9-10.8)
Total patients daily on day of ICU admission	9.0 (7.0-11.0)
New patients daily averaged over ICU stay	0.8 (0.5-1.0)
New patients daily on day of ICU admission	1.0 (1.0-2.0)
During rounds (8:00 AM to 10:59 AM)	
Total patients daily averaged over ICU stay	7.9 (6.0-10.0)
Total patients daily on day of ICU admission	8.0 (6.0-10.0)
New paitnes daily averaged over ICU stay	0.0 (0.0-0.3)
New patients daily on day of ICU admission	0.0 (0.0-0.0)
Outcomes, %	
Ultimate hospital mortality	25.7
Original hospital mortality	25.0
Ultimate ICU mortality	19.1
Original ICU mortality	18.9
Original ICU length of stay, median (IQR), days	2.2 (1.1-5.0)

Abbreviations: ADLs, activities of daily living; ICU, intensive care unit; IM2013, ICNARC model, 2013 recalibration; IQR, interquartile range.

[a] Data were missing for comorbidities, n = 233 (0.5%); functional status prior to hospitalization n = 235 (0.5%); patient type, n = 5 (0.01%); predicted mortality (IM4), n = 12 (0.02%); level of care required, first 24 h, n = 191 (0.4%); level of care averaged over ICU stay, n = 20 (0.04%); treatment withheld/withdrawn, n = 1 (<0.01%); ultimate hospital mortality, n = 127 (3%), original hospital mortality n = 2 (<0.01%); ultimate ICU mortality n = 248 (0.5%).

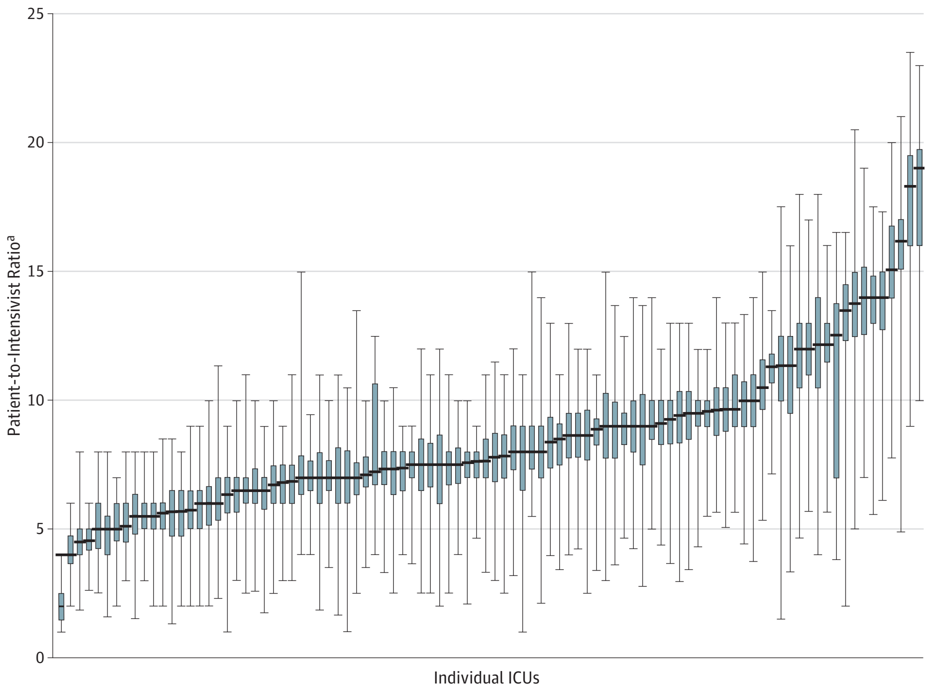
[b] Defined as receipt of invasive mechanical ventilation and/or extracorporeal respiratory support.

