



# Association between intensive care unit occupancy at discharge, afterhours discharges, and clinical outcomes: a historical cohort study

## Association entre le taux d'occupation de l'unité de soins intensifs au moment du congé, les congés donnés durant la nuit, et les devenir cliniques : une étude de cohorte historique

Nicholas A. Fergusson, MSc · Steve Ahkioon, PhD · Najib Ayas, MD · Vinay K. Dhingra, MD · Dean R. Chittock, MD · Mypinder S. Sekhon, MD · Anish R. Mitra, MD · Donald E. G. Griesdale, MD, MPH

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### Abstract

**Purpose** *There is a paucity of evidence evaluating whether intensive care unit (ICU) discharge occupancy is associated with clinical outcomes. It is unknown whether increased discharge occupancy leads to greater afterhours discharges and downstream consequences. We explore the*

*association between ICU discharge occupancy and afterhours discharges, 72-hr readmission, and 30-day mortality.*

**Methods** *This single-centre, historical cohort study included all patients discharged from the Vancouver General Hospital ICU between 5 April 2010 and 13 September 2017. Data were obtained from the British Columbia Critical Care Database. Occupancy was defined as the number of ICU bed hours utilized divided by the available bed hours for that day. Any discharge between 22:00 and 6:59 was considered afterhours. Logistic regression models adjusting for important covariates were constructed.*

**Results** *We included 8,862 ICU discharges representing 7,288 individual patients. There were 1,180 (13.3%) afterhours discharges, 408 (4.6%) 72-hr readmissions, and 574 (6.5%) 30-day post-discharge deaths. Greater discharge occupancy was associated with afterhours discharges (per 10% increase: adjusted odds ratio [aOR], 1.12; 95% confidence interval [CI], 1.03 to 1.20;  $P = 0.005$ ). Discharge occupancy was not associated with 72-hr readmission (per 10% increase: aOR, 0.97; 95% CI, 0.87 to 1.09;  $P = 0.62$ ) or 30-day mortality (per 10% increase: aOR, 1.05; 95% CI, 0.95 to 1.16;  $P = 0.32$ ). Afterhours discharge was not associated with 72-hr readmission (aOR, 1.15; 95% CI, 0.86 to 1.54;  $P = 0.34$ ) or 30-day mortality (aOR, 1.05; 95% CI, 0.82 to 1.36;  $P = 0.69$ ).*

**Conclusions** *Greater ICU discharge occupancy was associated with a significant increase in afterhours discharges. Nevertheless, neither discharge occupancy*

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N. A. Fergusson, MSc  
University of British Columbia, Vancouver, BC, Canada

S. Ahkioon, PhD  
Vancouver Coastal Health, Vancouver, BC, Canada

N. Ayas, MD · V. K. Dhingra, MD · D. R. Chittock, MD · M. S. Sekhon, MD · A. R. Mitra, MD  
Division of Critical Care Medicine, Department of Medicine, University of British Columbia, Room 2438, Jim Pattison Pavilion, 2nd Floor, 855 West 12th Avenue, Vancouver, BC V5Z 1M9, Canada

D. E. G. Griesdale, MD, MPH   
Division of Critical Care Medicine, Department of Medicine, University of British Columbia, Room 2438, Jim Pattison Pavilion, 2nd Floor, 855 West 12th Avenue, Vancouver, BC V5Z 1M9, Canada  
e-mail: donald.griesdale@vch.ca

Department of Anesthesiology, Pharmacology and Therapeutics, University of British Columbia, Vancouver, BC, Canada

Center for Clinical Epidemiology & Evaluation, Vancouver Coastal Health Research Institute, Vancouver, BC, Canada

nor afterhours discharge were associated with 72-hr readmission or 30-day mortality.

## Résumé

**Objectif** Il n'existe que peu de données probantes évaluant si le taux d'occupation de l'unité de soins intensifs (USI) au moment du congé est associé aux devenir cliniques. Nous ne savons pas si un taux d'occupation plus élevé au moment du congé entraîne davantage de congés pendant la nuit et si cette situation a des conséquences. Nous avons exploré l'association entre le taux d'occupation de l'USI au moment du congé et les congés donnés pendant la nuit, la réadmission dans les premières 72 h, et la mortalité à 30 jours.

**Méthode** Cette étude de cohorte historique et monocentrique a englobé tous les patients ayant reçu leur congé de l'USI de l'Hôpital général de Vancouver entre le 5 avril 2010 et le 13 septembre 2017. Les données ont été tirées de la Base de données des soins intensifs de Colombie-Britannique (British Columbia Critical Care Database). Le taux d'occupation était défini comme le nombre d'heures d'occupation de lit de l'USI utilisées divisé par le nombre d'heures d'occupation de lit disponibles pour ladite journée. Tout congé reçu entre 22 h et 6 h 59 était considéré comme survenant pendant la nuit. Des modèles de régression logistique ont été élaborés afin de tenir compte des covariables importantes.

**Résultats** Nous avons inclus 8862 congés de l'USI, représentant 7288 patients individuels. Au total, il y a eu 1180 (13,3 %) congés donnés pendant la nuit, 408 (4,6 %) réadmissions dans les 72 h suivantes, et 574 (6,5 %) décès à 30 jours après le congé. Un taux d'occupation plus élevé au moment du congé était associé à des congés pendant la nuit (par augmentation de 10 % : rapport de cotes ajusté [RCA], 1,12; intervalle de confiance [IC] 95 %, 1,03 à 1,20;  $P = 0,005$ ). Le taux d'occupation lors du congé n'a pas été associé à une réadmission dans les premières 72 h (par augmentation de 10 % : RCA, 0,97; IC 95 %, 0,87 à 1,09;  $P = 0,62$ ) ou à une mortalité à 30 jours (par augmentation de 10 % : RCA, 1,05; IC 95 %, 0,95 à 1,16;  $P = 0,32$ ). Les congés pendant la nuit n'ont pas été associés à une réadmission dans les 72 h suivantes (RCA, 1,15; IC 95 %, 0,86 à 1,54;  $P = 0,34$ ) ou à une mortalité à 30 jours (RCA, 1,05; IC 95 %, 0,82 à 1,36;  $P = 0,69$ ).

