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Time of admission to intensive care unit, strained capacity, and mortality: A retrospective cohort study

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ABSTRACT

Purpose: We sought to study the association between afterhours ICU admission and ICU mortality considering measures of strained ICU capacity.
Materials and methods: Retrospective analysis of 4141 admissions to 2 ICUs in Lisbon, Portugal (06/2016–06/2018). Primary exposure was ICU admission on 20:00 h–07:59 h. Primary outcome was ICU mortality. Measures of strained ICU capacity were: bed occupancy rate ≥ 90% and cluster of ICU admissions 2 h before or following index admission.
Results: There were 1581 (38.2%) afterhours ICU admissions. Median APACHE II score (19 vs. 20) was similar between patients admitted afterhours and others ($P = .27$). Patients admitted afterhours had higher crude ICU mortality (15.4% vs. 21.9%; $P < .001$), but similar adjusted ICU mortality (aOR [95%CI] = 1.15 [0.97–1.38]; $P = .12$). While bed occupancy rate ≥ 90% was more frequent in patients admitted afterhours (23.1% vs. 29.1%) or deceased in ICU (23.6% vs. 33.7%), cluster of ICU admissions was more frequent in patients admitted during daytime hours (75.2% vs. 58.9%) or that survived the ICU stay (70.1% vs. 63.9%; $P \leq .001$ for all). These measures of strained ICU capacity were not associated with adjusted ICU mortality ($P \geq .10$ for both).
Conclusions: Afterhours ICU admission and measures of strained ICU capacity were associated with crude but not adjusted ICU mortality.

1. Introduction

Afterhours intensive care unit (ICU) admission has been frequently associated with worse patients' outcomes worldwide [1-3]. However, studies evaluating this association have reported heterogeneous findings likely reflecting their diverse methodological characteristics [4,5]. In fact, several factors may contribute to negatively impact morbidity and mortality following afterhours ICU admission. Amongst such factors, the following are often accounted for: severity of the acute disease; comorbidities; and measures of overall clinical care during pre-ICU stay, actual ICU stay, and post ICU stay.

Strained ICU capacity has emerged as one set of heterogeneous factors influencing the quality and efficiency of care delivered during the ICU stay. It has been perceived by healthcare providers as a time-varying imbalance between the ICU resources available and the demand to provide high-quality care for critically-ill patients [6,7]. Furthermore, it has also been associated with worse patients' outcomes [8,9].

Several measures of strained ICU capacity have been reported, the most common being acuity, readmission, afterhours discharge, and census [10]. Recently, a high ICU-bed occupancy rate or the occurrence of various ICU admissions in a short-period of time (clusters) has been shown to be associated with increased ICU mortality, especially in the context of late-night ICU admission [11,12].

Accordingly, we hypothesized that afterhours ICU admission could also negatively impact patients' outcomes in Lisbon, a region in the south of Portugal. Therefore, firstly, we sought to study the association of afterhours ICU admission with ICU mortality. And secondly, we sought to study the influence of measures of strained ICU capacity over such association.

2. Materials and methods

The study protocol was approved by the local ethics committee. As this was an observational study, the need for individual informed consent was waived. The study followed the principles of the Declaration

Abbreviations: APACHE II, Acute Physiology Age Chronic Health Evaluation II; aOR, adjusted odds ratio; ED, Emergency Department; CHLC, Central Lisbon Hospital Center; CI, confidence interval; CCH, Curry Cabral Hospital; ICU, intensive care unit; IQR, interquartile range; LOS, length of stay; OR, odds ratio; SJH, São José Hospital; STROBE, Strengthening the Reporting of Observational Studies in Epidemiology guideline.

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of Helsinki [13]. Its reporting followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guideline [14].

2.1. Design, setting, and participants

This was a retrospective cohort study including consecutive adult (≥16 years) admissions to 2 ICUs from 2 different hospitals in Lisbon, Portugal (Curry Cabral Hospital and São José Hospital) from June 2016 to June 2018 ($n = 4141$). The Curry Cabral Hospital (CCH) and the São José Hospital (SJH) both belonged to the Central Lisbon Hospital Center (CHLC), an academic center in Lisbon, Portugal.

