OPEN

Associations of 4 Nurse Staffing Practices With Hospital Mortality

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Background: Cross-sectional studies of hospital-level administrative data have suggested that 4 nurse staffing practices—using adequate staffing levels, higher proportions of registered nurses (RNs) (skill mix), and more educated and experienced RNs—are each associated with reduced hospital mortality. To increase the validity of this evidence, patient-level longitudinal studies assessing the simultaneous associations of these staffing practices with mortality are required.

Methods: A dynamic cohort of 146,349 adult medical, surgical, and intensive care patients admitted to a Canadian University Health Center was followed for 7 years (2010–2017). We used a multivariable Cox proportional hazards model to estimate the associations between patients' time-varying cumulative exposure to measures of RN understaffing, skill mix, education, and experience, each relative to nursing unit and shift means, and the hazard of in-hospital mortality, while adjusting for patient and nursing unit characteristics, and modeling the current nursing unit of hospitalization as a random effect.

Results: Overall, 4854 in-hospital deaths occurred during 3,478,603 patient-shifts of follow-up (13.95 deaths/10,000 patient-shifts). In multivariable analyses, every 5% increase in the cumulative proportion of understaffed shifts was associated with a 1.0% increase in mortality (hazard ratio: 1.010; 95% confidence interval: 1.002–1.017; $P=0.009$). Moreover, every 5% increase in the cumulative proportion of worked hours by baccalaureate-prepared RNs was associated with a 2.0% reduction of mortality (hazard ratio: 0.980; 95% confidence interval: 0.965–0.995, $P=0.008$). RN experience and skill mix were not significantly associated with mortality.

Conclusion: Reducing the frequency of understaffed shifts and increasing the proportion of baccalaureate-prepared RNs are associated with reduced hospital mortality.

Key Words: nurse staffing, nursing skill mix, nurse education, nurse experience, mortality, acute care hospitals, longitudinal study

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For many hospitals worldwide, ensuring adequate staffing on nursing units is a daily struggle due to persistent and growing shortages of registered nurses (RNs), unpredictable absenteeism, and financial pressures. To guide staffing decisions, research over the past decades has suggested that 4 staffing practices—using higher numbers of nursing hours per patient (staffing levels), higher proportions of RNs relative to nursing assistants (skill mix), higher proportions of RNs educated at the baccalaureate degree level (education mix), and more experienced teams of RNs—are each associated with lower rates of mortality and adverse events.[1–6]

Although there is abundant international evidence supporting these associations, its validity has been challenged because most of these studies were based on cross-sectional designs that preclude the assessment of the temporal sequence linking exposure to its presumed outcome.[2,6] Moreover, researchers typically relied on hospital-level administrative data that imprecisely measure the allocation of nursing resources to individual patients.[7–9] For these reasons, it has also been difficult to translate existing evidence into specific staffing recommendations applicable at the bedside.[1,4]

In 2011, Needleman et al[8] addressed these methodological challenges to some extent. In a single-site cohort study focusing on nurse staffing levels, they found that each additional shift during which RN staffing was 8 hours or more below the shift-specific target (ie, higher RN understaffing) was associated with a 2% increase in the hazard of death.[8]

More recently, Griffiths and colleagues provided evidence that patient cumulative exposure to higher proportions of non-RN staff (ie, a higher non-RN skill mix)—a commonly used staffing strategy to mitigate the shortage of RNs or meet budgetary targets[10,11]—was independently associated, in addition to higher RN understaffing, with increased hospital mortality.[12]

Although these studies have made important contributions to the field, none has accounted for and estimated the effects of patient cumulative exposure to more highly educated and experienced teams of RNs on the risk of mortality. Estimating these effects, along with those of RN understaffing and non-RN skill mix, is important to more accurately characterize the number and type of nursing resources required at the bedside,[13] and to help managers identify which staffing practices are potentially of greater risk/benefit to patients. Therefore, we sought to simultaneously estimate the associations of RN understaffing, RN education, RN experience, and non-RN skill mix with hospital mortality, while accounting for the effect of each other.

