Online Data Supplement

Associations of ICU Capacity Strain with Disposition and Outcomes of Patients with Sepsis Presenting to the Emergency Department

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Supplemental Figure Legend

Figure E1. ICU capacity strain metric variability by ED disposition decision time
The degree of ICU capacity strain metrics (vertical axes) is plotted at each study patient ED disposition time at the three study hospitals, represented by different colors, over a representative three month period during the study period. The figure demonstrates that the ICU capacity strain metrics varied on granular level at study patient ED disposition times both within and among study hospitals over the duration of the study period.

Figure E2. LOWESS plots of ICU turnover, ICU census acuity, and ward occupancy against ICU admission
Among patients presenting to the ED with sepsis who do not receive life support therapies, the likelihood of ICU (versus ward) admission (vertical axes) is plotted against the degree of ICU capacity strain metrics (ICU turnover, ICU census acuity, and ward occupancy), with capacity strain increasing from left to right on the horizontal axes. With respect to the likelihood of ICU admission, ICU turnover demonstrates a consistently negative but non-linear relationship with an inflection point at approximately 20% ICU turnover, ICU census acuity demonstrates a negative linear relationship, and ward occupancy demonstrated no relationship. (The plots were restricted to ICU turnover $\leq$ 41.7% accounting for 95% of the study population and ward occupancy $\geq$ 55.6% accounting for 95% of the study population.)

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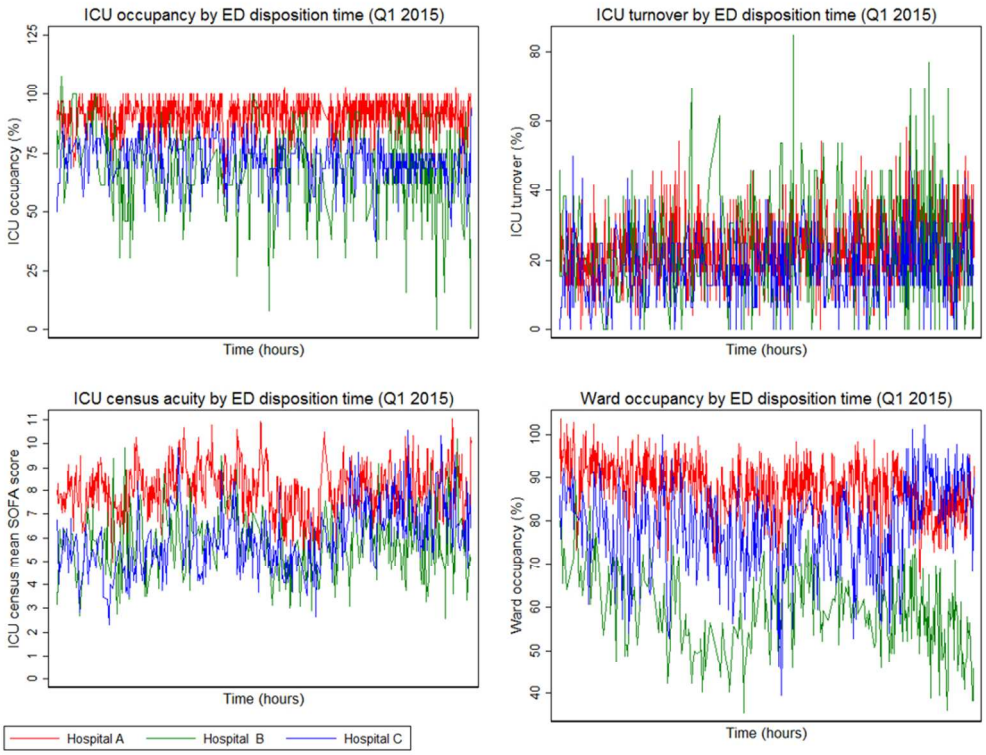

