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Intensive Care Unit Capacity Strain and Outcomes of Critical Illness in a Resource-Limited Setting: A 2-Hospital Study in South Africa

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Abstract

Objective: To measure the association of intensive care unit (ICU) capacity strain with processes of care and outcomes of critical illness in a resource-limited setting.

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Declaration of Conflicting Interests

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Supplemental Material

Supplemental material for this article is available online.

Methods: We performed a retrospective cohort study of 5332 patients referred to the ICUs at 2 public hospitals in South Africa using the country's first published multicenter electronic critical care database. We assessed the association between multiple ICU capacity strain metrics (ICU occupancy, turnover, census acuity, and referral burden) at different exposure time points (ICU referral, admission, and/or discharge) with clinical and process of care outcomes. The association of ICU capacity strain at the time of ICU admission with ICU length of stay (LOS), the primary outcome, was analyzed with a multivariable Cox proportional hazard model. Secondary outcomes of ICU triage decision (with strain at ICU referral), ICU mortality (with strain at ICU admission), and ICU LOS (with strain at ICU discharge), were analyzed with linear and logistic multivariable regression.

Results: No measure of ICU capacity strain at the time of ICU admission was associated with ICU LOS, the primary outcome. The ICU occupancy at the time of ICU admission was associated with increased odds of ICU mortality (odds ratio = 1.07, 95% confidence interval: 1.02–1.11; $P = .004$), a secondary outcome, such that a 10% increase in ICU occupancy would be associated with a 7% increase in the odds of ICU mortality.

Conclusions: In a resource-limited setting in South Africa, ICU capacity strain at the time of ICU admission was not associated with ICU LOS. In secondary analyses, higher ICU occupancy at the time of ICU admission, but not other measures of capacity strain, was associated with increased odds of ICU mortality.

Keywords

intensive care unit (ICU) capacity strain; resource-limited setting; low- and middle-income countries (LMICs); resource allocation; global critical care

Introduction

Intensive care unit (ICU) capacity strain refers to the potential limits placed on an ICU's ability to provide high-quality care for all patients who may need it at a given time.^{1,2} Previous studies have shown that ICU occupancy, turnover, and census acuity may contribute to capacity strain. The impact of ICU capacity strain on processes of care and patient outcomes has been studied demonstrating associations with ICU protocol adherence, rounding time, and triage decisions influencing ICU length of stay (LOS), but only modest associations with ICU mortality.^{3–6}

The ICU capacity strain research has been performed almost exclusively in resource-rich settings. Single-center studies in resource-limited settings have assessed ICU bed capacity and timing of ICU admission as they relate to ICU outcomes.⁷ To our knowledge, the association of formal ICU capacity strain metrics with processes of care and patient outcomes in resource-limited settings has not been previously studied. The ICU capacity strain, triage decisions, and processes of care may vary significantly in resource-limited settings compared to resource-rich settings. Additionally, the burden of critical illness in resource-limited settings is growing and will likely require a different management approach than that developed and used in resource-rich settings.^{8–10}

In a 2-hospital retrospective cohort study, we sought to utilize the first published multicenter electronic critical care database in South Africa¹¹ to measure the association of ICU capacity strain at various time points along the trajectory of critical illness with patient outcomes and processes of care in a resource-limited setting.

Materials and Methods

Study Setting and Data Source

South Africa is an upper-middle-income country¹² and wealthy compared to its region¹³ and the African continent, but has a resource-limited public health-care system that treats 84% of the population¹⁴ and accounts for 43% of the country's ICU beds. South Africa has 8.9 ICU beds per 100 000 population; in comparison, the United States has greater than 30 ICU beds per 100 000 population.¹⁵ The Integrated Critical Care Electronic Database (ICED) is the first published multicenter database of its kind in South Africa.¹¹ It includes all referrals for ICU care at 2 public hospitals within the KwaZulu-Natal Department of Health (Pietermaritzburg, South Africa): Greys Hospital (beginning November 2013), a tertiary hospital with approximately 530 inpatient beds, and Edendale Hospital (beginning July 2014), a regional hospital with approximately 900 inpatient beds. Both hospitals have one mixed medical-surgical ICU that admit adult and pediatric patients and have closed, high-intensity staffing models (see Online Appendix 1 for details). In these tax-funded public hospitals, individual patient finances do not overtly influence clinical decisions including ICU admission, diagnostic testing, therapeutic interventions, and LOS.

