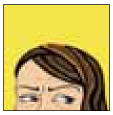

Effect of Ambient Workload in the Intensive Care Unit on Mortality and Time to Discharge Alive

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Abstract

The purpose of this study was to determine the relationship between ambient workload and outcomes of patients in the intensive care unit (ICU). Measures of workload evaluated for each patient on each day of ICU admission were the number of new admissions, ICU census, "code blue" patients not admitted and Acute Physiology and Chronic Health Evaluation (APACHE) II scores and Multiple Organ Dysfunction Scores (MODSs) for admitted patients. Patients were defined as the patient at risk (the "index" patient) and the other patients in the ICU at the same time (the "non-index" patients). Logistic regression (for hospital mortality) and Cox proportional hazards regression (for time to discharge alive) were used to investigate the association between workload and outcomes.

In total, 1,705 patients were included. Higher MODSs of non-index patients on the last day of the ICU admission were associated with lower mortality (odds ratio [OR] 0.82 per MODS point, 95% CI 0.72–0.94). A higher number of code blues during the ICU stay was associated with higher mortality (OR 1.18 per event, 95% CI 1.01–1.37). A higher ICU census and MODS of the non-index patients on the day of ICU admission were associated with a shorter time to discharge alive (hazard rate [HR] 1.03 per patient, 95% CI: 1.01–1.06, and 1.07 per MODS point, 95% CI: 1.01–1.15, respectively).

The association between measures of ambient workload in the ICU and patient outcomes is variable. Future resource planning and studies of patient safety would benefit from a prospective analysis of these factors to define workload limits and tolerances.

Many **intensive care units** (ICUs) operate near full capacity. Aging populations and limited resources place increasing demands on space and personnel, with little capability to adapt to episodes of increased workload (Hick et al. 2004). For critically ill patients, day-to-day surges in demand on ICU resources could create an environment of increased risk. Consequences of excess workload, such as an increased incidence of human error or iatrogenic complications, or delays in necessary interventions, such as weaning from mechanical ventilation, could contribute to adverse patient outcomes (Tarnow-Mordi et al. 2000).

Previous studies have examined how the time of service delivery affects critical care outcomes (Bell and Redelmeier 2001; Morales et al. 2003). Ball and colleagues (2006) recently investigated the effect of variability in demand for trauma services on patient outcomes. Others have examined the relationship between ICU nursing workload, or intensivist-to-bed ratio, and in-hospital morbidity and mortality (Amaravadi et al. 2000; Dara et al. 2005; Tarnow-Mordi et al. 2000). Many authors have demonstrated that busier ICUs have better outcomes (Glance et al. 2006; Iapichino et al. 2004; Kahn et al. 2006; Needham et al. 2006). However, we are unaware of any studies that have examined the effect of specific determinants of workload on ICU patient outcomes.

The purpose of this study was to examine the relationship between ambient workload in the ICU and patient outcomes. We hypothesized that an increased workload would be associated with higher mortality and longer ICU lengths of stay.

Methods

Data Source, Study Population and Setting

Data were extracted from a database that is the repository for clinical information from two tertiary care adult ICUs in Vancouver, British Columbia – the Vancouver Hospital and Health Sciences Centre, and St. Paul's Hospital. Both are university-affiliated teaching hospitals that receive critically ill patients from throughout British Columbia.

The ICU at the Vancouver Hospital and Health Sciences Centre is a 26-bed multidisciplinary unit that cares for all critically ill patients in the hospital except for uncomplicated cardiac and cardiac surgery patients. The case mix of this unit includes burn, bone marrow transplant, solid organ transplant, neurosurgical and trauma patients.

The ICU at St. Paul's Hospital is a similar unit, but it has 14 beds. The case mix includes many patients with severe sepsis related to community and healthcare-associated infections and a wide variety of post-surgical patients.

Trained data collectors gather clinical data prospectively in both ICUs. The reliability of the data has been repeatedly verified using samples of records. The study population consisted of all patients admitted to both ICUs between April 1, 2002, and September 30, 2003.