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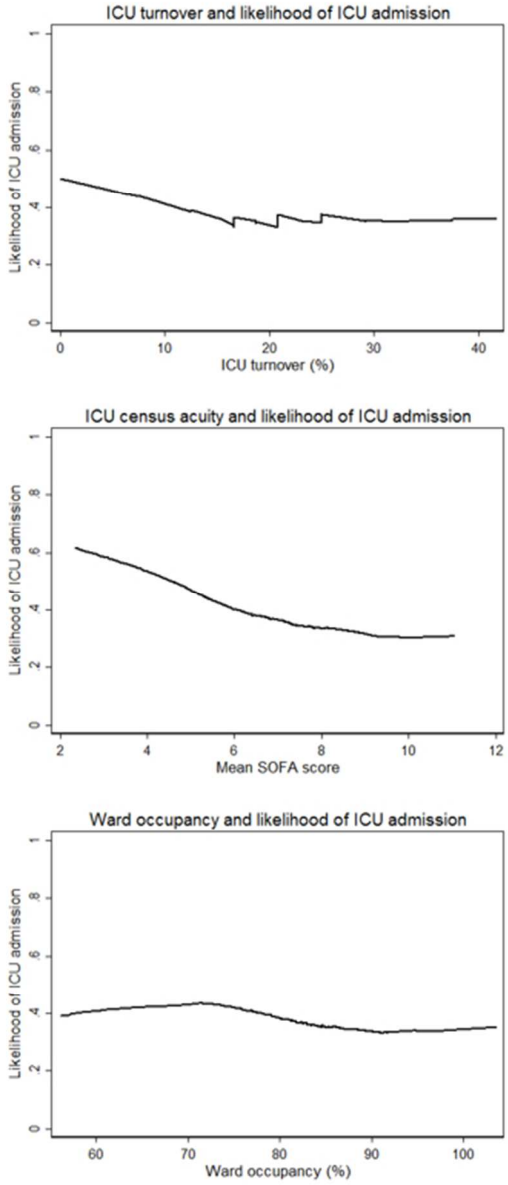

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Appendix E1. Quick Sequential [Sepsis-related] Organ Failure Assessment (qSOFA) score

A qSOFA score of two or greater required meeting at least two of the following criteria (using the most abnormal value of each variable recorded during the ED stay): Glasgow Coma Score ≤ 14; respiratory rate ≥ 22 breaths per minute; and systolic blood pressure ≤ 100 mmHg. qSOFA was used rather than the complete Sequential [Sepsis-related] Organ Failure Assessment (SOFA) due to better availability of physiologic data collected exclusively in the ED prior to the study exposure and the comparability of qSOFA to SOFA in predicting mortality among patients with suspected infection outside of the ICU.

Appendix E2. Definition of ventilatory assistance at the time of admission

Ventilatory assistance at the time of admission was defined as any mechanical ventilation (MV) or non-invasive bilevel positive airway pressure (BiPAP) order placed within one hour after the inpatient admission order and within two hours after hospital admission in an attempt to appropriately categorize patients admitted with a plan for immediate intubation or BiPAP and patients with an unplanned new requirement for ventilatory support in the early hours after admission.

Appendix E3. Definition of Do Not Resuscitate (DNR) status at the time of admission

Do Not Resuscitate (DNR) status at the time of admission was defined by any DNR order (i.e., do not resuscitate, do not resuscitate/do not intubate, no escalation of care, or comfort measures only) placed within the first three hours after hospital admission, as DNR orders are infrequently placed in the ED and a DNR order placed more than three hours after admission was thought to more likely represent a response to a change in clinical status.

Appendix E4. Additional ICU capacity strain metric calculation details

At one study hospital, beds in an adjacent 12-bed cardiac care unit (CCU) to which medical ICU patients are routinely admitted were included in calculations for ICU occupancy, as they were thought to directly influence strain assessments by ICU and ED clinicians whether being occupied by medical or cardiac patients; ICU turnover and acuity calculations were restricted to the medical ICU census alone, as fluctuations in these metrics in the CCU's predominantly cardiac patient census were thought to be less directly felt by the medical ICU clinician team and ED clinicians triaging patients to a medical ICU service.