The 2 ICUs admitted medical and surgical patients, used a closed model, and were staffed by on-site certified intensivists (at least one specialist, one senior fellow, and one resident) 24 h per every day. While the SJH ICU is the first responder to the CHLC Emergency Department (ED), the CCH ICU supports mainly critically-ill inpatients, including the ones from the local intra-abdominal surgical and transplant programs.

While the standard capacity of CCH ICU varied between 16 and 18 beds (with 10 of level III - respiratory support or ≥ 3 organ failures - and the remaining of level II - <3 organ failures provided no respiratory support) throughout the study period, the one of SJH was uniformly 24 beds (with 16 of level III and the remaining of level II). Level III beds could be converted to level IV beds in SJH ICU for patients needing extracorporeal membrane oxygenation. The nurse to patient ratio for level III beds in both ICUs was 1:2 24 h per every day (convertible to 1:1 only for a level IV bed), with one or 2 nurse coordinators able to provide extra help in strain circumstances. Both CCH and SJH have an ICU outreach team 24 h per every day staffed with one ICU or Anaesthesiology specialist or senior fellow and one ICU nurse.

A total of 175 (4.1%) ICU admissions were excluded due to missing data whether on the hour of ICU admission or on the vital status at the end of the ICU stay.

2.2. Data collection, exposures, and outcomes

Patients were identified on the prospective and standardized database the 2 ICUs share. Data was retrieved by 2 investigators (FSC and PF). The following characteristics on ICU admission were collected: age, sex, site previous to ICU admission, readmission status, cause of ICU admission, surgical status, date and hour of ICU admission, cluster of ICU admissions (index patient admitted to ICU with at least one other ICU admission up to 2 h before or afterwards), monthly average ICU capacity in use, APACHEII score, ICU and hospital vital status, and pre-ICU, ICU, and hospital length of stay (LOS).

Primary exposure was afterhours ICU admission defined as between 20:00 h and 7:59 h, based on the organization of local ICU staff. The primary outcome was ICU all-cause mortality. The secondary outcomes were hospital all-cause mortality and ICU and hospital LOS.

2.3. Statistical plan

Descriptive analysis used *n* (%) for categorical variables and median (interquartile range [IQR]) for continuous variables, with comparisons being done with Chi-square (or Fisher's) or Mann–Whitney tests, respectively. Missing data across all variables was 4.3%, therefore no multiple imputation was performed.

Adjusted analysis considered all variables clinically or statistically ($P < .10$ on unadjusted analysis) relevant. Given the risk of collinearity, adjusted analysis with APACHE II score was done separately. Internal validation was tested with bootstrapping analysis (1000 samples).

Sensitivity analyses were performed using different definitions of afterhours ICU admission: early-morning ICU admission defined as between 00:00 h and 07:59 h; early-morning ICU admission with cluster of ICU admissions; and early-morning ICU admission with an ICU capacity ≥90%. Furthermore, sensitivity analyses were also performed with the standard definition of afterhours ICU admission following exclusion of elective surgical patients or patients with an ICU stay of ≤6 h.

For all comparisons, statistical significance was defined as $\alpha = 0.05$ (2-tailed). Statistical analysis was done with IBM SPSS Statistics, version 25 (IBM Corporation, North Castle, New York, United States).

3. Results

3.1. Baseline characteristics stratified by time of ICU admission

Of a total of 4141 ICU admissions, 1581 (38.2%) occurred afterhours (Fig. 1). The proportion of afterhours ICU admission was significantly higher in SJH (29.3% vs. 48.5%; $P < .001$) likely because of its proximity to the ED (Table 1).

Overall, most afterhours ICU admissions came from the ward (49.3%) or ED (39.4%). Patients with non-surgical conditions represented the majority of afterhours ICU admissions (63.6%). Cardiovascular (26.9%), gastrointestinal (20.2%), or respiratory (18.0%) dysfunctions were the most frequent causes of afterhours ICU admission.

