Staffing Ratios and Workload in Critically Ill Patients: Do They Impact Outcomes?*

Stephen M. Pastores, MD, FCCM
Department of Anesthesiology and Critical Care Medicine
Memorial Sloan-Kettering Cancer Center
New York, NY

The delivery of safe, timely, consistent, and effective care for patients admitted to the ICU requires the availability and appropriate staffing of critical care nurses and intensivist physicians. A few observational studies (1–6) and comprehensive reviews (7–10) have suggested that adequate nurse-to-patient and intensivist-to-patient ratios are associated with improved outcomes in ICU patients. A multidisciplinary task force concluded that in academic medical ICUs, intensivist-to-patient ratios more than 1:14 was associated with negative effects on patient care, staff well-being, and resident education (10). However, accurately determining the optimal or maximum threshold for nurse and physician staffing levels that are associated with patient outcomes in the ICU is a complex task. Several factors have to be considered, including patient acuity and turnover, case mix, and in the case of intensivists, duties outside the ICU, educational responsibilities, and the availability of housestaff and nonphysician providers (10). Similarly, the burden of workload based on staffing levels, patient severity and volume of procedures performed, and throughput, especially for the nursing staff, may impact outcomes for both the staff and the patients (11, 12).

In this issue of *Critical Care Medicine*, Neuraz et al (13) shed further light on the association between nurse and physician staffing-to-patient ratios and workload on patient mortality in the ICU. The authors conducted a multicenter longitudinal study involving 5,718 patients who were admitted to eight adult ICUs in four university hospitals in France over a 1-year period. Their primary outcome was patients' mortality at the time of ICU discharge excluding patients who refuse life-sustaining procedures during the ICU stay. The authors employed shift-by-shift analysis of both staffing levels and workload measures (proxied by patient turnover and the volume of life-sustaining procedures) to establish their relationships with ICU mortality over time.

The authors found that ICU patient mortality increased when the number of patients was above 2.5 per nurse and was above 14 per physician. Shifts with inadequate staffing occurred mostly during weekends for nurses and nights for physicians. Higher risk of death was also correlated with heavy workload. Although some of these findings are in agreement with previously published reports, the present study is unique in providing the specific thresholds of nurse and physician staffing levels in the ICU on a shift-by-shift basis that play a significant role in outcome. The authors also confirm the association between a heavy workload during shifts and higher risk of death. Their results demonstrate that real-time monitoring of ICU staffing levels and workload is feasible and can lead to improvements in care efficiencies and outcomes.

The study has several important limitations. First, the study had a limited sample size, and the findings may not be generalizable to teaching and nonteaching hospitals in other countries. Second, the authors did not include any open ICUs that exist in the majority of U.S. hospitals and may have different optimal provider-to-patient ratios. Third, there was no adjustment made for the primary specialty of the ICU physician (anesthesiology, medicine, or mixed). Fourth, the proxy measures of workload (patient turnover and the volume of life-sustaining procedures) in the ICU that the authors used do not account for the care of patients already consulted by critical care teams and left on the wards to be managed by consult teams or other providers. Finally, given the observational nature of the study, the authors could not control for other confounding factors affecting ICU mortality, such as hospital throughput and non-ICU bed availability, the safety culture of the ICU, and the role of effective teamwork and communication (14).

Notwithstanding these limitations, the present study is important for clinicians, physician and nursing leaderships, hospital administrators, and payers as it provides a quantitative measure to an already existing qualitative perception: higher provider-to-patient ratios in ICU patients appear to be associated with increased mortality, as does a higher workload. It would certainly be interesting to explore the reproducibility of these findings in larger studies in different countries. Until then, both hospital and ICU leaderships should work on ensuring that staff resources and workload are adapted to patients' needs and staff capabilities with particular attention to the usual culprits for staffing reductions that occur on weekends for nurses and nights for physicians.

***See also p. 1587.**

Key Words: intensive care unit; intensivists; outcomes; staffing; workload

The author has disclosed that he does not have any potential conflicts of interest.

DOI: 10.1097/CCM.0000000000001040

REFERENCES

1. Kelly DM, Kutney-Lee A, McHugh MD, et al: Impact of critical care nursing on 30-day mortality of mechanically ventilated older adults. *Crit Care Med* 2014; 42:1089–1095
2. Ali NA, Hammersley J, Hoffmann SP, et al; Midwest Critical Care Consortium: Continuity of care in intensive care units: A cluster-randomized trial of intensivist staffing. *Am J Respir Crit Care Med* 2011; 184:803–808
3. Cho SH, Hwang JH, Kim J: Nurse staffing and patient mortality in intensive care units. *Nurs Res* 2008; 57:322–330

4. Amaravadi RK, Dimick JB, Pronovost PJ, et al: ICU nurse-to-patient ratio is associated with complications and resource use after esophagectomy. *Intensive Care Med* 2000; 26:1857–1862
5. West E, Barron DN, Harrison D, et al: Nurse staffing, medical staffing and mortality in intensive care: An observational study. *Int J Nurs Stud* 2014; 51:781–794
6. Dara SI, Afessa B: Intensivist-to-bed ratio: Association with outcomes in the medical ICU. *Chest* 2005; 128:567–572
7. Penoyer DA: Nurse staffing and patient outcomes in critical care: A concise review. *Crit Care Med* 2010; 38:1521–1528; quiz 1529
8. McGahan M, Kucharski G, Coyer F; Winner ACCCN Best Nursing Review Paper 2011 sponsored by Elsevier: Nurse staffing levels and the incidence of mortality and morbidity in the adult intensive care unit: A literature review. *Aust Crit Care* 2012; 25:64–77
9. Numata Y, Schulzer M, van der Wal R, et al: Nurse staffing levels and hospital mortality in critical care settings: Literature review and meta-analysis. *J Adv Nurs* 2006; 55:435–448
10. Ward NS, Afessa B, Kleinpell R, et al; Members of Society of Critical Care Medicine Taskforce on ICU Staffing: Intensivist/patient ratios in closed ICUs: A statement from the Society of Critical Care Medicine Taskforce on ICU Staffing. *Crit Care Med* 2013; 41:638–645
11. Diya L, Van den Heede K, Sermeus W, et al: The relationship between in-hospital mortality, readmission into the intensive care nursing unit and/or operating theatre and nurse staffing levels. *J Adv Nurs* 2012; 68:1073–1081
12. Needleman J, Buerhaus P, Pankratz VS, et al: Nurse staffing and inpatient hospital mortality. *N Engl J Med* 2011; 364:1037–1045
13. 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; 43:1587–1594
14. Reader TW, Flin R, Mearns K, et al: Developing a team performance framework for the intensive care unit. *Crit Care Med* 2009; 37:1787–1793

