Association Between Nurse Copatient Illness Severity and Mortality in the ICU

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OBJECTIVES: In the context of traditional nurse-to-patient ratios, ICU patients are typically paired with one or more copatients, creating interdependencies that may affect clinical outcomes. We aimed to examine the effect of copatient illness severity on ICU mortality.

DESIGN: We conducted a retrospective cohort study using electronic health records from a multihospital health system from 2018 to 2020. We identified nurse-to-patient assignments for each 12-hour shift using a validated algorithm. We defined copatient illness severity as whether the index patient's copatient received mechanical ventilation or vasoactive support during the shift. We used proportional hazards regression with time-varying covariates to assess the relationship between copatient illness severity and 28-day ICU mortality.

SETTING: Twenty-four ICUs in eight hospitals.

PATIENTS: Patients hospitalized in the ICU between January 1, 2018, and August 31, 2020.

INTERVENTIONS: None.

MEASUREMENTS AND MAIN RESULTS: The main analysis included 20,650 patients and 84,544 patient-shifts. Regression analyses showed a patient's risk of death increased when their copatient received both mechanical ventilation and vasoactive support (hazard ratio [HR]: 1.30; 95% CI, 1.05–1.61; $p = 0.02$) or vasoactive support alone (HR: 1.82; 95% CI, 1.39–2.38; $p < 0.001$), compared with situations in which the copatient received neither treatment. However, if the copatient was solely on mechanical ventilation, there was no significant increase in the risk of death (HR: 1.03; 95% CI, 0.86–1.23; $p = 0.78$). Sensitivity analyses conducted on cohorts with varying numbers of copatients consistently showed an increased risk of death when a copatient received vasoactive support.

CONCLUSIONS: Our findings suggest that considering copatient illness severity, alongside the existing practice of considering individual patient conditions, during the nurse-to-patient assignment process may be an opportunity to improve ICU outcomes.

KEYWORDS: critical care; electronic health records; mechanical ventilation; nursing; workforce

Nurse workload is a major determinant of patient outcomes in the ICU (1–3). To optimize patient outcomes, many hospitals attempt to limit nurse-to-patient ratios, with a typical maximum ratio being one nurse for every two patients (4, 5). Yet even within the constraints of a 1:2 nurse-to-patient ratio, nurse workload can still fluctuate significantly due to variations in patient acuity, unexpected events, and the need for specialized interventions (6–8). In addition, enforcing a strict nurse-to-patient ratio of 1:2 may not be feasible during times of strain, such as with the recent COVID-19 pandemic where demand for critical care surged (9). For these reasons, novel and complementary approaches are needed to further understand and manage nurse workload in intensive care.

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KEY POINTS

Question: What is the effect of copatient illness severity on ICU mortality?

Findings: Copatient illness severity, specifically the use of vasoactive support or both mechanical ventilation and vasoactive support, was associated with an increased risk of ICU mortality. However, copatient mechanical ventilation alone did not show a significant association with mortality.

Meaning: Considering the illness severity of copatient s when assigning nurses in the ICU could potentially improve clinical outcomes and reduce ICU mortality rates.

An aspect of nurse workload that has received limited attention is the illness severity of the other patient within a shared 1:2 nurse–patient assignment, which we term "copatient illness severity." When one patient in a 1:2 nurse–patient assignment is extremely ill, the nurse's focus may shift to that patient, potentially compromising the care of the other patient and affecting their outcomes. A greater understanding of the role of copatient illness severity may provide a more nuanced understanding of nursing workload in the ICU over and above nurse-to-patient ratios and help identify more actionable targets for managing workload. Specifically, consideration of copatient illness severity during the daily nurse assignment process may enable more targeted nurse staffing and facilitate real-time management of nurse workload in ways not possible under current paradigms.

To better understand this issue, we empirically examined the relationship between copatient illness severity and patient outcomes in the ICU. We hypothesized that higher copatient illness severity would be associated with increased mortality among ICU patients.