Medical teams in the ICUs consist of a staff intensivist, an ICU fellow and three to seven residents. Two in-house residents or clinical associates provide overnight and weekend coverage. A staff intensivist is available for callback and return to hospital after hours. Residents come from multiple postgraduate programs, including emergency and internal medicine, surgical specialties and anesthesiology.

All nursing staff in both ICUs are trained to care for critically ill patients. The nurse-to-patient ratio is usually one to one but may be one to two for less seriously ill patients.

The ICU teams at each hospital are responsible for providing care to all admitted ICU patients, as well as for managing all cardiac or respiratory arrests ("code blues") throughout the hospital. In addition, teams provide consultations for hospital patients outside the ICU.

For some therapeutic interventions, we are becoming more aware that timing of delivery of care may be as important as the intervention itself.

Data Elements

For each admitted patient, age, sex, dates of ICU admission and discharge, ICU admission diagnosis, Acute Physiology and Chronic Health Evaluation (APACHE) II score on the day of admission (Knaus et al. 1985) and Multiple Organ Dysfunction Scores (MODS) for each of the first seven days of the ICU admission (Marshall et al. 1995) were extracted from the database. In addition, we recorded the number of newly admitted patients and number of code blues requiring attendance by ICU staff for each day. Outcome measures were hospital mortality and time to discharge alive from the ICU.

Statistical analyses were carried out for each patient individually, using the patient's data as that of the "index" patient and the data of the other patients in the ICU at the same time as those of the "non-index" patients.

Workload Measures

Workload variables were chosen based on interviews with ICU physicians and residents. We found that the main tasks that consume clinicians' time are daily rounds, procedures such as intubations or line insertions, assessment and admission of new patients, responding to code blue emergency calls throughout the hospital and formal teaching sessions. The number of patients and their severity of illness influence the workload associated with most tasks.

The following measures of workload were extracted from the ICU database: ICU census, APACHE II scores and MODSs for all admitted patients, the number of new admissions and the number of code blues patients attended but not admitted. Using these measures, ambient workload was determined for each patient for each day of that patient's ICU stay.

The time-dependant effects of the workload measures were assessed by tabulating variables for each patient at three different time points during the ICU stay: the day of admission, day of discharge and average of the intermediate days. Because we record MODSs only for the first seven days of a patient's ICU stay, if an ICU stay was longer than seven days, we assumed that the MODS after the seventh day was the same as the last MODS recorded.

If a patient was admitted and discharged on the same day, variables at admission day, intermediate days and discharge dates were the same. If a patient had an ICU length of stay of two days, values for the intermediate days were an average of those for the admission and the discharge days. Therefore, the final analysis examined five workload variables per patient (number of new admissions, ICU census, number of code blues, average APACHE II score and average MODS) at three different time points during the ICU stay (at admission, at discharge and averaged during the intermediate days) for a total of 15 ambient workload variables computed for each admitted patient.

Statistical Analysis

Statistical analyses were done using the Statistical Analysis System software, Version 9.1.3 (SAS Institute, Cary, North Carolina).

It may be that during busier times, there is a greater sense of urgency or attentiveness, which may positively influence outcomes.

Hospital Mortality

Logistic regression models were used to assess the relationship between hospital mortality and each workload variable individually, after adjusting for age, sex, APACHE II score and hospital site. Variance inflation factors were calculated to assess the degree of multicollinearity between the workload variables. Due to high degrees of collinearity, four workload variables (ICU census on the middle and last days of ICU stay and mean APACHE II scores of the non-index patients on the middle and final days of the ICU stay) were excluded from the analysis. Thus, the final model assessing the association between hospital mortality and workload included 11 variables. In this model, all variance inflation factors were in an acceptable range (<1.8).

