Original Article

Nurse Staffing Practices and Postoperative Atrial Fibrillation Among Cardiac Surgery Patients: A Multisite Cohort Study

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ABSTRACT

Background: Postoperative atrial fibrillation (POAF) is a frequent complication of cardiac surgery that is associated with increased morbidity, mortality, and costs. Recent studies suggest that nurse staffing practices are associated with adverse postoperative events, but whether these practices are also related to POAF occurrence is unknown.

Methods: To fill this knowledge gap, a cohort of 6401 cardiac surgery patients admitted to 2 Canadian university health centres (UHC A and UHC B) between 2014 and 2018 was studied. Patients' cumulative exposure to 4 staffing practices (registered nurse [RN] understaffing, education, experience, and non-RN skill mix) was measured every shift over the first 6 postoperative days, during which 96% of POAF cases occur. The associations of these exposures with in-hospital POAF occurrence were estimated using site-specific multivariable logistic

RÉSUMÉ

Contexte : La fibrillation auriculaire postopératoire (FAPO) constitue une complication fréquente de la chirurgie cardiaque. Elle est associée à une morbidité, à une mortalité et à des coûts accrus. Des études récentes donnent à penser que les pratiques de dotation en personnel infirmier sont associées à des événements postopératoires indésirables, mais on ne sait pas si ces pratiques sont également liées à la survenue de la FAPO.

Méthodologie : Pour combler cette lacune dans nos connaissances, une étude a été menée sur une cohorte de 6 401 patients ayant subi une chirurgie cardiaque et ayant été admis dans deux centres hospitaliers universitaires canadiens (CHU A et CHU B) entre 2014 et 2018. L'exposition cumulative des patients à quatre pratiques de dotation (travail en sous-effectif, éducation, expérience et éventail de compétences non infirmières du personnel infirmier) a été mesurée au

Postoperative atrial fibrillation (POAF) is the most common complication of cardiac surgery, affecting 15% to 60% of patients, depending on the type of procedure performed.[1-3] POAF onset peaks 2-4 days after surgery,[4,5] and 96% of cases are estimated to occur within the first 6 postoperative days.[1,4] POAF occurrence is associated with increased

short-term and long-term morbidity, including higher rates of embolic events (eg, stroke, venous thromboembolism), cardiac complications (eg, heart failure, myocardial infarction, cardiac arrest), and renal and respiratory failure.[5-10] Moreover, PAOF after cardiac surgery increases the risks of all-cause 30-day, 6-month, and 3-year mortality,[5,6] as well as intensive-care unit (ICU) and hospital stays by 12-24 hours and by 2-5 days, respectively.[10,11] Patients who develop POAF incur an average of USD $10,000 to $20,000 in additional costs, owing to longer stays in the hospital, investigations, and treatments.[4,10] Given these figures, preventing POAF occurrence is a high priority.[3,10]

However, efforts to prevent and manage POAF after cardiac surgery have thus far been challenging, and highly effective interventions are still lacking.[2,10] Consequently, despite numerous clinical trials examining a variety of prophylactic and treatment modalities, the incidence of POAF after cardiac surgery has not declined over the past several decades, and new interventions must now be identified.[12-14]

regression models and a mixed-effect model combining data from both sites.

Results: Overall, 563 (27.2%) and 1336 (30.8%) cases of POAF occurred at UHC A and UHC B, respectively. In site-specific models, every 5% increase in the cumulative proportion of understaffed shifts over the first 6 postoperative days was associated with a 3.5% increase in the odds of POAF (adjusted odds ratio [aOR] for UHC A: 1.035; 95% confidence interval [CI]: 1.000-1.070, $P = 0.0472$; aOR for UHC B: 1.035; 95% CI: 1.013-1.057, $P = 0.0019$). In the mixed-effect model combining data from both sites, RN understaffing remained significant and was associated with a 3.1% increase in the odds of POAF (aOR: 1.031; 95% CI: 1.014-1.048, $P = 0.0003$). No other staffing practices were significantly associated with POAF occurrence.