MATERIALS AND METHODS

Study Design, Setting, and Data

We conducted a retrospective cohort study using data collected from 24 ICUs in eight hospitals within the UPMC health system, an integrated healthcare delivery network in the mid-Atlantic region of the United States. The data collection period spanned from January 1, 2018, to August 31, 2020. The data included patient demographics, vital signs, laboratory values, respiratory flow sheet data, medication administration records, ICU admission source, and hospitalization and ICU-stay level outcomes. The study received approval from the University of Pittsburgh Institutional Review Board (protocol 19040420; approved January 23, 2020; "Precision decision support in intensive care"). Procedures were followed in accordance with the ethical standards of the responsible committee on human experimentation (institutional or regional) and with the Helsinki Declaration of 1975.

Identification of Patient–Nurse Pairings

We first divided all ICU admissions into 12-hour nursing shifts, with the day shift defined as 07:00:00 AM to 06:59:59 PM, and the night shift defined as 07:00:00 PM to 06:59:59 AM the following day. We then linked patients and nurses for each shift of the ICU stay using a validated algorithm based on nursing documentation in the electronic health record system (10). A complete description of the algorithm is available elsewhere (10). Briefly, the algorithm used date-and-time stamps from medication administration and clinical assessment data to pair specific nurses to specific patients, with each ICU patient being assigned to one and only one registered nurse per shift. These data enabled us to both identify patient pairings and calculate a nurse-to-patient ratio for each nursing shift. These steps were performed prior to any patient exclusions.

Patients

All patients in the ICU were initially eligible for the study. We then implemented the following exclusion criteria:

- Patients experiencing one or more shifts with a nurse-to-patient ratio of 1:4 or higher.
- Patients who never had a shift with a 1:2 nurse-to-patient ratio.

This exclusion was premised on the assumption that such patients might have been admitted to the ICU as boarders or in a "step-down" capacity (11, 12).

From the remaining patients, we defined three cohorts:

Primary cohort:

- Patients who maintained a 1:2 or 1:3 nurse-to-patient ratio throughout their entire ICU stay. We concentrated on this cohort as they had at least one copatient throughout their ICU stay, enabling us to assess copatient illness severity with minimal assumptions (e.g., avoiding the need to impute copatient illness severity when the ratio was 1:1 and no copatient was present).

Secondary cohorts:

- Primary exclusive cohort: patients who consistently had a 1:2 nurse-to-patient ratio throughout their ICU stay. This group was more restrictive, excluding more patients but requiring fewer assumptions.
- Primary inclusive cohort: patients who maintained a 1:1, 1:2, or 1:3 nurse-to-patient ratio during the ICU stay. This group was less restrictive, excluding fewer patients but necessitating more assumptions.

Variables

The primary exposure variable was copatient illness severity, which we categorized into four groups based on the copatient's receipt of mechanical ventilation and/or vasoactive support during the first four hours of the shift. The four groups were: 1) use of both mechanical ventilation and vasoactive support, 2) use of mechanical ventilation only, 3) use of vasoactive support only, or 4) use of neither mechanical ventilation nor vasoactive support. We defined mechanical ventilation as any mode of ventilation provided through an artificial airway for any duration during the initial 4 hours of the shift. We defined vasoactive support as continuous provision of dobutamine, dopamine, epinephrine, isoproterenol, norepinephrine, phenylephrine, or vasopressin for any duration during the initial 4 hours of the shift. If a patient had two copatients, we classified them into the relevant illness severity category based on the use of vasoactive support or mechanical ventilation for either copatient. For patients with no copatient during the shift we considered the copatient to require neither vasoactive support nor mechanical ventilation.

The primary outcome measure was in-ICU mortality truncated at 28 days. We used in-ICU (instead of in-hospital) mortality due to the specifics of our statistical approach, which necessitated the continuous exposure of the patient to the ICU setting. We applied the 28-day mortality cutoff, a widely used timeframe in critical care studies, given it captures immediate outcomes likely to be influenced by copatient illness severity (13–15). Although this short-term outcome might not entirely reflect long-term, patient-centered outcomes, it offers valuable insights that can guide clinicians, researchers, and decision-making in the ICU, leading to further investigations into long-term patient outcomes.

We defined potential confounding variables at both the patient level and the shift level. Patient-level confounders included age, gender, ICU admission source (emergency department, operating room, procedure unit, intermediate care unit, ward, or other), and comorbidities, as defined by the *International Classification of Diseases*, Version 10, diagnosis codes, in accordance with the Elixhauser method (16). Shift-level confounders included the number of copatients during the shift, which could influence the time and attention allocated to each patient, potentially affecting their condition and outcomes. We also considered the patient's sequential organ failure assessment (SOFA) score during the first four hours of the shift. This score, which reflects the acute physiological condition and level of organ dysfunction, could vary due to differences in shift-to-shift care and thus was also treated as a potential shift-level confounder.