Study Population

We included all patients of any age in the database referred to the ICU at Greys Hospital or Edendale Hospital from November 5, 2013, to June 5, 2016.

Study Design

We performed a retrospective cohort study to assess the association of multiple ICU capacity strain metrics at different exposure time points along the trajectory of critical illness with clinical and process of care outcomes. Figure 1 provides a conceptual model of the study.

Intensive Care Unit Capacity Strain Exposure Variables

The exposure variables were 4 ICU capacity strain metrics³: ICU occupancy, turnover, census acuity, and referral burden. The ICU occupancy was defined as the percentage of ICU bed capacity occupied at the time of ICU referral, admission, or discharge. The ICU turnover was defined as the percentage of ICU bed capacity newly admitted to the ICU during the 24 hours after ICU admission, the 24 hours before ICU discharge, or the calendar day of ICU referral. The ICU census acuity was defined as the mean predicted hospital mortality of all patients admitted to the ICU (excluding the index patient) at the time of ICU referral, admission, or discharge. Predicted hospital mortality was calculated by the Mortality Probability Admission Model-III (MPM₀-III),¹⁶ a composite model based on clinical and historical data obtained within 1 hour of ICU admission. For patients with missing MPM₀-III-predicted hospital mortalities, we used the mean MPM₀-III-predicted hospital mortalities from 10 imputed data sets (see Appendices 2 and 3 for details). The ICU referral burden was

defined as the number of patients, expressed as a percentage of ICU bed capacity, who were referred but declined for ICU admission on the calendar day of ICU admission, discharge, or referral. The ICU occupancy, turnover, and census acuity were calculated on an hourly level, and ICU referral burden was calculated on the level of the calendar day over the duration of the study period. The ICU occupancy, turnover, and referral burden were standardized to ICU bed capacity (ie, total ICU beds) by hospital.

Outcomes

Our conceptual model posits that clinical outcomes would be most affected by capacity strain felt near ICU admission and therefore closer to the onset of critical illness,³ while processes of care (ie, admission and discharge decisions) would be most affected by strain near ICU referral and ICU discharge.⁴ The primary outcome was ICU LOS in hours (clinical outcome analyzed relative to ICU capacity strain at the time of ICU admission). Secondary outcomes included ICU mortality (clinical outcome analyzed relative to ICU capacity strain at the time of ICU admission), ICU LOS in hours (among ICU survivors, process of care outcome analyzed relative to ICU capacity strain at the time of ICU discharge), and ICU triage decision (among all ICU referrals, process of care outcome analyzed relative to ICU capacity strain at the time of ICU referral). The ICU mortality was defined as a death in the ICU or a palliative discharge from the ICU.

Adjustment Variables

Regression models were adjusted a priori for age, gender, race, hospital, prereferral hospital LOS, calendar year of ICU admission or referral, chronic comorbidities, and MPM₀-III-predicted hospital mortality (see Online Appendix 3 for details).^{3,16}

Statistical Analysis and Missing Data

The association of ICU capacity strain at the time of ICU admission with ICU LOS, the primary clinical outcome, was analyzed with a multivariable Cox proportional hazard model with deaths considered as censoring events.¹⁷ The association of ICU capacity strain at the time of ICU discharge with ICU LOS among ICU survivors (secondary process of care outcome) was analyzed using multivariable linear regression.⁴ The association of ICU capacity strain with ICU mortality and ICU triage decision, binary secondary outcomes, was analyzed using multivariable logistic regression. All models included the 4 ICU capacity strain metrics and all a priori adjustment variables. Final models were also analyzed stratified by hospital to assess for any among-hospital differences or bias due to combining a small number of hospitals in the primary analysis. Figure 1 summarizes the study analytic plan.

Exposures, outcomes, and non-MPM₀-III adjustment variables had either complete data or were missing in 1.3% of patients. MPM₀-III-predicted hospital mortalities were missing for 21.3% of admitted patients and 27.5% of referred patients and were multiply imputed; 10 imputed data sets were created (see Online Appendix 2 for details).