[c] 1 = risk of their condition deteriorating, or those recently relocated from higher levels of care, whose needs can be met on an acute ward with additional advice and support from the critical care team; 2 = requiring more detailed observation or intervention including support for a single failing organ system or postoperative care and those stepping down from higher levels of care; 3 = requiring advanced respiratory support alone or monitoring and support for 2 or more organ systems including all complex patients requiring support for multiorgan failure.

mortality when the PIR was lower or higher than this value. A similar association was seen in the majority of the 20 bootstrapped samples. Similar U-shaped associations were seen for PIR with our other prespecified mortality outcomes: ultimate ICU mortality (nadir PIR of 7.8; $P < .001$); original ICU mortality (nadir PIR of 7.8; $P < .001$); original hospital mortality (nadir PIR of 7.6; $P = .006$) (eFigure 2 in the Supplement).

Using the alternate, prespecified definitions of PIR revealed varying associations with ultimate hospital mortality. Mortality increased monotonically and significantly with PIR defined as the number of new admissions (during daytime hours, **Figure 4**A; during the daily rounding period, Figure 4D). Significant U-shaped associations were seen with PIR defined as average severity of illness of all patients in the ICU averaged over the ICU stay of the index patient (Figure 4B) and as the number of patients in the ICU during the daily rounding period (Figure 4C). Definitions of PIR defined by

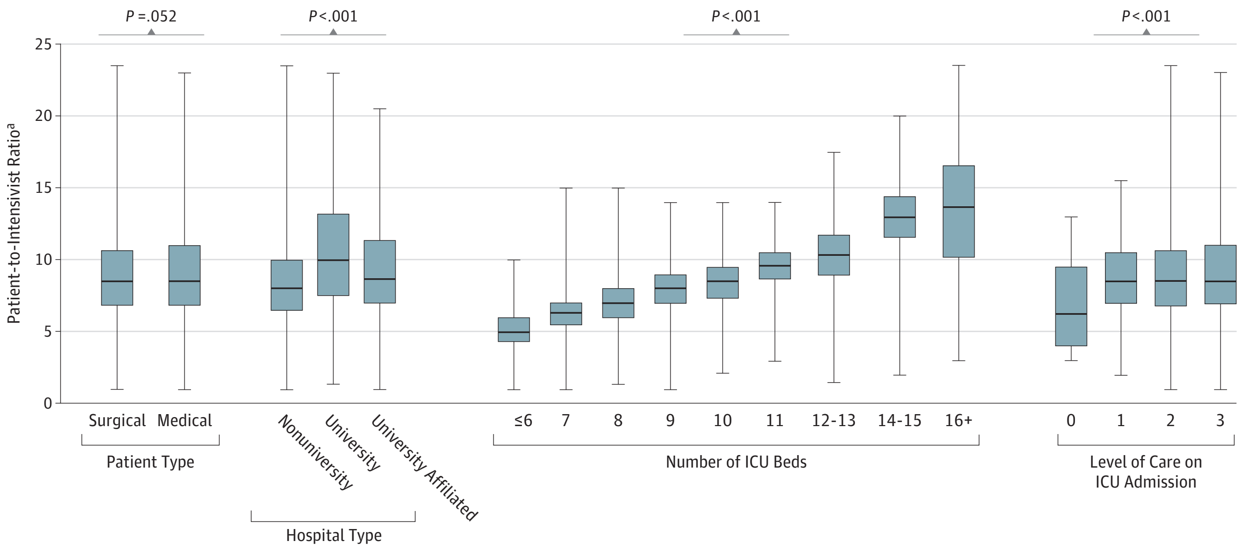
Figure 1. Patient-to-Intensivist Ratios Across Intensive Care Units



Black line indicates median; blue rectangle, interquartile range; bars, full range.

[a] Total number of patients in the unit daily from 8:00 AM to 3:59 PM averaged over the patient's stay.

Figure 2. Patient-to-Intensivist Ratios Stratified by Patient and Hospital Factors



Black line indicates median; blue rectangle, interquartile range; bars, full range.

[a] Total number of patients in the unit daily from 8:00 AM to 3:59 PM averaged over the patient's stay.

workload on the day of a patient's admission were not significantly associated with ultimate hospital mortality (eFigure 3 in the Supplement).