**Conclusion** Un taux d'occupation de l'USI plus élevé au moment du congé était associé à une augmentation significative des congés donnés pendant la nuit. Cependant, ni le taux d'occupation lors du congé, ni le congé donné pendant la nuit, n'étaient associés à une réadmission à 72 h ou une mortalité à 30 jours.

**Keywords** intensive care unit · occupancy · capacity strain · process-of-care · afterhours discharge · readmission · mortality

Over the last decade, average intensive care unit (ICU) occupancy at larger tertiary and quaternary centres has steadily increased with many sites routinely operating near or over capacity.<sup>1,2</sup> As a result, there is growing interest and acknowledgment that capacity strain in the ICU may significantly impact patient processing, decision-making, and clinical outcomes.<sup>3-7</sup>

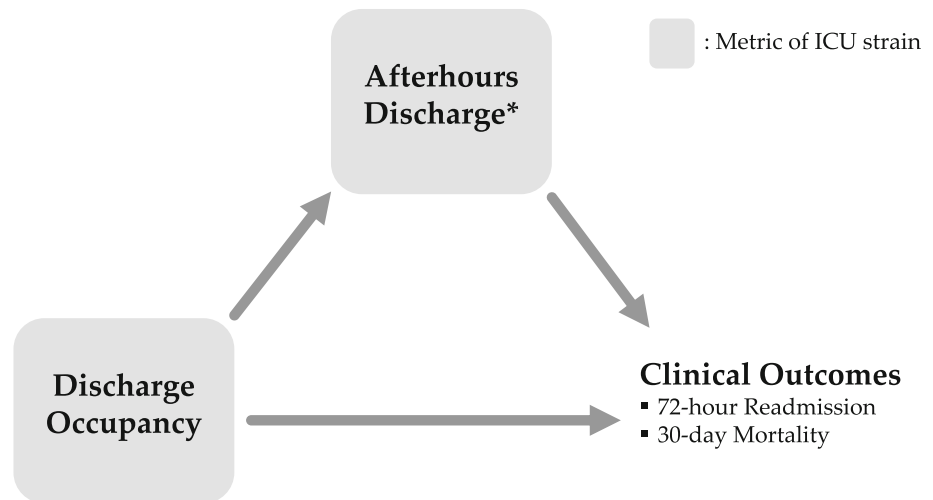
In the ICU, capacity strain has been defined as the discrepancy between available resources (beds, staff, equipment, etc.) and the current demand to admit patients in need of intensive care.<sup>3,7</sup> Two commonly utilized metrics of capacity strain in the ICU are occupancy and afterhours discharge.<sup>3</sup> Afterhours discharge is an important metric of strain as these discharges are ideally avoided because they are associated with increased mortality and ICU readmission.<sup>4,5,8-11</sup> Since they are avoided, afterhours discharges are also considered an outcome of strain.<sup>3</sup> Occupancy is a broader, system-level indicator of strain and reflects the current environment in the ICU on a given day. Yet, while many analyses have focused on the impact of high occupancy at the time of admission,<sup>7,12-15</sup> few have assessed the impact of occupancy at ICU discharge.<sup>6</sup>

Theoretically, occupancy strain at discharge may lead to patients being discharged prematurely and/or sub-optimally, resulting in clinical consequences such as readmission and mortality. Afterhours discharge may act as a mediator between discharge occupancy and clinical outcomes (Fig. 1). As occupancy strain increases, clinicians may be pushed to discharge patients at non-optimal times resulting in communications errors and a mismatch between the care available and the needs of the patient.<sup>3,8,9</sup> Nevertheless, it is unknown whether discharge occupancy is associated with afterhours discharge. Additionally, there is a paucity of contemporary, patient-level data evaluating the association between high occupancy at ICU discharge and clinical outcomes such as readmission and subsequent mortality. Many tertiary and quaternary centres have developed new strategies to deal with increasing admission demand, and previous studies that used aggregate data from mostly small centres with fixed ICU capacities and open models of care are unlikely to be applicable.<sup>6</sup>

The objective of this single-centre historical cohort study was to explore the association between ICU occupancy on the day of discharge and afterhours discharges, subsequent 72-hr readmission, and 30-day mortality.

**Fig. 1** Schematic of the theoretical relationship between discharge occupancy, afterhours discharge, and clinical outcomes in the ICU.

\*Afterhours discharge is also considered an outcome of ICU strain; ICU = intensive care unit.



## Methods

### Study design and setting

We conducted a historical cohort study of all patients discharged from the ICU at Vancouver General Hospital between 5 April 2010 and 13 September 2017. Results are reported in accordance with the STrengthening the Reporting of Observational Epidemiology (STROBE) statement and the REporting of studies Conducted using Observational Routinely-collected health Data (RECORD) extension for routinely collected data.<sup>16,17</sup> The ICU is a closed, 32-bed mixed medical surgical unit affiliated with the University of British Columbia. It operates on an approximately 1:1.2 nurse to patient ratio. When all ICU beds are filled, additional patients admitted to the ICU are attended to by the ICU care team in off-service beds (e.g., post-anesthetic care unit and emergency department). During the study period in April 2014, the size of the ICU increased from 27 to 31 physical beds and then from 31 to 32 beds in April 2016. There is also a 12-bed high acuity unit (HAU) for patients needing a higher level of care but not requiring advanced life-sustaining therapies. The HAU opened in September 2015 and admits patients who require vasoactive medications or non-invasive ventilation. Additionally, the HAU can function as a step-down unit for the ICU. Patients admitted solely to the HAU were excluded from this analysis. Patients in the ICU and HAU are cared for by one of three physician teams, each consisting of an attending intensive care physician, resident physicians (variety of subspecialty residents, including critical care medicine fellows) and other clinical staff (nurses, respiratory therapists, pharmacists, dieticians, and physical and occupational therapists). Discharge readiness is assessed by the attending physician.