Automated Sepsis Detection, Alert, and Clinical Decision Support: Act on It or Silence the Alarm?*

Andrew M. Harrison, BS
Medical Scientist Training Program
Mayo Graduate School
Mayo Clinic
Rochester, MN

Vitaly Herasevich, MD, PhD
Department of Anesthesiology
Mayo Clinic
Rochester, MN

Ognjen Gajic, MD, MSc
Department of Internal Medicine
Division of Pulmonary and Critical Care Medicine
Mayo Clinic
Rochester, MN

With the 2014 publication of the multicenter, international Protocolized Care for Early Septic Shock (1) and Australasian Resuscitation in Sepsis Evaluation (2) trials for the best management of septic shock, as well as the revelation that as many as half of all hospital deaths may be sepsis related (3), interest in compliance with the Surviving Sepsis Campaign “care bundles” for best patient outcomes is at an all-time high (4). Although the relative contribution of each bundle component is a matter of debate, there is little controversy about the value of early recognition and treatment of both infection and hypoperfusion, including timely and adequate fluid resuscitation, antimicrobial management, and source control. Many pathways exist to improve the care and outcomes of patients with sepsis. One of these pathways includes the use of automated, electronic medical record (EMR)-based sepsis detection and alert systems.

The earliest prospective studies used sepsis detection and alert systems developed and implemented for clinical trial enrollment purposes (5). The earliest prospective studies examining the effect of electronic sepsis detection on direct patient outcomes were performed in the hospital floor and emergency department settings (6, 7). In the first real-world implementation study of electronic sepsis alert in the ICU, researchers at Vanderbilt University Medical Center randomized 442 consecutive medical ICU admissions over a 4-month period using a “listening application” to generate either a text page alert to ICU physicians (requiring acknowledgement of sepsis or no sepsis) or no alert (8). Automated sepsis alert had a modest positive predictive value and had no impact on processes of care and clinical outcomes.

In this issue of *Critical Care Medicine*, Semler et al (9) expand upon the their previous work (8) to test if enhancing the electronic alert by adding EMR-based clinical decision support (including evidence-based guidelines and an order-entry component) would be more fruitful. During a 2012 study period, 447 patients over a 4-month period with a clinical diagnosis of sepsis at admission to the medical or surgical ICU were randomized to an “integrated sepsis assessment and management tool” or no sepsis tool. Unfortunately, as in the first study (8), no improvement in

*See also p. 1595.

Key Words: alert clinical decision support; critical care; detection; intensive care; sepsis

Dr. Herasevich received royalties from the Ambient Clinical Analytics and has stock options in Ambient Clinical Analytics. His institution has a patent with the Mayo Clinic (patent on sepsis sniffer). Dr. Gajic has disclosed work for hire. He and his institution received royalties from Ambient Clinical Analytics. (The related research has been reviewed by the Mayo Clinic Conflict of Interest Review Board and is being conducted in compliance with Mayo Clinic Conflict of Interest policies. Mayo Clinic and Dr. Gajic have a financial conflict of interest related to software applications licensed to commercial entities.) Mr. Harrison has disclosed that he does not have any potential conflicts of interest.

DOI: 10.1097/CCM.0000000000001099

Patient Mortality Is Associated With Staff Resources and Workload in the ICU: A Multicenter Observational Study*

Antoine Neuraz, MD, MSc[1,2]; Claude Guérin, MD, PhD[2,3,4]; Cécile Payet, MSc[1,5]; Stéphanie Polazzi, MPH,[1,5]; Frédéric Aubrun, MD, PhD[2,5,6]; Frédéric Dailler, MD, PhD[7]; Jean-Jacques Lehot, MD, PhD[2,8]; Vincent Piriou, MD, PhD[5,9,10]; Jean Neidecker, MD, PhD[11]; Thomas Rimmelé, MD, PhD[2,12]; Anne-Marie Schott, MD, PhD[1,2,5]; Antoine Duclos, MD, PhD[1,2,5]

Objective: Matching healthcare staff resources to patient needs in the ICU is a key factor for quality of care. We aimed to assess the impact of the staffing-to-patient ratio and workload on ICU mortality.

Design: We performed a multicenter longitudinal study using routinely collected hospital data.

Setting: Information pertaining to every patient in eight ICUs from four university hospitals from January to December 2013 was analyzed.

Patients: A total of 5,718 inpatient stays were included.

Interventions: None.

Measurements and Main Results: We used a shift-by-shift varying measure of the patient-to-caregiver ratio in combination with workload to establish their relationships with ICU mortality over time, excluding patients with decision to forego life-sustaining therapy. Using a multilevel Poisson regression, we quantified ICU mortality-relative risk, adjusted for patient turnover, severity, and staffing levels. The risk of death was increased by 3.5 (95% CI, 1.3–9.1) when the patient-to-nurse ratio was greater than 2.5, and it was increased by 2.0 (95% CI, 1.3–3.2) when the patient-to-physician ratio exceeded 14. The highest ratios occurred more frequently during the weekend for nurse staffing and during the night for physicians ($p < 0.001$). High patient turnover (adjusted relative risk, 5.6 [2.0–15.0]) and the volume of life-sustaining procedures performed by staff (adjusted relative risk, 5.9 [4.3–7.9]) were also associated with increased mortality.

Conclusions: This study proposes evidence-based thresholds for patient-to-caregiver ratios, above which patient safety may be endangered in the ICU. Real-time monitoring of staffing levels and workload is feasible for adjusting caregivers' resources to patients' needs. (*Crit Care Med* 2015; 43:1587–1594)

Key Words: intensive care units; medical staffing; mortality; multilevel modeling; nurse staffing

***See also p. 1775.**

[1]Hospices Civils de Lyon, Pôle Information Médicale Évaluation Recherche, Lyon, France.

[2]Université Claude Bernard Lyon 1, Faculté de Médecine Lyon Est, Lyon, France.

[3]Hospices Civils de Lyon, Service de Réanimation Médicale, Hôpital de la Croix Rousse, Lyon, France.

[4]IMRB INSERM 955Eq13, Créteil, France.

[5]Health Services and Performance Research Lab, Lyon, France

[6]Department of Anesthesiology and Critical Care Medicine, Hospices Civils de Lyon, Croix Rousse Hospital, Lyon, France.

[7]Hospices Civils de Lyon, Service de Réanimation Neurologique, Hôpital Pierre Wertheimer, Groupement Hospitalier Est, Lyon, France.