METHODS

Study Design, Setting, and Population

The overall design for this study has been described previously.[14] Briefly, a dynamic cohort included all adult (18 y and older) medical, surgical, and intensive care unit (ICU) patients admitted between January 1, 2010, and January 15, 2017, to an 800-bed University Health Center (UHC) in Montreal, Canada. The cohort excluded labor/delivery, psychiatric, and palliative care patients. Patients in the cohort were followed during the inpatient period.[14] The participating UHC is an urban level 1 trauma center with the full range of specialists and technologies available 24/7. The research ethics committee at this UHC authorized this study.

Data Sources

Denominated patient-level data were extracted from the UHC's data warehouse: a relational database containing demographic, administrative, clinical, and laboratory data obtained from the UHC's major information systems and linked using unique patient and hospitalization identifiers. The payroll database provided data on nursing staff's worked hours and RNs' levels of education and experience. Patient and staffing data were linked by date, nursing unit, and shift.

Measures

In-hospital Mortality

The date of in-hospital death was determined using patient disposition data contained in discharge abstracts.

Registered Nurse Understaffing

Although most nursing units at the participating UHC use 12-hour rotating shift schedules, RNs report their worked hours following the traditional 8-hour shift pattern to benefit from distinct pay premiums associated with working evenings or nights (ie, a 7:00 AM–7:00 PM shift will be reported as 8 h on days and 4 h on evenings and a 7:00 PM–7:00 AM shift as 4 h on evenings and 8 h on nights). Therefore, to measure patient exposure to understaffed shifts, we first calculated, for each nursing unit and 8-hour blocks corresponding to the night (00:00 AM–7:59 AM), day (08:00 AM–03:59 PM), and evening (04:00 PM–11:59 PM) shifts (referred to hereafter as unit-shifts), the average RN-to-patients ratio for that specific unit-shift as observed over the entire study period. Then, for each shift of hospitalization, the start-of-shift patient census on the current unit of hospitalization was multiplied by the corresponding average RN-to-patients ratio and subsequently multiplied by 8 to generate the expected number of RN hours for that specific unit-shift, given current patient census. For example, on a unit where the start-of-shift census was 20 patients and the average RN-to-patients ratio for an 8-hour day-shift is 1:4, the expected RN hours for that specific unit-shift would equal to 40 (20 patients × 0.25 RN/patient × 8 h = 40). Next, shifts for which the observed number of RNs' worked hours was lower than the expected value by at least 8 hours were flagged as "understaffed."[12] Finally, for each patient and shift during his/her hospitalization, the updated cumulative proportion of understaffed shifts, among all shifts from hospital admission to the current shift, was calculated and modeled as a time-varying exposure. This approach avoided immortal time bias,[15] and correctly represented the cumulative effects of past exposures,[16] while accounting for the fact that patients with longer hospital stays have an increased opportunity to be exposed to understaffed shifts. In sensitivity analyses, we assessed whether alternative definitions of RN understaffing offered a better fit to the data by using 3 different cut points corresponding to at least 4, 12, or 16 RNs' worked hours below the expected unit-shift value. In addition, because some experts recommend measuring staffing (instead of understaffing),[17] we also tested a measure of RN staffing on the basis of the cumulative average number of RNs' worked hours per patient per shift.

Nonregistered Nurse Skill Mix

Non-RN skill mix was measured by the proportion of non-RNs' (ie, nursing assistants and patient care attendants) worked hours among all nursing staff (ie, RN, nursing assistant, and patient care attendant) worked hours for a given unit-shift.[10,18] This measure was modeled, from hospital admission to the current shift, as a time-varying cumulative average deviation from the corresponding unit-shift mean. This approach accounted for between-unit and between-shift differences in the proportion of non-RN staff (eg, higher on medical-surgical units than ICUs) (see the Results section).

Registered Nurse Education

For each unit-shift, the observed proportion of baccalaureate-prepared RNs' worked hours among all RNs' worked hours (education mix) was calculated.[17] This proportion was subsequently centered at the unit-shift mean value observed over the study period to account for higher proportions of baccalaureate-prepared RNs in ICUs, where mortality was also higher than on medical-surgical units (see the Results section). Then, for every patient, a time-varying covariate representing the cumulative average deviation from the unit-shift mean, since hospital admission to the current shift, was calculated.