Table E1. Study hospital characteristics

Characteristics	Hospital A	Hospital B	Hospital C
Overall description	Quarternary academic center	Academically-affiliated community hospital	Academically-affiliated tertiary teaching hospital
Total inpatient beds	695	515	317
Annual inpatient admissions	38,213	23,903	15,519
Medical ICU beds	36 (including CCU beds)	13	14
Residency/fellowship presence	Comprehensive residency/fellowship programs	Non-comprehensive resident/fellow staffing; some shared residents/fellows with Hospital A; some indepenent local residents	Shared residents/fellows with Hospital A
Medical ICU staffing model	Closed: attending, fellow, residents	Closed: attending, residents	Closed: attending, hospitalists
Intermediate care	Cardiac step-down	Mixed medical/surgical step-down	Mixed cardiac medical/surgical step-down
Among-hospital attending overlap	Rare overlap with Hospital C	None	Rare overlap with Hospital A
Primary ICU triage decision-maker	ED physicians	ED physicians	ED physicians

Notes: ED, emergency department; ICU, intensive care unit.

Table E2. Patient characteristics by ED disposition decision

Characteristics	Ward admissions (n=1,960)	ICU admissions (n=1,107)
Hospital, n (%)		
A	1468 (74.9)	640 (57.8)
B	258 (13.2)	130 (11.7)
C	234 (11.9)	337 (30.4)
Age, mean years (SD)	59.9 (18.1)	62.3 (16.5)
Male, n (%)	925 (47.2)	609 (55.0)
Race, n (%)		
White	917 (46.8)	427 (38.6)
Black	915 (46.7)	611 (55.2)
Asian	67 (3.4)	37 (3.3)
Other[a]	61 (3.1)	32 (2.9)
Non-Hispanic ethnicity, n (%)	1901 (97.0)	1087 (98.2)
qSOFA[b] score, n (%)		
2 points	1800 (91.8)	880 (79.5)
3 points	160 (8.2)	227 (20.5)
COPS2 score, mean (SD)	114 (73)	143 (75)
Hospital LOS, median days (IQR)	4.3 (2.6-7.3)	6.8 (4.1-12.5)
Hospital mortality, n (%)	98 (5.0)	192 (17.3)
Day of ED disposition decision[c]		
Weekday	1502 (76.6)	842 (76.1)
Weekend	458 (23.4)	265 (23.9)
Time of ED disposition decision		
7a-7p	982 (50.1)	651 (58.8)
7p-7a	978 (49.9)	456 (41.2)

Notes: [a] Includes Hawaiian/Pacific Islander, American Indian/Native American, and self-reported race as "other". [b] Inclusion criteria restricted patients to those with qSOFA≥2. [c] Weekend = Saturday or Sunday (by calendar day). COPS2, COmorbidity Point Score v2; ED, emergency department; ICU, intensive care unit; IQR, interquartile range; LOS, length of stay; qSOFA, Quick Sequential [Sepsis-related] Organ Failure Assessment; SD, standard deviation.

Table E3. ICU capacity strain metrics at ED disposition times for the study population

Hospital	% ICU occupancy, median (IQR)	% ICU turnover, median (IQR)	ICU census acuity, mean SOFA score (SD)	% Ward occupancy, median (IQR)
A	91.7 (88.9-97.2)	25.0 (16.7-29.2)	7.9 (1.0)	87.7 (84.2-91.3)
B	69.2 (53.8-76.9)	23.1 (15.4-38.5)	5.7 (1.4)	59.0 (53.5-65.3)
C	68.8 (68.8-75.0)	18.8 (12.5-25.0)	6.1 (1.3)	79.1 (71.4-85.7)

Notes: ICU occupancy, ICU turnover, and ward occupancy are calculated at the level of the hour over the study period. ICU census acuity is calculated at the level of the day over the study period. Values of capacity strain metrics were assigned to study patients based on the most recently calculated strain metric score prior to the time of each patient's ED disposition decision. ED, emergency department; ICU, intensive care unit; IQR, interquartile range; SD, standard deviation; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.