Post hoc sensitivity analyses indicated that the PIR-ultimate hospital mortality relationship depended on ICU size (eTable 2, eFigures 4 and 5 in the Supplement). Smaller ICUs had significant U-shaped associations but, as ICUs increased in size, the association was nonsignificant or more complex in shape. For ICUs with more than 1 daytime intensivist (30 409 patients in 42 ICUs in 41 hospitals), a nonsignificant, U-shaped pattern in the association of PIR with ultimate hospital mortality was seen (eFigure 6 in the Supplement); of note, the nadir PIR was similar to that in the main analyses.

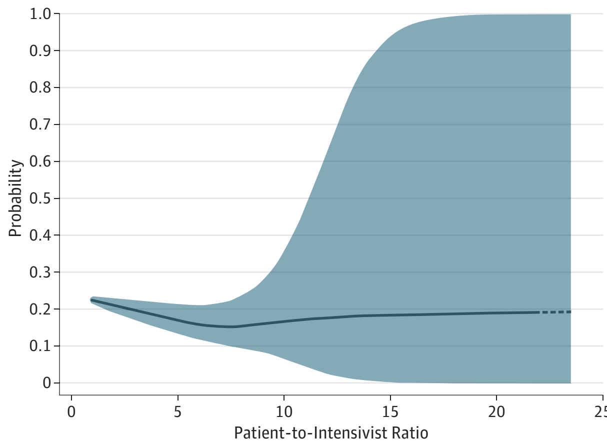
Discussion

Across UK ICUs, we demonstrated significant variation in the average number of patients cared for by a single intensivist. The PIR, calculated as the total number of patients cared for by the intensivist for all or any portion of daytime hours averaged over the patient's ICU stay, had a U-shaped association with mortality until a PIR of 12 after which no association was observed. The ultimate hospital mortality nadir occurred at a PIR of 7.5 with higher mortality when the intensivists' patient-load was either increased or decreased. We found no association between mortality and the PIR when the PIR was based on the intensivists' patient-load on the day of a patient's admission or between PIR and mortality for larger ICUs in our cohort. Several alternate definitions of PIR accounting for a patient's full ICU stay did not reveal similar U-shaped associations.

The association of lower PIRs with higher hospital mortality may be explained by the volume-outcome relationship. This construct characterizes a situation in which "practice makes perfect"—the more frequently one does something (higher volume), the more likely it is to be done well (better outcome). In a recent meta-analysis of critically ill patients, significantly higher mortality was associated with being cared for in lower-volume centers.[15] By definition, individual intensivists who care for patients with lower PIRs are caring for fewer patients. At an extreme, this may negatively impact the outcome for these patients. Also, as seen in eTable 1 in the Supplement, at lower PIRs intensivists are asked to take on responsibilities outside the ICU that take them away from direct ICU patient care and, thereby, may impact outcomes. Finally, the abundance and experience of ancillary staff in very small ICUs (those more likely to have patients cared for by intensivists with low PIRs) may differ from that in larger units.

The association of higher hospital mortality with higher PIRs may be explained by the fact that 1 intensivist only has a set amount of time and energy to devote to his/her patients; the more patients there are, the less attention each may receive. In a prospective study of allocation of time on rounds, as the number of new patients increased, the time spent on each patient, particularly new patients, decreased.[16] In a study of US hospitalists, hospital LOS and LOS-adjusted cost rose with an increasing patient-to-physician ratio; of note, at higher hospital occupancy levels, the association of this ratio with hospital LOS was U-shaped.[17] Similar concerns exist for other health care workers; in the US, California mandates maximum patient-to-nurse ratios in ICUs.[18] We see a threshold effect at a PIR of approximately 12, after which further increases in PIR are not associated with hospital mortality. While this nonassociation may represent a truth—that above a certain PIR spreading an intensivist thinner makes no difference to his/her patients' outcomes, care must be taken in interpreting this result because only 17% of our cohort had PIRs greater than 12. Moreover, it is possible that some higher PIR intensivists have good patient outcomes, potentially as a result of more ancillary staffing to offset their patient load and/or more time to spend exclusively in the ICU without external responsibilities.