Registered Nurse Experience

To capture the overall level of experience of a team of RNs, we calculated, for each unit-shift, the average number of years of experience held by all RNs who worked during that specific unit-shift.[17] This approach was meant to reflect that patient care is a team effort by RNs.[19–21] As for other exposures, this measure of "collective RN experience" was modeled, from hospital admission to the current shift, as a time-varying cumulative average deviation from the corresponding unit-shift mean.

Patient Characteristics

Patient age on admission and sex were obtained from discharge abstracts. Comorbidities were measured at the time of hospital admission using the Charlson Comorbidity Index, specifically designed to quantify their impact on mortality.[22,23] Comorbidities were identified using the International Classification of Diseases, 10th revision, discharge diagnostic codes from all previous hospitalizations at the participating UHC since 2000 (ie, the maximum time frame for which complete data were available).[14] The severity of illness on admission was measured using the Laboratory-based Acute Physiology Score (LAPS), which integrates the results of 14 laboratory tests performed within the first 24 hours of hospital admission in a continuous score.[24] LAPS can range from 0 to 256, with higher scores indicating a higher risk of death.[24] The type of hospital admission (urgent, semiurgent, or elective/nonurgent), which is a mandatory physician-assessed severity of illness indicator assigned on hospital admission, and the admitting service (medical, surgical, or ICU) were obtained from discharge abstracts.[25] To adjust for possible temporal trends, the year and month of hospitalization were accounted for in the analyses.[26] These patient characteristics were selected because they have previously been validated as risk-adjusters of in-hospital mortality, with excellent calibration and discrimination (*c*-statistic of 0.81–0.89).[27–29] In the current study, these characteristics yielded a *c*-statistic of 0.84.

Nursing Unit Characteristics

To adjust for unit-specific work environment characteristics that may facilitate or constrain nursing practice,[2,21] the nursing unit on which a patient was located on a given shift was included as a random effect in the model. Additional time-varying covariates, with fixed effects, indicated (1) whether the patient was currently hospitalized in a medical, surgical, or ICU; (2) the current shift of hospitalization (night, day, evening); (3) whether the current shift of hospitalization was on a weekend/statutory holiday or not[30]; and (4) the number of patients present at the beginning of current unit-shift. Finally, the cumulative proportion of shifts spent in an ICU since hospital admission was modeled to account for increased mortality among ICU patients.[8]

Statistical Analysis

Descriptive statistics were used to summarize the study variables and to assess for potential multicollinearity among the 4 nurse staffing practices. To examine the associations between the selected nurse staffing practices and in-hospital death of any cause, we estimated a multivariable Cox proportional hazards regression model with a normally distributed random effect for the current nursing unit of hospitalization (considered frailty).[31] Time zero corresponded to hospital admission. Patients were censored at discharge or after 90 shifts (30 d) since admission, whichever came first, to limit the analyses to acute in-hospital mortality.[32] The model adjusted the effects of the time-varying cumulative measures of staffing (RN understaffing, non-RN skill mix, RN education, and RN experience) for patient and nursing unit characteristics described above. Squared terms accounted for nonlinear effects of age, Charlson Comorbidity Index, and LAPS. Adjusted hazard ratios (HRs) and their 95% confidence intervals (CIs) were reported, and *P*-value <0.05 for the 2-tailed Cox model-based Wald tests was used as a criterion for statistical significance. The proportional hazards assumption was verified with interaction terms between variables and indicators of the current time.[33,34] All statistical analyses were carried out using SAS software, version 9.4 (SAS Institute, Cary, NC).

Sensitivity Analyses

To determine whether the effect of each nurse staffing practice varied over the course of a hospitalization and whether alternative exposure models offered a better fit to the data, 2 separate sensitivity analyses were carried out. First, the cumulative staffing exposures were calculated over the first 72 and 120 hours of the hospitalization, with their values, maintained constant after that initial period. Second, the exposures were cumulated over the most recent 72 and 120 hours before the current patient-shift. The fit of these alternative models was compared using the Akaike Information Criterion, with lower values indicating a better fit.[35] A difference of ≥ 4 Akaike Information Criterion points was considered important.[36,37] Finally, the selected (best fitting) model was reestimated by randomly selecting only 1 hospitalization per patient to account for repeated hospitalizations for 28% of patients over the 7-year study period (17% with 2, 6% with 3, and 5% with 3 or more hospitalizations). To assess for possible nonlinear relationships between the cumulative nurse staffing exposure measures and the logarithm of the mortality hazard, the significance of their quadratic terms was tested.