Conclusion: Higher RN understaffing postoperatively is associated with increased POAF occurrence among cardiac surgery patients.

cours de chaque quart de travail pendant les six premiers jours de la période postopératoire, au cours desquels 96 % des cas de FAPO se produisent. L'association des expositions avec les cas de FAPO survenus en cours d'hospitalisation a été estimée à l'aide de modèles de régression logistique à variables multiples tenant compte du lieu et d'un modèle à effets mixtes combinant les données des deux centres.

Résultats : Globalement, 563 (27,2 %) et 1 336 (30,8 %) cas de FAPO sont survenus respectivement au CHU A et au CHU B. Dans les modèles tenant compte du lieu, chaque augmentation de 5 % de la proportion cumulative de quarts de travail en sous-effectif au cours des six premiers jours de la période postopératoire était associée à une hausse de 3,5 % du risque de FAPO (rapport de cotes ajusté [RCa] pour le CHU A : 1,035; intervalle de confiance [IC] à 95 % : 1,000-1,070, $P = 0,0472$; RCa pour le CHU B : 1,035; IC à 95 % : 1,013-1,057, $P = 0,0019$). Dans le modèle à effets mixtes combinant les données des deux centres, le travail infirmier en sous-effectif demeurait significatif et était associé à une hausse de 3,1 % du risque de FAPO (RCa : 1,031; IC à 95 % : 1,014-1,048, $P = 0,0003$). Aucune autre pratique de dotation en personnel infirmier n'a été associée de façon significative à la survenue de FAPO.

Conclusion : Un taux élevé de travail infirmier en sous-effectif pendant la période postopératoire est associé à une fréquence accrue des cas de FAPO chez les patients qui ont subi une chirurgie cardiaque.

In parallel, an increasing number of studies have suggested that nurse staffing practices in the postoperative period (eg, using adequate staffing levels, a richer registered-nurse (RN) skill mix, higher numbers of RNs educated at the baccalaureate degree level, and more-experienced teams of RNs), which are amenable to managerial intervention, are associated with lower rates of surgical mortality and fewer adverse events.[15-18] Similarly, several recent investigations pointed out that suboptimal nurse staffing practices (eg, higher RN understaffing and a higher non-RN skill mix) are correlated with worse patient outcomes.[19-21] To explain these associations, it has been proposed that nurse staffing practices can improve or weaken nurse surveillance, one of the most important functions of RNs.[22]

Nurse surveillance is defined as the continuous process through which RNs monitor patients for early signs of complications and subsequently implement a variety of interventions to prevent or minimize their impacts.[15,22,23] Adequate staffing levels and a richer RN skill mix are assumed to increase the effectiveness of nurse surveillance by allowing RNs to spend more time at the bedside, therefore increasing the rapidity with which they can detect any change in a patient's condition and intervene.[18,23,24] Higher education, at the baccalaureate degree level, and greater work experience are assumed to improve nurse surveillance by providing RNs with more knowledge, better patient surveillance skills, and a broader repertoire of interventions.[15,22,25]

Although growing international evidence suggests that these 4 nurse staffing practices are linked to improved surgical outcomes, to our knowledge, no previous study has examined whether they are associated with POAF occurrence in cardiac surgery patients. Estimating the simultaneous associations of these staffing practices with POAF occurrence is important to help hospital managers determine the number and type of nursing resources required at the bedside postoperatively and to identify which staffing practices can minimize the risk of this serious postoperative complication. Therefore, the objective of this study was to simultaneously estimate the associations of RN understaffing, RN education, RN experience, and non-RN skill mix with in-hospital POAF, while accounting for the effect of each other.

Methods

Settings

This study was conducted at 2 urban university health centres (UHC A and UHC B) located in the Canadian province of Quebec. These UHCs are level I trauma centres with the full range of specialists and technologies available day and night, every day. They annually perform approximately 20% of all cardiac surgeries in the province and are part of Quebec's Tertiary Cardiology Network (*Réseau Québécois de cardiologie tertiaire*), which is comprised of 8 UHCs located in the province's major urban centres.[26] The research ethics committees at both sites authorized this study, including providing access to patient electronic health record data (project MP-31-2020-3340). The need for patient consent was waived due to the retrospective nature of the study.