Table E4. Association of open ICU beds and ICU admission

ICU occupancy variable[a]	OR (95% CI)a	p-value
Open ICU beds (continuous)	1.11 (1.07-1.14)	<0.001*
Open ICU beds (Ref: 0 beds)		
1 bed	1.22 (0.83-1.81)	0.31
2 or more beds	2.06 (1.48-2.87)	<0.001*

*Notes: [a] Adjusted for all patient-level covariates. * p < 0.05. CI, confidence interval; ICU, intensive care unit; OR, odds ratio.*

Table E5. Association of ICU capacity strain and ICU admission with iterative exclusion of strain metrics

Variables[a]	Primary model	Excluding ICU turnover	Excluding ICU census acuity	Excluding ward occupancy	Excluding ICU occupancy
	OR (95% CI)				
ICU occupancy[b]	0.87 (0.79-0.96)*	0.89 (0.81-0.97)*	0.87 (0.79-0.96)*	0.88 (0.80-0.96)*	excluded
ICU turnover[b]	1.08 (0.99-1.17)	excluded	1.08 (0.99-1.17)	1.08 (0.99-1.18)	1.05 (0.96-1.14)
ICU census acuity[c]	1.00 (0.93-1.07)	0.99 (0.92-1.07)	excluded	1.00 (0.93-1.08)	0.99 (0.92-1.07)
Ward occupancy[b]	1.05 (0.93-1.18)	1.05 (0.94-1.18)	1.05 (0.93-1.18)	excluded	1.01 (0.90-1.14)

*Notes: [a] Other covariates not shown. [b] ORs reflect a 10% increase in ICU occupancy, ICU turnover, and ward occupancy. [c] ORs reflect a 1-point increase in the mean SOFA score. * $p < 0.05$. CI, confidence interval; ICU, intensive care unit; OR, odds ratio; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*

Table E6. Association of ICU capacity strain and ICU admission adjusted for ED time

Variables[a]	Primary model	Including total ED time	Including duration of time from ED disposition to admission
	OR (95% CI)		
ICU occupancy[b]	0.87 (0.79-0.96)*	0.91 (0.83-1.01)	0.90 (0.82-1.00)*
ICU turnover[b]	1.08 (0.99-1.17)	1.08 (0.99-1.18)	1.08 (0.99-1.18)
ICU census acuity[c]	1.00 (0.93-1.07)	0.98 (0.91-1.06)	0.99 (0.92-1.07)
Ward occupancy[b]	1.05 (0.93-1.18)	1.25 (1.10-1.42)*	1.22 (1.08-1.38)*
Total time in ED[d]	excluded	0.86 (0.85-0.88)*	excluded
Duration of time from ED disposition decision to inpatient admission[d]	excluded	excluded	0.88 (0.86-0.90)*

*Notes: [a] Other patient-level covariates not shown. [b] ORs reflect a 10% increase in ICU occupancy, ICU turnover, and ward occupancy. [c] ORs reflect a 1-point increase in the mean SOFA score. [d] ORs reflect a 1-hour difference in ED time. * p < 0.05. CI, confidence interval; ED, emergency department; ICU, intensive care unit; OR, odds ratio; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*

Table E7. Association of ICU capacity strain and ICU admission including SDU admissions

Variables[a]	SDU excluded (n=3,067)[e]		SDU included (n=3,451)[f]	
	OR (95% CI)	p-value	OR (95% CI)	p-value
ICU occupancy[b]	0.87 (0.79-0.96)	0.005*	0.87 (0.79-0.94)	0.001*
ICU turnover[b]	1.08 (0.99-1.17)	0.08	1.08 (0.99-1.17)	0.07
ICU census acuity[c]	1.00 (0.93-1.07)	0.93	0.98 (0.91-1.05)	0.62
Ward occupancy[b]	1.05 (0.93-1.18)	0.44	1.06 (0.93-1.19)	0.39
SDU occupancy[b]	not included		1.02 (0.94-1.10)	0.61
Age	1.00 (1.00-1.01)	0.37	1.00 (1.00-1.01)	0.36
Male gender	1.20 (1.02-1.42)	0.03*	1.16 (0.99-1.36)	0.07
Race (ref: white)				
Black	1.17 (0.98-1.39)	0.09	1.17 (0.99-1.39)	0.07
Asian	1.27 (0.81-2.01)	0.30	1.46 (0.93-2.28)	0.10
Other	1.01 (0.62-1.65)	0.96	1.07 (0.66-1.72)	0.79
SOFA score	1.31 (1.26-1.35)	<0.001*	1.29 (1.25-1.33)	<0.001*
COPS2 score[d]	1.04 (1.03-1.05)	<0.001*	1.03 (1.02-1.05)	<0.001*
Hospital (ref: A)				
B	1.21 (0.76-1.95)	0.41	0.50 (0.30-0.82)	0.006*
C	3.31 (2.42-4.53)	<0.001*	2.91 (2.15-3.94)	<0.001*