RESULTS

Patient, Nursing Unit, and Shift Characteristics

Our cohort included 146,349 patients. These patients were followed over 3,478,603 shifts, across 32 distinct nursing units, and for a median follow-up time of 14 shifts (4.7 d) (Table 1). The mean age on admission was 61.7 years (SD: 17.3 y) and 55.7% were male. Most patients (59.2%) required urgent hospital admission, and 33.0% stayed in the ICU at some point during their hospitalization. ICU stays lasted on average 4.5 shifts (SD: 16.4). Most shifts were spent on medical-surgical units (78.1%) (Table 1). Additional details on the 32 nursing units can be found in Table S1 (Supplemental Digital Content 1, http://links.lww.com/MLR/C69).

In-hospital Mortality

A total of 4854 in-hospital deaths occurred during the first 30 days (90 shifts) after hospitalization, representing an incidence rate of 13.95 deaths/10,000 patients-shifts. Although a larger

TABLE 1. Characteristics of the Hospitalizations, Nursing Units, and Shifts

Patients (N = 146,349)	Values [n (%)]
Age [*M* (SD)]	61.7 (17.3)
Sex	
Male	81,476 (55.7)
Female	64,873 (44.3)
Comorbidities (CCI) [*M* (SD)]	2.03 (2.12)
Severity of illness on admission (LAPS) [*M* (SD)]	25.9 (28.4)
Admission type	
Elective (nonurgent)	33,373 (22.8)
Semiurgent	26,300 (17.8)
Urgent	86,676 (59.2)
Required any ICU stay	
Yes	48,356 (33.0)*
No	97,993 (67.0)
ICU shifts per hospitalization	
No. shifts spent in an ICU [*M* (SD)]	4.5 (16.4)
Range	0–589
Admission year	
2010	20,376 (13.9)
2011	20,267 (13.8)
2012	21,164 (14.5)
2013	21,587 (14.8)
2014	21,692 (14.8)
2015	20,770 (14.2)
2016–2017	20,493 (14.0)
Follow-up time in shifts [median (range)]	14 (1–90)
Status on discharge	
Death	4854 (3.3)
Nursing units (N = 32)	
Type of nursing unit	
Surgical	14 (43.7)
Medical	11 (34.4)
ICU	7 (21.9)
Shifts (N = 3,478,603)	
Type of nursing unit	
Surgical	1,720,176 (49.5)
Medical	1,180,670 (33.9)
ICU	577,757 (16.6)

*When considering all hospitalizations at the participating UHC (ie, including labor and delivery, psychiatric, and palliative care unit patients along with medical, surgical, and ICU patients), only 15.7% of them required an ICU stay. This figure is slightly higher than but comparable to the Canadian average (ie, 11.0% for all Canadian hospitals) (CIHI, 2016).[38] Excluding labor and delivery, psychiatric, and palliative care unit patients from the study cohort therefore artificially increased the proportion of patients requiring an ICU stay.

CCI indicates Charlson Comorbidity Index; ICU, intensive care unit; LAPS, Laboratory-based Acute Physiology Score.

number of deaths occurred on medical-surgical units, the unadjusted incidence of death was 3.6 times higher on ICUs (35.24 vs. 9.71 deaths/10,000 patient-shifts) (Table 2).

TABLE 2. Incidence Rate of Mortality by Type of Nursing Units

Measures	Medical and Surgical Units	ICUs	All Units
Deaths [n (%)]	2818 (58.1)	2036 (41.9)	4854 (100.0)
Patient-shifts [n (%)]	2,900,846 (83.4)	577,757 (16.6)	3,478,603 (100.0)
Incidence—IR* (95% CI)	9.71 (9.36–10.07)	35.24 (33.71–36.77)	13.95 (13.56–1435)

*Incidence rate per 10,000 patient-shifts.

CI indicates confidence interval; ICU, intensive care unit; IR, incidence rate.