Afterhours ICU admission was significantly more frequent on the weekends (23.6% vs. 15.7%; $P < .001$), but not during the autumn-winter season (51.4% vs. 52.6%; $P = .46$). The cluster of ICU admissions was significantly more frequent during daytime hours (75.2% vs. 58.9%; $P < .001$). An ICU capacity ≥90% was significantly more frequent when there were afterhours ICU admissions (23.1% vs. 29.1%; $P < .001$).

Patients admitted to ICU afterhours had similar median APACHE II (19 vs. 20) scores to others ($P = .27$). All baseline characteristics stratified by the time of ICU admission were depicted in Table 1.

3.2. Association of afterhours ICU admission with outcomes

Overall, all-cause ICU and hospital mortality rates were 17.9% and 26.0%, respectively (Table 1). Median (IQR) time to ICU mortality was 3.8 (1.1–9.8) days, with 68 (9.2%) patients dying up to 6 h in the ICU (Fig. S1). The ICU (12.4% vs. 24.4%) and hospital (21.6% vs. 31.2%) mortality rates were significantly higher in SJH ($P < .001$ for both). However, these differences in mortality rates between sites lost significance following adjustment for APACHE II score ($P \geq .17$ for both).

Median (IQR) pre-ICU, ICU, and hospital LOS were 1.3 (0.7–5.0), 2.8 (0.9–6.5), 12.0 (6.0–24.5) days, respectively. While median pre-ICU (1.4 vs. 1.1 days) and ICU (1.6 vs. 4.5 days) LOS were significantly different between sites ($P < .001$ for both), median hospital (11.4 vs. 13.0 days) LOS was similar between them ($P = .16$).

Crude all-cause ICU (15.4% vs. 21.9%) and hospital (23.6% vs. 30.0%) mortality rates were significantly higher in patients admitted to ICU afterhours in comparison to others (Table 1: $P < .001$ for both). Patients admitted to ICU afterhours had significantly higher median pre-ICU (1.3 vs. 1.3 days) and ICU (2.2 vs. 3.4 days) LOS than others (Table 1: $P < .001$ for both), but similar median hospital LOS to others (12.0 vs. 12.1 days; $P = .78$).

In the unadjusted analysis, the following baseline characteristics were significantly associated with higher ICU mortality: higher median age (64 vs. 69 years); transfer from ED (26.2% vs. 34.6%); readmission ≥48 h (5.2% vs. 8.1%); cardiovascular (16.8% vs. 43.5%), respiratory (14.8% vs. 23.2%), or neurological (5.5% vs. 12.0%) dysfunctions as causes of ICU admission; non-operative diagnosis (46.4% vs. 86.1%); afterhours ICU admission (36.3% vs. 46.8%); weekend ICU admission (17.2% vs. 25.6%); absence of cluster of ICU admissions (70.1% vs. 63.9%); an ICU capacity ≥90% (23.6% vs. 33.7%); higher median APACHE II score (17 vs. 25); and higher median pre-ICU LOS (1.3 vs. 2.1 days) (Table 2: $P \leq .008$ for all).

Given the risk of collinearity between APACHE II score with several other baseline characteristics, as this score includes several of those parameters, the adjusted analysis was performed using 2 different models based on the clinical and statistical criteria specified in the Methods