[8]Hospices Civils de Lyon, Fédération Hospitalo-Universitaire d'Anesthésie-Réanimation, Hôpital Neurologique P. Wertheimer, France.

[9]Hospices Civils de Lyon, Service d'Anesthésie Réanimation, Centre Hospitalier Lyon Sud, Lyon, France.

[10]Université Claude Bernard Lyon 1, Faculté de Médecine Lyon Sud, Lyon, France.

[11]Hospices Civils de Lyon, Hôpital Louis Pradel, Service d'Anesthésie-Réanimation, Lyon, France.

[12]Anesthesiology and Intensive care Medicine, Edouard Herriot hospital, Hospices Civils de Lyon, University Claude Bernard Lyon 1, Lyon, France.

Dr. Neidecker received support for travel from Heart Ware (Travel Expenses paid directly by the company). Dr. Rimmelé consulted and lectured for Gambro-Hospal. The remaining authors have disclosed that they do not have any potential conflicts of interest.

For information regarding this article, E-mail: Antoine.duclos@chu-lyon.fr

DOI: 10.1097/CCM.0000000000001015

Matching healthcare staff resources with patients' needs is a key factor to maintain safe care in ICUs. Adequate patient-to-nurse (P/N) and patient-to-physician (P/P) ratios may be associated with higher survival rates and a lower risk of failure to rescue (1, 2). However, the optimal ratios have not been completely established. An optimal ratio should be that above which a significant deterioration in patient outcome is observed. Although arbitrary thresholds have been set, these recommendations are based on experts' opinions rather than on scientific evidence (3–6). Several studies assessing the influence of nurse staffing on mortality resulted in inconsistent findings (7–14). Some works found a significant association between mortality and P/N ratio (7, 10–13), but others did not (8, 9, 14–16). Even though it is commonly accepted that the physician staffing level affects mortality, no objective P/P ratio has been worked out to date (17).

Although it is commonly believed that patient mortality is influenced by the number of caregivers in charge of patient care, there is a lack of evidence to support this assumption. In principle, to guarantee consistent patient outcomes, staff resources should continuously mirror the burden of workload that intensive care teams are facing. In addition to staffing levels, patient severity and volume of life-sustaining procedures were performed; the workload is traditionally estimated based on patient turnover (18–20). Here, we assumed that both the staffing level and the burden of clinical activity may influence ICU patients' outcomes. We used a shift-by-shift varying measure of patient-to-caregiver ratios in combination with workload assessment to establish their relationships with ICU mortality over time.

METHODS

Study Design and Data Sources

We performed a multicenter longitudinal study in eight adult ICUs located in four university hospitals in Lyon, France. Of the eight ICUs, two were mostly medically oriented, four were mostly surgically oriented, and two were mixed medical-surgical units. All were closed ICUs directed by anesthesiologists, medical intensivists, or mixed medical teams.

Three large databases used for routine tasks were merged to accurately establish where and when caregivers worked and patients were treated: 1) claims data used for billing inpatient stay, 2) the day-by-day, hour-by-hour planning of medical and nurse staff databases, and 3) the human resources database containing information about qualifications and affiliations of staff members. In addition, we reviewed the medical records of every deceased patient to accurately identify any decision to forego life-sustaining therapy (DFLST) during the ICU stay. According to the French law, our study was exempt from approval per local ethics committee.

Information pertaining to every patient admitted to these ICUs between January 1 and December 31, 2013, was used in the present analysis. Standard discharge abstracts for every hospitalization contained compulsory information about patients (ie, gender, age, and residence), admission context (ie, emergency status, surgical, or medical care), the Simplified Acute Physiology Score (SAPS) II (21) measured over the first 24 hours of ICU admission, a selection of life-sustaining medical procedures (LSP; eg, mechanical ventilation, vasopressive drugs, renal replacement therapy, and extracorporeal membrane oxygenation), and 31 coexisting conditions extracted from the Elixhauser list of comorbidities (22).

We extracted caregiver presence at work on an hourly basis for each ICU employee (ie, nurses and physicians) and for each day of the study period. Work was mainly organized on a 12-hour basis but, during the day, additional staff with varying work hours could be present. To minimize staffing variations observed during each period while maintaining a sufficient granularity, shift was selected as a temporal unit for analysis. A shift was split into the following four time frames: 7:00 AM to 0:59 PM, 1:00 PM to 6:59 PM, 7:00 PM to 0:59 AM and 1:00 AM to 6:59 AM.

Main Outcome and Key Predictors

The primary outcome was mortality at time of ICU discharge by shift, excluding patients for whom a DFLST was made. Primary outcome was initially adjusted for age, gender, admission context, emergency status, SAPS II, and comorbidities.

Apart from these common confounding factors, the staffing and the caregiver workload were used as key predictors. Nurse and medical staffing were defined as P/N and P/P ratios, respectively, by shift. We split P/N into the following five categories: less than or equal to 1:1, greater than 1:1 to less than or equal to 1.5:1, greater than 1.5:1 to less than or equal to 2:1, greater than 2:1 to less than or equal to 2.5:1, and greater than 2.5:1 (2:1 meaning two patients for one nurse). The following four categories for P/P were defined as follows: less than or equal to 8:1, greater than 8:1 to less than or equal to 10:1, greater than 10:1 to less than or equal to 14:1, and greater than 14:1 (10:1 meaning 10 patients for one physician). Medical residents were included in the count of physicians. We calculated the resident-to-physician ratio (R/P) as the number of residents divided by the number of physicians.

Two additional metrics were used to describe workload. The turnover of patients was measured by dividing the cumulative number of ICU admission and ICU discharge (excluding deaths) during a shift with the number of patients actually staying in the ICU during that shift (20). The mean number of LSPs per patient performed during a shift was also considered a marker of both the workload and the patient severity. We reasoned that the higher the LSP number, the higher the number of procedures performed by the team and presumably the higher the number of failing organs.

Statistical Analysis

Categorical variables are presented using absolute and relative frequencies and were compared using the chi-square test. Continuous variables are presented using mean and one SD and were compared using the Mann-Whitney *U* test. Shifts with missing values regarding staffing resources were not included in the analyses.

To explore the determinants of ICU mortality per shift and to adjust for site in analysis, we performed multilevel Poisson regression taking into account the clustering effect of patients within the ICU (23). Death was the outcome of interest in the model, while staffing and workload were the main predictors. To control for potential confounding variables, patients' characteristics were a priori selected as clinically important covariates. The proportion of surgical cases versus medical cases was used to adjust on the type of patient case-mix admitted to ICU. The final multivariate model included the following variables: P/N, P/P and residents-to-physicians ratios, patient turnover, number of LSP, proportion of men, proportion of surgical cases, SAPSII, and number of comorbidities. The results are presented as adjusted relative risks with their corresponding 95% CIs. Potential variations over time in the highest values of P/N and P/P ratios, as well as patient turnover, are described according to shifts and calendar days. All analyses were performed using R version 3.02 and the package lme4 (glmer function) (24, 25).