Study design and population

The overall design of this study has been described previously.[19,27] Briefly, we assembled a retrospective cohort of all adult patients who received cardiac surgery at the participating sites between January 1, 2014, and December 31, 2018. To be included in the cohort, patients had to be 18 years of age or older and have undergone, via a traditional sternotomy, any of the following surgical procedures due to an underlying cardiac illness: (i) coronary artery bypass graft (CABG); (ii) valve replacement; (iii) valve repair; or (iv) a combination of CABG and valve surgery. Patients in the cohort were followed during the inpatient period.[27]

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Data sources

Deidentified patient-level data were extracted at each site from their clinical data warehouses. These warehouses are relational databases containing demographic, administrative, clinical, and laboratory data extracted from each UHC's major information systems and linked using unique patient and hospitalization identifiers.[19] The payroll database provided data on the nursing staffs' worked hours and the RNs' levels of education and experience. This database is regularly audited by administrators at both sites to ensure data completeness and accuracy. Patient and staffing data were linked by date, nursing unit, and shift.[19]

Measures

Study outcome: POAF. The occurrence of POAF, defined as new-onset atrial fibrillation in the immediate postoperative period in a patient without a prior diagnosis of atrial fibrillation,[1,4] was assessed from discharge diagnostic codes using a method previously validated at the study sites by our research group.[28] Briefly, to be considered POAF-positive, patients needed to have: (i) International Classification of Diseases, 10th revision (ICD-10), diagnostic codes I48.0 (paroxysmal atrial fibrillation), I48.1 (persistent atrial fibrillation), I48.9 (unspecified atrial fibrillation and atrial flutter) or I48.90 (unspecified atrial fibrillation) in the discharge abstract of their current hospitalization and (ii) no evidence of ICD-10 codes I48.0, I48.1, I48.2 (chronic atrial fibrillation), I48.9, or I48.90 in the discharge abstracts of their previous hospitalizations over the past 6 years.[28] This algorithm achieved 70.4% sensitivity (95% confidence interval (CI): 65.1%-75.3%), 86.0% specificity (95% CI: 83.1%-88.6%), and 71.5% positive predictive value (95% CI: 66.2%-76.4%) in identifying incident POAF cases.[28]

Nurse staffing practices

RN understaffing. Although several RNs at the participating UHCs work on 12-hour shift schedules, they all report their worked hours using the traditional 8-hour shift pattern to benefit from distinct pay premiums associated with working evenings or nights.[19] Therefore, to measure patient exposure to understaffed shifts, we first calculated, for each nursing unit and 8-hour periods corresponding to the night (midnight to 7:59 AM), day (8 AM to 3:59 PM), and evening (4 PM to 11:59 PM) shifts (hereafter referred to as a unit-shift), the average RN-to-patients ratio as observed over the entire study period for that specific unit-shift.[19] Then, for each postoperative shift from day 0 onward, 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.[19] For example, in a unit where the start-of-shift census is 30 patients and the average RN-to-patients ratio for an 8-hour day shift is 1:5, the expected RN hours for that specific unit-shift would equal 48 (30 patients × 0.20 RN/patient × 8 hours = 48).[19] Next, shifts for which the observed number of RN worked hours was lower than the expected value, by 8 or more hours, were flagged as "understaffed."[21] Finally, for each patient and shift during his/her hospitalization, the updated cumulative proportion of understaffed shifts, among all shifts from the first postoperative shift until hospital discharge, was calculated.[19] In prior research work using related data, we found that using 8 hours as the cutoff value for defining a shift as "understaffed" provided a better fit for the data than using alternative cut-points (eg, 4, 12, or 16 hours).[19] Moreover, we showed that measuring understaffing (instead of staffing using a measure of RNs' worked hours per patient per shift) also resulted in a better fit.[19]

RN education. RNs in Quebec can practice in the nursing profession with either a college degree or a baccalaureate degree. Currently, 48% of the RNs throughout the province are baccalaureate-prepared, with important within- and between-hospital variations.[29] RN education (education mix) was therefore measured as the proportion of baccalaureate-prepared RNs' worked hours among all RNs' worked hours on a given unit-shift.[30] This proportion was subsequently centered at the unit-shift mean value observed over the study period to account for between-unit, between-shift, and between-UHC variations in the availability of baccalaureate-prepared RNs.[19] Then, for every patient, the cumulative average deviation from the unit-shift mean, from the first postoperative shift until hospital discharge, was calculated.[19]