The ICU LOS was natural log-transformed for linear regression modeling; results are presented back-transformed ($e^{\beta}-1$) to reflect a proportional change in ICU LOS. Reported

hazard ratios, odds ratios (ORs), and coefficients are scaled to represent the change in the outcome associated with a 10% change in ICU occupancy, turnover, or referral burden or a 1-percentage point change in the mean census MPM₀-III-predicted hospital mortality. *P*-values <.05 were considered statistically significant.

All analyses were conducted using Stata version 14.2 (StataCorp LP, College Station, Texas). The ICED and the study protocol were approved by the Biomedical Research Ethics Administration of the University of the KwaZulu-Natal (Pietermaritzburg, South Africa). The study protocol was approved by the institutional review board (IRB) of the University of Pennsylvania (Philadelphia, Pennsylvania).

Results

Characteristics of Patients Referred and Admitted to the ICU

Five thousand three hundred thirty-two patients were referred for ICU admission at the 2 study hospitals during the study period, with 2630 (49.3%) patients admitted to an ICU. Admitted patients compared with patients declined for admission were more likely to be referred for trauma (33.0% vs 22.8%), and require invasive mechanical ventilation at the time of referral (61.8% vs 23.0%), and be assessed as Society of Critical Care Medicine (SCCM) ICU Triage Priority I (59.5% vs 9.8%, ie, “[C]ritically ill, unstable patients in need of intensive treatment and monitoring that cannot be provided outside of the ICU. Usually, these treatments include ventilator support, continuous vasoactive drug infusions, etc”¹⁸). Patients admitted and declined for admission were similar in gender (46.7% vs 47.6% female), race (88.0% vs 87.2% black), and rates of human immunodeficiency virus (HIV) infection (19.3% vs 20.6%) and highly active antiretroviral therapy (HAART) treatment status (74.4% vs 70.7%). Table 1 illustrates characteristics of the study patients overall and by ICU triage decision.

In-ICU Outcomes

Patients admitted to the ICU had a median ICU LOS of 2.2 days (IQR: 1.0–4.8) and an ICU mortality of 15.0% (17.5% when including palliative ICU discharges). Among 2219 patients discharged alive, 91 (4.1%) were discharged early (expedited ICU discharge due to patient flow demands, as judged by ICU clinicians) and 66 (3.0%) had a palliative ICU discharge (transition to comfort-focused care and transfer to the ward with death expected imminently). In-ICU outcomes were similar between study hospitals. Table 2 illustrates outcomes among patients admitted to the ICU.

Intensive Care Unit Capacity Strain Metrics

During the study period, ICU occupancy, turnover, and referral burden were higher at hospital B, but there was similar ICU census acuity at the 2 hospitals. eTables 1–3 summarize the ICU capacity strain metrics by hospital relative to the study population ICU referral, admission, and discharge time points.

Association of ICU Capacity Strain and ICU LOS

No measure of ICU capacity strain at the time of ICU admission, adjusted for patient-level covariates, was associated with ICU LOS for the index patient, the primary outcome (Table 3). Among patient-level covariates, prereferral hospital LOS, chronic respiratory disease, HIV-positivity (with or without HAART), and MPM₀-III-predicted hospital mortality were associated with shorter ICU LOS, while male gender was associated with a longer ICU LOS.

In secondary analyses, ICU occupancy at the time of ICU discharge was associated with increased ICU LOS ($e^{\beta}-1 = 0.04$, 95% confidence interval [CI]: 0.02–0.07; $P < .001$) and ICU turnover in the 24 hours before ICU discharge was associated with reduced ICU LOS ($e^{\beta}-1 = -0.14$, 95% CI: -0.16 to -0.11; $P < .001$) of the index patient, both adjusted for patient-level covariates. For example, compared to a patient with the study median 2.2-day (53.3-hour) ICU LOS, a patient with a 10% higher ICU occupancy at the time of ICU discharge (eg, one additional patient in a 10-bed ICU) would be expected to have a 2.4-hour (4%) longer ICU LOS, and a patient with a 10% higher ICU turnover in the 24 hours before ICU discharge (eg, one additional admission in a 10-bed ICU) would be expected to have a 7.5-hour (14%) shorter ICU LOS. The ICU census acuity at the time of ICU discharge ($e^{\beta}-1 = -0.17$, 95% CI: -0.68 to 1.17; $P = .70$) and ICU referral burden on the calendar day of ICU discharge ($e^{\beta}-1 = 0.01$, 95% CI: -0.01 to 0.04; $P = .35$), both adjusted for patient-level covariates, were not associated with ICU LOS of the index patient (Table 4).