TABLE 3. Nurse Staffing Practices by Type of Nursing Units and Shifts

	M (SD)		
Nurse Staffing Practices	Medical or Surgical Units	ICUs	All Units
Night shifts			
Total number of shifts (n)	53,026	15,743	68,769
Understaffed* [n (%)]	6530 (12.3)	2847 (18.1)	9377 (13.7)
Non-RN skill mix†	27.8 (15.1)	12.5 (10.7)	24.3 (15.6)
Education mix‡	31.1 (28.1)	56.4 (21.3)	36.9 (28.7)
RN collective experience§	11.1 (6.4)	11.6 (4.7)	11.2 (6.1)
Day shifts			
Total number of shifts (n)	53,570	15,773	69,343
Understaffed [n (%)]	15,134 (28.2)	5128 (32.5)	20,262 (29,2)
Non-RN skill mix	35.9 (11.0)	19.8 (6.7)	32.2 (12.2)
Education mix	40.4 (23.6)	59.0 (18.7)	44.7 (23.9)
RN collective experience	10.4 (5.2)	11.4 (4.0)	10.6 (5.0)
Evening shifts			
Total number of shifts (n)	53,475	15,745	69,220
Understaffed [n (%)]	11,862 (22.2)	3222 (20.5)	15,084 (21.8)
Non-RN skill mix	29.5 (11.4)	17.0 (6.7)	26.6 (11.7)
Education mix	34.2 (22.5)	52.0 (17.6)	38.2 (22.7)
RN collective experience	10.2 (5.0)	11.7 (4.4)	10.6 (4.9)
All shifts			
Total number of shifts (n)	160,071	47,261	207,332
Understaffed [n (%)]	33,526 (20.9)	11,197 (23.7)	44,723 (21.6)
Non-RN skill mix	31.1 (13.1)	16.4 (8.8)	27.7 (13.7)
Education mix	35.3 (25.2)	55.8 (19.5)	40.0 (25.5)
RN collective experience	10.6 (5.6)	11.6 (4.3)	10.8 (5.4)

*Shifts with an observed number of RNs' worked hours at least 8 hours below the expected unit-shift value according to patient census (see the "Registered nurse understaffing" in the Methods section for details).

†Proportion of non-RNs' worked hours among all nursing staff's worked hours for each unit-shift, represented in percent.

‡Proportion of baccalaureate-prepared RNs' worked hours among all RNs' worked hours for each unit-shift, represented in percent.

§Mean number of years of experience held by all RNs who reported worked hours for each unit-shift, represented in year.

ICU indicates intensive care unit; RN, registered nurse.

Nurse Staffing Practices

During the study period, there were a total of 207,332 unit-shifts and 21.6% of these were understaffed. Understaffed shifts were slightly more frequent in ICUs than on medical-surgical units (23.7% vs. 20.9%), and more common during days (29.2%) than on evenings or nights (Table 3). The mean non-RN skill mix was higher on medical-surgical units than on ICUs (31.1% vs. 16.4%), and higher on days compared with evenings or nights (Table 3). For education mix, over all unit-shifts, the mean proportion of worked hours by baccalaureate-prepared RNs was 40.0%, with considerable between-unit and between-shift variations (SD: 25.5%). Education mix was higher on ICUs than on medical-surgical units (mean of 55.8% vs. 35.3%) and higher on days (44.7%) than on any other shifts. RN collective experience was evenly distributed across nursing units and shifts (Table 3). Correlations among the 4 nurse staffing exposures were low, ranging from −0.011 to 0.186 (Table S2, Supplemental Digital Content 1, http://links.lww.com/MLR/C69).

TABLE 4. Adjusted Associations Between Nurse Staffing Practices and the Risk of Mortality*

Cumulative Nurse Staffing Practices Measured Over All Shifts Since Hospital Admission (AIC = 98,552)	HR (95% CI)	*P*
RN understaffing† (per 5% ↑)	1.010 (1.002–1.017)	**0.009**
Non-RN skill mix‡ (per 1% ↑)	1.004 (0.997–1.011)	0.261
Education mix§ (per 5% ↑)	0.980 (0.965–0.995)	**0.008**
RN collective experience‖ (per 1 y ↑)	0.993 (0.978–1.008)	0.369

Bold values indicate statistically significant $P < 0.05$ threshold.