RN experience. Nursing care is generally described as a team effort, and several RNs are typically involved in the care of a given patient on a specific unit-shift.[22,31] Therefore, to capture patient exposure to the overall level of experience of a team of RNs, we calculated the average number of years of experience held by all RNs who worked during a given unit-shift.[19] This measure of "collective RN experience" was then modeled, from the first postoperative shift until hospital discharge, as a cumulative average deviation from the corresponding unit-shift mean value.[19]

Non-RN skill mix. Non-RNs (ie, nursing assistants [NAs] and patient care attendants [PCAs]) are increasingly employed by hospitals to mitigate the shortage of RNs as well as for budgetary reasons.[32,33] Patient exposure to the non-RN skill mix was measured as the proportion of non-RNs' worked hours among all nursing staff (ie, RN, NA, and PCA) worked hours for a given unit-shift.[27,32,34] This measure was modeled from the first postoperative shift until hospital discharge as a cumulative average deviation from the corresponding unit-shift mean. This approach was selected to account for between-unit, between-shift, and between-UHC variations in the proportion of non-RN staff (eg, typically higher in surgical units than in ICUs and higher in UHC A; see the Results section).[19]

Duration of patient exposure to nurse staffing practices. In the statistical analyses given below, the 4 nurse staffing exposure measures were cumulated over the first 6 postoperative days (ie, over the first 18 shifts). This is because 96% of all POAF cases are expected to occur within 6 days of cardiac surgery,[1,35] and because we wanted to estimate the potential effects of the 4 staffing practices during that specific period. In the sensitivity analyses (below), we explored

Table 1. Patient characteristics

Patient characteristics	UHC A (n = 2067)	UHC B (n = 4334)
Age, y, mean (SD)	68.7 (9.7)	66.8 (11.0)
Male sex	1567 (75.8)	3130 (72.2)
Charlson Comorbidity Index, mean (SD)	1.59 (1.51)	1.63 (1.58)
Severity of illness on admission (LAPS), mean (SD)	12.4 (20.1)	25.4 (35.7)
Year of surgical procedure		
2014	417 (20.2)	884 (20.4)
2015	422 (20.4)	834 (19.3)
2016	412 (19.9)	875 (20.2)
2017	414 (20.0)	885 (20.4)
2018	402 (19.5)	856 (19.7)
Most common primary diagnoses		
Atherosclerotic heart disease	452 (21.9)	2412 (55.6)
Aortic valve stenosis	555 (26.9)	735 (17.0)
Mitral valve insufficiency	84 (4.1)	321 (7.4)
Acute subendocardial myocardial infarction	220 (10.6)	117 (2.7)
Aortic valve insufficiency	54 (2.6)	73 (1.7)
Type of cardiac surgery		
CABG only	1023 (49.5)	2529 (58.3)
Valve surgery only	735 (35.6)	1165 (26.9)
CABG and valve surgery	309 (14.9)	643 (14.8)
Type of valve surgery		
Repair	191 (18.3)	567 (27.0)
Replacement	853 (81.7)	1537 (73.0)
Postoperative atrial fibrillation		
CABG only	251 (44.6)	666 (50.1)
Valve surgery only	199 (35.3)	378 (28.4)
CABG and valve surgery	113 (20.1)	285 (21.5)
Total	563 (27.2)	1,329 (30.8)
Death	89 (4.3)	174 (4.0)
Length of hospital stay		
In days	11 (1−118)	9 (0−298)
In shifts	28 (2−353)	25 (1−716)
Percentage of shifts spent in an ICU		
Over the first 6 postoperative days	55.6 (0−100)	33.3 (0−100)
Over the entire hospitalization	36.0 (0−100)	24.1 (0−100)

Values are n (%), or median (range), unless otherwise specified.

CABG, coronary artery bypass graft; ICU, intensive care unit; LAPS, laboratory-based acute physiology score; SD, standard deviation; UHC, university health centre.

whether using alternative time windows for cumulating these exposure measures provided a better fit for the data.

