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ORIGINAL RESEARCH

Transition From an Open to Closed Staffing Model in the Cardiac Intensive Care Unit Improves Clinical Outcomes

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BACKGROUND: Several studies have shown improved outcomes in closed compared with open medical and surgical intensive care units. However, very little is known about the ideal organizational structure in the modern cardiac intensive care unit (CICU).

METHODS AND RESULTS: We retrospectively reviewed consecutive unique admissions (n=3996) to our tertiary care CICU from September 2013 to October 2017. The aim of our study was to assess for differences in clinical outcomes between an open compared with a closed CICU. We used multivariable logistic regression adjusting for demographics, comorbidities, and severity of illness. The primary outcome was in-hospital mortality. We identified 2226 patients in the open unit and 1770 in the closed CICU. The unadjusted in-hospital mortality in the open compared with closed unit was 9.6% and 8.9%, respectively (P=0.42). After multivariable adjustment, admission to the closed unit was associated with a lower in-hospital mortality (odds ratio [OR], 0.69; 95% CI: 0.53–0.90, P=0.007) and CICU mortality (OR, 0.70; 95% CI, 0.52–0.94, P=0.02). In subgroup analysis, admissions for cardiac arrest (OR, 0.42; 95% CI, 0.20–0.88, P=0.02) and respiratory insufficiency (OR, 0.43; 95% CI, 0.22–0.82, P=0.01) were also associated with a lower in-hospital mortality in the closed unit. We did not find a difference in CICU length of stay or total hospital charges (P>0.05).

CONCLUSIONS: We found an association between lower in-hospital and CICU mortality after the transition to a closed CICU. These results may help guide the ongoing redesign in other tertiary care CICUs.

Key Words: acute cardiovascular care ■ healthcare delivery ■ intensive care

The coronary care unit was initially created to care for patients with acute coronary syndrome and those requiring arrhythmia monitoring.[1] Over the past several decades, there has been an evolution in the modern cardiac intensive care unit (CICU), as patients frequently have multiple cardiac and noncardiac comorbidities, require complex ICU procedures and therapies, and develop multiorgan failure.[2–4] Despite this shift in patient complexity and case-mix, the organizational structure and delivery of care has lagged to meet these challenges.[5,6] As the population ages and newer technologies become available to treat previously terminal diseases,[7] the complexity and volume in the CICU will likely increase.[5]

In the United States, nearly 75% of CICUs have an “open” staffing model, where multiple attending physicians are admitting and managing patients, as opposed to a “closed” unit where there is a dedicated team or teams caring for the entire unit.[8] In comparison, several studies in the medical and surgical ICUs have described improved outcomes after transition to a closed staffing model.[9–14] In addition to reductions

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CLINICAL PERSPECTIVE

What Is New?

- Compared with an open staffing model, transition to a closed unit was associated with lower in-hospital and cardiac intensive care unit (CICU) mortality.
- Admissions to the CICU, primarily for cardiac arrest, respiratory insufficiency, and patients with higher severity of illness, were similarly associated with lower in-hospital and CICU mortality.

What Are the Clinical Implications?

- While the medical complexity of patients admitted to the contemporary CICU continues to increase, very few changes have been made to the organizational structure or staffing models. In the United States, the majority of CICUs are still open units, which represents a potential area of care improvement.
- Larger, multicenter studies are needed to assess for the optimal delivery of critical care in the modern CICU.

Nonstandard Abbreviations and Acronyms

CICU	cardiac intensive care unit

in mortality, closed units have been associated with several improvements in efficiency and quality, such as shorter lengths of stay and fewer nosocomial infections.[11,15]

Given that there are few studies assessing the ideal staffing models in the CICU, we aimed to assess for associations between our transition from an open to a closed CICU with clinical outcomes, including mortality, length of stay, utilization of ICU therapies, and total hospital charges.

METHODS

The authors declare that all the supporting data are available within the article and its online supplementary files, and additional data will not be made available to other researchers. The Institutional Review Board of Yale University approved the study. Because of the retrospective nature of our study, informed consent was waived.

Study Population

Yale New Haven Hospital is a 1541-bed tertiary care center, and the primary teaching hospital of the Yale School of Medicine. It operates a 14-bed CICU that manages and monitors patients with complex cardiovascular disease. In order to address the increasing complexity of patients admitted to the CICU, physician and nursing leadership decided to close the unit to minimize variability of care. Simultaneously, the university and several private groups merged, creating the opportunity to create a group of dedicated CICU providers.

Before November 2015, patients were managed in an open unit by their admitting cardiologist, which included various university-based cardiovascular subspecialties, as well as several private cardiology groups (Figure 1). Following this, the CICU transitioned to a 2-team closed unit, where patients were managed by either a heart failure or interventional team with rare exception. Intensivist consultation was available 24 hours a day during both time periods. During the day, 1 of 3 resident teams cared for each CICU patient, in addition to patients on the cardiac stepdown unit. At night, a cardiology fellow was available in-house with an on-call attending at home. Other than closure of the CICU, there were no organizational, staffing, or consultative changes throughout the study period. Specifically, there were no differences in training or expertise between attending physicians, changes in nurse-to-patient ratio, admission criteria, or changes to CICU directorship or nursing leadership during either study period.