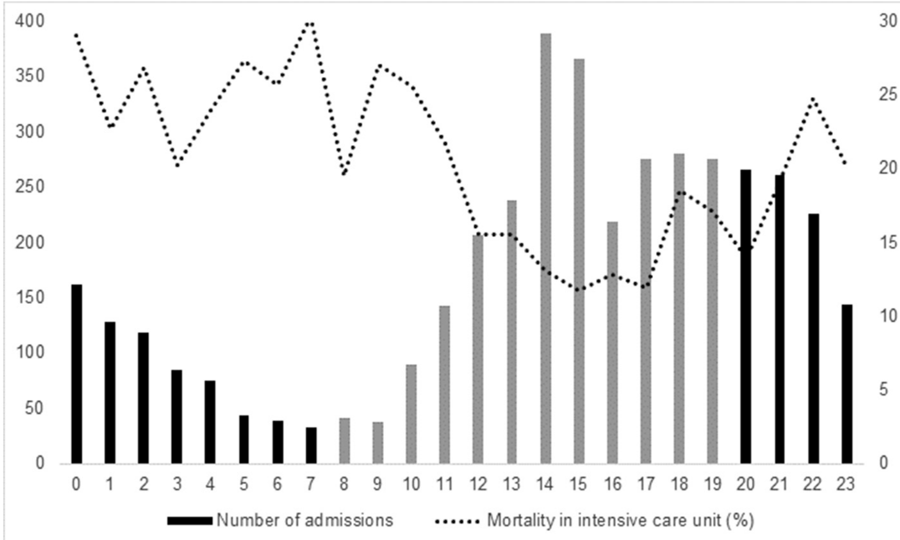

Fig. 1. Time of intensive care unit admission and intensive care unit mortality.

section (Table 3). Following adjustment to several important cofactors, there was no significant association of afterhours ICU admission with ICU mortality (Model 1: aOR [95%CI] = 1.15 [0.97–1.38]). Furthermore, following adjustment for early severity of disease, based on APACHE II score, there was also no significant association of afterhours ICU admission with ICU mortality (Model 2: aOR [95%CI] = 1.20 [0.93–1.53]). Therefore, afterhours ICU admission was significantly associated with crude ICU mortality, but not with adjusted ICU mortality.

While afterhours ICU admission was not associated with ICU mortality in the adjusted analysis, the following covariates were independently associated with higher ICU mortality: admission to SJH ICU (aOR [95%CI] = 1.42 [1.16–1.75]); higher median age (aOR [95%CI] = 1.02 [1.02–1.03]); non-operative diagnosis (aOR [95%CI] = 5.12 [4.02–6.52]); cardiovascular dysfunction as cause of ICU admission (aOR [95%CI] = 1.69 [1.40–2.04]); and higher APACHE II score (aOR [95%CI] = 1.14 [1.12–1.16]). Therefore, neither the cluster of ICU

Table 1
Baseline characteristics stratified by time of admission to the intensive care unit.

	Total ($n = 4141$)	ICU admission: 08:00 h–19:59 h ($n = 2560$)	ICU admission: 20:00 h–7:59 h ($n = 1581$)	P*
Age (years)	65 (53–76)	65 (53–76)	65 (52–76)	.38
Sex (male)	2520 (60.9%)	1583 (61.8%)	937 (59.3%)	.10
Admitted/transferred from				<.001
ED	1146 (27.7%)	523 (20.4%)	623 (39.4%)	
Other ICU	115 (2.8%)	69 (2.7%)	46 (2.9%)	
Ward	2593 (62.6%)	1814 (70.9%)	779 (49.3%)	
Other hospital	287 (6.9%)	154 (6.0%)	133 (8.4%)	
Readmission				.86
<48 h	67 (1.6%)	40 (1.6%)	27 (1.7%)	
≥48 h	236 (5.7%)	143 (5.6%)	93 (5.9%)	
Cause				<.001
Neurological	276 (6.7%)	140 (5.5%)	136 (8.6%)	
Respiratory	674 (16.3%)	389 (15.2%)	285 (18.0%)	
Cardiovascular	895 (21.6%)	470 (18.4%)	425 (26.9%)	
Renal/Urinary	209 (5.0%)	132 (5.2%)	77 (4.9%)	
Gastrointestinal	1300 (31.4%)	981 (38.3%)	319 (20.2%)	
Transplant	172 (4.2%)	116 (4.5%)	56 (3.5%)	
Trauma	171 (4.1%)	101 (3.9%)	70 (4.4%)	
Other	444 (10.8%)	231 (8.9%)	213 (13.3%)	
Surgery				<.001
Elective	1376 (33.2%)	1087 (42.5%)	289 (18.3%)	
Emergent	550 (13.3%)	264 (10.3%)	286 (18.1%)	
Non-operative	2215 (53.5%)	1209 (47.2%)	1006 (63.6%)	
Weekend (Saturday–Sunday)	776 (18.7%)	403 (15.7%)	373 (23.6%)	<.001
Season (autumn–winter)	2149 (51.9%)	1317 (51.4%)	832 (52.6%)	.46
Cluster of admissions (±2 h)	2856 (69.0%)	1925 (75.2%)	931 (58.9%)	<.001
ICU capacity ≥90%	1051 (25.4%)	591 (23.1%)	460 (29.1%)	<.001
APACHE II ($n = 1586$)	20 (14–25)	19 (14–25)	20 (14–26)	.27
Pre ICU hospital stay (days) ($n = 4008$)	1.3 (0.7–5.0)	1.3 (0.9–5.3)	1.3 (0.4–4.5)	<.001
ICU stay (days)	2.8 (0.9–6.5)	2.2 (0.9–5.9)	3.4 (1.4–7.2)	<.001
Post ICU hospital stay (days)	12.0 (6.0–24.5)	12.0 (6.1–24.0)	12.1 (5.8–25.7)	.78
ICU mortality	742 (17.9%)	395 (15.4%)	347 (21.9%)	<.001
Hospital mortality	1078 (26.0%)	604 (23.6%)	474 (30.0%)	<.001