### Data

Data were obtained from the British Columbia Critical Care Database, which records patient-specific data for all patients admitted to the ICU. Patient-specific data included baseline demographics (age, sex), primary diagnosis, and illness acuity. Illness acuity was characterized by the sequential organ function assessment (SOFA), which is a commonly utilized mortality prediction score based on the level of dysfunction present in six organ systems.<sup>18</sup> Scores can range from 0 to 24 and greater scores are associated with greater risk of mortality and readmission to the ICU.<sup>9–11</sup> The SOFA score was determined at the time of ICU admission. This database also included daily operational factors such as the number of patients discharged, hours of patient care performed, and number of available beds. There were 152 discharges (1.7%) missing an admission SOFA score. Of these 152, 120 (79%) had SOFA scores calculated at some point during their ICU stay but not at admission. Discharges missing admission SOFA scores were not included in the logistic regression models. There were no other missing data. Study investigators had full access to the data set.

### Exposure

By linking each ICU discharge to daily ICU characteristics, we were able to identify several indicators of capacity strain for each individual ICU discharge. Our principal exposure included ICU occupancy at discharge. Occupancy was defined as the number of hours of ICU patient care delivered in a day divided by the total amount of hours of care available for that day (number of funded beds × 24 hr). This method is considered to be a better representation of ICU capacity strain compared with other methods of determining occupancy, such as a simple patient

census.<sup>19,20</sup> The occupancy on the day of ICU discharge was calculated for each discharge. Additional exposures of ICU capacity strain included the total number of admissions in the 24 hr preceding that specific discharge. For example, if a patient was discharged at 15:00, all ICU admissions from that instance to 15:00 the day prior were totalled. Delayed discharge was defined as a delay of six or more hours between the time a patient was labelled appropriate for discharge and when that patient physically left the ICU. This definition of delayed discharge has been utilized in a previous analysis<sup>21</sup> while other studies have used either four or eight hours.<sup>22</sup> Temporal factors were also included such as weekend discharge (Saturday to Sunday) and season of discharge (winter [December to February], spring [March to May], summer [June to August], fall [September to November]). The number of funded beds by era were also included as a categorical variable ( $n = 27$  [April 2010 to March 2014],  $n = 31$  [April 2014 to March 2016],  $n = 32$  [April 2016 to August 2017]) along with a binary variable of pre- and post-HAU creation (September 2015).

## Outcomes

Outcomes of interest included afterhours discharge, 72-hr readmission, and 30-day mortality. Afterhours discharge was defined as any discharge from the ICU between 22:00 and 06:59. This definition is a commonly used standard in Canadian and United Kingdom practice and has been used in more contemporary analyses of larger tertiary and quaternary centres.<sup>4,23</sup> Seventy-two-hour readmission was defined as any patient who was discharged and admitted back to the ICU within 72 hr. We chose 72 hr as our readmission time frame as it is commonly used metric to indicate readmissions that are thought to be avoidable, and it represents the median time to ICU readmission from previous large epidemiological studies.<sup>24,25</sup> Thirty-day mortality was defined as any death (regardless of location) that occurred within 30 days of being discharged from the ICU. A period of 30 days was chosen as it represents a reasonable timeframe to assume that mortality may be related to ICU discharge. Deaths occurring 30 days post discharge are very unlikely to be related to any strain factor that occurred at discharge.

## Statistical methods

The base unit of analysis was ICU discharge and data were treated as longitudinal, controlling for repeatedly discharged patients. Sample size was one of convenience, acknowledging that over a seven-year period we would have an adequate number of events to build a robust multivariable model. Descriptive statistics were presented

for the overall cohort and for each ascending quintile of discharge occupancy. All continuous variables were presented as mean (standard deviation) and categorical variables were presented as total number (%) unless otherwise stated.

We constructed three logistic regression models to evaluate the association between ICU discharge occupancy (per 10% increase) and afterhours discharge, 72-hr readmission, and 30-day mortality. Since patients could have more than one ICU discharge, we accounted for within-patient correlation using a mixed-effects logistic regression model with the random-effect specified at the patient level (STATA command *xtlogit*). Standard errors were determined from the observed information matrix based on the asymptotic maximum-likelihood theory. In each model, we controlled for important baseline covariates such as age (per one-year increase), sex (male vs female), admission SOFA score (per one-unit increase), primary diagnosis category (e.g., shock), season of discharge (e.g., winter), discharge location (e.g., medical ward), HAU epoch (pre vs post), and number of funded beds epoch (e.g., April 2010 to March 2014). Other possible metrics of capacity strain such as the total number of ICU admissions in the 24 hr prior to discharge, delayed discharges (yes/no), and weekend discharge (Sat/Sun) were included. For the 72-hr readmission model, we included afterhours discharge as a predictor variable. Additionally, for the 30-day mortality model, we included both afterhours discharge and 72-hr readmission as predictor variables. Results of the logistic regression models were displayed as odd ratios (OR) with 95% confidence intervals (CI). Conceptually, we considered afterhours discharge to be a potential mediator between discharge occupancy and clinical outcomes (Fig. 1). Nevertheless, based on null associations with 72-hr readmission and 30-day mortality in our model, a mediation analysis was not justified.<sup>26,27</sup>

To adjust for non-linear relationships, we incorporated restricted cubic spline transformations within our logistic regression models (STATA commands *mkspline* & *xbrcspline*) to visually characterize the relationship between discharge occupancy and the odds of afterhours discharges, 72-hr readmission, and 30-day mortality. These models consisted of four knots and adjusted for important baseline covariates (same as logistic regression models). Discharge occupancy was rounded to the nearest 5% and corresponding adjusted odds ratios (aOR) with 95% CI were determined for afterhours discharges, 72-hr readmission, and 30-day mortality. A reference value of 70% was chosen as it corresponded with the lowest occupancy value.

Several sensitivity analyses were conducted to ensure the robustness of our results. We assessed whether altering the definition of afterhours discharge from 22:00–6:59 to



19:00–6:59 would alter any study results. This more liberal definition has sometimes been used in previous literature.<sup>3</sup> We conducted an analysis of ICU discharges with a SOFA score at the time of discharge available. This applied only to patients with an ICU length of stay less than seven days as SOFA is only calculated daily for the first week. We also wanted to evaluate whether weekend discharge modified any associations between discharge occupancy, afterhours discharge, and clinical outcomes. We also evaluated whether afterhours discharge modified the effect of discharge occupancy on 72-hr readmission and 30-day mortality. Lastly, multicollinearity between the number of admissions in the 24 hr prior to discharge and discharge occupancy was evaluated. All analyses were performed using STATA (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, StataCorp LLC, TX, USA).