Data Source

We identified consecutive CICU patients from September 6, 2013 to October 10, 2017. The Yale New Haven Hospital Joint Data Analytics Team extracted detailed patient-level characteristics from the electronic medical record. We were able to identify the majority of postdischarge outcomes, including 30-day and 1-year mortality, by leveraging the large catchment area of the Yale New Haven Health system, which includes 5 hospitals and >1000 locations spanning from New York to Massachusetts. Although a majority of variables were extracted from the electronic health record, we also conducted a detailed chart review to ensure accuracy. Specifically, trained abstractors reviewed each chart (P.E.M., A.T., Y.K., F.A.) for medical comorbidities, procedures only completed in the CICU, and primary indication for CICU admission.

Variables of Interest

Covariates of interest included patient demographics (age, sex, and race), body mass index, medical comorbidities, history of tobacco use (yes/no), hospital admission source (emergency department, other hospital, direct admission, and postprocedure), discharge disposition (home, hospice, skilled nursing facility or rehab, against medical advice, died, and other), primary CICU admission indication, severity of illness score (first CICU Rothman Index), total hospital charges, and in-hospital procedures. If a patient was readmitted back to the CICU during the same admission, procedures and additional CICU days accrued from CICU readmissions were included.

The Rothman Index is a measure of illness severity that incorporates 26 clinical measurements extracted from the electronic medical record. Components of the Rothman Index include vital signs, laboratory values, nursing assessment, and cardiac rhythm (Table S1). Scores range from −91 (high illness severity) to 100 (low illness severity).[16] The Rothman Index has been validated in a variety of populations and has been shown to correlate with the APACHE III (Acute Physiology, Age, Chronic Health Evaluation) score, length of stay, mortality,[16–18] and strongly correlated with in-hospital mortality in our analysis (C-statistic=0.84).

Exposure and Outcomes

Our exposure of interest was admission to the open compared with the closed CICU physician staffing structure. The primary outcome was in-hospital mortality. Secondary outcomes included CICU mortality, CICU and hospital length of stay, utilization of ICU procedures and therapies, and total hospital charges. For patients who survived the hospitalization, postdischarge mortality was assessed at 30 days and 1 year as an exploratory end point. In addition, we compared in-hospital mortality for 4 a priori selected CICU admission indications based on the frequent need for ICU therapies to treat these conditions.[2] Cardiac arrest diagnoses included out-of-hospital and in-hospital events, all of which occurred before CICU admission. Respiratory insufficiency was defined as admissions requiring noninvasive (bilevel or continuous positive pressure) or invasive mechanical ventilation.

Statistical Analysis

Continuous variables were described as means and SD and categorical variables were described as frequencies and percentage. The *t* test was used for continuous variables and χ^2 test for categorical variables. Using logistic regression modeling, we assessed the association between the transition from an open to a closed CICU with in-hospital mortality. We included a liberal threshold of $P<0.20$ with purposeful selection as well as known variables of interest in our multivariable model. The final regression model included age, sex, body mass index, CICU admission indication, diabetes mellitus, coronary artery disease, left ventricular assist device, heart failure, coronary artery bypass grafting, end-stage renal disease, chronic kidney disease, peripheral vascular disease, pulmonary hypertension, chronic lung disease, cancer, permanent pacemaker or implantable cardioverter defibrillator, atrial fibrillation or flutter, first CICU Rothman Index, and tobacco use. To minimize the risk of survival and treatment biases associated with repeat admissions, only the patients' first CICU admission was included in the final analysis. To account for potentially artificially shortened lengths of stay because of transfer, death, or leaving against medical advice, we utilized the log-rank test to assess for differences in CICU and hospital length of stay. In addition, we used the Cox proportional hazard model for our adjusted length of stay analysis. All secondary outcomes were completed with the same multivariable model. We used postestimation methods to test final regression model fit with our primary outcome of in-hospital mortality (C-statistic=0.89).

In addition, we performed several sensitivity analyses to confirm the robustness of our findings. First, we repeated our analysis for patients with high severity of illness scores (Rothman Index ≤40). Second, in order to give each admission an equal chance of inclusion, we conducted a sensitivity analysis where 1 hospitalization (n=3996) was randomly selected for patients with 2 or more admissions.[19] Third, for our postdischarge outcomes, we repeated our analysis excluding those discharged to hospice (n=3899). Finally, in order to exclude temporal trends as a potential explanation for our findings, we predicted the in-hospital mortality using linear regression of the open unit and compared it with the observed in-hospital mortality for the first year after closure (2016). All sensitivity analyses were adjusted for the same covariates as the primary analysis.

Since the study period continued over several years, charges were inflation adjusted to the year 2017.[20] All analyses were performed on STATA 16.0 (Stata Corp, College Station, TX) with statistical significance considered at a 2-tailed $P<0.05$. Graphics were produced by GraphPad Prism version 8.3.0 (GraphPad Software, La Jolla, CA).