Figure 3. Association of Patient-to-Intensivist Ratio and Ultimate Hospital Mortality

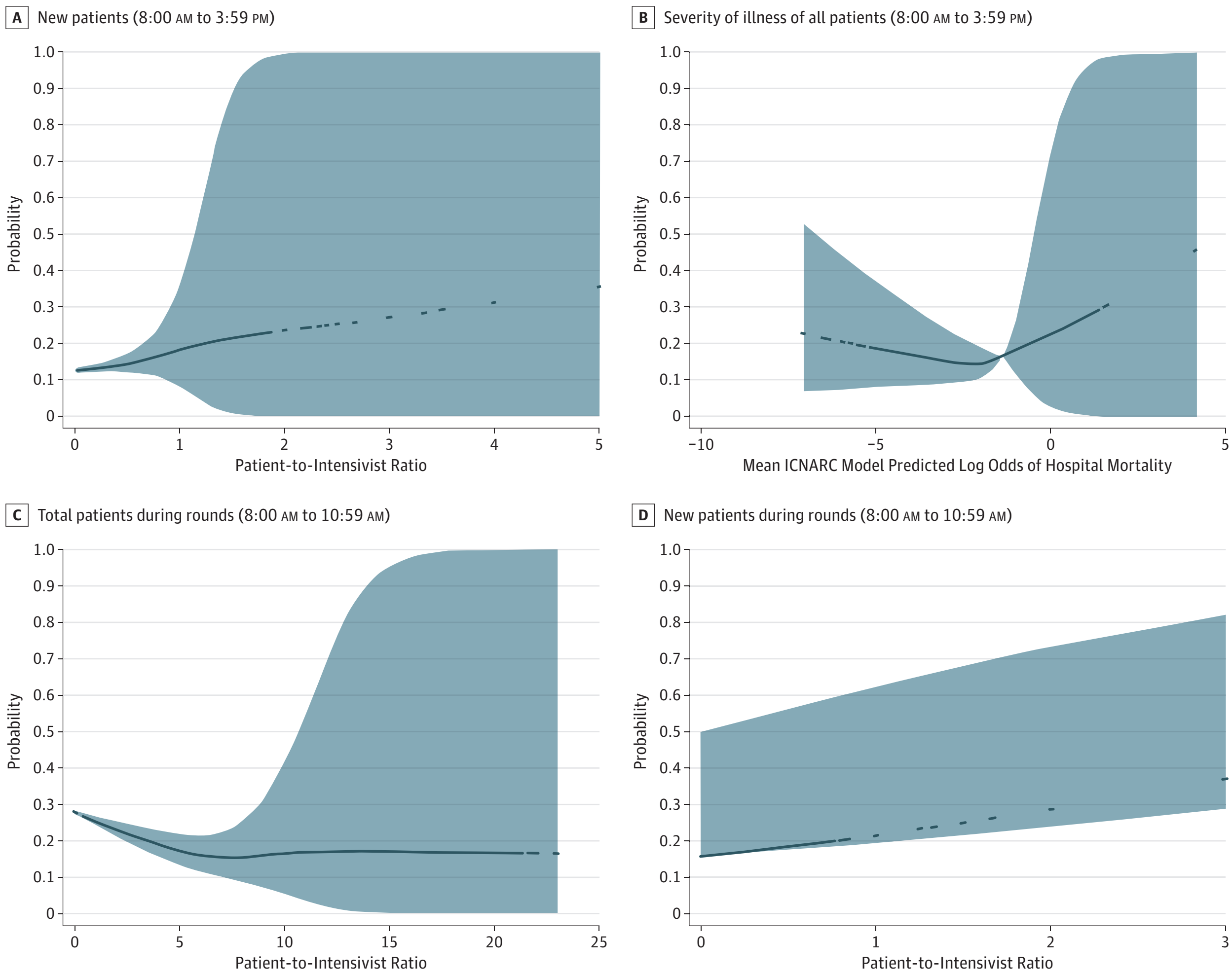


The plotted curve depicts the effect on mortality for an average patient (defined as having the average of all non–patient-to-intensivist ratio covariates) as a function of patient-to-intensivist ratio. Definition of patient-to-intensivist ratio is the total number of patients in the unit daily from 8:00 AM to 3:59 PM averaged over the patient's stay; there is an association between patient-to-intensivist ratio and ultimate hospital mortality (*P* = .006); and the association is nonlinear (*P* = .003). Blue dashes indicate point estimates; light blue bands, 95% CIs.