Patient characteristics. Patient age on admission and sex were obtained from their discharge summaries. Comorbidities were assessed at the time of hospital admission, with the Charlson Comorbidity Index.[36-38] Comorbidities were identified using ICD-10 discharge diagnostic codes from all prior hospitalizations at the participating UHCs since 2010 (ie, the maximum time frame for which complete data were available).[27] 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 into a continuous score.[39] LAPS scores can range from 0 to 256, and higher scores indicate a greater severity of illness.[39] Procedure codes were used to characterize the type of surgical procedure performed as one of the following: (i) CABG; (ii) valve repair or replacement; and (iii) mixed surgery (ie, CABG and valve surgery; see Supplemental Table S1, for the complete list of procedure codes used). To adjust for possible temporal trends, the year of cardiac surgery was accounted for in the analyses.

These patient characteristics were selected because they have been used previously as risk adjusters for POAF.[40-42] In the current study, these characteristics yielded c-statistics ranging between 0.61 and 0.66 across models. Although limited, the accuracy of this model nonetheless compares to the accuracy of other commonly used POAF risk-adjustment models (eg, **C**ongestive heart failure, **H**ypertension, **A**ge $\geq$ 75 (doubled), **D**iabetes, **S**troke (doubled), **VA**scular disease, age 65 to 74 and **S**ex **C**ategory [CHA$_2$-DS$_2$-VASC], Cohorts for Heart and Aging Research in Genomic Epidemiology model for Atrial Fibrillation [CHARGE-AF], POAF Score, Atrial Fibrillation Risk Index or Society of Thoracic Surgeons [STS] score), for which the reported c-statistics range from 0.56 to 0.69.[40-42]

Statistical analysis

Descriptive statistics were used to summarize the study variables and to check for potential multicollinearity among the 4 nurse staffing practices. To examine the simultaneous associations between the selected nurse staffing practices and POAF occurrence, we first estimated site-specific multivariable logistic regression models. These models adjusted the effects of the cumulative measures of nurse staffing (RN

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Table 2. Nurse staffing practices over the first 6 postoperative days and over the entire hospitalization period

Nurse staffing practices	UHC A		UHC B	
	First 6 d	Overall	First 6 d	Overall
Total number of unit-shifts	12,177	15,125	13,364	15,650
RN understaffing,* n (%)	2105 (17.3)	2664 (17.6)	3478 (26.0)	3772 (24.1)
Education mix,† %	44.6 (19.2)	43.5 (19.8)	57.3 (15.7)	55.7(17.7)
RN collective experience, y‡	10.4 (6.4)	10.2 (6.2)	10.3 (2.8)	10.7 (3.5)
Non-RN skill mix,§ %	32.4 (22.4)	33.1 (22.1)	15.9 (5.0)	16.6 (6.7)

Values are mean (standard deviation), unless otherwise specified.

RN, registered nurse; UHC, university health centre.

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

† Proportion of baccalaureate-prepared RNs' worked hours among all RNs' worked hours for each unit-shift.

‡ Mean number of years of experience held by all RNs who reported worked hours for each unit-shift.

§ Proportion of non-RNs' worked hours among all nursing staff worked hours for each unit-shift.

understaffing, RN education, RN experience, and non-RN skill mix) for the patient characteristics described above. Then, these associations were re-estimated using a mixed-effect logistic regression model combining data from both sites and treating the hospital site (UHC A or UHC B) as a random effect. Adjusted odds ratios (aORs) and their 95% CIs were reported for all models, and $P < 0.05$ was used as the criterion for statistical significance. Multiple imputation was used to address the presence of missing data. All statistical analyses were performed using SAS software, version 9.4 (SAS Institute, Cary, NC).

Sensitivity analyses

To determine whether alternative exposure models offered a better fit for the data, the cumulative nurse staffing exposures were calculated over 4 different time windows—the first 2, 4, and 8 postoperative days (ie, over the first 6, 12, and 24 shifts), as well as the entire in-hospital postoperative period. The fit of these alternative models was compared using the Akaike information criterion (AIC), with lower values indicating a better fit.[43] We considered a difference of ≥ 4 AIC units to be important.[44,45] To assess possible nonlinear relationships between the nurse staffing exposure measures and the odds of POAF occurrence, the significance of their quadratic terms was tested.