RESULTS

We identified 3996 unique consecutive admissions, which included 2226 patients in the open unit and 1770 patients in the closed unit. Demographics, including age, sex, race, and first mean CICU Rothman Index were similar between groups ($P>0.05$, all) (Table 1). Patients in the closed unit were more likely to have higher acuity admissions (Rothman Index ≤40 [$P=0.01$] and ≤20 [$P<0.001$]). Comorbidities, including chronic lung, kidney, and liver disease were similar between staffing models ($P>0.05$). The most 5 most

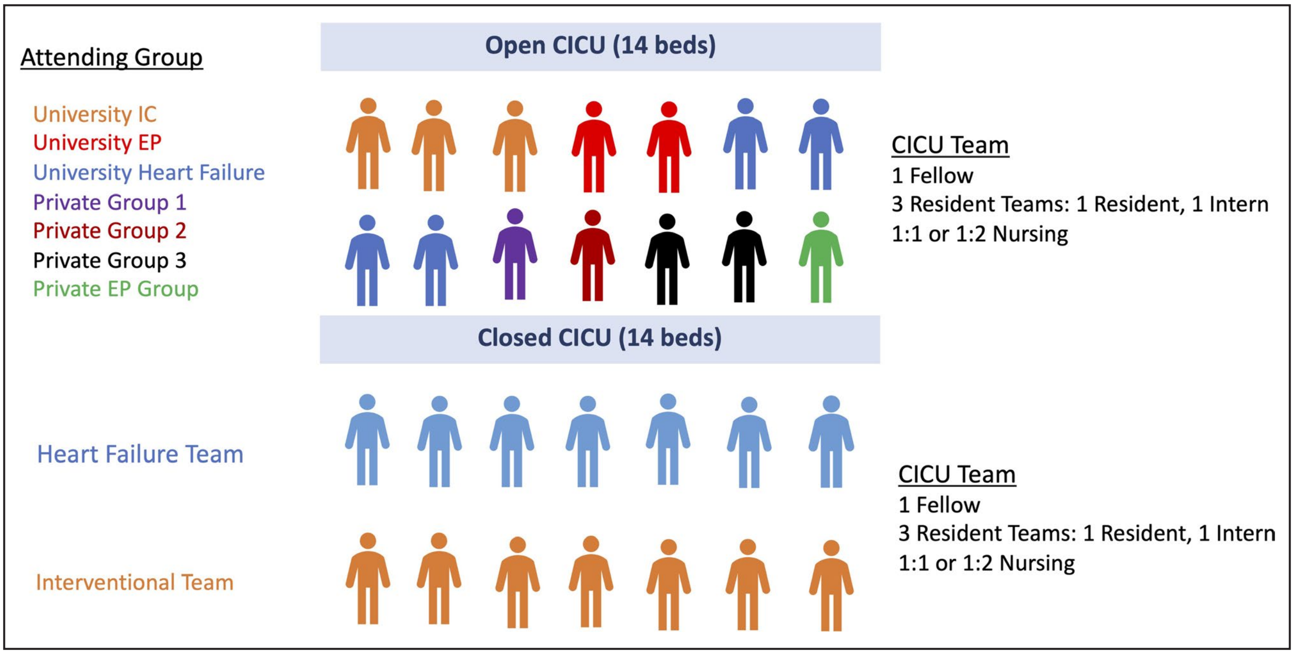

Figure 1. Organizational staffing change in the cardiac intensive care unit*.
*Example staffing. CICU indicates cardiac intensive care unit.

common CICU admissions included ST-segment–elevation myocardial infarction (15.0%) followed by postprocedural monitoring (12.2%), decompensated heart failure (11.1%), respiratory insufficiency (10.4%), and non-ST–segment myocardial infarction (9.5%). Cardiogenic shock and cardiac arrest represented 7.1% and 6.4% of admissions, respectively (Table 2). Cardiac arrest (5.6% versus 7.6%, *P*=0.02) and ST-segment–elevation myocardial infarction were more common in the closed unit, whereas respiratory insufficiency (11.3% versus 9.2% *P*=0.03) was more common in the open unit. Coronary angiography and percutaneous coronary intervention, and bronchoscopy were slightly more common in the closed unit (all *P*<0.05) while all other CICU procedures and therapies showed similar frequencies between time periods (*P*>0.05, all) (Table 3).

Outcomes

The unadjusted in-hospital mortality in the open compared with the closed unit was 9.6% (n=214) and 8.9% (n=157), respectively (*P*=0.42). The CICU mortality in the open unit was 7.3% (n=162) compared with 6.9% (n=122) in the closed unit (*P*=0.64). After multivariable adjustment, admission to the closed CICU was associated with a lower in-hospital mortality (odds ratio [OR], 0.69; 95% CI, 0.53–0.90, *P*=0.007) and CICU mortality (OR, 0.70; 95% CI, 0.52–0.94, *P*=0.02) (Figure 2). Excluding patients who died in the hospital, the postdischarge 30-day mortality (OR, 0.75; 95% CI, 0.54–1.06, *P*=0.10) and 1-year mortality (OR, 0.93; 95% CI, 0.76–1.14, *P*=0.47) were not statistically different.