Statistical Analysis

We presented descriptive statistics as means and SDs, medians, and interquartile ranges, or frequencies, whichever was appropriate. To evaluate the relationship between copatient illness severity and 28-day ICU mortality, we used a series of patient-level proportional hazards models with time-varying covariates (17). These models allowed us to estimate hazards over the course of the ICU stay while allowing the copatient illness severity to change from shift to shift. copatient illness severity was modeled using dummy variables with "neither mechanical ventilation nor vasoactive support" as the referent group. We censored the follow-up time at 28 days and used Huber-White sandwich estimators, a statistical method to calculate standard errors that are robust to potential violations of standard statistical assumptions, to account for clustering at the ICU level (18). To check the proportionality assumption, we used Schoenfeld residual plots (19). We performed data management and statistical analyses using Microsoft SQL Server (Microsoft, Redmond, WA) and Stata 17.0 (Statacorp, College Station, TX), and we considered a p value of less than 0.05 to be statistically significant.

RESULTS

During the study period, there were 31,699 patients and 154,410 patient-shifts. Of these shifts, 16,673 (10.8%) were 1:1, 119,270 (77.2%) were 1:2, 17,553 (11.4%) were 1:3, and 914 (0.6%) were 1:4 or greater. After excluding 2,136 patients who did not meet the inclusion criteria, the final sample included 29,563 patients and 147,183 shifts. **Figure 1** provides a visual representation of the nurse-to-patient ratios at the level of the shift and the patient, separated by analytic cohort. For the primary cohort (patients who only had 1:2 or 1:3 staffing for their entire ICU stay), most shifts were staffed 1:2 (86.5%) and most patients had only 1:2 staffing (55.8%). For the secondary exclusive cohort (patients who experienced only 1:2 staffing for their entire ICU stay), as expected there were substantially fewer patients and shifts compared to the primary cohort. For the secondary inclusive cohort (which includes patients who had 1:1, 1:2, or 1:3 staffing during their entire ICU stay), most shifts were still staffed at 1:2 (79.3%) but the majority of patients had staffing at various levels.

Table 1 presents patient demographic and clinical characteristics separated by analytic cohort. For the primary cohort, the average age was 63.2 years, 46% were female, the average SOFA score was 2.8, within ICU mortality at 28 days was 8.0%, and the average number of shifts in the ICU was 4.1. The secondary inclusive cohort, which brought in patients who were 1:1 at some point in their ICU stay, appeared to be sicker than the primary cohort, with a longer length of stay (5.0 shifts), a higher SOFA score on admission (3.0), and higher ICU mortality (9.1%). The secondary