RESULTS

Population and Shifts Description

A total of 5,718 patients were hospitalized in eight ICUs during the 1-year study period (**Table 1**). The mean number of patients per shift ranged from 8.3 to 22.2 according to ICU size. Overall, 67% of them were men, aged 60.6 ± 6.3 years, and SAPSII was 50.5 ± 10.6 with an average of 2.2 comorbidities per patient. Regarding the

TABLE 1. Description of Studied ICUs

	Hospital A		Hospital B		Hospital C		Hospital D		
	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Total
	n = 393	*n* = 973	*n* = 578	*n* = 353	*n* = 647	*n* = 1,520	*n* = 590	*n* = 644	*n* = 5,718
No. of deaths (%)	86 (22)	114 (8.5)	138 (23)	68 (19)	69 (11)	127 (8)	155 (26)	94 (14)	851 (15)
No. of deaths (no decision to forego life-sustaining therapy) (%)	41 (10)	36 (3)	53 (9)	25 (7)	44 (7)	110 (7)	72 (12)	43 (7)	424 (7)
Description of staff (per shift):									
Mean patients-to-nurse ratio (SD)	2 (0.5)	1.7 (0.5)	1.7 (0.3)	1.6 (0.3)	1.6 (0.3)	1.7 (0.3)	2 (0.4)	1.9 (0.5)	1.8 (0.4)
Mean patients-to-physician ratio (SD)	5.1 (3.3)	4.5 (2.2)	6.0 (5.2)	3.2 (1.4)	5.9 (3.4)	9.5 (3.3)	7.2 (4.9)	3.9 (1.9)	5.6 (3.2)
Description of workload (per shift)									
Mean patient turnover (SD)[a]	5.8 (9.3)	10 (11.0)	7.1 (9.4)	5.8 (9.2)	5.1 (6.6)	8.4 (9.8)	5.6 (7.6)	7.5 (10.0)	6.9 (9.0)
Mean number of life-sustaining procedure (SD)[b]	1.3 (0.4)	1.2 (0.3)	1.6 (0.3)	1.8 (0.3)	0.9 (0.2)	1.3 (0.2)	1.2 (0.2)	1.1 (0.3)	1.3 (0.3)
Description of patients (per shift)									
Mean number of patients (SD)	8.3 (1.4)	12. 5(2.7)	11.9 (2.6)	8.7 (1.3)	17.0 (2.6)	22.2 (4.3)	12.2 (2.2)	11 (2.2)	13.3 (5.1)
Mean proportion of men (SD)	0.7 (0.2)	0.7 (0.1)	0.7 (0.1)	0.7(0.17)	0.6 (0.1)	0.6 (0.1)	0.6 (0.1)	0.7 (0.2)	0.7 (0.1)
Mean age (SD)	63.8 (5.5)	56.4 (6.4)	63.6 (5.5)	60.6 (4.4)	53.9 (3.6)	61.4 (3.2)	65.8 (5.6)	58.4 (5.3)	60.6(4.9)
Mean proportion of surgical cases (SD)	0.5 (0.2)	0.7 (0.1)	0.2 (0.1)	0.7 (0.1)	0.8 (0.1)	0.9 (0.1)	0.2 (0.1)	0.7 (0.1)	0.6 (0.1)
Mean Simplified Acute Physiology Score II (SD)	55.5 (6.9)	52.8 (6.1)	46.4 (6.1)	58.2 (8.8)	36.4 (4.3)	49.8 (5.0)	62.4 (6.1)	52.7 (8.0)	50.5(6.4)
Mean number of comorbidities (SD)[c]	2.6 (0.8)	2.8 (0.6)	1.9 (0.5)	2.1 (0.5)	1.9 (0.4)	2.4 (0.5)	2.3 (0.5)	1.8 (0.5)	2.2 (0.5)

[a]Number of admissions plus discharges (excluding death) over the census during the shift, in percentage.

[b]Mean number of life-sustaining procedures per patient-day.

[c]Conditions extracted from the Elixhauser list of comorbidities (22).

Deaths with and without decision to forego life-sustaining therapy are described with their number and proportion; all other variables are described with their mean/proportion and SD.

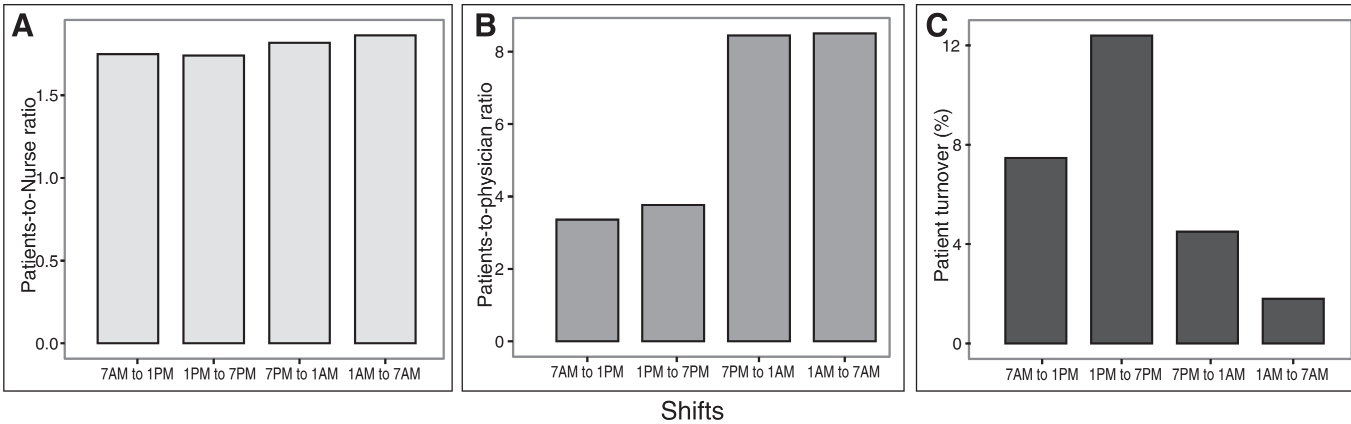

Figure 1. Ratios of patients per nurse and per ICU physician and patient turnover by shift. **A**, Patients-to-nurse ratio. **B**, Patients-to-physician ratio. **C**, Patient turnover.

workload, there were 1.3 LSPs per patient-shift and a mean patient turnover of 6.9%. The overall mortality rate was 14.9% (851/5,718) and 7% (424/5,718) of deaths occurred without a DFLST order.