In the subgroup, multivariable analysis stratified by CICU indication, admission for cardiac arrest (OR, 0.42; 95% CI, 0.20–0.88, *P*=0.02), and respiratory insufficiency (OR, 0.43; 95% CI, 0.22–0.82, *P*=0.01) was associated with a lower in-hospital mortality in the closed CICU (Figure 3). Admission for decompensated heart failure favored the closed unit but was not statistically significant (OR, 0.64; 95% CI, 0.31–1.32, *P*=0.23). We did not find a difference in in-hospital mortality for patients presenting with cardiogenic shock (OR, 1.08; 95% CI, 0.57–2.06, *P*=0.81).

The median CICU length of stay was 2 days (interquartile range [IQR], 1–4 days, *P*=0.29) for both staffing models while the hospital length of stay was 6 days (IQR, 3–11 days) for the open unit and 5 days (IQR, 3–11 days) for the closed unit (*P*=0.14). After multivariable adjustment, there was no difference in the CICU length of stay (hazard ratio, 0.99; 95% CI, 0.93–1.06, *P*=0.95), but a slightly longer total hospital length of stay (hazard ratio, 1.09; 95% CI, 1.02–1.16, *P*=0.02). Discharge disposition was not significantly different between groups (*P*=0.12) (Table 4).

The median inflation-adjusted charges per patient were similar in the open ($28 588; IQR, $16 888–$58 222) compared with the closed unit ($28 537; IQR, $16 694–$60 738, *P*=0.75) (Table 4). Multivariable and inflation-adjusted total hospital charges were not significantly different between groups (change in estimate, $2657; 95% CI, –$2500 to $7814, *P*=0.31).

Table 1. Baseline Admission Characteristics Stratified by CICU Staffing Model

	Open Unit N=2226	Closed Unit N=1770	*P* Value
Age, y	68.5 (14.8)	68.8 (14.7)	0.53
Men	1407 (63.2%)	1112 (62.8%)	0.80
Race			0.62
Black	226 (10.2%)	164 (9.8%)	
White	1814 (81.5%)	1452 (82.0%)	
Other (Asian, American Indian or Alaskan Native, unknown)	186 (8.4%)	154 (8.7%)	
Body mass index, kg/m^2	28.8 (7.1)	28.8 (6.9)	0.80
Admission ejection fraction*	49 (33–60)	48 (33–60)	0.85
First CICU Rothman Index (RI)	60.9 (22.0)	59.6 (23.3)	0.07
RI ≤40	413 (18.7%)	384 (21.8%)	0.01
RI ≤20	110 (5.0%)	141 (8.0%)	<0.001
Comorbidities			
Hyperlipidemia	1453 (65.3%)	1168 (66.0%)	0.64
Diabetes mellitus	733 (32.9%)	576 (32.5%)	0.80
Hypertension	1616 (72.6%)	1312 (74.1%)	0.28
Coronary artery disease	1085 (48.7%)	852 (48.1%)	0.70
History of PCI	489 (22.5%)	439 (24.1%)	0.25
History of CABG	374 (16.8%)	253 (14.3%)	0.03
Severe valvular disease	398 (17.9%)	354 (20.0%)	0.09
Heart failure	988 (44.4%)	761 (43.0%)	0.38
LVAD	23 (1.0%)	10 (0.6%)	0.10
Congenital heart disease	15 (0.7%)	20 (1.1%)	0.12
OHT	18 (0.8%)	5 (0.3%)	0.03
Peripheral vascular disease	438 (19.7%)	338 (19.1%)	0.64
Chronic kidney disease	539 (24.2%)	408 (23.1%)	0.39
End-stage renal disease	73 (3.3%)	60 (3.4%)	0.85
Pulmonary hypertension	126 (5.7%)	92 (5.2%)	0.52
Chronic lung disease	407 (18.3%)	341 (19.3%)	0.43
Chronic liver disease	48 (2.2%)	45 (2.5%)	0.42
Cancer	469 (21.1%)	416 (23.5%)	0.07
VTE	167 (7.5%)	138 (7.8%)	0.73
Stroke/TIA	285 (12.8%)	225 (12.7%)	0.93
ICD/PPM	427 (19.2%)	289 (16.3%)	0.02
Atrial fibrillation/flutter	663 (29.8%)	517 (29.2%)	0.6

Data are presented as mean (SD) or median (interquartile range)* for continuous measures, and n (%) for categorical values. CABG indicates coronary artery bypass graft; CICU, cardiac intensive care unit; ICD, implantable cardioverter-defibrillator; LVAD, left ventricular assist device; OHT, orthotopic heart transplant; PCI, percutaneous coronary intervention; PPM, permanent pacemaker; TIA, transient ischemic attack; and VTE, venous thromboembolism.

Sensitivity Analysis

In sensitivity analysis, including only higher-acuity patients (Rothman Index ≤40), the in-hospital mortality in the open and closed CICU was 25.0% and 18.0%, respectively (*P*=0.39). Similarly, the CICU mortality was 16.0% and 18.0% (*P*=0.78). Multivariable results were similar to the primary findings (Table S2). Including only a randomly selected index admission (Table S3), the point estimates and findings were similar. Excluding patients discharged to hospice, the adjusted (OR, 0.64; 95% CI, 0.41–0.98, *P*=0.041) postdischarge 30-day mortality was lower in the closed unit (Table S4). In our analysis to exclude temporal trends as a potential explanation for the improved mortality in the closed unit, we found a statistically significant difference between the predicted (9.4%; 95% CI, 8.0–10.7%) and observed (7.3%) in-hospital mortality for the first year after CICU closure (*P*<0.001).