Results

Patient characteristics

Our cohort included 6401 patients, 2067 from UHC A, and 4334 from UHC B (Table 1). There were fewer than 10 patients per site, for which some data were missing (eg, age, sex, primary diagnosis), and these were replaced using multiple imputation. The median length of follow-up was 11 days (28 shifts) at UHC A and 9 days (25 shifts) at UHC B (Table 1).

Overall, the patient characteristics across the UHCs were similar, with 4 exceptions. First, with respect to the severity of illness on admission, patients from UHC B appeared sicker, with higher LAPS scores (25.4 vs 12.4 LAPS points; Table 1). Second, regarding the type of surgical procedures performed, valve surgeries were more common at UHC A (35.6% vs 26.9%), possibly due to the higher proportion of patients with

aortic valve stenosis at this site (26.9% vs 17.0%; Table 1). Conversely, CABGs were more frequently performed at UHC B (58.3% vs 49.5%), potentially because of a higher prevalence of patients with atherosclerotic heart disease at this site (55.6% vs 21.9%; Table 1). Third, among patients who received valve surgery, valve replacements were more frequent at UHC A (81.7% vs 73.0%), and valve repair was more common at UHC B (27.0% vs 18.3%). Last, patients from UHC A spent a greater proportion of time in the ICU during the first 6 postoperative days, as well as over their entire hospitalization (Table 1).

POAF

The incidence of POAF was similar across sites (UHC A: 27%; UHC B: 30.8%), and higher among patients who underwent CABG (Table 1). Specifically, at both sites, roughly half of the POAF cases occurred among patients who received CABG; one-third occurred among patients with valve surgery; and one-fifth occurred among patients with both CABG and valve surgery (Table 1).

Nurse staffing practices

Over the study period, the first 6 postoperative days for the patients in the cohort totaled 12,177 and 13,364 distinct unit-shifts at UHC A and UHC B, respectively (Table 2). During the first 6 postoperative days, understaffed unit-shifts were more common at UHC B (26.0% vs 17.3%) (Table 2). Moreover, compared to UHC A, the first 6 postoperative days at UHC B were characterized by higher staff proportions of baccalaureate-prepared RNs (57.3% vs 44.6%) and a lower proportion of non-RN staff (15.9% vs 32.4%; Table 2). The RN collective experience was similar across sites, averaging approximately 10 years (Table 2). Last, at both sites, the nurse staffing practices observed over the first 6 postoperative days were comparable to those observed over the entire hospitalization (Table 2). Correlations among the 4 nurse staffing exposures were low, ranging from −0.127 to 0.167 at UHC A and from −0.270 to 0.254 at UHC B (Supplemental Table S2).

Site-specific associations between cumulative measures of nurse staffing and POAF

In the fully adjusted logistic regression model using data from UHC A, every 5% increase in the cumulative

Table 3. Adjusted associations between nurse staffing practices over the first 6 postoperative days and the risk of postoperative atrial fibrillation, stratified by hospital site

Cumulative nurse staffing practices over the first 6 postoperative days	UHC A (n = 2067)		UHC B (n = 4334)	
	OR (95% CI)*,†	P	OR (95% CI)*,†	P
RN understaffing‡ (per 5% ↑), %	1.035 (1.000–1.070)	**0.0472**	1.035 (1.013–1.057)	**0.0019**
Education mix§ (per 5% ↑), %	0.991 (0.970–1.013)	0.4283	0.997 (0.979–1.015)	0.7147
RN experience‖ (per 1 year ↑), y	1.089 (0.997–1.190)	0.0590	0.898 (0.826–0.976)	**0.0112**
Non-RN skill mix¶ (per 1% ↑), %	0.992 (0.935–1.052)	0.7903	1.024 (0.960–1.093)	0.4686

Boldface indicates significance.

CI, confidence interval; OR, odds ratio; RN, registered nurse; UHC, university health centre.

* Odds ratios are from a logistic regression model adjusting for patient characteristics on admission (age, sex, Charlson Comorbidity Index, severity of illness (LAPS—laboratory-based acute physiology score, type and year of cardiac surgery).