*Notes: [a] Academic year covariate not shown. [b] ORs reflect a 10% increase in ICU occupancy, ICU turnover, ward occupancy, and SDU occupancy. [c] ORs reflect a 1-point increase in the mean SOFA score. [d] ORs reflect a 10-point increase in the COPS2 score. [e] Primary analysis model. [f] SDU admissions included as ward admissions. * p < 0.05. CI, confidence interval; COPS2, COmorbidity Point Score v2; ICU, intensive care unit; OR, odds ratio; SDU, step-down unit; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*

Table E8. Association of ICU capacity strain and ICU admission by DNR status

Variables[a]	DNR excluded (n=3,067)[e]		DNR included (n=3,082)	
	OR (95% CI)	p-value	OR (95% CI)	p-value
ICU occupancy[b]	0.87 (0.79-0.96)	0.005*	0.88 (0.80-0.96)	0.006*
ICU turnover[b]	1.08 (0.99-1.17)	0.08	1.08 (0.99-1.17)	0.08
ICU census acuity[c]	1.00 (0.93-1.07)	0.93	1.00 (0.93-1.07)	0.94
Ward occupancy[b]	1.05 (0.93-1.18)	0.44	1.05 (0.93-1.18)	0.46
Age	1.00 (1.00-1.01)	0.37	1.00 (1.00-1.01)	0.24
Male gender	1.20 (1.02-1.42)	0.03*	1.19 (1.01-1.40)	0.04*
Race (ref: white)				
Black	1.17 (0.98-1.39)	0.09	1.16 (0.97-1.38)	0.10
Asian	1.27 (0.81-2.01)	0.30	1.28 (0.82-2.02)	0.28
Other	1.01 (0.62-1.65)	0.96	0.99 (0.61-1.62)	0.97
SOFA score	1.31 (1.26-1.35)	<0.001*	1.31 (1.26-1.35)	<0.001*
COPS2 score[d]	1.04 (1.03-1.05)	<0.001*	1.04 (1.03-1.05)	<0.001*
Hospital (ref: A)				
B	1.21 (0.76-1.95)	0.41	1.19 (0.74-1.91)	0.470
C	3.31 (2.42-4.53)	<0.001*	3.28 (2.40-4.49)	<0.001*

*Notes: [a] Academic year covariate not shown. [b] ORs reflect a 10% increase in ICU occupancy, ICU turnover, and ward occupancy. [c] ORs reflect a 1-point increase in the mean SOFA score. [d] ORs reflect a 10-point increase in the COPS2 score. [e] Primary analysis model. * p < 0.05. CI, confidence interval; COPS2, COmorbidity Point Score v2; DNR, do not resuscitate; ICU, intensive care unit; OR, odds ratio; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*

Table E9. Association of ICU occupancy and in-hospital outcomes (including patients DNR at admission)

Model	Patient group	Hospital mortality[a]		Hospital LOS[b]		Discharge home[a]	
		OR (95% CI)	p-value	HR (95% CI)	p-value	OR (95% CI)	p-value
Unadjusted	All patients	1.04 (0.95-1.14)	0.39	0.97 (0.95-1.00)	0.05	0.96 (0.90-1.02)	0.19
	ICU patients	1.02 (0.91-1.14)	0.74	0.94 (0.90-0.98)	0.008*	0.98 (0.89-1.07)	0.60
	Ward patients	1.62 (1.28-2.07)	<0.001*	0.94 (0.91-0.97)	<0.001*	0.76 (0.67-0.86)	<0.001*
Adjusted	All patients	1.05 (0.90-1.22)	0.54	0.96 (0.92-1.02)	0.06	0.96 (0.86-1.07)	0.50
	ICU patients	0.95 (0.79-1.14)	0.56	0.93 (0.86-1.00)	0.04*	1.02 (0.87-1.19)	0.82
	Ward patients	1.50 (1.11-2.04)	0.009*	0.96 (0.92-1.01)	0.13	0.86 (0.72-1.02)	0.08