DISCUSSION

In this single-center, retrospective study, we assessed for differences in clinical outcomes after transition in

Table 2. Admission Indication Stratified by CICU Staffing Model

	Open Unit N=2226	Closed Unit N=1770	*P* Value
CICU admission diagnosis			
Cardiogenic shock	150 (6.7%)	134 (7.6%)	0.31
Cardiac arrest*	124 (5.6%)	134 (7.6%)	0.02
Ventricular tachycardia	100 (4.5%)	96 (5.4%)	0.18
Respiratory insufficiency†	252 (11.3%)	163 (9.2%)	0.03
STEMI‡	309 (13.9%)	289 (16.3%)	0.03
NSTEMI‡	226 (10.2%)	152 (8.6%)	0.09
Decompensated heart failure	260 (11.7%)	182 (10.3%)	0.16
Planned procedure	265 (11.9%)	222 (12.5%)	0.54
Infection	49 (2.2%)	42 (2.4%)	0.72
Bleeding	33 (1.5%)	16 (0.9%)	0.10
Atrial arrhythmia	83 (3.8%)	57 (3.1%)	0.23
Neurologic emergency‡	12 (0.6%)	6 (0.3%)	0.29
Hypertensive urgency	26 (1.2%)	32 (1.8%)	0.14
Unstable bradyarrhythmia or high-degree heart block§	123 (5.5%)	85 (4.8%)	0.31
Monitoring	134 (6.0%)	99 (5.6%)	0.57
Other‖	40 (1.8%)	35 (2.0%)	0.68

Data are presented as n (%). CICU indicates cardiac intensive care unit; NSTEMI, non-ST-segment–elevation myocardial infarction; and STEMI, ST-segment–elevation myocardial infraction.

*Includes out-of-hospital and in-hospital cardiac arrest before CICU admission.

†Requiring noninvasive (bilevel and continuous) or invasive mechanical ventilation.

‡Without cardiogenic shock or cardiac arrest.

§Type 2 second-degree or third-degree heart block.

‖Includes admissions for ICU protocols (eg, aspirin desensitization), implantable cardioverter defibrillator/permanent pacemaker lead revisions, and laboratory abnormalities requiring ICU care.

CICU organizational structure from an open to a closed unit. Patient comorbidities, procedural utilization, and CICU admission indications were similar between groups. We found that the transition from an open to a closed CICU was associated with a lower in-hospital and CICU mortality, despite higher acuity admissions (eg, cardiac arrest) and severity of illness scores in the closed unit. When stratified by CICU admission diagnosis, admissions to the CICU for cardiac arrest and respiratory insufficiency were associated with lower in-hospital mortality in the closed CICU. Postdischarge 30-day mortality and 1-year mortality were not statistically different between groups. Adjusted hospital length of stay was slightly lower in the open unit, but of unclear clinical significance. Finally, we did not find a difference in CICU length of stay or total hospital charges.

While our results are consistent with previous studies from medical and surgical ICUs,[9–14] the mechanism by which closed ICUs improve outcomes is likely multifactorial. Previous studies have shown that closed ICUs are associated with improved efficiency in the delivery of ICU therapies, such as mechanical ventilation,[11,12] nursing satisfaction and retention,[9,21] reduced healthcare-associated infections,[15,22] and communication and collaboration among ICU team members.[23] In addition, we hypothesize that the closed unit was associated with greater coordination and processes of care driven by improved attending availability, dedicated team-based rounds, more timely patient evaluation, and treatment initiation when a physician's main responsibility was to provide care in the CICU. However, it is difficult to know which of these elements may have influenced our findings the most.

Few studies have assessed staffing models in the CICU, and this is the first to show a mortality difference for closed CICUs. In a single-center study (n=670), Katz et al found that the transition to a closed unit was associated with a shorter CICU length of stay as well as improvement in nursing and resident perception of communication and collaboration.[23] There was no difference in CICU or in-hospital mortality, although the authors noted insufficient power for these outcomes. In a subsequent single-center study from South Korea (n=2431), Na et al reported that their transition from an open to a closed intensivist staffed unit was associated with a lower CICU mortality.[24] However, the applicability of this study to the United States is less clear. First, their transition to a closed unit included staffing with a cardiac intensivist (dual-boarded), in addition to a team with