Time to Discharge Alive

Using Cox proportional hazards regression, we first assessed the association between the time to discharge alive and each workload variable individually, adjusted for age, sex, APACHE II score and hospital site. We then fitted a multivariate regression model that included all workload variables to assess their association with patient outcomes when adjusted for each other. Because patients who have high APACHE II scores often die before being in the ICU long enough for workload factors to have meaningful impact on their outcome, we restricted these analyses to patients who had APACHE II scores <25. Because of the reduced sample size (n = 1,187) for this analysis only, we limited our investigation to the workload variables measured on the day of admission. Patients who died during their ICU stay were censored from the time to discharge alive analysis at the time of their death. This allowed the analysis to recognize that non-survivors would have continued to contribute to length of stay had they not died.

For all analyses, results are reported using 95% confidence intervals (CIs). A p value less than .05 was treated as statistically significant.

The Research Ethics Boards of Providence Health Care and Vancouver Hospital approved this study.

Results

Patient Characteristics

During the period of interest, 597 patients were admitted to the ICU at St. Paul's Hospital, and 1,108 patients were admitted to the ICU at Vancouver Hospital. Table 1 describes the patients' characteristics by hospital and survival status.

Hospital Mortality

Overall hospital mortality was 32%. For most covariates, the analysis showed no statistically significant effect of workload variables on mortality (Table 2). However, a higher average MODS of the non-index patients on the last day of the ICU stay was associated with lower hospital mortality (odds ratio [OR] 0.82 per MODS point, 95% CI 0.72–0.94) for the index patients. In addition, a higher number of code blues during the middle days of an ICU stay was associated with higher mortality (OR 1.18 per event, 95% CI 1.01–1.37).

Time to Discharge Alive from the ICU

A higher census on the day of admission was associated with a shorter time to discharge alive (HR 1.03 per patient, 95% CI 1.01–1.06). In addition, higher MODSs of the other patients in the ICU on the day of admission were associated with a shorter time to discharge alive (HR 1.07 per MODS point, 95% CI 1.01–1.15). None of the other first-day workload variables were found to be significantly associated with shorter ICU stays, but the estimates for all HRs were >1 (Table 3).

Discussion

Our findings suggest that ICU workload is associated with outcomes in the critically ill. It is not difficult to surmise how increased workload, in the form of more code blues attended, might increase mortality for ICU patients. Duties that remove staff from the ICU can limit or delay necessary attention to ICU patients. For some therapeutic interventions, we are becoming more aware that timing of delivery of care may be as important as the intervention itself (Rivers et al. 2001). The absence of staff from the ICU may lead to delays in the recognition of important changes in patient status, administration of time-sensitive critical therapies such as antibiotics, or performance of procedures such as central line insertions or intubations.

It is more difficult to explain how an increased workload, as indicated by higher MODSs of other patients, may be associated with reduced individual mortality. One possibility is that this finding is due to a "ramping up" effect, whereby a more demanding environment brings more resources to bear. In the ICUs examined in this study, sicker patients are consistently nursed in a one-to-one ratio, while less sick patients are often

Table 1. Characteristics of the ICU index patients admitted to SPH or VHHSC April 2002–September 2003*