ICU: intensive care unit. ED: emergency department. APACHE II: Acute Physiology and Chronic Health Evaluation II.
* Chi-square or Mann–Whitney tests: $\alpha = 0.05$ (2-tailed).

Table 2
Baseline characteristics stratified by intensive care unit mortality.

	Total (n = 4141)	ICU alive (n = 3399)	ICU deceased (n = 742)	P[*]
Age (years)	65 (53–76)	64 (51–74)	69 (59–79)	<.001
Sex (male)	2520 (60.9%)	2049 (60.3%)	471 (63.5%)	.11
Admitted/transferred from				<.001
ED	1146 (27.7%)	889 (26.2%)	257 (34.6%)	
Other ICU	115 (2.8%)	75 (2.2%)	40 (5.4%)	
Ward	2593 (62.6%)	2223 (65.4%)	370 (49.9%)	
Other hospital	287 (6.9%)	212 (6.2%)	75 (10.1%)	
Readmission				.008
<48 h	67 (1.6%)	54 (1.6%)	13 (1.8%)	
≥48 h	236 (5.7%)	176 (5.2%)	60 (8.1%)	
Cause				<.001
Neurological	276 (6.7%)	187 (5.5%)	89 (12.0%)	
Respiratory	674 (16.3%)	502 (14.8%)	172 (23.2%)	
Cardiovascular	895 (21.6%)	572 (16.8%)	323 (43.5%)	
Renal/Urinary	209 (5.0%)	185 (5.4%)	24 (3.2%)	
Gastrointestinal	1300 (31.4%)	1223 (36.0%)	77 (10.4%)	
Transplant	172 (4.2%)	157 (4.6%)	15 (2.0%)	
Trauma	171 (4.1%)	157 (4.6%)	14 (1.9%)	
Other	444 (10.9%)	416 (12.3%)	28 (3.7%)	
Surgery				<.001
Elective	1376 (33.2%)	1350 (39.7%)	26 (3.5%)	
Emergent	550 (13.3%)	473 (13.9%)	77 (10.4%)	
Non-operative	2215 (53.5%)	1576 (46.4%)	639 (86.1%)	
ICU admission (20:00 h–07:59 h)	1581 (38.2%)	1234 (36.3%)	347 (46.8%)	<.001
Weekend (Saturday–Sunday)	776 (18.7%)	586 (17.2%)	190 (25.6%)	<.001
Season (autumn–winter)	2149 (51.9%)	1759 (51.8%)	390 (52.6%)	.69
Cluster of admissions (±2 h)	2856 (69.0%)	2382 (70.1%)	474 (63.9%)	.001
ICU capacity ≥90%	1051 (25.4%)	801 (23.6%)	250 (33.7%)	<.001
APACHE II (n = 1586)	20 (14–25)	17 (12−23)	25 (20−31)	<.001
Pre ICU hospital stay (days) (n = 4008)	1.3 (0.7–5.0)	1.3 (0.7–3.9)	2.1 (0.4–13.0)	<.001
ICU stay (days)	2.8 (0.9–6.5)	2.6 (0.9–5.9)	3.8 (1.1–9.8)	<.001
Post ICU hospital stay (days)	12.0 (6.0–24.5)	14.1 (7.8–27.7)	3.8 (1.1–9.8)	<.001