Table 3. ICU Procedures and Therapies Stratified by CICU Staffing Model

	Open Unit N=2226	Closed Unit N=1770	*P* Value
Cardiac procedures			
Coronary angiography	889 (39.9%)	775 (42.3%)	0.01
PCI	606 (27.2%)	543 (20.7%)	0.02
RHC or pulmonary artery catheter	315 (14.2%)	225 (12.7%)	0.19
Central line	728 (32.7%)	534 (30.2%)	0.09
Arterial line	440 (19.8%)	351 (19.8%)	0.96
Pericardiocentesis	88 (4.0%)	65 (3.7%)	0.65
Intra-aortic balloon pump	152 (6.8%)	142 (8.0%)	0.15
Impella	12 (0.5%)	15 (0.8%)	0.24
Transcatheter valve replacement	167 (7.5%)	148 (8.4%)	0.32
Valvuloplasty	19 (0.9%)	14 (0.8%)	0.83
TTM	39 (1.8%)	34 (1.9%)	0.69
Permanent device	144 (6.5%)	119 (6.7%)	0.75
ICD	39 (1.8%)	35 (2.0%)	0.60
PPM	130 (5.8%)	102 (5.8%)	0.92
Cardioversion/defibrillation	122 (5.5%)	87 (4.9%)	0.43
Temporary pacemaker	120 (5.4%)	90 (5.1%)	0.67
Carotid stent	75 (3.4%)	46 (2.6%)	0.16
Surgical procedures*			
CABG	102 (4.6%)	66 (3.7%)	0.18
Heart transplantation	3 (0.1%)	7 (0.4%)	0.10
LVAD	25 (1.1%)	27 (1.5%)	0.26
ECMO	20 (0.9%)	11 (0.4%)	0.32
Surgical valve replacement	30 (1.3%)	23 (1.3%)	0.90
Noncardiac procedures			
NPPV	242 (10.9%)	203 (11.5%)	0.55
Mechanical ventilation	423 (19.0%)	331 (18.7%)	0.82
Ventilation time, d	1.5 (0.6–3.5)	1.39 (0.6–3.5)	0.68
Re-intubation	41 (9.7%)	22 (6.7%)	0.14
Endoscopy†	26 (1.2%)	20 (1.1%)	0.91
Thoracentesis	73 (3.3%)	62 (3.5%)	0.70
Bronchoscopy	7 (0.3%)	14 (0.8%)	0.04
CRRT	59 (2.7%)	46 (2.6%)	0.92

Data are presented as n (%). CABG indicates coronary artery bypass graft; CICU, cardiac intensive care unit; CRRT, continuous renal replacement therapy; ECMO, extracorporeal membrane oxygenation; ICD, implantable cardioverter-defibrillator; LVAD, left ventricular assist device; NPPV, noninvasive positive pressure ventilation; PCI, percutaneous coronary intervention; PPM, permanent pacemaker; RHC, right heart catheterization; and TTM, targeted temperature management.

*Procedures completed directly upon transfer out of the CICU.

†Colonoscopy and esophagogastroduodenoscopy.

a general cardiologist and intensivist. Second, mortality both before and after closure is much lower than most North American tertiary care CICUs.[25] Our study builds on this important work by including a substantially larger sample size in the United States, and being the first study, to our knowledge, to show a mortality difference. In addition, we extended our analyses to postdischarge outcomes, cost, and subgroup analysis of some of the more common and life-threatening indications for CICU admission.

Of the 4 subgroup admission indications, the closed unit was associated with a lower in-hospital mortality for patients presenting with cardiac arrest and respiratory insufficiency. In-hospital mortality for cardiogenic shock was not different between CICU care models. One potential explanation is the relatively limited development of effective treatment options for cardiogenic shock over the past several decades beyond early revascularization,[26] which would have been completed by the same interventional team during both time periods. In comparison, respiratory insufficiency is an increasing, but not traditionally common, indication for CICU admission, which has complicated and increasing treatment options.[2,27] Similarly, the treatment of

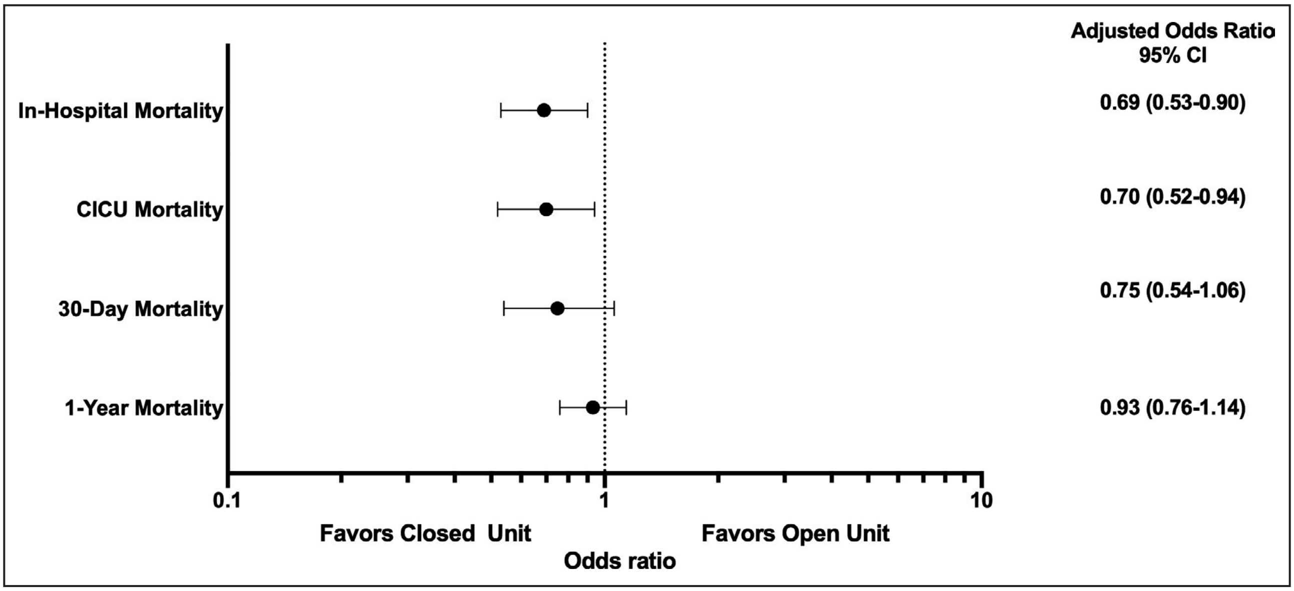

Figure 2. Forest plot of odds ratios for mortality outcomes.
CICU indicates cardiac intensive care unit.