	SPH		VHHSC	
	Survivors	**Non-survivors**	**Survivors**	**Non-survivors**
N = 1,705	352	245	803	305
APACHE II <25 (*n* = 1,187)	267	120	663	137
Age (yr)	53.7 ± 17.0	62.9 ± 16.2	50.0 ± 19.3	57.3 ± 19.4
Male sex (%)	63	62	68	62
APACHE II score – median (IQR)	20 (15–24)	25 (20–31)	18 (14–23)	25 (20–29)
Hospital mortality (%)	41		28	
ICU length of stay – median days (IQR)	4 (2–9)	5 (2–11)	6 (3–13)	4 (1–10)
Hospital length of stay – median days (IQR)	13 (6–31)	16 (6–32)	17 (8–30)	19 (8–37)
ICU census on day of ICU admission	9.6 ± 1.5	9.7 ± 1.6	25.9 ± 2.8	25.8 ± 2.8
ICU census on middle days of ICU stay	10.1 ± 1.3	10.1 ± 1.3	26.5 ± 2.4	26.4 ± 2.6
ICU census on last day of ICU stay	10.3 ± 1.5	10.0 ± 1.6	26.6 ± 2.4	26.6 ± 2.9
Other new admissions on day of ICU admission	0.09 ± 0.8	0.9 ± 0.8	2.0 ± 1.3	1.9 ± 1.4
New admissions on middle days of ICU stay	1.1 ± 0.6	1.0 ± 0.6	2.1 ± 0.7	2.1 ± 1.0
New admissions on last day of ICU stay	1.4 ± 1.0	1.5 ± 1.0	2.4 ± 1.3	2.2 ± 1.5
MODSs of other patients on day of ICU admission	5.9 ± 1.0	5.8 ± 0.8	6.0 ± 1.1	5.7 ± 1.1
MODSs of other patients on middle days of ICU stay	5.9 ± 0.8	5.8 ± 0.7	6.2 ± 0.6	6.2 ± 0.6
MODSs of other patients on last day of ICU stay	5.9 ± 1.0	5.9 ± 0.9	6.1 ± 1.1	5.8 ± 1.1
Number of "code blues" on day of ICU admission	0.7 ± 1.0	0.7 ± 1.0	0.3 ± 0.6	0.4 ± 0.6
Number of code blues on middle days of ICU stay	0.7 ± 0.6	0.8 ± 0.7	0.3 ± 0.3	0.3 ± 0.3
Number of code blues on last day of ICU stay	0.6 ± 1.0	0.7 ± 1.1	0.3 ± 0.6	0.4 ± 0.6

APACHE = Acute Physiology and Chronic Health Evaluation; ICU = intensive care unit; IQR = interquartile range; MODS = Multiple Organ Dysfunction Score; SPH = St. Paul's Hospital; VHHSC = Vancouver Hospital and Health Sciences Centre. *All values are mean ± *SD* except where noted.

"doubled" in a one-to-two ratio. It may be that in less busy times, with more doubled patients and fewer nurses in the unit, we are actually taxing our staff to a greater degree and exposing patients to more risk (Amaravadi et al. 2000). Alternatively, it may be that during busier times, there is a greater sense of urgency or attentiveness, which may positively influence outcomes.

Although we did not examine the number of procedures done, it is possible that busier environments may be associated with fewer individual procedural interventions or investigations. This may protect patients from associated complications. For example, it has been shown that some previously well-regarded interventions, such as the placement of a pulmonary artery catheter, may in fact increase morbidity and mortality (Connors et al. 1996; Shah et al. 2005).

In modelling time to discharge alive, our results suggest that a higher ICU workload is associated with shorter ICU stays for the index patient (see Table 3). These findings are consistent with results recently demonstrated in the neonatal ICU setting

Table 2. Odds ratios for workload covariates included in hospital mortality model*

	OR (95% CI)	Unit
Mean APACHE II scores of other patients on day of admission	1.01 (0.92, 1.11)	Per point
ICU census on day of ICU admission	0.97 (0.92, 1.02)	Per patient
Other new admissions on day of ICU admission	0.98 (0.89, 1.09)	Per patient
New admissions on middle days of ICU stay	0.94 (0.80, 1.12)	Per patient
New admissions on last day of ICU stay	0.92 (0.84, 1.02)	Per patient
MODS of other patients on day of ICU admission	0.94 (0.82, 1.07)	Per point
MODS of other patients on middle days of ICU stay	0.95 (0.77, 1.17)	Per point
MODS of other patients on last day of ICU stay	**0.82 (0.72, 0.94)**	Per point
Number of "code blues" on day of ICU admission	0.96 (0.82, 1.11)	Per event
Number of code blues on middle days of ICU stay	**1.18 (1.01, 1.37)**	Per event
Number of code blues on last day of ICU stay	0.99 (0.75, 1.30)	Per event

APACHE = Acute Physiology and Chronic Health Evaluation; CI = confidence interval; ICU = intensive care unit; MODS = Multiple Organ Dysfunction Score; OR = odds ratio.
*Adjusted for age, sex and APACHE II score of the index patient at admission.