## Results

### Descriptive statistics

A total of 8,862 discharges, representing 7,288 individual patients from the ICU, occurred between 5 April 2010 and 13 September 2017. All discharges during this period were included in this analysis. A total of 1,180 (13.3%) afterhours discharges, 408 (4.6%) 72-hr readmissions, and 574 (6.5%) 30-day post-discharge deaths occurred. Complete descriptive statistics for the overall cohort and by discharge occupancy quintile are presented in Table 1. The range of discharge occupancy values associated with each quintile are 68–90% (quintile 1), 91–94% (quintile 2), 95–99% (quintile 3), 100–106% (quintile 4), and 106–137% (quintile 5).

### Afterhours discharges

In the crude analysis, each 10% increase in discharge occupancy was associated with an 19% increase in the odds of afterhours discharge (OR, 1.19; 95% CI, 1.11 to 1.27;  $P < 0.001$ , per 10% increase). After adjusting for covariates, increasing discharge occupancy remained significantly associated with afterhours discharge (Table 2). An adjusted restricted cubic spline model for the association between discharge occupancy and afterhours discharge is presented in both Figs 2 and 3. Each additional admission to the ICU in the 24 hr prior to discharge resulted in a 12% increase in the odds of afterhours discharge (aOR, 1.12; 95% CI, 1.08 to 1.16;  $P < 0.001$ ) (Table 2). The remaining results of the adjusted logistic regression model for afterhours discharge are presented in Table 2.

### Seventy-two hour readmission

In the crude analysis, there was no association between discharge occupancy and 72-hr readmission to the ICU (OR, 1.00; 95% CI, 0.89 to 1.11;  $P = 0.97$ , per 10% increase). After adjustment, the lack of association between increasing discharge occupancy and the odds of 72-hr readmission persisted (Table 2). An adjusted restricted cubic spline model for the association between discharge occupancy and 72-hr readmission is presented in Fig. 2. In the adjusted model, afterhours discharges from the ICU were not associated with any statistically significant difference in the odds of 72-hr readmission (aOR, 1.15; 95% CI, 0.86 to 1.54;  $P = 0.34$ ) (Table 2). The remaining results of the adjusted logistic regression model for 72-hr readmission are presented in Table 2.

### Thirty-day mortality

In the crude analysis, discharge occupancy was not associated with 30-day mortality (OR, 1.04; 95% CI, 0.96 to 1.14;  $P = 0.32$ , per 10% increase). In the adjusted model, the lack of association between discharge occupancy and 30-day mortality persisted (Table 2). An adjusted restricted cubic spline model for the association between discharge occupancy and 30-day mortality is presented in Fig. 3. In the adjusted model, afterhours discharge was not associated with any statistically significant difference in the odds of 30-day mortality (aOR, 1.05; 95% CI, 0.82 to 1.36;  $P = 0.69$ ) (Table 2). Seventy-two-hour readmission to the ICU was associated with a statistically significant increase in the odds of 30-day mortality (aOR, 1.51; 95% CI, 1.07 to 2.14;  $P = 0.02$ ) (Table 2). The remaining results of the adjusted logistic regression model for 30-day mortality are presented in Table 2.

### Sensitivity analyses

Altering the definition of afterhours discharge to any discharge between 19:00 and 6:59 (*vs* 22:00–6:59) did not alter the study findings (eTable 1, available as Electronic Supplementary Material [ESM]). Furthermore, there were no significant differences in model results when readmission timeframe was extended to seven days and 30 days and all (< 30 day and > 30 day) post-discharge deaths were included (eTables 2 and 3, available as ESM). Sensitivity analyses of ICU length of stay and discharge year are also provided (eTables 4 and 5, available as ESM). A subgroup analysis of 6,347 discharges (5,526 unique patients) with discharge SOFA scores available (ICU length of stay less than seven days) did not result in any deviations from study findings (eTable 6, available as