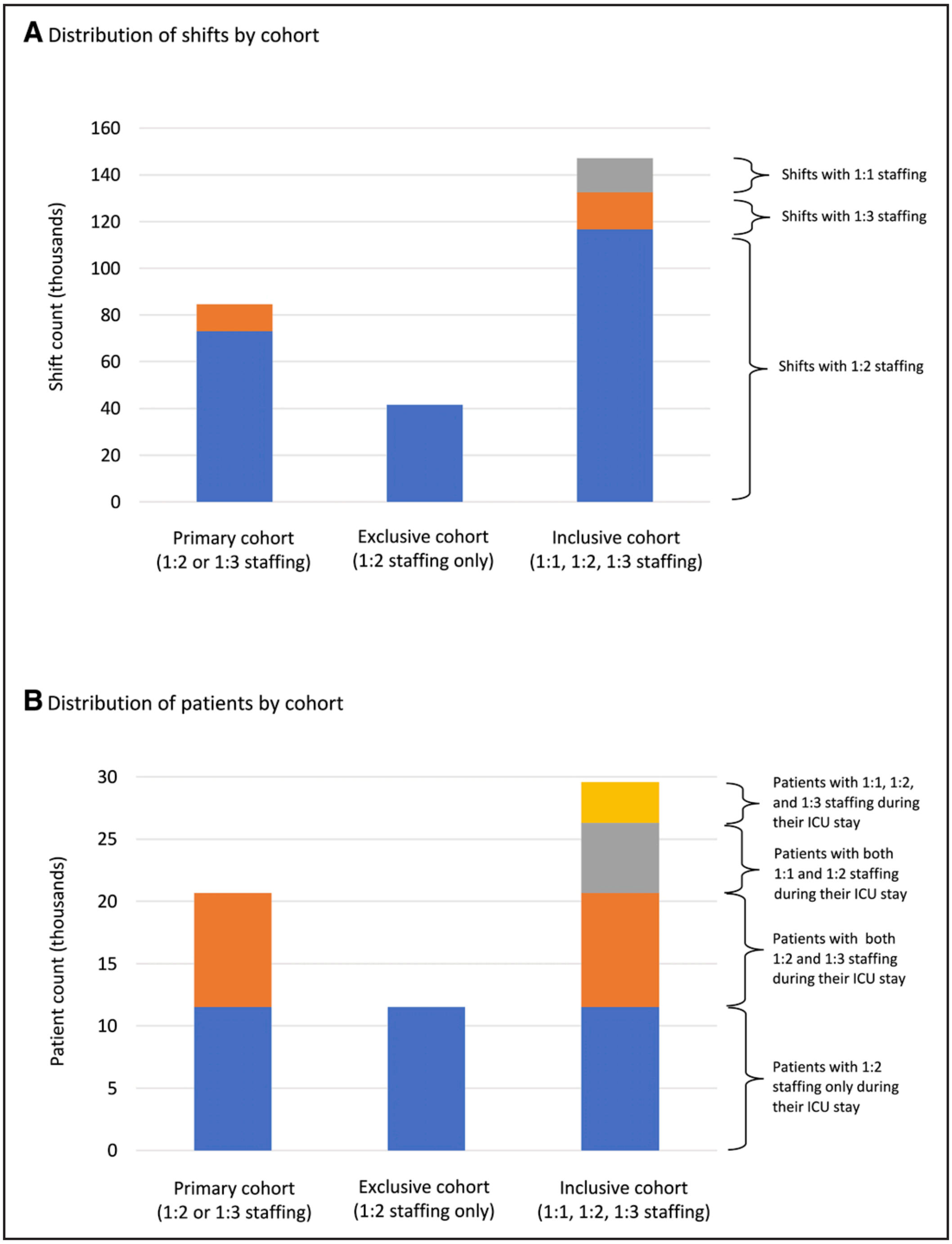

Figure 1. Nurse-to-patient ratios at the level of the patient-shift (**A**) and patient (**B**) for each analytic cohort.

TABLE 1.
Patient Cohort Characteristics

Characteristic	Cohort		
	Primary Analysis: 1:2 and 1:3	Secondary Analysis: 1:1, 1:2, and 1:3	Secondary Analysis: 1:2
Number of patients	20,650	29,563	11,518
Number of shifts	4.1 ± 2.9	5.0 ± 4.1	3.6 ± 2.6
Age	63.2 ± 17.4	63.5 ± 17.1	63.1 ± 17.6
Female	9,493 (46.0)	13,396 (45.3)	5,273 (45.8)
Race			
White	17,069 (82.7)	24,650 (83.4)	9,477 (82.3)
Black	2,058 (10.0)	2,836 (9.6)	1,194 (10.4)
Missing	1,315 (6.4)	1,798 (6.1)	739 (6.4)
Other	208 (1.0)	279 (0.9)	108 (0.9)
Comorbidities			
0	1,202 (5.8)	1,593 (5.4)	674 (5.9)
1	1,624 (7.9)	2,140 (7.2)	924 (8.0)
2–3	5,771 (28.0)	7,850 (26.6)	3,173 (27.6)
4 or more	12,053 (58.4)	17,980 (60.8)	6,747 (58.6)
ICU admission source			
Emergency department	10,182 (49.3)	13,966 (47.2)	5,817 (50.5)
Operating room	2,268 (11.0)	3,729 (12.6)	1,167 (10.1)
Procedure unit	2,235 (10.8)	2,842 (9.6)	1,111 (9.7)
Intermediate care unit	1,235 (6.0)	1,971 (6.7)	685 (6.0)
Ward	2,403 (11.6)	3,629 (12.3)	1,366 (11.9)
Other	1,971 (9.5)	2,866 (9.7)	1,173 (10.2)
Missing	356 (1.7)	560 (1.9)	199 (1.7)
Patient sequential organ failure assessment score on admission	2.8 ± 2.4	3.0 ± 2.5	2.9 ± 2.4
Within ICU mortality (truncated at 28-d)	1,659 (8.0)	2,702 (9.1)	1,031 (9.0)

Values are mean ± SD or frequency (percent).

restrictive cohort, which excluded patients who were 1:3 at some point during the ICU stay, was substantively similar to the primary cohort.