Prior literature on the impact of PIRs in ICUs is limited. To our knowledge, the only publication directly addressing this question was a historically controlled observational study[8] from the medical ICU at the Mayo Clinic. Over 2 years, the ICU structure was sequentially altered and the bed-to-intensivist ratio (similar to our patient-to-intensivist ratio) varied. While neither the standardized ICU nor hospital mortality ratio was associated with the bed-to-intensivist ratio, the observed/predicted ICU LOS was highest with the highest (15 to 1) bed-to-intensivist ratio.

Four other studies indirectly address this issue of the association of PIR and outcomes. A multicenter study of US ICU patients found no association of hospital death with ICU census on each patient's day of admission.[19] Whether 1 intensivist cared for all of the patients in the ICU, however, was not reported. A survey[20] of academic pulmonary and critical care program directors in the United States estimated median census for intensivists was 13 and respondents reported more time constraints, more stress, and more difficulties teaching trainees when caring for more than 13 patients. An observational study[21] from 8 ICUs in 4 French university hospitals reported that the adjusted risk of dying on a given shift was 2.0 times higher (95% CI, 1.3-3.2) if the PIR was more than 14:1 vs less than 8:1 on that shift. Finally, in a study[9] also using data from ICNARC CMP and UK-3Cs to look at UK ICUs, no association was found between having more fulltime equivalent intensivists on staff per ICU bed and hospital mortality. Because in this study intensivist-to-bed ratio was quantified as the average over the study period, it likely did not fully capture the experience for each individual patient whose PIR may signifi-

Figure 4. Association of 4 Alternate Definitions of Patient-to-Intensivist Ratio and Ultimate Hospital Mortality



The plotted curves depict the effect on mortality for an average patient (defined as having the average of all non–patient-to-intensivist ratio covariates) as a function of patient-to-intensivist ratio. Displayed are the alternate patient-to-intensivist ratios with which there was a statistically significant association with ultimate hospital mortality; all are using daily data averaged over the index patient's ICU stay; there was no association found for patient burden or severity of illness on the day of an index patient's ICU admission (see eFigure 1 in the Supplement). Blue dashes indicate point estimates; light blue bands, 95% CIs. A, Definition of patient-to-intensivist ratio is the number of new patients in the unit daily from 8:00 AM to 3:59 PM averaged over the patient's stay; there is an association between patient-to-intensivist ratio and ultimate hospital mortality ($P < .001$); the association is not nonlinear ($P = .02$). B, Definition of patient-to-intensivist ratio is the severity of illness by Intensive Care National Audit and Research Centre (ICNARC) model of all patients in the unit daily from 8:00 AM to 3:59 PM averaged over the patient's stay; there is an association between patient-to-intensivist ratio and ultimate hospital mortality ($P < .001$); and the association is nonlinear ($P = .002$); a similar association was found when severity of illness was assessed by the average level of care for each patient (rather than the ICNARC model). C, Definition of patient-to-intensivist ratio is the total number of patients in the unit during daily rounding period (8:00 AM-10:59 AM) averaged over the patient's stay; there is an association between patient-to-intensivist ratio and ultimate hospital mortality ($P < .001$); and the association is nonlinear ($P < .001$). D, Definition of patient-to-intensivist ratio is the number of new patients in the unit during daily rounding period (8:00 AM-10:59 AM) averaged over the patient's stay; given the data distribution, this patient-to-intensivist ratio could not be modeled using restricted cubic splines; there is an association (modeled as linear) between patient-to-intensivist ratio and ultimate hospital mortality ($P < .001$).

cantly differ from the average. In addition, this measure of physicians-to-beds speaks more to the diversity and depth of the intensivist staff rather than the workload of any 1 intensivist when caring for an individual patient.