*Notes: ORs and HRs reflect a 10% increase in ICU occupancy. [a] Logistic regression models. [b] Cox proportional hazard models censoring on death. HRs < 1 indicate a reduced likelihood of discharge and are therefore interpreted as an association with a longer LOS. * p < 0.05. CI, confidence interval; DNR, do not resuscitate; HR, hazard ratio; ICU, intensive care unit; LOS, length of stay; OR, odds ratio.*

Table E10. Association of ICU capacity strain and ICU admission excluding readmissions

Variables[a]	First admissions (n=2,174)[e]	
	OR (95% CI)	p-value
ICU occupancy[b]	0.89 (0.79-0.99)	0.04*
ICU turnover[b]	0.99 (0.90-1.10)	0.92
ICU census acuity[c]	0.97 (0.88-1.06)	0.47
Ward occupancy[b]	1.04 (0.91-1.20)	0.57
Age	1.00 (1.00-1.01)	0.40
Male gender	1.20 (0.98-1.47)	0.08
Race (ref: white)		
Black	1.22 (0.98-1.51)	0.07
Asian	1.45 (0.83-2.53)	0.20
Other	0.91 (0.51-1.62)	0.75
SOFA score	1.34 (1.29-1.40)	<0.001*
COPS2 score[d]	1.05 (1.03-1.07)	<0.001*
Hospital (ref: A)		
B	1.17 (0.67-2.04)	0.57
C	3.29 (2.25-4.81)	<0.001*

*Notes: [a] Academic year covariate not shown. [b] ORs reflect a 10% increase in ICU occupancy, ICU turnover, and ward occupancy. [c] ORs reflect a 1-point increase in the mean SOFA score. [d] ORs reflect a 10-point increase in the COPS2 score. [e] Included only the first admission for each unique patient during the study period. * p < 0.05. CI, confidence interval; COPS2, COmorbidity Point Score v2; ICU, intensive care unit; OR, odds ratio; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*

Table E11. Association of ICU occupancy and in-hospital outcomes excluding readmissions

Model	Patient group	Hospital mortality[a]		Hospital LOS[b]		Discharge home[a]	
		OR (95% CI)	p-value	HR (95% CI)	p-value	OR (95% CI)	p-value
Unadjusted	All patients	1.03 (0.93-1.14)	0.52	0.98 (0.95-1.02)	0.35	0.97 (0.90-1.05)	0.45
	ICU patients	1.02 (0.90-1.17)	0.74	0.94 (0.89-0.99)	0.03*	0.98 (0.88-1.09)	0.71
	Ward patients	1.58 (1.19-2.08)	0.001*	0.95 (0.91-0.99)	0.01*	0.79 (0.69-0.91)	0.001*
Adjusted	All patients	0.98 (0.82-1.17)	0.82	0.99 (0.94-1.04)	0.60	1.00 (0.88-1.14)	0.97
	ICU patients	0.89 (0.72-1.10)	0.26	0.96 (0.88-1.04)	0.32	1.09 (0.91-1.30)	0.34
	Ward patients	1.37 (0.96-1.95)	0.08	0.98 (0.93-1.04)	0.56	0.88 (0.73-1.07)	0.20

*Notes: ORs and HRs reflect a 10% increase in ICU occupancy. [a] Logistic regression models. [b] Cox proportional hazard models censoring on death. HRs < 1 indicate a reduced likelihood of discharge and are therefore interpreted as an association with a longer LOS. * p < 0.05. CI, confidence interval; DNR, do not resuscitate; HR, hazard ratio; ICU, intensive care unit; LOS, length of stay; OR, odds ratio.*