**Table 1** Demographics

	Total	ICU discharge occupancy quintile					<i>P</i> value <sup>a</sup>
		Quintile 1 (68–90%) <sup>c</sup>	Quintile 2 (91–94%) <sup>c</sup>	Quintile 3 (95–99%) <sup>c</sup>	Quintile 4 (100–106%) <sup>c</sup>	Quintile 5 (106–137%) <sup>c</sup>	
No. of discharges	8,862	1,736	1,790	1,797	1,769	1,770	
No. of unique patients	7,288 (82.2%)	1,460 (84.1%)	1,467 (82.0%)	1,484 (82.6%)	1,448 (81.9%)	1,429 (80.7%)	0.12
Age	57.2 (17.4)	57.1 (17.1)	57.3 (17.4)	57.1 (17.6)	57.1 (17.3)	57.5 (17.4)	0.94
Female	3,175 (35.8%)	606 (34.9%)	662 (37.0%)	668 (37.2%)	626 (35.4%)	613 (34.6%)	0.36
SOFA at admission	4.3 (3.2)	4.1 (3.2)	4.2 (3.1)	4.4 (3.2)	4.3 (3.2)	4.3 (3.3)	0.03
Afterhours discharges (22:00–6:69)	1,180 (13.3%)	162 (9.3%)	236 (13.2%)	257 (14.3%)	259 (14.6%)	266 (15.0%)	<0.001
Weekend discharges	2,554 (28.8%)	542 (31.2%)	503 (28.1%)	497 (27.7%)	526 (29.7%)	486 (27.5%)	0.07
No. of ICU admissions in 24 hr Prior to discharge <sup>b</sup>	4 [3–5]	4 [3–5]	4 [3–5]	4 [3–5]	5 [4–6]	5 [4–6]	<0.001
Delayed discharge (≥ 6 hr)	2,670 (30.1%)	557 (32.1%)	581 (32.5%)	536 (29.8%)	530 (30.0%)	466 (26.3%)	<0.001
Primary diagnosis							
Shock	1,260 (14.2%)	222 (12.8%)	236 (13.2%)	270 (15.0%)	262 (14.8%)	270 (15.3%)	0.22
MSK/dermatological	112 (1.3%)	20 (1.2%)	20 (1.1%)	30 (1.7%)	19 (1.1%)	23 (1.3%)	
Metabolic/toxicity	394 (4.4%)	98 (5.6%)	76 (4.2%)	75 (4.2%)	65 (3.7%)	80 (4.5%)	
GI/urologic	1,362 (15.4%)	278 (16.0%)	284 (15.9%)	267 (14.9%)	259 (14.6%)	274 (15.5%)	
Hematologic	659 (7.4%)	120 (6.9%)	138 (7.7%)	139 (7.7%)	132 (7.5%)	130 (7.3%)	
Neurologic	2,359 (26.6%)	467 (26.9%)	481 (26.9%)	464 (25.8%)	454 (25.7%)	493 (27.9%)	
Pulmonary/pneumonia	2,716 (30.6%)	531 (30.6%)	555 (31.0%)	552 (30.7%)	578 (32.7%)	500 (28.2%)	
Source of discharge							
Home	85 (1.0%)	39 (2.2%)	19 (1.1%)	5 (0.3%)	14 (0.8%)	8 (0.5%)	<0.001
Ward	5,043 (56.9%)	1,054 (60.7%)	1,056 (59.0%)	1,029 (57.3%)	966 (54.6%)	938 (53.0%)	
ICU transfer	309 (3.5%)	41 (2.4%)	44 (2.5%)	56 (3.1%)	63 (3.6%)	105 (5.9%)	
HAU	321 (3.6%)	53 (3.1%)	47 (2.6%)	46 (2.6%)	106 (6.0%)	69 (3.9%)	
SCU	3,104 (35.0%)	549 (31.6%)	624 (34.9%)	661 (36.8%)	620 (35.0%)	650 (36.7%)	
Season							
Winter	2,092 (23.6%)	221 (12.7%)	347 (19.4%)	503 (28.0%)	554 (31.3%)	467 (26.4%)	<0.001
Spring	2,352 (26.5%)	392 (22.6%)	502 (28.0%)	570 (31.7%)	461 (26.1%)	427 (24.1%)	
Summer	2,361 (26.6%)	720 (41.5%)	539 (30.1%)	375 (20.9%)	326 (18.4%)	401 (22.7%)	
Fall	2,057 (23.2%)	403 (23.2%)	402 (22.5%)	349 (19.4%)	428 (24.2%)	475 (26.8%)	
No. funded beds							

**Table 1** continued

	Total	ICU discharge occupancy quintile					<i>P</i> value <sup>a</sup>
		Quintile 1 (68–90%) <sup>c</sup>	Quintile 2 (91–94%) <sup>c</sup>	Quintile 3 (95–99%) <sup>c</sup>	Quintile 4 (100–106%) <sup>c</sup>	Quintile 5 (106–137%) <sup>c</sup>	
27 (Apr 2010–Mar 2014)	4,626 (52.2%)	847 (48.8%)	914 (51.1%)	959 (53.4%)	755 (42.7%)	1,151 (65%)	<0.001
31 (Apr 2014–Mar 2015)	2,539 (28.7%)	408 (23.5%)	582 (32.5%)	562 (31.3%)	586 (33.1%)	401 (22.7%)	
32 (Apr 2016–Aug 2017)	1,697 (19.1%)	481 (27.7%)	294 (16.4%)	276 (15.4%)	428 (24.2%)	218 (12.3%)	
Post-HAU creation (Sep 2015)	2,444 (27.6%)	562 (32.4%)	407 (22.7%)	383 (21.3%)	668 (37.8%)	424 (24.0%)	<0.001

Data are presented as mean (standard deviation) or median [interquartile range] for continuous measures, and *n* (%) for categorical measures.

<sup>a</sup> Significance tests were analysis of variance, Pearson's Chi squared, and Kruskal–Wallis when appropriate.

<sup>b</sup> Results presented as median [interquartile range]. <sup>c</sup> Range of occupancy within each respective quintile. ICU = intensive care unit; GI = gastrointestinal; HAU = high acuity unit; MSK = musculoskeletal; SCU = special care unit; SOFA = sequential organ function assessment.

ESM). Weekend discharge was not found to modify the effect between discharge occupancy, afterhours discharge, and clinical outcomes (72-hr readmission and 30-day mortality) (eTable 7, available as ESM). Additionally, afterhours discharge itself did not modify the effect of discharge occupancy on 72-hr readmission and 30-day mortality (eTable 8, available as ESM). There was no indication of significant collinearity between discharge occupancy and number of admissions in the prior 24 hr (eTable 9, available as ESM).

## Discussion

In our single-centre historical study of 8,862 ICU discharges over a seven-year period, ICU occupancy on the day of discharge was associated with increased odds of afterhours discharge. Yet, neither discharge occupancy nor afterhours discharge were associated with clinical outcomes such as 72-hr readmission and 30-day post-discharge mortality.

This study presents a novel analysis of the association between ICU discharge occupancy and the odds of afterhours discharge. Previous studies have focused solely on either afterhours discharge<sup>4,6,9–11,23,28</sup> or discharge occupancy<sup>6,29</sup> separately when assessing their independent effects on patient outcomes. We specifically wanted to evaluate if greater strain, such as higher occupancy on the day of discharge, would modify the discharge process by pushing clinicians to discharge patients from the ICU at night. It is known that afterhours or night-time discharges

are strongly avoided because of the strong association with increased readmission and mortality risk in previous studies.<sup>4,5,8–11</sup> Our results show that higher discharge occupancy is associated with increased odds of afterhours discharge, but not in a linear fashion. Instead, there appears to be a steady climb in the odds of afterhours discharge as occupancy approaches near capacity (100%), which then plateaus once occupancy is over capacity (> 100%). This mirrors results from a large Scottish analysis that found a notable increase in early discharges from the ICU when ICU occupancy was > 80%, which plateaued once overcapacity was reached.<sup>30</sup> Furthermore, we included the number of ICU admissions in the 24 hr prior to discharge as an additional measure of capacity strain. We observed that for each additional admission to the ICU in the preceding 24 hr there was a statistically significant increase in the odds of afterhours discharge. These are important findings as it shows that capacity strain, as indicated by both high discharge occupancy and the number of admissions in the 24 hr prior to discharge, can impact the timing, and more broadly, the process of discharge.