*HRs are from a Cox proportional hazards regression model treating the current unit of hospitalization as a random effect and adjusting for patient characteristics on admission [age, age^2, sex, Charlson Comorbidity Index (CCI), CCI^2, severity of illness (Laboratory-based Acute Physiology Score, LAPS), LAPS^2, type, year, and month of hospital admission], whether the current unit of hospitalization provides medical, surgical or intensive care, current shift (night, day, or evening), current unit occupancy, whether the current day is a weekend/statutory holiday or not, and the cumulative proportion of shifts spent in an intensive care unit since hospital admission, and the square of that cumulative proportion.

†Cumulative proportion of shifts with an observed number of RNs' worked hours at least 8 hours below the expected unit-shift value according to the patient census (see the "Registered nurse understaffing" in the Methods section for details), represented in percent.

‡Cumulative proportion of non-RNs' worked hours among all nursing staff's worked hours relative to the unit-shift mean, represented in percent.

§Cumulative average baccalaureate-prepared RNs' worked hours among all RNs' worked hours relative to the corresponding unit-shift mean, represented in percent.

‖Cumulative mean number of years of experience held by all RNs who reported worked hours relative to the corresponding unit-shift mean, represented in years.

AIC indicates Akaike Information Criterion; CI, confidence interval; HR, hazard ratio; RN, registered nurse.

Associations Between Cumulative Measures of Nurse Staffing and Mortality

In the fully adjusted multivariable Cox regression model, every 5.0% increase in the cumulative proportion of understaffed shifts since admission, relative to the corresponding unit-shift mean values, was associated with a 1.0% increase in the risk of hospital death (adjusted HR: 1.010; 95% CI: 1.002–1.017, $P = 0.009$) (Table 4). Moreover, every 5.0% increase in the cumulative proportion of worked hours by baccalaureate-prepared RNs above the unit-shift mean was associated with a 2.0% reduction of in-hospital mortality (adjusted HR: 0.980; 95% CI: 0.965–0.995, $P = 0.007$). In contrast, neither RN cumulative average experience nor the proportion of non-RN staff was significantly associated with mortality (Table 4). The full results of the multivariable Cox regression model are presented in Table S3 (Supplemental Digital Content 1, http://links.lww.com/MLR/C69). The proportional hazards assumption was confirmed for nurse staffing exposures.

Sensitivity Analyses

In sensitivity analyses, all alternative definitions of RN understaffing using different cutpoints provided a worse fit to the data (Tables S4, S5, Supplemental Digital Content 1, http://links.lww.com/MLR/C69). Similarly, all alternative models with shorter durations either of initial or more recent cumulative exposures yielded similar estimates, and thus the same conclusions as the main model, with marginally worse fit to data and slightly weaker associations (Table S6, Supplemental Digital Content 1, http://links.lww.com/MLR/C69). This suggests that mortality is associated with cumulative nurse staffing exposures calculated over the entire duration of hospitalization. None of the quadratic terms tested for the nurse staffing exposures reached statistical significance (data not shown). Finally, because death can occur only once for a given patient, randomly selecting only 1 hospitalization per patient yielded almost identical point estimates of adjusted HRs and the same conclusions on statistical significance as the original analyses that included all hospitalizations, but with higher *P*-values due to lower sample size (2,105,131 vs. 3,478,663 patient-shifts) and number of events (3486 vs. 4854 deaths) (Table S7, Supplemental Digital Content 1, http://links.lww.com/MLR/C69).

DISCUSSION

The purpose of this longitudinal study was to simultaneously estimate the associations of 4 nurse staffing practices—RN understaffing, RN education, RN experience, and non-RN skill mix—with hospital mortality. We found that patients cared for by greater proportions of baccalaureate-prepared RNs throughout their hospitalization appear to have a significant survival advantage over those exposed to less educated ones. Moreover, this finding was independent of RN understaffing, which was associated with higher mortality. Together, these findings provide further evidence that higher RN education at the baccalaureate-degree level and adequate staffing levels are important determinants of safer patient care.[21]

Moreover, we found that RNs' collective experience was not a predictive factor of mortality. This counter-intuitive finding, which is nonetheless consistent with the results of several earlier cross-sectional investigations,[6] could suggest that, contrary to what is commonly believed, the accumulation of years of work experience may not translate into safer care.[6,39] Alternatively, it is also possible that this finding could be attributable to a shift rotation policy at the participating UHC, which may have reduced between-shift variations in RNs' levels of experience (Table 3) and, consequently, our ability to associate this exposure with patient mortality. Additional research using data from hospitals with greater between-shift variations in RN experience is required to address this possibility. Further research is also required to examine whether alternative but less commonly available measures of expertise, such as the proportion of RNs participating in continuing education activities or holding specialty certifications, would provide similar or different results.