Association of ICU Capacity Strain and ICU Mortality

The ICU occupancy at the time of ICU admission, adjusted for patient-level covariates, was associated with increased odds of ICU mortality for the index patient (OR = 1.07, 95% CI: 1.02–1.11; $P = .004$), such that a 10% increase in ICU occupancy at the time of ICU admission would be associated with a 7% increased odds of ICU mortality for the index patient. The ICU turnover in the 24 hours after ICU admission (OR = 0.97, 95% CI: 0.90–1.04; $P = .33$), ICU census acuity at the time of ICU admission (OR = 1.15, 95% CI: 0.11–11.82; $P = .91$), and ICU referral burden on the calendar day of ICU admission (OR = 1.01, 95% CI: 0.96–1.06; $P = .76$), all adjusted for patient-level covariates, were not associated with ICU mortality for the index patient (Table 4). Similar associations persisted when stratified by ICU admission diagnosis (ie, trauma, infection, or nontrauma/noninfection; eTable 4).

Association of ICU Capacity Strain and ICU Triage Decision

The ICU turnover on the calendar day of ICU referral, adjusted for patient-level covariates, was associated with increased odds of ICU admission for the index patient (OR = 1.03, 95% CI: 1.03–1.03; $P < .001$). The ICU referral burden on the calendar day of ICU referral, adjusted for patient-level covariates, was associated with decreased odds of ICU admission for the index patient (OR = 0.66, 95% CI: 0.64–0.69; $P < .001$). The ICU occupancy on the calendar day of ICU referral (OR = 1.00, 95% CI: 0.97–1.02; $P = .79$) and ICU census acuity on the calendar day of ICU referral (OR = 1.05, 95% CI: 0.22–5.05; $P = .96$), both adjusted for patient-level covariates, were not associated with ICU admission for the index patient (Table 4).

Stratification by Hospital

When stratified by hospital, the models for ICU LOS (primary and secondary outcomes) and ICU triage decision demonstrated consistent results with no changes in significance compared to the pooled analyses. The models for ICU mortality maintained significance for ICU occupancy at hospital A (OR = 1.13, 95% CI: 1.01–1.26; $P = .03$) and lost significance for ICU occupancy at hospital B but with a similar point estimate (OR = 1.04, 95% CI: 0.99–1.10; $P = .10$), and were otherwise unchanged (eTable 5).

Discussion

In a resource-limited setting in South Africa, multiple previously studied ICU capacity strain metrics were not associated with ICU LOS, the primary outcome. In secondary analyses, higher ICU occupancy at the time of ICU admission, but not other measures of capacity strain, was associated with increased odds of ICU mortality with an effect similar to prior findings in resource-rich settings.³

At the time of ICU referral, ICU turnover was associated with increased odds of ICU admission, which may represent periods dominated by shorter stay elective surgical admissions during which the ICU is busier but has a higher “rolling capacity.” In contrast, ICU referral burden at the time of ICU referral (ie, a higher number of simultaneously referred patients) was associated with decreased odds of ICU admission. The likely causal pathway here has clear face validity: a patient is less likely to be admitted to a scarce ICU bed when competing with a greater number of simultaneously referred patients for that bed.

At the time of ICU discharge, ICU turnover was associated with reduced ICU LOS while ICU occupancy was associated with an increased ICU LOS. Higher levels of strain may alternatively motivate more discharges⁴ or delay discharges due to clinician time constraints, but we cannot determine from this study what differences between these types of strain at ICU discharge might explain their observed divergent associations with ICU LOS.

Human immunodeficiency virus infection rates in the study population appear consistent with the 18.9% national HIV infection prevalence among South African adults aged 15 to 49 years,¹⁹ although not all patients were tested. Patients admitted to the ICU had only slightly higher MPM₀-III-predicted hospital mortalities than patients declined for ICU admission (10.5% vs 9.2%). This likely reflects patients being declined for ICU admission both for being deemed too well for ICU care (SCCM ICU Triage Priority IVA) who have low predicted mortality and also for being deemed too sick to benefit from ICU care (SCCM ICU Triage Priority IVB) who have very high predicted mortality.