Table 2 presents shift characteristics separated by analytic cohort. In the primary cohort, one or more copatients received only mechanical ventilation in 32.9% of shifts, only vasoactive support in 6.9% of shifts, both in 11.3% of shifts, and neither in 48.9% of shifts. The relative distribution of copatient illness severity was similar in the secondary cohorts compared to the primary cohort.

Table 3 presents hazard ratios (HRs) and 95% CIs for the relationship between copatient illness severity and 28-day ICU mortality by analytic cohort. The primary cohort analysis revealed a significant increase in the risk of mortality for the index patient when a copatient required both mechanical ventilation and vasoactive support (HR: 1.30; 95% CI, 1.05–1.61; $p = 0.02$), as well as when the copatient required vasoactive support only (HR: 1.82; 95% CI, 1.39–2.38; $p < 0.001$), compared to an index patient with a copatient who received neither intervention. These findings were consistent with those from the secondary cohorts, except for the restrictive cohort, where the increase in mortality risk for the index patient was not statistically significant when a copatient required both mechanical

TABLE 2.
Patient-Shift Cohort Characteristics

Characteristic	Cohort		
	Primary Analysis: 1:2 and 1:3	Secondary Analysis: 1:1, 1:2, and 1:3	Secondary Analysis: 1:2
Number of shifts	84,544	147,183	41,651
Patient sequential organ failure assessment score	3.1 ± 2.5	3.5 ± 2.9	3.1 ± 2.5
Copatient illness severity			
Neither mechanical ventilation nor vasoactive support	41,366 (48.9)	81,556 (55.4)	19,914 (47.8)
Mechanical ventilation only	27,801 (32.9)	40,752 (27.7)	13,976 (33.6)
Vasoactive support only	5,844 (6.9)	10,843 (7.4)	2,886 (6.9)
Both mechanical ventilation and vasoactive support	9,533 (11.3)	14,032 (9.5)	4,875 (11.7)

Values are mean ± SD or frequency (percent).

TABLE 3.
Association Between Patient-Shift Copatient Factors and 28-Day ICU Mortality

Copatient Factors	Hazard Ratio (95% CI)	*p*
Primary cohort (1:2 and 1:3 shifts only)		
Neither mechanical ventilation nor vasoactive support	Reference	–
Mechanical ventilation only	1.03 (0.86–1.23)	0.78
Vasoactive support only	1.82 (1.39–2.38)	< 0.001
Both mechanical ventilation and vasoactive support	1.30 (1.05–1.61)	0.02
Secondary cohort 1 (1:1, 1:2, and 1:3 shifts)		
Neither mechanical ventilation nor vasoactive support	Reference	–
Mechanical ventilation only	1.13 (0.97–1.32)	0.13
Vasoactive support only	1.69 (1.39–2.06)	< 0.001
Both mechanical ventilation and vasoactive support	1.29 (1.03–1.62)	0.03
Secondary cohort 2 (1:2 only)		
Neither mechanical ventilation nor vasoactive support	Reference	–
Mechanical ventilation only	0.83 (0.64–1.08)	0.17
Vasoactive support only	1.65 (1.22–2.23)	0.001
Both mechanical ventilation and vasoactive support	1.12 (0.90–1.41)	0.32

All models control for shift-level factors (number of copatients and patient sequential organ failure assessment score) and patient-level factors (age, gender, ICU admission source, and comorbidities) using a multivariate proportional hazards model with time-varying covariates. Hazard ratios are interpreted as the relative hazard of death for patients with one or more copatients in that group during the shift, compared with patients in the reference group. Dashes indicate data is not applicable.

ventilation and vasoactive support compared to an index patient with a copatient who did not require these interventions (HR: 1.12; 95% CI, 0.90–1.41; $p = 0.32$).