In addition, we observed that the non-RN skill mix was not significantly associated with hospital mortality. Although this finding contrasts with Griffiths et al's[12] recent patient-level observations in the UK, it should be interpreted with caution owing to methodological differences between studies (eg, we accounted for RN education and experience) and since UK hospitals typically employ greater numbers of non-RN staff than those in Canada, United States, or other European countries.[10,40] Consequently, it may be that non-RN staffing in our study did not reach the levels at which it would correlate with mortality. Multisite and cross-jurisdictional replications of the current study are required to further explore the associations of non-RN staffing (and of other staffing practices) with outcomes.

Overall, our findings suggest that hospital mortality could be reduced by preventing RN understaffing on nursing units.

However, with an international shortage of RNs that is expected to worsen in the coming years,[41–43] reducing RN understaffing will require a 2-tiered policy response. At the national level, policies are required to rectify the shortage and retain existing RNs within the workforce (eg, through higher wages, immigration, or graduation rates).[43,44] At the hospital level, additional resources should be devoted to assist managers in implementing evidence-based strategies, such as those found in "magnet hospitals," whose organizational features (eg, decentralized decision-making, increased RN's professional autonomy) not only attract and retain RNs at the bedside but are also associated with better patient outcomes.[2,45]

In addition to reducing RN understaffing, greater emphasis should be placed on increasing the proportion of baccalaureate-prepared RNs at the bedside. Although the National Academy of Medicine sets this proportion at a minimum of 80%,[46] many hospitals (including the study hospital) are still far from this recommendation due to the limited availability of baccalaureate-prepared RNs. Across Canadian provinces, between 46% and 67% of RNs are baccalaureate-prepared (Quebec having the lowest proportion),[40,47] and similar figures have been reported in Europe (54%)[48] and the United States (65%).[49] This suggests that ongoing international efforts to further increase the overall workforce of baccalaureate-prepared RNs must be continued, which entails policies and incentives for attracting and retaining greater numbers of students into baccalaureate training programs (eg, financial assistance, flexible scheduling, education-based pay scales, and career opportunities) and for assisting hospitals in moving toward a more educated RN workforce (eg, performance-based payments).[6,7]

Study Limitations

First, although the use of a patient-level longitudinal design addressed many of the limitations of earlier cross-sectional studies and eliminated many plausible alternative explanations, causation cannot be inferred from the observed associations, and confounding remains a possibility. For instance, no data were available on certain nursing unit characteristics (eg, work environment, care delivery model) or the availability and qualifications of physicians and other health care professionals aside from the nursing staff, all of which might have an influence on RN's work and patient outcomes.[2,50] Nonetheless, by modeling the current nursing unit of hospitalization as a time-varying variable, we could indirectly control for many of these unmeasured factors. Second, although this was a single-site study, we investigated 4 staffing practices that characterize the availability and use of nursing resources at most hospitals. We are therefore confident that these measures, along with the methodological approach outlined to examine their association with hospital mortality, are relevant to other institutions. Third, our measure of RN understaffing was relative to unit-shift mean values observed over the study period, which might not accurately reflect patient requirements for nursing care. However, as in most hospitals, no better alternative was available, such as a validated patient classification system specifying the required number of RNs per unit-shift. Fourth, our measures of understaffing and education were calculated using both regular and overtime hours. Disentangling the effect on outcomes of patient exposure to understaffed shifts (whether overtime was used or not) from that of overtime (whether a shift was understaffed or not) represents an important next step in an investigation. Finally, whether our observations hold for other types of adverse events is unknown.

CONCLUSIONS

Reducing the number of understaffed shifts and increasing the proportion of baccalaureate-prepared RNs in hospitals are associated with lower mortality. These findings highlight the importance of improving current workforce planning mechanisms and the strategies aimed at further increasing the number of baccalaureate-prepared RNs.

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