Our next objective was to assess whether high occupancy at discharge was associated with clinical outcomes such as 72-hr readmission and 30-day mortality. Few studies have evaluated the effects of high occupancy at discharge on subsequent clinical outcomes. One study using aggregate data from 155 ICUs in the US between 2001 and 2008 determined that a higher census on the day of discharge was associated with ICU readmissions but not subsequent mortality.<sup>6</sup> Although a signal for

**Table 2** Adjusted logistic regression models for afterhours discharge, 72-hr readmission, and 30-day mortality

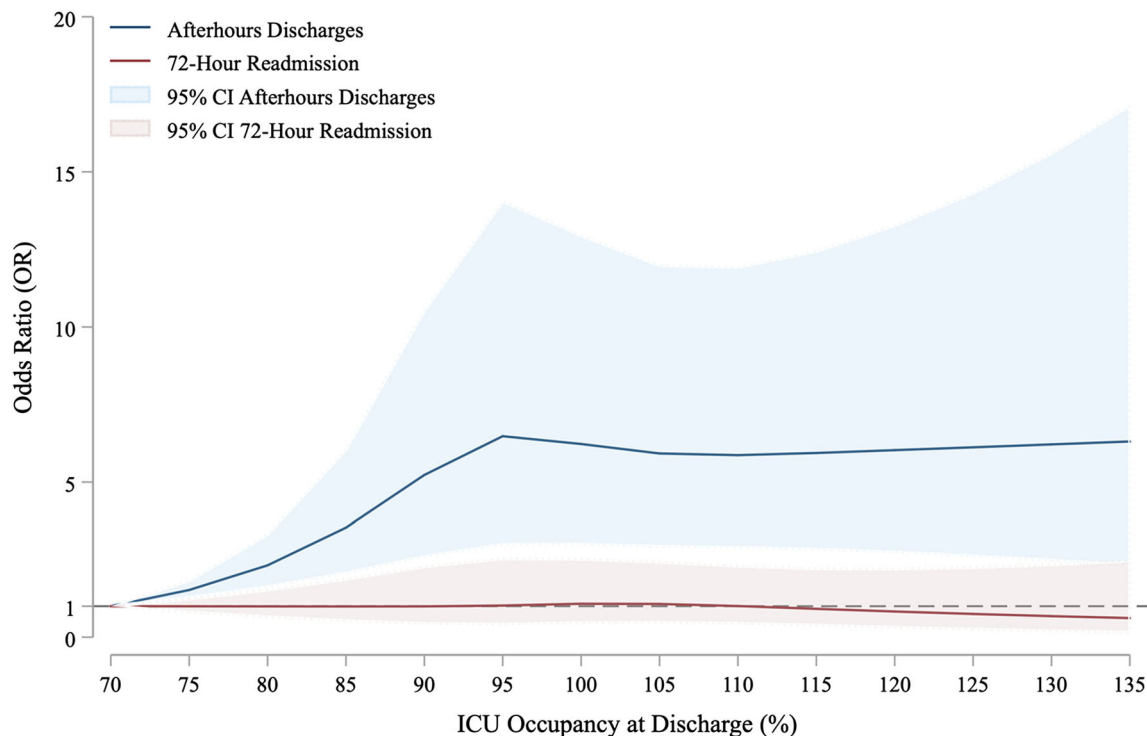
	Afterhours discharge			72-hr readmission			30-day mortality		
	OR	95% CI	P value	OR	95% CI	P value	OR	95% CI	P value
Discharge occupancy (per 10%)	1.12	1.03 to 1.20	0.005	0.97	0.87 to 1.09	0.62	1.05	0.95 to 1.16	0.32
Afterhours discharge (22:00–6:59)	–	–	–	1.15	0.86 to 1.54	0.34	1.05	0.82 to 1.36	0.69
72-hr readmission	–	–	–	–	–	–	1.51	1.07 to 2.14	0.02
No. of admissions in 24 hr before discharge	1.12	1.08 to 1.17	< 0.001	1.02	0.97 to 1.08	0.39	1.03	0.98 to 1.08	0.30
Weekend discharge (Sat/Sun)	0.92	0.79 to 1.07	0.28	1.16	0.93 to 1.45	0.17	0.90	0.74 to 1.10	0.29
Delayed discharge ( $\geq$ 6 hr)	2.20	1.89 to 2.54	< 0.001	0.75	0.59 to 0.94	0.02	0.97	0.80 to 1.17	0.72
SOFA at admission	1.01	0.99 to 1.03	0.15	1.03	1.00 to 1.06	0.03	1.08	1.06 to 1.11	< 0.001
Age	1.00	0.99 to 1.01	0.78	1.00	0.99 to 1.01	0.93	1.04	1.03 to 1.04	< 0.001
Female sex	1.03	0.89 to 1.18	0.71	0.97	0.78 to 1.20	0.79	1.05	0.87 to 1.26	0.61
No. funded beds in ICU (yr)									
27 (2010–2014)	1.00	(ref)		1.00	(ref)		1.00	(ref)	
31 (2014–2015)	0.82	0.68 to 0.99	0.04	0.96	0.72 to 1.27	0.77	0.89	0.69 to 1.40	0.34
32 (2016–2017)	0.86	0.60 to 1.22	0.40	0.74	0.44 to 1.24	0.26	0.90	0.56 to 1.46	0.67
Post-HAU creation (Sept 2015)	1.00	0.75 to 1.33	0.97	1.41	0.93 to 2.13	0.10	0.99	0.67 to 1.46	0.94
Source of discharge									
Medical ward	1.00	(ref)		1.00	(ref)		1.00	(ref)	
Home	0.14	0.02 to 1.03	0.05	NE <sup>a</sup>	NE	NE	NE	NE	NE
ICU transfer	2.30	1.63 to 3.23	< 0.001	0.13	0.03 to 0.53	0.004	0.08	0.02 to 0.32	0.001
HAU	5.07	3.64 to 7.05	< 0.001	1.65	1.01 to 2.71	0.046	1.70	1.11 to 2.62	0.02
SCU	1.61	1.36 to 1.90	< 0.001	1.09	0.85 to 1.39	0.52	0.73	0.58 to 0.92	0.007
Primary diagnosis category									
Shock	1.00	(ref)		1.00	(ref)		1.00	(ref)	
MSK/dermatologic	0.66	0.32 to 1.34	0.25	0.31	0.07 to 1.29	0.11	0.30	0.07 to 1.27	0.10
Metabolic/toxicity	1.29	0.89 to 1.87	0.17	0.16	0.05 to 0.51	0.002	0.73	0.41 to 1.30	0.29
Gastrointestinal/urologic	1.16	0.90 to 1.49	0.26	0.97	0.69 to 1.37	0.88	0.71	0.52 to 0.96	0.03
Hematologic	1.24	0.92 to 1.67	0.15	1.36	0.93 to 2.01	0.12	1.26	0.90 to 1.77	0.18
Neurologic	1.11	0.88 to 1.41	0.37	0.64	0.45 to 0.91	0.01	1.09	0.81 to 1.48	0.57
Pulmonary/pneumonia	1.05	0.84 to 1.31	0.66	0.81	0.59 to 1.11	0.19	0.85	0.66 to 1.11	0.24
Season of discharge									
Winter	1.00	(ref)		1.00	(ref)		1.00	(ref)	
Spring	1.01	0.84 to 1.22	0.91	1.33	1.00 to 1.78	0.05	0.97	0.75 to 1.25	0.79
Summer	0.99	0.81 to 1.20	0.89	1.23	0.91 to 1.66	0.19	1.12	0.87 to 1.44	0.37
Fall	1.06	0.87 to 1.28	0.58	1.12	0.82 to 1.52	0.48	1.11	0.86 to 1.44	0.41