The potential confounding of the observed association of PIR with hospital and ICU mortality by ICU size is addressed by our sensitivity analyses. In smaller units, with many patients with PIRs near 7.5, we see the same relationship as for the full cohort. The relationship is lost in larger ICUs, however, where fewer patients have PIRs near 7.5; in this setting, we have limited power to identify the initial descending limb of the U-shaped curve. Also, our analysis of large ICUs with multiple daytime intensivists allows for disentangling of ICU size from PIR. Although not statistically significant, this analysis demonstrates a similar U-shaped relationship of PIR and mortality with a nadir value of 7, close to that for our primary analysis; these results suggest we are seeing a robust association of outcome with PIR irrespective of ICU size. Finally, if the association with mortality was dictated solely by ICU size, we would expect that it would follow a strict volume-outcome relationship—namely, that higher PIRs would be associated with better outcomes across all PIR values. The fact that this is not the case at higher PIRs suggests that other factors are at play—namely, limits on time and mental-reserve which are felt by physicians.

Ours is the first multicenter study to assess how outcomes for critically ill patients are related specifically to the patient-load of the intensivists caring for them throughout their ICU stay. Its strengths include a large sample of patients and ICUs, detailed clinical and validated severity of illness information available for each patient, and the wide variation in PIRs.

Limitations

Our study has several limitations. First, critical care is a multidisciplinary undertaking and care teams are composed of providers across many specialties and levels of training. We did not have information on the particular composition of each patient's care team and it is likely that the impact of the intensivist workload is affected by the presence of other staff members.[7] Our results must be interpreted as the impact of the patient-to-intensivist led team ratio on mortality, therefore, with recognition that team structure surely mediates this interaction.

Second, the generalizability of our quantitative results outside of the UK is likely limited. The precise nadir value for a given context is likely influenced by numerous factors—including intensivist training and experience, details of ICU structure, staffing by other health care workers, and patient type and severity—which can differ across ICUs and countries. For example, the United Kingdom has substantially fewer ICU beds and admissions per capita than most of Western Europe or the United States.[22] And (in comparison with the United States) UK ICU patients are younger, have greater physiologic abnormalities, more frequently receive mechanical ventilation, and have higher hospital mortality.[23] This high severity of illness of the patients in UK ICU beds may mean that the optimal PIR is lower than in other places that do not have such high acuity of illness, but this remains speculative. Finally, our aim was to understand the relationship of hospital mortality with a simple measure of PIR rather than a more complex construct of workload which may include patient volume, illness severity, and patient turnover together. Assessing the association of workload conceived in this way with outcomes will be important to address in future studies.

Conclusions

In many regions, intensivists are perceived to be in short supply and the movement to have intensivists physically present in ICUs at all times further stretches available manpower.[24] Our findings indicate that caution is needed in designing intensivist staffing models in this supply-limited environment. While our finding that the optimal PIR is 7.5 may not be generalizable to non-UK ICUs, or ICUs with strong ancillary staffing or senior trainees, the drivers of the association between PIR and hospital mortality are likely universal; thus, the U-shaped relationship we found is likely broadly applicable. Responding to the increasing demand for ICU care by stretching available intensivist resources ever thinner may be detrimental to patients. Conversely, having intensivists care for too few patients may also result in poor outcomes. While our analyses cannot demonstrate causality and PIR may be a marker of other ICU staffing or structural differences that impact patient outcomes, our results suggest there may be a "sweet spot" for the PIR. Further study is needed to identify drivers (eg, ancillary staffing) of the optimal PIR value across different critical care settings and to investigate whether altering the PIR causes patient outcomes to change.