Observed ICU mortality in our study was notably low (15.0%, or 17.5% including palliative discharges) compared to prior reported literature from resource-limited regions.^{7,20} This may be explained by comparatively better resources in South Africa than in other studied resource-limited settings, measurement of ICU mortality rather than hospital or 30-day mortality (due to availability in the database), a high proportion of surgical admissions (80.0%), or, relatedly, evidence of robust gate-keeping by ICU clinicians at the study hospitals to select for patients with reversible pathology, for example based on SCCM ICU

Triage Priority. The high proportion of surgical admissions likely reflects both this gatekeeping to allocate ICU beds to patients perceived to have reversible pathology (common but not universal among ICUs in resource-limited settings) as well as the high surgical volume of the study hospitals, which serve a large urban/suburban area in addition to patients referred for surgery from surrounding district and community hospitals. In prior studies in resource-rich settings, the association of ICU capacity strain with mortality had a stronger point-estimate among medical, rather than surgical patients, but with no overall significant difference between ICUs of different medical/surgical patient case-mix.³ The MPM₀-III model includes a variable for medical or unscheduled surgical admission; in a sensitivity analysis, we repeated our models for ICU LOS and ICU mortality with inclusion of an additional medical/surgical covariate which showed similar results to the original models (eTable 6).

The difference between the MPM₀-III predicted hospital mortality (10.5%) and the observed ICU mortality (17.5%) may reflect that MPM₀-III, like other acute risk adjusters developed and validated in resource-rich settings, does not fully capture acute severity in a resource-limited setting,²¹ as well as any under-recording of MPM₀-III variables in the database.

Overall, our study is consistent with research from resource-rich settings demonstrating that ICU capacity strain has modest associations with clinical outcomes such as ICU mortality but stronger associations with processes of care such as triage decisions and discharge timing.

Limitations

The main strength of this study is the novel assessment of ICU capacity strain metrics and their behaviors in a resource-limited setting. South Africa's public health system and other resource-limited settings have the greatest need for more efficient and effective resource allocation strategies, yet have lacked rigorous capacity strain research to inform such policies. This study also examined a novel strain metric—ICU referral burden—appropriate to resource-limited settings where there is a greater mismatch in the demand and supply of critical care resources and ICU clinicians may have greater gatekeeping privileges.

The findings of this study should be interpreted in the context of a number of important limitations. First, calculations of strain metrics are based on assumptions of maximum ICU bed capacity that may in reality be more dynamic, based in particular on changes in ICU nurse staffing and “functional beds,”²² than could be captured in our study. Furthermore, while the fidelity of the utilized database is likely superior to that often available outside of resource-rich settings, it remains with the caveats of retrospective data entered by busy clinicians in a resource-limited setting. There may be unmeasured missingness or inaccuracies in specific data fields or whole referral records unknown to the investigators. Our findings should be replicated when superior retrospective or prospective databases are available, in particular those that record real-time ICU nurse staffing.

Second, while South Africa is decidedly resource-limited compared to resource-rich regions, it is wealthy by comparison to its sub-Saharan African neighbors,¹³ and the study's findings may not be relevant or applicable to extremely low-resourced regions where critical care is

wholly different or entirely absent.²³ The study also included only 2 ICUs from 2 hospitals within close geographic proximity in a single country, which limits generalizability.

Third, the use of MPM₀-III as an acute risk adjuster is imperfect. Risk adjustment using MPM₀-III-predicted hospital mortality, which is based on data at the time of ICU admission, does not account for longitudinal changes in clinical status after admission and therefore is a less accurate measure than if daily physiologic data were available. Although our use of multiple imputation for the MPM₀-III missingness is superior to complete case or single imputation approaches, it cannot guarantee the absence of bias especially with the high level of missingness in our study. Additionally, MPM₀-III, like most other acute risk adjusters, has been developed and validated in resource-rich settings and may not fully capture acute severity in a resource-limited setting.²¹

Finally, the database restricted our analysis to in-ICU outcomes, as patients were not followed longitudinally after ICU discharge.