ICU: intensive care unit. ED: emergency department. APACHE II: Acute Physiology and Chronic Health Evaluation II.
[*] Chi-square or Mann–Whitney tests: α = 0.05 (2-tailed).

admissions nor an ICU capacity ≥90% were found to be associated with adjusted ICU mortality.

3.3. Sensitivity analyses

Of a total of 4141 ICU admissions, 684 (16.5%) occurred in the early-morning (00:00 h–07:59 h). Patients admitted during early-morning to ICU had significantly higher crude ICU mortality than others (15.0% vs. 23.6%; $P < .001$), but this association lost significance following adjustment for the confounders considered in the primary analysis (Table 4: aOR [95%CI] = 1.23 [0.99–1.53]).

Amongst patients admitted in the early-morning to ICU, the ones admitted also within a cluster of ICU admissions (6.4% vs. 10.0%) or with an ICU capacity ≥90% (4.4% vs. 8.5%) had significantly higher crude ICU mortality ($P \leq .001$ for both). However, these associations lost significance following adjustment for the confounders considered in the primary analysis (Table 4: aOR [95%CI] = 1.16 [0.86–1.57] and aOR [95%CI] = 1.24 [0.88–1.73], respectively). Therefore, even for patients admitted in the early-morning to ICU, none of the measures of strained ICU capacity studied were associated with adjusted ICU mortality.

Following exclusion of elective surgical patients (n = 1376), afterhours ICU admission was not associated with ICU mortality (25.7% vs. 26.1%; $P = .83$). Furthermore, while patients admitted to ICU within a cluster of ICU admissions had similar crude ICU mortality than others (27.0% vs. 25.3%; $P = .35$), the ones admitted to ICU with an ICU capacity ≥90% had significantly higher crude ICU mortality (24.8% vs. 28.4%; $P = .04$). However, following adjustment for the confounders considered in the primary analysis, ICU capacity ≥90% was also not associated with ICU mortality (Table S1: aOR [95%CI] = 1.19 [0.97–1.45]).

Following exclusion of patients with an ICU stay of ≤6 h (n = 113), patients admitted to ICU afterhours had significantly higher crude ICU mortality than others (14.4% vs. 20.5%; $P < .001$), but this association also lost significance following adjustment for the confounders considered in the primary analysis (Table S1: aOR [95%CI] = 1.12 [0.96–1.39]). Furthermore, while patients admitted to ICU within a cluster of ICU admissions had significantly lower crude ICU mortality than others (19.8% vs. 15.4%), the ones admitted to ICU with an ICU capacity ≥90% had significantly higher crude ICU mortality (15.1% vs. 21.5%; $P <$ .001 for both). However, these associations also lost significance following adjustment for the confounders considered in the primary analysis (Table S1: aOR [95%CI] = 0.83 [0.68–1.00] and aOR [95%CI] = 1.11 [0.90–1.36], respectively).

Table 3
Association of afterhours intensive care unit admission (20:00 h–07:59 h) with intensive care unit mortality.