The mean P/N was stable across the shifts, with an average of 1.8 patients per nurse (**Fig. 1*A***). On the contrary, P/P varied dramatically between day and night shifts, with a mean of 3.6 patients per physician during the day versus 8.5 during the night (**Fig. 1*B***). The turnover varied depending on the hour of the day. It was maximal during the day shifts, with a mean of 9.9 between 7:00 am and 6:59 pm, and lower during night shifts, with a mean of 3.2 between 7:00 pm and 6:59 am (**Fig. 1*C***).

Relationship of Patients to Caregivers' Ratio and ICU Mortality

A total of 11,666 shifts in the eight ICUs were studied over 1 year (14 shifts with missing values were not included in the analysis), including 415 shifts during which at least one death occurred (**Table 2**). The fully adjusted model, taking into account both staffing and workload levels, showed an increased risk of mortality, with the highest values for P/P and P/N. The ICU risk of death increased by a factor of 3.5 (1.3–9.1) when the number of patients was above 2.5 per nurse and by a factor of 2.0 (1.3–3.2) when the number of patients was above 14 per physician. The presence of medical residents did not influence inpatient mortality ($p = 0.6$). Patient turnover supported a adjusted relative risk of 5.9 (2–15) for ICU deaths. SAPSII and LSP were also associated with increased ICU mortality.

The highest values of P/P (ie, > 14 patients per physician) were represented during 3% of the time shifts and occurred mainly at night (87% vs 13%; $p < 0.001$) (**Fig. 2*A***). The highest values of P/N (ie, > 2.5 patients per nurse) affected 5% of the time shifts. These were uniformly distributed across the day ($p = 0.53$) (**Fig. 2*B***) but occurred more frequently during the weekend ($p < 0.001$) (**Fig. 3*B***).

DISCUSSION

This multicenter study proposes evidence-based thresholds of five patients to two nurses and 14 patients to one physician, above which there is an increase in ICU mortality. Those shifts with inadequate staffing resources, given the patients' needs, occurred mostly during weekends for nurses and at nights for physicians. In addition, higher risk of death was strongly influenced by heavy workload during shifts based on increased patient turnover and volume of LSPs performed by ICU teams.

Although some subsets of these parameters have been explored previously, the literature is scarce regarding the shift-by-shift analysis of both staffing and workload measures in a multicenter setting. Studies are traditionally based on fixed levels of staff (ie, ratios fixed a priori for periods of a few months) (26), instead of considering daily staff variations. This lack of granularity may explain why there is currently inconsistent association between medical staffing and patient outcome (2). In agreement with the guidelines of the Society of Critical Care Medicine for safe care, the present results clearly highlight a threshold effect regarding medical staff size relative to the number of patients and their needs. The present results also support previous observations, suggesting a potential relationship between ICU mortality and nurse staffing (2, 7, 10–13, 16, 20).

This study opens the way to an automated monitoring system. All types of data computed in the present work were collected routinely. Therefore, automating the process to provide a continuous follow-up of the adequacy of staffing levels and workload is possible. Such a monitoring tool would help manage staffing adequately and optimize patient flow. However, using routinely collected data to investigate preventable deaths caused by failures in ICU organization have clear limitations. In addition to excluding deaths with DFLST orders from our dataset, a solution would be to collect specific causes of death, such as "failure to rescue," which may reflect an unbalanced staffing level (1). In addition, we primarily used a combination of patient turnover and LSPs to assess work intensity at the team level. In the studied ICUs and in the majority of French ICUs, there is no consult team to take care of less-sick patients in ICUs. The same team is in charge of new admissions and other patients at the same time. So the observed workload is the sum of the patients in the ICU and new admissions.

TABLE 2. Characteristics of Shifts Without Any Death or With At Least One Death

	Shifts Without Death ($n = 11{,}251$)	Shifts With ≥ 1 Death ($n = 415$)	Unadjusted RR (95% CI)	Adjusted RR (95% CI)
Patients-to-nurse ratios (%)				
< 1:1	290 (2.6)	5 (1.2)	1	1
1:1–1.5:1	2,748 (24.4)	91 (21.9)	1.6 (0.8–2.9)	1.9 (0.7–4.6)
1.5:1–2:1	5,143 (45.7)	181 (43.7)	1.7 (0.9–3.1)	2.0 (0.8–5.0)
2:1–2.5:1	2,461 (21.9)	103 (24.8)	1.8 (0.9–3.2)	2.3 (0.9–5.8)
> 2.5:1	609 (5.4)	35 (8.4%)	2.2 (1.2–4.3)	3.5 (1.3–9.1)[a]
Patients-to-physician ratios (%)				
< 8	8,144 (72.4)	256 (61.7)	1	1
8:1–10:1	1,391 (12.4)	59 (14.2)	1.0 (0.8–1.3)	0.9 (0.7–1.3)
10:1–14:1	1,408 (12.5)	74 (17.8)	1.0 (0.8–1.3)	1.1 (0.8–1.5)
> 14:1	308 (2.7)	26 (6.3)	1.5 (1.0–2.1)	2.0 (1.3–3.2)[a]
Residents-to-physicians ratio (SD)	0.27 (0.26)	0.26 (0.25)	0.7 (0.4–1.1)	0.9 (0.5–1.5)
Mean patient turnover (SD)[b]	6.8 (9.2)	7.8 (11)	2.3 (1.1–4.7)	5.6 (2.0–15.0)[c]
Mean number of life-sustaining procedure (SD)[d]	1.3 (0.4)	1.4 (0.4)	4.4 (3.5–5.4)	5.9 (4.3–7.9)[c]
Mean proportion of men (SD)	0.6 (0.1)	0.6 (0.1)	1.6 (0.9–2.8)	1.8 (0.8–3.8)
Mean proportion of surgical cases (SD)	0.6 (0.3)	0.6 (0.3)	0.6 (0.4–1.0)	0.5 (0.2–1.1)
Mean Simplified Acute Physiology Score II[e] (SD)	50 (11)	52 (11)	1.5 (1.4–1.7)	1.5 (1.3–1.7)[c]
Mean number of comorbidities (SD)[f]	2.2 (0.6)	2.3 (0.6)	1.1 (0.9–1.3)	0.9 (0.8–1.1)

RR = relative risk.
[a]$p < 0.01$.
[b]Number of admissions plus discharges (excluding death) over the census during the shift, in percentage.
[c]$p < 0.001$.
[d]Mean number of life-sustaining medical procedure (LSPs; Annex 1) per patient-day.
[e]Risk ratios for Simplified Acute Physiology Score (SAPS) II are computed for 10-point increase.
[f]Conditions extracted from the Elixhauser list of comorbidities (22).
Risk ratios correspond to a bivariate Poisson mixed model with random effect on ICU. Adjusted risk ratios and p values correspond to a multivariate Poisson mixed model with random effect on ICU. The multivariate model includes the following variables: patient-to-nurse, patient-to-physician, and residents-to-physicians ratios, patient turnover, number of LSP, proportion of men, proportion of surgical cases, SAPSII and number of comorbidities.