<sup>a</sup> Cannot be estimated because of lack of events. CI = confidence interval; GI = gastrointestinal; HAU = high acuity unit; ICU = intensive care unit; MSK = musculoskeletal; NE = cannot be estimated; OR = odds ratio; SCU = special care unit; SOFA = sequential organ function assessment

increased readmissions was present, the authors stressed that the lack of mortality signal may indicate that clinicians are safely discharging ICU patients even during periods of increased strain. One drawback of this analysis is that occupancy was the census on the day of discharge standardized to the average annual census from the respective centre. Although grossly indicative of capacity strain, total daily census is a less desirable measure of occupancy as it is summation of total patients rather than

the quantity of patient care hours provided.<sup>19,20</sup> For instance, if five patients are discharged from the ICU in the morning, all five of those patients are included in the daily census despite them not being present in the ICU. A more precise and accurate method of calculating occupancy, and the method used in this analysis, is to calculate the fraction total hours of patient care delivered in a day by the total funded hours available.<sup>20</sup> A single-centre analysis of 8,693 discharges between 1989 and 1996





**Fig. 2** Adjusted <sup>a</sup> restricted cubic splines for ICU occupancy at discharge vs odds of afterhours discharge and 72-hr readmission. <sup>a</sup> Regression models are adjusted for age, female sex, SOFA score at admission, afterhours discharges, weekend discharges, delayed

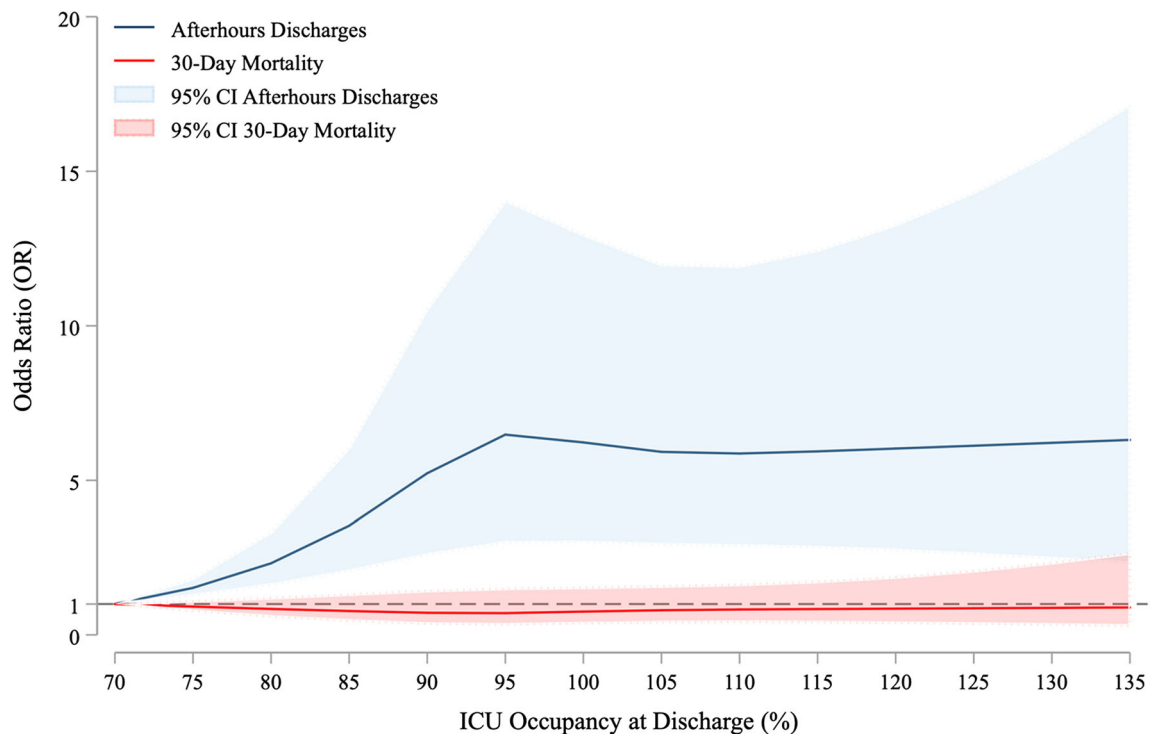
discharge, number of ICU admissions in 24 hr prior to discharge, primary diagnosis, source of discharge, season, number of funded ICU beds, and post-HAU creation. HAU = high acuity unit; ICU = intensive care unit; SOFA = sequential organ function assessment.