ARTICLE INFORMATION

Published Online: January 24, 2017. doi:10.1001/jamainternmed.2016.8457

Author Affiliations: Division of Critical Care Medicine, Albert Einstein College of Medicine, Montefiore Medical Center, Bronx, New York (Gershengorn); Intensive Care National Audit & Research Centre, Napier House, London, United Kingdom (Harrison, Rowan); Departments of Medicine and Community Health Sciences, University of Manitoba, Winnipeg, Canada (Garland); Interdepartmental Division of Critical Care Medicine, University of Toronto, University Health Network, Toronto, Ontario, Canada (Wilcox); Interdepartmental Division of Critical Care Medicine, University of Toronto, Sunnybrook Health Sciences Center, Toronto, Ontario, Canada (Wunsch); Department of Anesthesiology, College of Physicians and Surgeons, Columbia University, New York, New York (Wunsch); Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, New York (Wunsch).

Author Contributions: Dr Gershengorn had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: All authors.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Gershengorn, Garland, Rowan, Wunsch.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Gershengorn, Harrison, Garland.
Administrative, technical, or material support: Rowan, Harrison, Wunsch.
Study supervision: Rowan.

Conflict of Interest Disclosures: None reported.

Meeting Presentation: This paper was presented at the 46th Critical Care Congress of the Society of Critical Care Medicine; January 24, 2017; Honolulu, Hawaii.

Disclaimer: The views and opinions expressed herein are those of the authors and do not necessarily reflect those of ICNARC.

Additional Contributions: These data derive from the Intensive Care National Audit & Research Centre (ICNARC) Case Mix Programme Database. The Case Mix Programme is the national, comparative audit of patient outcomes from adult critical care coordinated by ICNARC. We thank all the staff in the critical care units participating in the Case Mix Programme. For more information on the representativeness and quality of these data, please contact ICNARC.

REFERENCES

1. 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.

2. 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.

3. Gunning K, Gillbe C. Intercollegiate Board for Training in Intensive Care Medicine. Standards for Consultant Staffing of Intensive Care Units. 2007. http://icmwk.com/wp-content/uploads/2013/12/Standards-for-Consultant-Staffing-of-ICUs.pdf. accessed December 20, 2016.

4. Haupt MT, Bekes CE, Brilli RJ, et al; Task Force of the American College of Critical Care Medicine, Society of Critical Care Medicine. Guidelines on critical care services and personnel: recommendations based on a system of categorization of three levels of care. *Crit Care Med*. 2003;31(11):2677-2683.

5. The Leapfrog Group. ICU Physician Staffing. http://www.leapfroggroup.org/sites/default/files/Files/IPS%20Fact%20Sheet.pdf. Accessed December 20, 2016.

6. Hutchings A, Durand MA, Grieve R, et al. Evaluation of modernisation of adult critical care services in England: time series and cost effectiveness analysis. *BMJ*. 2009;339:b4353.

7. Kim MM, Barnato AE, Angus DC, Fleisher LA, Kahn JM. The effect of multidisciplinary care teams on intensive care unit mortality. *Arch Intern Med*. 2010;170(4):369-376.

8. Dara SI, Afessa B. Intensivist-to-bed ratio: association with outcomes in the medical ICU. *Chest*. 2005;128(2):567-572.

9. Wilcox ME, Harrison DA, Short A, Jonas M, Rowan KM. Comparing mortality among adult, general intensive care units in England with varying intensivist cover patterns: a retrospective cohort study. *Crit Care*. 2014;18(4):491.

10. Health & Social Care Information Centre, National Health Service. 2016. http://www.datadictionary.nhs.uk/data_dictionary/messages/supporting_data_sets/data_sets/critical_care_minimum_data_set_fr.asp?shownav=1. Accessed May 6, 2016.

11. Harrison DA, Parry GJ, Carpenter JR, Short A, Rowan K. A new risk prediction model for critical care: the Intensive Care National Audit & Research Centre (ICNARC) model. *Crit Care Med*. 2007;35(4):1091-1098.

12. Harrell F. *Regression Modeling Strategies: With Applications to Linear Models, Logistic Regression, and Survival Analysis*. New York, NY: Springer; 2001.

13. Marrie RA, Dawson NV, Garland A. Quantile regression and restricted cubic splines are useful for exploring relationships between continuous variables. *J Clin Epidemiol*. 2009;62(5):511-7.e1.