Representing the workload as a combination of LSPs, patient severity and turnover allowed us to take into account both patients present in the ICU and new admissions. Tracking the caregivers' well-being and how they are experiencing the burdens of daily activities may provide additional information (27). Furthermore, several nursing workload scores have been previously developed, such as the therapeutic intervention scoring system, the nursing activities score, or the nine equivalents of nursing manpower use score (28). Unfortunately, these metrics were not present in available databases.

In terms of generalizability, this study was performed over eight closed ICUs in four academic hospitals. Despite a limited sample size, we think that the findings can probably be generalized to the other French academic hospitals given that their organization does not vary much. Also, our analyses showed no influence of the number of residents per physician on patient mortality. Therefore, we can argue that our findings may also apply to nonacademic hospitals. Although any ICU with an organization similar to the ICUs from this study could benefit from the present results, it would be interesting to validate our findings although replication studies in other countries. The optimal P/P ratios may be different in the context of open ICUs, where the physician formally responsible for the patient is not the intensivist and physicians from outside of the ICU may participate in patient care. Another limitation to this study is that no adjustment was feasible regarding the specialty of ICU physicians (ie, intensivist, anesthesia, and mixed) that may have influenced patients' outcomes.

Representing a real picture of daily workload in the ICU, this study raises further unresolved questions. What are the exact conditions of excessive workload and insufficient staffing that lead to avoidable deaths in the ICU? Ideally, investigating shift-to-shift variations of caregivers staffing and patient turnover would allow identification of which caregiver is assigned to a given patient at any time in a particular ICU. Here, we provided this information at the unit level at each time period. The next step would be to introduce the linking of individual data between patients and caregivers, allowing for a dynamic

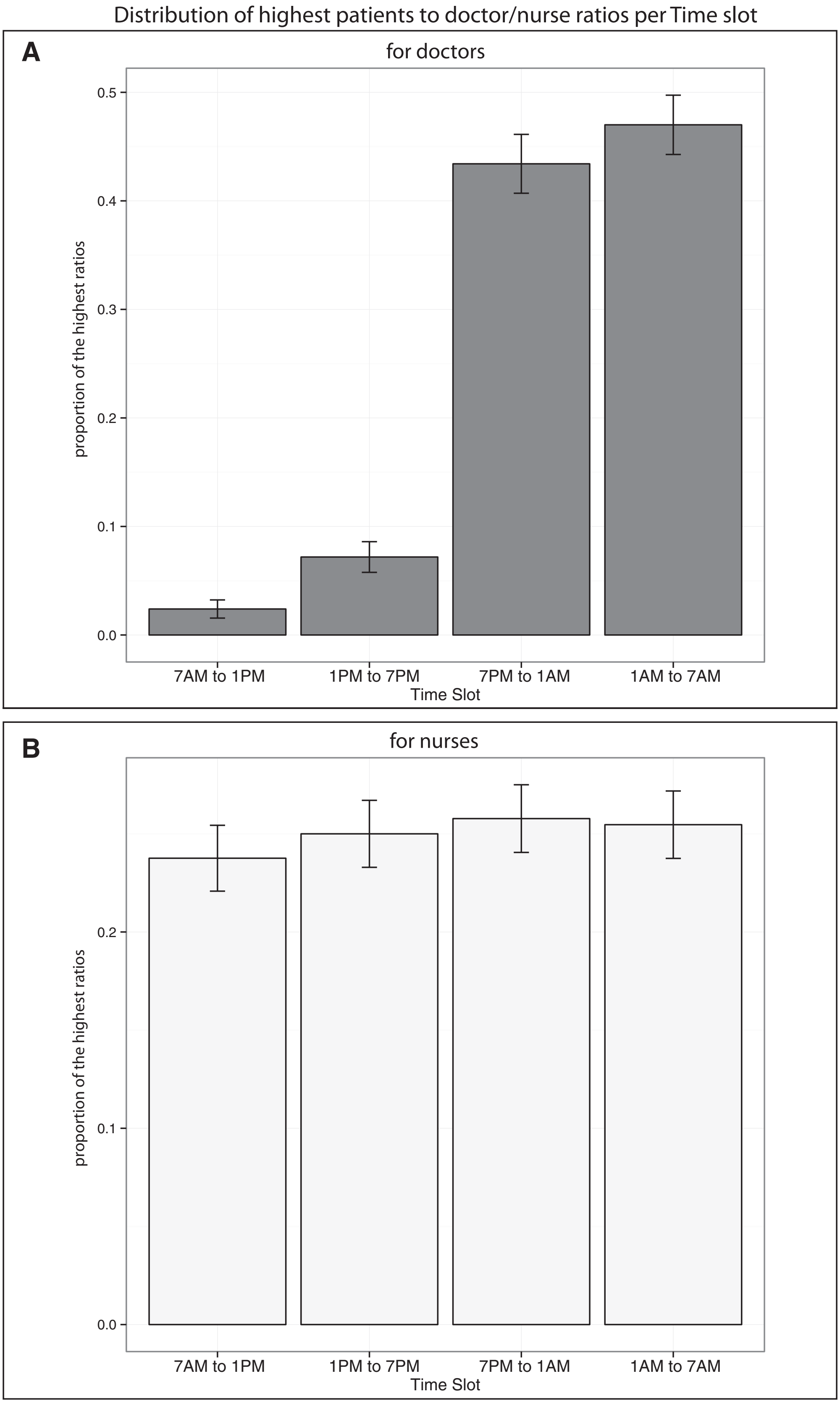

Figure 2. Distribution of highest ratios across shifts. Highest ratios correspond to > 2.5 patients per nurse and > 14 patients per physician.