Conclusions

In a resource-limited setting in South Africa, ICU capacity strain at the time of ICU admission was not associated with ICU LOS, the primary outcome. In secondary analyses, higher ICU occupancy at the time of ICU admission, but not other measures of capacity strain, was associated with increased odds of ICU mortality with an effect similar to prior findings in resource-rich settings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Figure 1.
Conceptual model and analytic plan.

Table 1.

Study Population Characteristics by ICU Admission Status.^a

Characteristics	All Referred (N = 5332)	Declined (n = 2702; 50.7%)	Admitted (n = 2630; 49.3%)
Age, mean years (SD)	41.7(19.0)	43.4 (19.4)	40.0 (18.4)
Among age 18	43.5 (18.1)	44.8 (18.7)	42.2 (17.4)
Female, n (%)	2507 (47.1)	1280 (47.6)	1227 (46.7)
Race, n (%)			
Black	4593 (87.6)	2309 (87.2)	2284 (88.0)
White	226 (4.3)	124 (4.7)	102 (3.9)
Asian and South Asian	339 (6.5)	173 (6.5)	166 (6.4)
Colored ^b	85 (1.6)	41 (1.6)	44 (1.7)
Hospital, n (%)			
Hospital A	2139 (40.1)	982 (36.3)	1157 (44.0)
Hospital B	3193 (59.9)	1720 (63.7)	1473 (56.0)
Referring specialty, n (%)			
Surgical	4265 (81.9)	2143 (80.8)	2122 (83.0)
Medical	944(18.1)	511 (19.3)	433 (17.0)
Prereferral hospital LOS, median days (IQR)	1 (0–2)	1 (0–2)	0 (0–2)
ICU readmission, n (%)	235 (5.2)	87 (4.0)	148 (6.5)
SCCM ICU triage priority, n (%)			
I (needs ICU-specific therapy) ^c	1545 (35.0)	214 (9.8)	1331 (59.5)
II (needs intensive monitoring)	838 (19.0)	131 (6.0)	707 (31.6)
III (less likely to benefit from ICU)	241 (5.5)	66 (3.0)	175 (7.8)
IVA (too well to benefit from ICU)	1229 (27.8)	1208 (55.3)	21 (0.9)
IVB (too sick to benefit from ICU)	568 (12.9)	564 (25.8)	4 (0.2)
Invasive mechanical ventilation at time of referral, n (%)	1387 (30.8)	508 (23.0)	1421 (61.8)
Referral diagnosis type, n (%)			
Trauma	1273 (28.0)	506 (22.8)	767 (33.0)
Infection	1105 (24.3)	571 (25.7)	534 (23.0)

Characteristics	All Referred	Declined	Admitted
	(N = 5332)	(n = 2702; 50.7%)	(n = 2630; 49.3%)
Nontrauma/noninfection	2170 (47.7)	1147 (51.6)	1023 (44.0)
HIV positive	1064 (20.0)	556 (20.6)	508 (19.3)
on HAART	771 (72.5)	393 (70.7)	378 (74.4)
MPM ₀ -III-predicted hospital mortality %, mean (SD)	9.9 (11.9)	9.2 (12.0)	10.5 (11.8)

Abbreviations: HAART, highly active antiretroviral therapy; HIV, human immunodeficiency virus; ICU, intensive care unit; IQR, interquartile range; LOS, length of stay; MPM, Mortality Probability Model; SCCM, Society of Critical Care Medicine; SD, standard deviation.

^aReported values and percentages based on complete cases for that variable.
^bAn accepted South African ethnorracial group originating in colonial South Africa with ancestry from Europe, Africa, and Asia.
^cMechanical ventilation, continuous vasoactive drug infusions, and so on.

Table 2.

Outcomes Among Patients Admitted to the ICU.

Outcomes	All Admitted	Hospital A	Hospital B
ICU LOS, median days (IQR)	2.2 (1.0–4.8)	2.3 (1.2–4.7)	2.1 (0.9–4.8)
ICU discharge disposition, n (%)			
Dead	390 (15.0)	163 (14.1)	227 (15.6)
Alive	2219 (85.1)	990 (85.9)	1229 (84.4)
Early discharge ^a	91 (4.1)	20 (2.0)	71 (5.8)
Palliative discharge ^b	66 (3.0)	24 (2.4)	42 (3.4)

Abbreviations: ICU, intensive care unit; IQR, interquartile range; LOS, length of stay.