14. Field C, Welsh A. Bootstrapping clustered data. *J R Stat Soc Series B Stat Methodol*. 2007;69(3):369-390.

15. 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.

16. Brown SE, Rey MM, Pardo D, et al. The allocation of intensivists' rounding time under conditions of intensive care unit capacity strain. *Am J Respir Crit Care Med*. 2014;190(7):831-834.

17. Elliott DJ, Young RS, Brice J, Aguiar R, Kolm P. Effect of hospitalist workload on the quality and efficiency of care. *JAMA Intern Med*. 2014;174(5):786-793.

18. 22 Ca ADC §70217.

19. Iwashyna TJ, Kramer AA, Kahn JM. Intensive care unit occupancy and patient outcomes. *Crit Care Med*. 2009;37(5):1545-1557.

20. Ward NS, Read R, Afessa B, Kahn JM. Perceived effects of attending physician workload in academic medical intensive care units: a national survey of training program directors. *Crit Care Med*. 2012;40(2):400-405.

21. Neuraz A, Guérin C, Payet C, et al. Patient mortality is associated with staff resources and workload in the ICU: a multicenter observational study. *Crit Care Med*. 2015;43(8):1587-1594.

22. 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, e1-e9.

23. Wunsch H, Angus DC, Harrison DA, Linde-Zwirble WT, Rowan KM. Comparison of medical admissions to intensive care units in the United States and United Kingdom. *Am J Respir Crit Care Med*. 2011;183(12):1666-1673.

24. Gershengorn HB, Garland A. Who should be at the bedside 24/7: doctors, families, nurses? *Semin Respir Crit Care Med*. 2016;37(1):107-118.

Invited Commentary

Toward the Ideal Ratio of Patients to Intensivists
Finding a Reasonable Balance

Elizabeth M. Viglianti, MD, MPH; Theodore J. Iwashyna, MD, PhD

More than 5.7 million patients are admitted annually to an intensive care unit (ICU) in the United States, accounting for approximately 20% of all acute care admissions.[1] With the aging population and its increasing comorbidity burden, the number of ICU patients and the projected costs associated with their care is expected to rise.[2]

Alongside the increased number and complexity of ICU patients has been the development and common use of intensivists to staff ICUs. Intensivists are the hospitalists of the ICU—physicians who dedicate much or all of their clinical practice to the ICU, and who take primary responsibility (or an aggressive "consult" comanagement) for patients while they are in the ICU. Although there is only ambiguous evidence of better outcomes with intensivists,[3] the practical necessity of having physicians who are readily available for emergencies, capable of handling ventilators, complicated hemodynamics, and coordinating complex multidisciplinary care and quality improvement in the ICU has resulted in their growing adoption.

Related article page 388

What is not known and has rarely been studied is the ideal ratio of patients to intensivists. If an intensivist has too many patients he or she would not be able to attend to the many complicated issues, potentially resulting in missed details, a slower or less thoughtful response, and less time with the patient and their family. With too few patients, intensivists may not have enough experience for making rapid decisions and perfecting complex procedures, as well as other potential challenges (**Figure**).

In this issue of *JAMA Internal Medicine*, Gershengorn et al[4] provide data to inform decisions on an optimal patient to intensivist ratio (PIR) in ICUs in the United Kingdom (UK) and its association with hospital and ICU mortality. The authors performed a retrospective cohort analysis in ICUs in the UK from 2010-2013 and limited their analysis to ICUs staffed with 1 intensivist during daytime hours. The authors defined PIR for each patient as the number of patients cared for by the intensivist each day averaged over the patients' stay. In this sample of UK hospitals, the median PIR for patients was 8.5 (interquartile range, 6.8-10.8). Provocatively, the association between PIR and hospital mortality was U-shaped, with a reduction in the odds of mortality peaking at 7.5 and no additional association seen above a ratio of 12. Therefore a PIR less than or greater than 7.5 was associated with higher hospital and ICU mortality. The absolute effect sizes of exposure to intensivists who deviated from 7.5 in either direction were