analysis of their interactions (29, 30). Indeed, workload may not be uniformly distributed over time across different team members. For example, two patients assigned to the same caregiver may need urgent care, whereas other caregivers might simultaneously experience a lower workload. In this situation, it is likely that the latter helps the former. A solution to this issue was proposed in some ICUs. Teams dedicated to managing new ICU admissions have been implemented in a delimited ICU zone. The performance of such organizations, which aim to prevent ICU malfunction that results from excessive turnover, should be assessed. Furthermore, what are the determinants of clinical team performance, and how can we make efficient teams? Quantifying the patient-to-caregiver ratio in real time provides an overall view of the appropriate staffing level. A more accurate evaluation of the capability of a team to properly handle difficult situations represents the next step. Analysis of individual characteristics and interactions among team members should be considered because team composition and familiarity might influence its resilience to intense workload variations (31). Thus, high-performance teams would maintain high levels of quality when exposed to stressful situations, and teamwork skills may surpass the sum of individual talent. Staff experience, or the number of shifts involving the same colleagues, may reflect expertise and how well people communicate with each other through the acquisition of skills that allow for quick responses that can guarantee patient safety (32). In the same

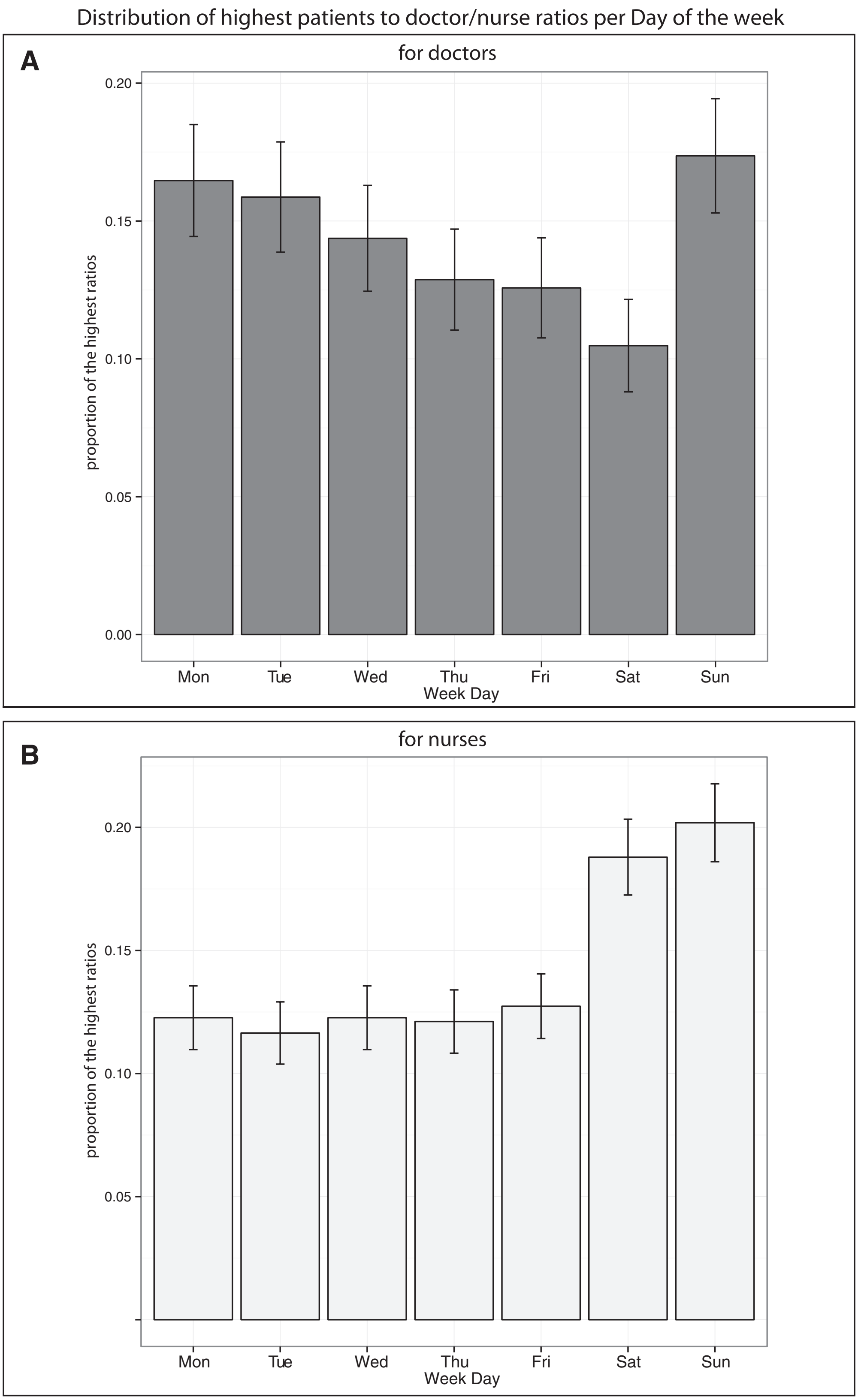

Figure 3. Distribution of highest ratios across days of the week. Highest ratios correspond to > 2.5 patients per nurse and > 14 patients per physician.

manner, safety culture in the team may play a role in patient safety. Methods such as crew resource management imported from aviation were implemented in surgical settings (33). Team training might be useful to improve patient outcome in ICUs (34, 35).

This study proposes evidence-based ratios of patients per nurse and physician in the context of ICUs. Our findings support recommendations for adapting caregivers' resources to patients' needs in real time. Insufficient staffing above the observed maximum thresholds showed an increased risk of mortality. Particular attention should be paid to critical periods identified to be at risk of high patient-to-caregiver ratios (ie, on weekends for nurses and at night for physicians). Moreover, identification of patient turnover as an independent risk factor of mortality should lead to a thoughtful management of patient influx during a single shift. Delaying admissions during periods when teams are experiencing a heavy workload with unbalanced patients-to-caregivers ratios could prevent ICU disorganization. However, the heterogeneity staffing patterns in ICUs around the world cannot be overlooked: larger studies involving different countries will be needed to validate these findings. Because all data used in this study were routinely collected in hospital information systems, real-time monitoring of staffing levels and workload with dedicated alarms is feasible. Such monitoring of patient-to-caregiver ratios would help not only to have sufficient resources for guaranteeing patient safety when needed but also to avoid wasting in case of temporary overstaffing. Hence, continuous balancing between staffing resources and workload may increase care efficiency in ICUs. Otherwise, a cost-effective solution would consist of smoothing activity and staff presence over time according to threshold recommendations.