cardiac arrest, while likely more familiar to the general cardiologist, has become increasingly complex.[28]

In 2012, a landmark scientific statement proposed a modern schema that categorized CICUs based on 3 levels of care. Analogous to American College of Surgeons trauma center designation,[29] level 1 CICUs were described as capable of caring for the most complicated patients with the most advanced therapies.[30] In addition, based on extrapolation from other ICUs,[9–13] a closed CICU was suggested as the preferred model of care based on expert consensus. We believe our findings further support these recommendations, in aggregate and in subgroup analyses, particularly for level 1 CICUs. Future multicenter studies are needed to further define the optimal organizational structure and staffing for the modern CICU.

Limitations

There are several limitations to our study, including being single-center and retrospective in nature. While patient populations and case-mix are known to vary between hospitals, the patient-mix, length of stay,

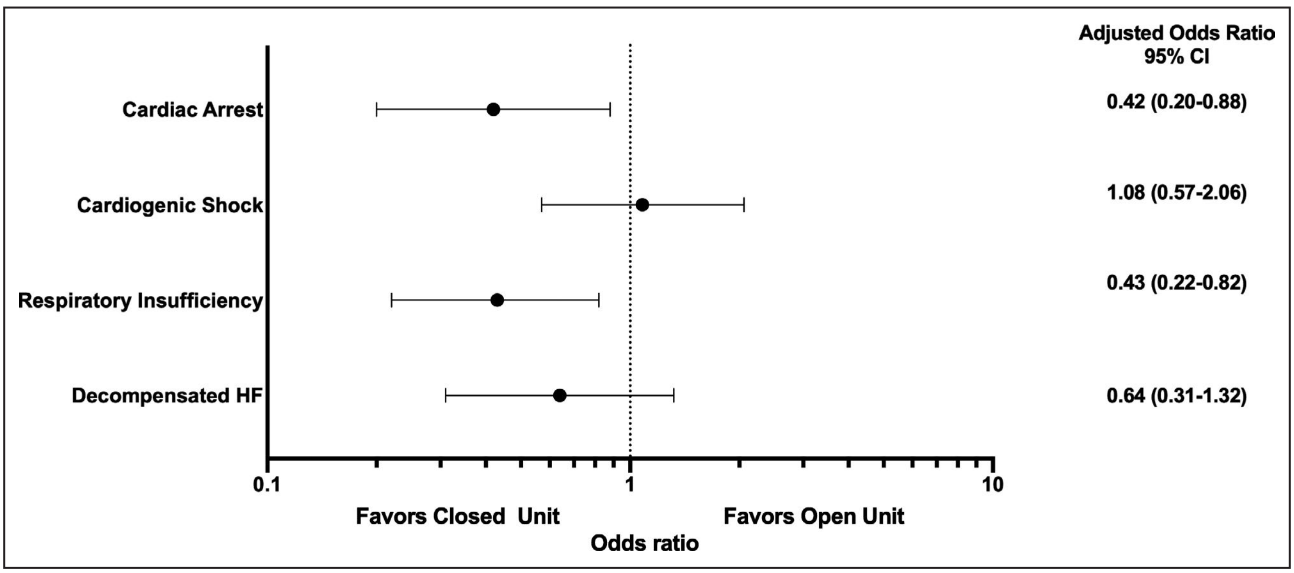

Figure 3. Forest plot of odds ratios for subgroup in-hospital mortality stratified by CICU indication.
CICU indicates cardiac intensive care unit; and HF, heart failure.

Table 4. Discharge Disposition and Total Hospital Charges Stratified by CICU Staffing Model

	Open Unit N=2226	Closed Unit N=1770	*P* Value
Discharge disposition			0.12
Home	1472 (66.1%)	1197 (67.6%)	
Nursing or rehab facility	471 (21.2%)	353 (19.9%)	
Hospice	45 (2.0%)	52 (2.9%)	
Against medical advice	12 (0.5%)	8 (0.5%)	
Died	214 (9.6%)	157 (8.9%)	
Other	12 (0.5%)	3 (0.2%)	
Total hospital charges*	\$28 588 (\$16 888–\$58 222)	\$28 537 (\$16 694–60 738)	0.75

Data are presented as n (%) for categorical values and median (interquartile range) for continuous measures. CICU indicates cardiac intensive care unit.
*Inflation adjusted to the year 2017.