	OR (95%CI)	aOR (95%CI)	P[*]
Model 1 (n = 4141; c-statistic (95%CI) 0.76 (0.75–0.78))			
ICU admission (20:00 h–07:59 h)	1.54 (1.31–1.81)	1.15 (0.97–1.38)	.12
Site (SJH)	2.29 (1.94–2.69)	1.42 (1.16–1.75)	.001
Age (years)	1.02 (1.02–1.03)	1.02 (1.01–1.03)	<.001
Admitted/transferred from (ED vs other)	1.50 (1.26–1.77)	0.85 (0.70–1.04)	.12
Type (medical vs surgical)	7.18 (5.77–8.93)	4.81 (3.77–6.14)	<.001
Cause (cardiovascular vs. other)	3.81 (3.21–4.52)	1.68 (1.39–2.03)	<.001
Readmission (yes vs no)	1.50 (1.14–1.98)	1.31 (0.97–1.77)	.08
Weekend	1.65 (1.37–1.99)	1.18 (0.96–1.45)	.11
Cluster of admissions (±2 h)	0.76 (0.64–0.89)	0.86 (0.81–1.03)	.10
ICU capacity ≥90%	1.65 (1.39–1.96)	1.17 (0.96–1.32)	.13
Model 2 (n = 1586; c-statistic (95%CI) 0.77 (0.74–0.79))			
ICU admission (20:00 h–07:59 h)	1.22 (0.98–1.53)	1.20 (0.93–1.53)	.16
APACHE II	1.14 (1.12–1.16)	1.14 (1.12–1.16)	<.001

OR: odds ratio. 95%CI: 95% confidence interval. aOR: adjusted odds ratio. ICU: intensive care unit. SJH: São José Hospital. ED: emergency department. APACHE II: Acute Physiology and Chronic Health Evaluation II.
[*] Logistic regression after bootstrapping (1000 samples): α = 0.05 (2-tailed).

4. Discussion

4.1. Key results

In our large cohort of Portuguese general critically-ill patients, close to 2 in 5 ICU admissions occurred between 20:00 h and

Table 4
Association of early-morning intensive care unit admission (00:00 h–07:59 h) with intensive care unit mortality: sensitivity analyses.

	Total (n = 4141)	aOR (95%CI)	P[*]
EM ICU admission	684 (16.5%)	1.23 (0.99–1.53)[a]	.07
EM ICU admission + Cluster of admissions (±2 h)	292 (7.1%)	1.16 (0.86–1.57)[b]	.32
EM ICU admission + ICU capacity ≥90%	214 (5.2%)	1.24 (0.88–1.73)[c]	.22

aOR: adjusted odds ratio. 95%CI: 95% confidence interval. EM: early-morning (00:00 h–07:59 h). ICU: intensive care unit. APACHE II: Acute Physiology and Chronic Health Evaluation II.
[*] Logistic regression after bootstrapping (1000 samples): α = 0.05 (2-tailed).
[a] n = 4141; c-statistic (95%CI) 0.76 (0.75–0.78).
[b] n = 4141; c-statistic (95%CI) 0.76 (0.75–0.78).
[c] n = 4141; c-statistic (95%CI) 0.76 (0.75–0.78).

07:59 h. Afterhours ICU admission was significantly associated with higher crude ICU mortality (absolute difference of 6.5%), but this association lost significance following adjustment for relevant clinical confounders. Furthermore, patients admitted afterhours to ICU had significantly higher crude hospital mortality (absolute difference of 6.4%) and median ICU LOS (absolute difference of 1.2 days), but not hospital LOS.

While the cluster of ICU admissions was significantly more frequent during daytime hours, an ICU capacity ≥90% was significantly more frequent following afterhours ICU admission. However, neither the cluster of ICU admissions nor an ICU capacity ≥90% were associated with adjusted ICU mortality.

4.2. Comparisons with previous studies

The impact of afterhours ICU admission in patients' outcomes has been reported inconsistently, most likely due to methodological differences in such studies including: different definitions of afterhours ICU admission and patients' outcomes; diverse ICU case-mix and severity of acute disease; heterogeneous country, region or hospital -related organizational structures; or specific types of limitations.

In 2 large cohort studies, one from the Netherlands and the other from Australia, afterhours ICU admission was significantly associated with higher adjusted hospital mortality [3,15]. However, in 2 large systematic reviews, while afterhours ICU admission was not associated with adjusted hospital mortality, weekend ICU admission was significantly associated with higher adjusted hospital mortality [4,5]. Differently from these studies, in our cohort, neither afterhours ICU admission nor weekend ICU admission were associated with adjusted ICU mortality ($P \geq .11$ for both).