REFERENCES

1. Griffiths P, Jones S, Bottle A: Is "failure to rescue" derived from administrative data in England a nurse sensitive patient safety indicator for surgical care? Observational study. *Int J Nurs Stud* 2013; 50:292–300
2. West E, Barron DN, Harrison D, et al: Nurse staffing, medical staffing and mortality in Intensive Care: An observational study. *Int J Nurs Stud* 2014; 51:781–794
3. Bray K, Wren I, Baldwin A, et al: Standards for nurse staffing in critical care units determined by: The British Association of Critical Care Nurses, The Critical Care Networks National Nurse Leads, Royal College of Nursing Critical Care and In-flight Forum. *Nurs Crit Care* 2010; 15:109–111
4. Ministère de l'emploi et de la solidarité: Décret no 2002–465 du 5 avril 2002 relatif aux établissements de santé publics et privés pratiquant la réanimation et modifiant le code de la santé publique [Internet]. JO 2002; [cited November 18, 2013]. Available at: http://www.srlf.org/Data/upload/Files/20121217_CE_DecretReanimation2002.pdf
5. ESICM Working Group on Quality Improvement, Valentin A, Ferdinande P: Recommendations on basic requirements for intensive care units: Structural and organizational aspects. *Intensive Care Med* 2011; 37:1575–1587
6. Ward NS, Afessa B, Kleinpell R, et al; Members of Society of Critical Care Medicine Taskforce on ICU Staffing: Intensivist/patient ratios in closed ICUs: A statement from the Society of Critical Care Medicine Taskforce on ICU Staffing. *Crit Care Med* 2013; 41:638–645
7. Tarnow-Mordi WO, Hau C, Warden A, et al: Hospital mortality in relation to staff workload: A 4-year study in an adult intensive-care unit. *Lancet* 2000; 356:185–189
8. Dimick JB, Swoboda SM, Pronovost PJ, et al: Effect of nurse-to-patient ratio in the intensive care unit on pulmonary complications and resource use after hepatectomy. *Am J Crit Care* 2001; 10:376–382
9. Metnitz PG, Reiter A, Jordan B, et al: More interventions do not necessarily improve outcome in critically ill patients. *Intensive Care Med* 2004; 30:1586–1593
10. Person SD, Allison JJ, Kiefe CI, et al: Nurse staffing and mortality for Medicare patients with acute myocardial infarction. *Med Care* 2004; 42:4–12
11. Tourangeau AE, Doran DM, McGillis Hall L, et al: Impact of hospital nursing care on 30-day mortality for acute medical patients. *J Adv Nurs* 2007; 57:32–44
12. Stone PW, Mooney-Kane C, Larson EL, et al: Nurse working conditions and patient safety outcomes. *Med Care* 2007; 45:571–578
13. Cho SH, Hwang JH, Kim J: Nurse staffing and patient mortality in intensive care units. *Nurs Res* 2008; 57:322–330
14. Kiekkas P, Sakellaropoulos GC, Brokalaki H, et al: Association between nursing workload and mortality of intensive care unit patients. *J Nurs Scholarsh* 2008; 40:385–390
15. Kane RL, Shamliyan TA, Mueller C, et al: The association of registered nurse staffing levels and patient outcomes: Systematic review and meta-analysis. *Med Care* 2007; 45:1195–1204
16. Numata Y, Schulzer M, van der Wal R, et al: Nurse staffing levels and hospital mortality in critical care settings: Literature review and meta-analysis. *J Adv Nurs* 2006; 55:435–448
17. Afessa B: Intensive care unit physician staffing: Seven days a week, 24 hours a day. *Crit Care Med* 2006; 34:894–895
18. Unruh LY, Fottler MD: Patient turnover and nursing staff adequacy. *Health Serv Res* 2006; 41:599–612
19. Evans WN, Kim B: Patient outcomes when hospitals experience a surge in admissions. *J Health Econ* 2006; 25:365–388
20. Needleman J, Buerhaus P, Pankratz VS, et al: Nurse staffing and inpatient hospital mortality. *N Engl J Med* 2011; 364:1037–1045
21. Le Gall JR, Lemeshow S, Saulnier F: A new Simplified Acute Physiology Score (SAPS II) based on a European/North American multicenter study. *JAMA* 1993; 270:2957–2963
22. Elixhauser A, Steiner C, Harris DR, et al: Comorbidity measures for use with administrative data. *Med Care* 1998; 36:8–27
23. Gelman A, Hill J: Data Analysis Using Regression and Multilevel/Hierarchical Models. Cambridge, NY: Cambridge University Press; 2007
24. R Development Core Team: R: A Language and Environment for Statistical Computing. [Internet]. 2014. Available at: http://www.R-project.org
25. Bates D, Maechler M, Bolker B: lme4: Linear mixed effects models using Eigen and S4. 2014. ArXiv e-print; submitted to Journal of Statistical Software. Available at: http://arxiv.org/abs/1406.5823. Accessed March 31, 2015
26. Dara SI, Afessa B: Intensivist-to-bed ratio: Association with outcomes in the medical ICU. *Chest* 2005; 128:567–572
27. Wallace JE, Lemaire JB, Ghali WA: Physician wellness: A missing quality indicator. *Lancet* 2009; 374:1714–1721
28. Debergh DP, Myny D, Van Herzeele I, et al: Measuring the nursing workload per shift in the ICU. *Intensive Care Med* 2012; 38:1438–1444
29. Gray JE, Davis DA, Pursley DM, et al: Network analysis of team structure in the neonatal intensive care unit. *Pediatrics* 2010; 125:e1460–e1467
30. Cusumano-Towner M, Li DY, Tuo S, et al.: A social network of hospital acquired infection built from electronic medical record data [Internet]. J Am Med Inform Assoc 2013 [cited March 6, 2013]. Available at: http://jamia.bmj.com/content/early/2013/03/05/amiajnl-2012-001401
31. Xu R, Carty MJ, Orgill DP, et al: The teaming curve: A longitudinal study of the influence of surgical team familiarity on operative time. *Ann Surg* 2013; 258:953–957
32. Choudhry NK, Fletcher RH, Soumerai SB: Systematic review: The relationship between clinical experience and quality of health care. *Ann Intern Med* 2005; 142:260–273
33. Neily J, Mills PD, Young-Xu Y, et al: Association between implementation of a medical team training program and surgical mortality. *JAMA* 2010; 304:1693–1700
34. Reader TW, Flin R, Mearns K, et al: Developing a team performance framework for the intensive care unit. *Crit Care Med* 2009; 37:1787–1793
35. Meurling L, Hedman L, Sandahl C, et al: Systematic simulation-based team training in a Swedish intensive care unit: A diverse response among critical care professions. *BMJ Qual Saf* 2013; 22:485–494