DISCUSSION

In a large multicenter cohort study of nurse staffing, we observed an association between copatient illness severity and increased mortality among ICU patients. Our main analysis revealed that the mortality risk for the index patient increased when the copatient required mechanical ventilation and/or vasoactive support, compared to when they required neither intervention. A likely mechanism for this finding is that when the copatient is extremely sick or otherwise unstable, they receive the nurses' time and attention in a way that detracts from the care of the index patient's care.

Notably, we observed these effects when the copatient received vasoactive support and mechanical ventilation or vasoactive support alone, but not when the copatient received mechanical ventilation alone. We suspect that this discrepancy arises from the relatively time-consuming nature of providing continuous intravenous drips for patients with hemodynamic instability, which places additional demands on nurses. In contrast, the care of mechanically ventilated patients involves a significant contribution from respiratory therapists, who play a pivotal role in managing ventilator settings, monitoring respiratory status, and performing necessary interventions. This assistance from respiratory therapists significantly reduces the direct nursing workload associated with mechanical ventilation (20). Perhaps paradoxically, we observed the greatest risk when the patient received vasoactive support alone compared to vasoactive support plus mechanical ventilation. Although this finding may seem counterintuitive, it's possible that when patients receive continuous vasoactive support but not mechanical ventilation, they are particularly time consuming, potentially due to less involvement from respiratory therapists. It's also possible that these estimates are qualitatively different but not statistically different, since the width of the CIs do not preclude the possibility that the increased risk is similar in the two groups.

Our study significantly expands on the existing literature about nursing workload. Prior studies demonstrate that a given patient's severity of illness is a determinant of nurse workload (6, 7, 21), yet these studies do not directly examine the role of copatients within a multipatient assignment. Prior studies also demonstrate that nurse-to-patient ratios are strongly associated with negative patient outcomes, particularly among high-acuity ICU patients (22–25). Our study expands on this work by indicating that workload might affect patient outcomes even within nurse-to-patient ratios that would traditionally be considered safe. More broadly, our study contributes valuable insights into the relationship between ICU census and patient mortality (26). It suggests a potential mechanism for how copatient illness severity may moderate this relationship, offering a novel perspective on capacity strain and resource allocation in the ICU setting. However, it is important to clarify that our study does not establish mechanistic role or measure mediation between these factors. Instead, it lays the foundation for further research and exploration of potential mechanisms.

One potential strategy to address our findings is the implementation of "intelligent pairing" of nurses and patients, which involves matching nurses with patients of balanced illness severity levels. By pairing a nurse caring for a patient requiring both mechanical ventilation and vasoactive support with another patient who does not require these interventions, we can ensure adequate care provision by the nurse. This approach has the potential to mitigate the negative impact of high workload on patient outcomes, while considering nurse-to-patient ratio constraints. Another potential strategy is to limit the nurse-to-patient ratios to 1:1 for patients receiving mechanical ventilation or vasopressors, thereby mitigating any direct effect these patients have on other patients in the ICU at the same time. Such an approach is unlikely to be feasible at present, given that most countries are currently experiencing extreme nursing shortages. Ultimately, policies may be needed to expand the pool of ICU nurses more aggressively, enabling more staffing flexibility.

This study has several limitations. First, the retrospective and observational nature of the study limits our ability to establish causality between copatient illness severity and patient outcomes. Second, conducting the study within a single healthcare system may limit the generalizability of our findings to other settings. However, the use of multiple ICUs within the system and the diverse study population increases the generalizability to some extent. Third, our simplified approach to measuring workload may have overlooked key nuances in the relationship between nurse workload and patient outcomes. Nevertheless, the simplicity of our approach makes it more feasible to design interventions for intelligently pairing patients within assignments. Lastly, the use of 28-day within ICU mortality as a cutoff in this study may not fully capture long-term outcomes from a patient-centered perspective. However, this approach was necessary due to the use of time-varying statistical models, which provide rigorous and valid answers to the research question.

CONCLUSIONS

The results of this study suggest that copatient illness severity is associated with outcomes in the ICU. These findings provide unique insights for making nurse-to-patient assignment decisions, suggesting that copatient severity could be an important consideration in the assignment process. Future work should focus on developing a better understanding of the relationship between copatient illness severity and patient outcomes to inform decision-making around nursing assignments and ultimately improve patient care in the ICU by mitigating the negative effects of workload.

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