In a recent Canadian cohort study, the association of afterhours ICU admission (22:00 h–06:59 h) with ICU mortality was studied taking into account measures of strained ICU capacity, namely the cluster of ICU admissions (+/− 2 h in relation to the index admission) and an ICU capacity ≥90% [12]. In this study, afterhours ICU admission was also not associated with adjusted ICU mortality. However, for patients admitted to ICU between 00:00 h and 06:59 h, they found an increased likelihood of ICU mortality if there was a cluster of ICU admissions or an ICU capacity ≥90%. Therefore, they concluded that the effect of ICU time of admission on the likelihood of ICU mortality may be sensitive to measures of strained ICU capacity.

In our cohort, the cluster of ICU admissions was significantly more frequent during daytime hours and significantly associated with lower crude ICU mortality. This was likely because of the higher proportion of elective surgical patients being admitted during daytime hours rather than afterhours (42.5% vs. 18.3%; $P < .001$). These patients were often admitted to a level II area, as they were frequently in need of vasopressors, therefore workload associated was surely lower than what would be generally required for level III patients. Conversely, in our cohort, an ICU capacity ≥90% was significantly more frequent following afterhours ICU admission and significantly associated with higher crude ICU mortality. However, none of these measures of strained ICU capacity were associated with adjusted ICU mortality. Therefore, taking into account the organizational structure of both ICUs at CHLC, the effect of such indicators of workload on patients' short-term outcomes was not as relevant as reported elsewhere [12].

Based on the organizational model of our institution and our results, we could speculate that our on-site certified intensivist 24-h presence plus our nurse to patient ratio (1:2 for level III beds) may have helped prevent a significant excess of afterhours adjusted ICU mortality. However, it remains controversial the impact of on-site certified intensivist overnight coverage on patients' outcomes [5,16-18]. Furthermore, other indicators of nursing workload and patients' outcomes should be taken into account, but our study was not targeted to address those specific issues [19-21].

4.3. Implications for practice, policy, and research

Overall, our findings add to the literature by showing how afterhours ICU admission and measures of strained ICU capacity may influence patients' short-term outcomes in another specific jurisdiction. With our study, we hope to inform future quality improvement initiatives both at the patient and system levels at our institution and those alike. Amongst these future management plans, discussions on the following topics could help to mitigate strained ICU capacity and its potential impact on patients' outcomes: the critically-ill patients' trajectories from hospital admission to ICU admission (e.g. time from source to ICU); the timing and level of support from ICU outreach teams mainly in the wards (e.g. activation criteria, expedited admission to ICU); the number, level of expertise, and team work of ICU staff [22,23].

In terms of future research, further prospective and multicenter studies about the time of ICU admission and its relation to other known measures of strained ICU capacity may help to clarify how could ICUs optimize their delivery of care processes and potentially improve patients' outcomes [10-12].

5. Limitations

The interpretation of our results warrant consideration of the following limitations. First, the observational and retrospective nature of our study may have potentiated the selection bias. However, given the large number of consecutive ICU admissions considered and that all of those were registered in a prospective and standardized database, the likelihood of such bias may have been mitigated. Second, we used a definition of afterhours ICU admission that reflects the organization of our ICUs, but that may not be directly translated to other jurisdictions. Third, we had no data regarding either pre-ICU care or the initial goals of care for patients that were then admitted to our ICUs. These factors may have influenced both the time of ICU admission and the levels of care offered following ICU admission. Fourth, we did not assess the impact of afterhours ICU admission on other outcomes, such as patients' morbidity or satisfaction, or hospital costs.

6. Conclusions

In a large Portuguese cohort of general critically-ill patients, afterhours ICU admission and measures of strained ICU capacity were associated with crude but not adjusted ICU mortality.

Conflicts of interest

None to declare.

Funding source

None to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jcrc.2019.06.028.

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