procedural utilization, and both in-hospital and CICU mortality observed in our analysis were similar to a recent multicenter, contemporary analysis of tertiary care CICUs.[2] However, our results may not be applicable to non–tertiary care CICUs. Second, although the cohorts were very similar, there were some differences in the patient populations. Admission for respiratory insufficiency was more common in the open unit. However, the overall use of noninvasive and invasive mechanical ventilation during the CICU stay was not different between groups. Furthermore, the severity of illness scores were lower (representing higher illness severity), and cardiac arrest was more frequent in the closed unit. One potential explanation for these differences could be the expansion of our healthcare system and increasing proportion of sicker patients sent to our "hub" hospital (eg, more cardiac arrest). Third, we lack data on unit complications such as iatrogenic infections or cardiac arrest occurring after CICU admission. Fourth, we cannot entirely exclude the possibility of unmeasured changes in care, other than the change in staffing model, which may have influenced our findings. However, it is important to note that there were no changes in physician or nursing leadership, changes in nursing ratio, admission criteria, and physician experience. In addition, as a reference, there was no change in the cardiovascular mortality in the state of Connecticut over the study period.[31] Lastly, our closed model included 2 teams, which may not be possible or ideal at all centers.

CONCLUSIONS

We found that the transition to a closed CICU was associated with a lower in-hospital and CICU mortality. While our CICU model may not be translatable to all centers contemplating CICU redesign, we believe it offers a potential template, as well as much-needed evidence for care models of the modern CICU.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Material

Tables S1–S4

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Supplemental Material

Table S1. Components of the Rothman Index.

Vital signs
Temperature
Diastolic blood pressure
Systolic blood pressure
Pulse oximetry
Respiration rate
Heart rate
Nursing assessment of 11 organ systems
Nursing Braden score (Pressure ulcer assessment)
Laboratory tests
Creatinine
Sodium
Chloride
Potassium
BUN
WBC
Hemoglobin
Cardiac rhythm
Asystole
Sinus rhythm
Sinus bradycardia
Atrial fibrillation
Atrial flutter
Heart block
Junctional rhythm
Paced
Ventricular fibrillation
Ventricular tachycardia

Table S2. Clinical Outcomes Including Only Higher Acuity Patients*

n= 3,996	Unadjusted OR (95% CI)	*P* value	Adjusted OR (95% CI)	*P* value
In-Hospital Mortality	0.79 (0.59-1.09)	0.152	0.63 (0.44-0.90)	0.012
CICU Mortality	0.87 (0.63-1.21)	0.409	0.72 (0.49-1.05)	0.09
30-Day Mortality	0.83 (0.62-1.11)	0.211	0.77 (0.45-1.32)	0.342
1-Year Mortality	0.82 (0.62-1.10)	0.189	0.91 (0.60-1.36)	0.632

CICU = Coronary intensive care unit
*Note: Rothman index ≤ 40 (Odds ratio 10.5; 95% Confidence Interval: 8.32-13.4, *P*<0.001 in univariate analysis)

Adjusted model: Age, sex, body mass index, CICU admission cause, diabetes mellitus, coronary artery disease, previous left ventricular assist device, heart failure, coronary artery bypass grafting, end-stage renal disease, chronic kidney disease, peripheral vascular disease, pulmonary hypertension, chronic lung disease, cancer, permanent pacemaker or implantable cardioverter defibrillator, atrial fibrillation or flutter, first CICU Rothman Index, and tobacco use.

Table S3. Clinical Outcomes Including a Randomly Selected Index Admission.

n= 3,996	Unadjusted OR (95% CI)	*P* value	Adjusted OR (95% CI)	*P* value
In-Hospital Mortality	0.87 (0.71-1.07)	0.198	0.66 (0.51-0.85)	0.001
CICU Mortality	0.89 (0.70-1.13)	0.344	0.65 (0.49-0.87)	0.004
30-Day Mortality	0.87 (0.73-1.04)	0.126	0.73 (0.52-1.03)	0.072
1-Year Mortality	0.92 (0.80-1.07)	0.288	0.91 (0.74-1.12)	0.374

CICU = Coronary intensive care unit

Adjusted model: Age, sex, body mass index, CICU admission cause, diabetes mellitus, coronary artery disease, previous left ventricular assist device, heart failure, coronary artery bypass grafting, end-stage renal disease, chronic kidney disease, peripheral vascular disease, pulmonary hypertension, chronic lung disease, cancer, permanent pacemaker or implantable cardioverter defibrillator, atrial fibrillation or flutter, first CICU Rothman Index, and tobacco use.

Table S4. Post-Discharge Clinical Outcomes Excluding Patients Discharged to Hospice.

n= 3,881	Unadjusted OR (95% CI)	*P* value	Adjusted OR (95% CI)	*P* value
30-Day Mortality	0.69 (0.46-1.05)	0.086	0.64 (0.41-0.98)	0.041
1-Year Mortality	0.91 (0.75-1.11)	0.348	0.89 (0.72-1.11)	0.325

Adjusted model: Age, sex, body mass index, CICU admission cause, diabetes mellitus, coronary artery disease, previous left ventricular assist device, heart failure, coronary artery bypass grafting, end-stage renal disease, chronic kidney disease, peripheral vascular disease, pulmonary hypertension, chronic lung disease, cancer, permanent pacemaker or implantable cardioverter defibrillator, atrial fibrillation or flutter, first CICU Rothman Index, and tobacco use.