Table 3. Hazard rates for time to discharge alive for patients with APACHE II scores <25*

	HR (95% CI)	Unit
Mean APACHE II scores of other patients on day of admission	1.03 (0.97, 1.08)	Per point
ICU census on day of ICU admission	**1.03 (1.01, 1.06)**	Per patient
Other new admissions on day of ICU admission	1.05 (0.99, 1.12)	Per patient
MODS of other patients on day of ICU admission	**1.07 (1.01, 1.15)**	Per point
Number of "code blues" on day of ICU admission	1.05 (0.96, 1.15)	Per event

APACHE = Acute Physiology and Chronic Health Evaluation; CI = confidence interval; HR = hazard rate; ICU = intensive care unit; MODS = Multiple Organ Dysfunction Score.
*Adjusted for age, sex and APACHE II score of the index patient at admission.

(Profit et al. 2007). During busier times, with more and sicker patients, ICUs may experience significant pressure to create spaces for new patients. In high-workload environments, patients may be transferred out of the ICU sooner. However, it is also possible that busier work environments lead to a more a timely institution of necessary treatments, and more rapid recovery. It would be instructive to examine the relationship between ICU workload and readmission to the ICU to help define which of these possibilities is the actual case.

It is difficult to interpret our findings relative to previous studies as we could find none that have assessed the impact of workload using measures similar to ours. Most previous efforts have focused on nursing requirements for individual patients (Reis Miranda et al. 1996; Tarnow-Mordi et al. 2000). However, given that our ICUs have some flexibility in matching nurse-to-patient requirements, we attempted a more inclusive quantification of total work demands.

Our analysis may be compromised by some missing determinants of workload, such as patients who were assessed but not admitted, time spent at code blue arrests, the level of ICU patient care (full aggressive care as opposed to limitations of care), comorbidities beyond those quantified by MODS or APACHE II scores, surgical procedures or admitting location or service.

A major determinant of workload that we were unable to incorporate is medical staff availability. While the number of intensivists and fellows available is constant in our units, the number of residents is variable. Further, the work accomplished by residents varies with their level of training and background specialty. In fact, residents themselves can contribute to workload as a large part of their role in the ICU is to learn academic and procedural skills from attending medical staff and fellows. Our analysis depends on the assumption that both the contribution and demands related to residents in our units is relatively constant.

Despite these shortcomings, the current study represents a novel attempt to correlate ICU environmental risk factors with patient outcomes. Through significant data-collection efforts on the part of our ICU teams, we were able to review a large number of patients over a recent time period. Our databases provide well-validated information on most of the major determinants of ICU workload. Although it complicated the analysis somewhat, our segregation of the effects of workload into discrete time variables addresses some of the complexity of workload impact.

It is notable that many of our workload measures were not significantly associated with patient outcomes. Nevertheless, given that our critical care resources are inherently finite, it is inevitable that some level of demand exists that would increase workload to a critical degree. For example, increased work demands such as those seen in multiple or mass casualty incidents negatively impact patient outcomes (Ball et al. 2006; Hirshberg et al. 2005). It is likely that our lack of data demonstrating large effects of workload indicates that day-to-day physician resources are generally adequate for the degree of workload that we routinely encounter. It would be useful to determine a threshold beyond which ambient workload has a serious impact on patient outcomes. This analysis would benefit from prospective data-collection methods, incorporating a detailed evaluation of available physician staffing levels.

The results of this unique investigation indicate that ICU workload has a measurable but variable effect on patient outcomes. Increased workload is associated with a shorter time to discharge alive for survivors of ICU admission. However, the association between ambient workload and mortality varies depending on the specific workload measure. Our results suggest that ICU staffing practices need to be tailored to the workload in order to limit workload's impact on patient outcomes. Given that our study does not allow us to define precise levels of workload that impart increased danger to our patients, future healthcare resources planning and studies of patient safety would benefit from prospective analysis of these factors to help define workload limits and tolerances. HQ

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