showed that lack of ICU bed vacancy at the time of discharge was associated with a statistically significant 56% increase in the odds of early death and readmission.<sup>29</sup> Nevertheless, lack of bed vacancy is a cruder, binary metric of occupancy that may be more reflective of the normality rather than increased strain in modern, large ICUs. As well, ICUs may “hold” patients that are ready for discharge when there are no incoming patients. In this circumstance, lack of an available bed may not necessarily reflect increased capacity strain. In our adjusted analysis, controlling for baseline covariates showed that discharge occupancy was not associated with 72-hr readmission or 30-day mortality. It was originally hypothesized that higher occupancy at discharge may lead to increased pressure on the ICU team to prematurely discharge patients, resulting in increased rates of 72-hr readmission and 30-day mortality. Nevertheless, our findings do not suggest this. Although high occupancy may impact discharge decisions, such as discharging during afterhours, it did not impact clinical outcomes at our centre.

Our final objective was to determine if afterhours discharge at our centre was associated with 72-hr readmission and 30-day mortality. Afterhours discharge has been previously shown to increase the risk of readmission and subsequent mortality.<sup>4,5,8–11</sup> A recent

meta-analysis pooling data from 1,191,178 patients across 18 cohort studies showed that afterhours discharges were associated with a statistically significant 42% increase in the odds of mortality (OR, 1.42; 95% CI, 1.32 to 1.53;  $P < 0.0001$ ).<sup>4</sup> Additionally, afterhours discharge was associated with a greater rate of readmission (6.3% vs 5.1%;  $P < 0.0001$ ). Interestingly, in our adjusted models, we did not observe any effect of afterhours discharge itself on 72-hr readmission or 30-day mortality. This aligns with our findings that occupancy at discharge was not associated with subsequent clinical outcomes.

A variety of centre-specific variables may explain why increased capacity strain did not result in clinical consequences. Similar to many larger ICUs in Canada, our ICU operates routinely near capacity and often, over capacity. Our total beds available are not fixed and patients can be admitted to the ICU service despite not physically being present in an ICU bed, leading to occupancy values above 100%. In response to this increasing burden, our centre introduced a Critical Care Outreach Team in 2008 that re-assesses all patients discharged from the ICU within 12 hr. Moreover, our centre possesses a 12-bed HAU that can admit patients from the ICU, functioning as a step-down unit for patients who may not be ready for the hospital wards. A recent analysis showed that



**Fig. 3** Adjusted <sup>a</sup> restricted cubic splines for ICU occupancy at discharge vs odds of afterhours discharge and seven-day mortality. <sup>a</sup> Regression models are adjusted age, female sex, SOFA score at admission, afterhours discharges, weekend discharges, delayed

discharge, number of ICU admissions in 24 hr prior to discharge, primary diagnosis, source of discharge, season, number of funded ICU beds, and post-HAU creation. HAU = high acuity unit; ICU = intensive care unit; SOFA = sequential organ function assessment.

implementation of a rapid response team, similar to our Critical Care Outreach Team, had marked benefits with respect to ICU workflow by reducing ICU admissions and occupancy.<sup>31</sup> Perhaps the combination of our flexible ICU capacity, Critical Care Outreach Team, and HAU services provides the structural support needed to mitigate the clinical consequences of capacity strain. It is well known and understandable that ICU physicians and staff experience increased stress during periods of increased capacity strain.<sup>32–34</sup> Our study does validate that capacity strain, such as high occupancy, modifies the discharge process by increasing the number of afterhours discharges. Yet, we show that despite increased capacity strain, clinicians at our centre appear to be efficiently and safely discharging patients from the ICU.

Limitations of our analysis should be noted. Our study is a single-centre analysis of a large quaternary ICU centre and our results may not be generalizable to other centres. Although we incorporated a more accurate and precise metric of determining occupancy on the day of discharge, this value is still ultimately aggregated over a calendar day and does not represent the instantaneous burden of occupancy at the exact time of discharge. An additional limitation of our analysis is the inability to determine whether a patient was discharged from the ICU with a “do

not readmit” status. This may occur if a patient is palliative and the level of care has been modified. In times of increased strain, these patients may be discharged from the ICU but are ineligible to be readmitted to the ICU. Theoretically, this would bias our results towards the null (type 2 error) for readmission and towards significance (type 1 error) for post-discharge mortality. Nevertheless, patients who are ineligible to return to the ICU likely represent a very small fraction of our overall population. Lastly, our study is historical and observational in nature and although we have attempted to adjust for important baseline covariates there is certainly unmeasured and residual confounding that could provide an alternate explanation for our findings.

## Conclusion

In summary, we showed that greater ICU occupancy on the day of discharge was associated with a significant increase in afterhours discharges. Nevertheless, neither discharge occupancy nor afterhours discharge were associated with an increase in 72-hr readmission or 30-day mortality at our large quaternary centre.

**Author contributions** *Nicholas A. Fergusson*: conceived and designed the overarching framework for the project, performed data retrieval, cleaning, and statistical analyses with the assistance and guidance of Steve Ahkioon and Donald Griesdale, and contributed to and critically reviewed the final version of this manuscript. *Steve Ahkioon* contributed to and critically reviewed the final version of this manuscript. *Najib Ayas, Vinay K. Dhingra, Dean R. Chittock, Mypinder S. Sekhon, and Anish R. Mitra* provided guidance and logistical feedback, and contributed to and critically reviewed the final version of this manuscript. *Donald E.G. Griesdale* conceived and designed the overarching framework for the project, and contributed to and critically reviewed the final version of this manuscript.

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