^aExpedited ICU discharge due to patient flow demands.^bShift to comfort-focused care and transfer to the ward with death expected imminently.

Table 3.Association of ICU Capacity Strain at ICU Admission With Primary Outcome ICU LOS.^a

Variables ^b	ICU LOS ^c	
	HR (95% CI)	P Value
ICU occupancy	1.03 (0.99–1.07)	.13
ICU turnover	1.00 (0.94–1.06)	.93
ICU census acuity	2.28 (0.28–18.34)	.44
ICU referral burden	0.98 (0.94–1.03)	.50
Age	1.01 (1.00–1.02)	.004 ^d
Male gender	0.77 (0.63–0.94)	.01 ^d
Race (ref: Black)		
White	1.20 (0.75–1.95)	.45
Asian and South Asian	1.14 (0.79–1.65)	.48
Colored ^e	1.04 (0.55–1.98)	.91
Hospital B (ref: A)	0.94 (0.73–1.22)	.66
Pre-referral hospital LOS	1.02 (1.00–1.03)	.04 ^d
Chronic respiratory disease	1.63 (1.10–2.43)	.02 ^d
HIV status (ref: negative)		
HIV positive on HAART	1.46 (1.11–1.92)	.01 ^d
HIV positive off HAART	1.04 (1.04–2.32)	.03 ^d
MPMo-III-predicted hospital mortality	3.67 (1.70–7.94)	.001 ^d

Abbreviations: CI, confidence interval; HAART, highly active antiretroviral therapy; HIV, human immunodeficiency virus; HR, hazard ratio; ICU, intensive care unit; LOS, length of stay; MPM, Mortality Probability Model.

^aResults for ICU occupancy, ICU turnover, and ICU referral burden represent a 10% increase in the tested strain metric; results for ICU census acuity represent a 1-percentage point increase in the census mean MPMo-III-predicted hospital mortality.

^bNot shown (all $P > .05$): year, cardiovascular disease, diabetes, hematologic malignancy, neurological disease, and non-HIV-related immunosuppression.

^cPrimary outcome; n = 2533.

^d $P < .05$.

^eAn accepted South African ethnoracial group originating in colonial South Africa with ancestry from Europe, Africa, and Asia.

Table 4.

Association of ICU Capacity Strain With Secondary Outcomes ICU LOS, ICU Mortality, and ICU Triage Decision.^a

Variables ^b	Secondary Outcomes					
	ICU Triage Decision ^c		ICU Mortality ^d		ICU LOS ^e	
	Strain at ICU Referral		Strain at ICU Admission		Strain at ICU Discharge	
	OR (95% CI)	P Value	OR (95% CI)	P Value	$e\beta$ -1 (95% CI) ^e	P Value
ICU occupancy	1.00 (0.97–1.02)	.79	1.07 (1.02–1.11)	.004 ^f	0.04 (0.02 to 0.07)	<.001 ^f
ICU turnover	1.03 (1.03–1.03)	<.001 ^f	0.97 (0.90–1.04)	.33	–0.14 (–0.16 to –0.11)	<.001 ^f
ICU census acuity	1.05 (0.22–5.05)	.96	1.15 (0.11–11.82)	.91	–0.17 (–0.68 to 1.17)	.70
ICU referral burden	0.66 (0.64–0.69)	<.001 ^f	1.01 (0.96–1.06)	.76	0.01 (–0.01–0.04)	.35

Abbreviations: CI, confidence interval; ICU, intensive care unit; LOS, length of stay; MPM, Mortality Probability Model; OR, odds ratio.

^aResults for ICU occupancy, ICU turnover, and ICU referral burden represent a 10% increase in the tested strain metric; results for ICU acuity represent a 1-percentage point increase in the census mean MPM0-III-predicted hospital mortality. β coefficients are back-transformed to reflect a proportional change in ICU LOS in hours.

^bPatient-level covariates not shown.

^cAmong all ICU referrals; n = 5098.

^dAmong ICU admissions; n = 2517.

^eAmong ICU survivors; n = 2089.

^fP < .05.