Table E12. Association of ICU capacity strain and ICU admission by hospital

Variables[a]	Pooled model[d]	Hospital A[e]	Hospital B[e]	Hospital C[e]
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
ICU occupancy[b]	0.87 (0.79-0.96)*	0.76 (0.65-0.90)*	0.97 (0.82-1.16)	0.89 (0.71-1.11)
ICU turnover[b]	1.08 (0.99-1.17)	1.13 (1.01-1.27)*	1.08 (0.90-1.29)	0.92 (0.74-1.13)
ICU census acuity[c]	1.00 (0.93-1.07)	1.08 (0.97-1.19)	0.88 (0.72-1.07)#	1.03 (0.87-1.22)
Ward occupancy[b]	1.05 (0.93-1.18)	0.96 (0.79-1.17)#	1.20 (0.86-1.69)	1.16 (0.95-1.42)

*Notes: [a] Patient-level covariates not shown. [b] ORs reflect a 10% increase in ICU occupancy, ICU turnover, and ward occupancy. [c] ORs reflect a 1-point increase in the mean SOFA score. d Includes hospital covariate. [e] Stratified on hospital and excludes hospital covariate. * p < 0.05. # Point-estimate direction different than primary pooled model. CI, confidence interval; ICU, intensive care unit; OR, odds ratio; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*

Table E13. Association of ICU occupancy and hospital mortality by hospital

Model	Patient group	Pooled model[a]	Hospital A[b]	Hospital B[b]	Hospital C[b]
		OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Unadjusted	All patients	1.03 (0.94-1.13)	1.09 (0.87-1.37)	0.89 (0.72-1.11)	0.96 (0.72-1.29)
	ICU patients	1.01 (0.90-1.13)	0.93 (0.69-1.27)	0.80 (0.60-1.08)	0.98 (0.72-1.33)
	Ward patients	1.62 (1.28-2.07)*	1.63 (1.10-2.42)*	1.14 (0.73-1.76)	1.59 (0.31-8.21)
Adjusted	All patients	1.00 (0.88-1.13)	1.17 (0.92-1.50)	1.01 (0.78-1.30)	0.96 (0.70-1.32)
	ICU patients	0.98 (0.84-1.14)	0.95 (0.69-1.32)	0.83 (0.59-1.17)	0.98 (0.70-1.38)
	Ward patients	1.61 (1.21-2.14)*	1.81 (1.19-2.77)*[c]	1.47 (0.78-2.77)[d]	3.34 (0.14-82.8)[e]

*Notes: ORs reflect a 10% increase in ICU occupancy. [a] Includes hospital covariate. [b] Stratified on hospital and excludes hospital covariate. [c] n = 1,468. [d] n = 232. [e] n = 52. * p < 0.05. CI, confidence interval; ICU, intensive care unit; OR, odds ratio.*

Table E14. Association of ICU occupancy and in-hospital outcomes by qSOFA and SOFA score

Sub-cohort	Hospital mortality, OR (95% CI)[a]	
	Ward patients	ICU patients
All patients	1.50 (1.11-2.04)*	0.94 (0.78-1.13)
ED qSOFA score[b]		
2	1.46 (1.07-2.00)*	0.93 (0.76-1.14)
3	2.34 (0.69-7.95)	0.98 (0.61-1.58)
ED SOFA score		
0	1.22 (0.19-7.82)	#
1	1.15 (0.62-2.12)	#
2	4.16 (1.00-17.3)	2.49 (0.64-9.74)
3	1.94 (0.69-5.49)	0.77 (0.43-1.39)
4	1.98 (0.67-5.79)	0.94 (0.51-1.74)
5	0.95 (0.35-2.56)	0.48 (0.23-0.99)*
6	0.76 (0.28-2.06)	0.77 (0.46-1.30)
7	2.03 (0.54-7.58)	1.21 (0.49-2.96)
>=8	2.28 (0.72-7.19)	1.04 (0.71-1.52)

*Notes: [a] Adjusted for all patient-level covariates (not shown). [b] Inclusion criteria dictated qSOFA≥2. * p < 0.05. # Sub-cohort sample size too small to calculate point estimate. CI, confidence interval; ED, emergency department; ICU, intensive care unit; OR, odds ratio; qSOFA, quick Sequential [Sepsis-related] Organ Failure Assessment; SOFA, Sequential [Sepsis-related] Organ Failure Assessment.*