† Akaike information criterion: UHC A = 2,395.477; UHC B = 5,070.256.

‡ Cumulative proportion of shifts with an observed number of RNs' worked hours that is at least 8 hours below the expected unit-shift value according to patient census (see "RN Understaffing" in the *Methods* section for details).

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

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

¶ Cumulative proportion of non-RNs' worked hours among all nursing staff worked hours relative to the unit-shift mean.

proportion of understaffed shifts over the first 6 post-operative days, relative to the unit-shift mean values, was associated with a 3.5% increase in the odds of POAF (adjusted odds ratio [aOR]: 1.035; 95% CI: 1.000-1.070, P = 0.0472; Table 3). No other staffing practices over the first 6 postoperative days at UHC A were significantly associated with the odds of POAF occurrence (Table 3).

Similarly, using data from UHC B, we observed that every 5% increase in the cumulative proportion of understaffed shifts over the first 6 postoperative days, relative to the unit-shift mean values, was associated with a 3.5% increase in the odds of POAF (aOR: 1.035; 95% CI: 1.013-1.057, P = 0.0019; Table 3). In addition, we noted that every additional year added to the cumulative mean number of years of experience held by RNs over the first 6 postoperative days, above the unit-shift mean values, decreased the odds of POAF by 10.2% (aOR: 0.898; 95% CI: 0.826-0.976, P = 0.0112; Table 3). RN education and non-RN skill mix over the first 6 postoperative days were not associated with the odds of POAF occurrence (Table 3). The complete results of the multivariable logistic regression models for both sites are presented in Supplemental Table S3.

Overall associations between cumulative measures of nurse staffing and POAF

In the mixed-effect logistic regression model combining data from both sites and treating the hospital site (UHC A vs UHC B) as a random effect, we observed that every 5% increase in the cumulative proportion of understaffed shifts over the first 6 postoperative days, relative to the unit-shift mean values, was associated with a 3.1% increase in the odds of POAF (aOR: 1.031; 95% CI: 1.014-1.048, P = 0.0003; Table 4; Supplemental Table S3). No other staffing practices were significantly associated with the incidence of POAF.

Sensitivity analyses

In the sensitivity analyses, all alternative models with shorter or longer durations of cumulative exposures yielded similar estimates, and thus the same conclusions as the main model, with marginally worse fit to data and slightly weaker associations (Supplemental Table S4). This result suggests that POAF occurrence is associated with cumulative nurse staffing practices observed over the first 6 postoperative days. None of the quadratic terms tested for the nurse staffing exposures reached statistical significance (data not shown).

Table 4. Adjusted associations between nurse staffing practices over the first 6 postoperative days and the risk of postoperative atrial fibrillation, for university health centre (UHC) A and B combined

Cumulative nurse staffing practices over the first 6 postoperative days	UHC A and B combined (n = 6401)	
	OR (95% CI)*	P
RN understaffing† (per 5% ↑), %	1.031 (1.014–1.048)	**0.0003**
Education mix‡ (per 5% ↑), %	0.973 (0.911–1.040)	0.4194
RN collective experience§ (per 1 year ↑), y	0.958 (0.904–1.015)	0.1422
Non-RN skill mix‖ (per 1% ↑), %	1.022 (0.980–1.065)	0.3124

Boldface indicates significance.

CI, confidence interval; OR, odds ratio; RN, registered nurse.

* Odds ratios are from a multivariable mixed-effect logistic regression model treating the hospital site (UHC A vs UHC B) as a random effect and adjusting for patient characteristics on admission (age, sex, Charlson Comorbidity Index, severity of illness [LAPS—laboratory-based acute physiology score], type and year of cardiac surgery).

† Cumulative proportion of shifts with an observed number of RNs' worked hours that is at least 8 hours below the expected unit-shift value according to patient census (see "RN Understaffing" in the *Methods* section for details).

‡ Cumulative average baccalaureate-prepared RNs' worked hours among all RNs' worked hours relative to the corresponding unit-shift mean.

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

‖ Cumulative proportion of non-RNs' worked hours among all nursing staff's worked hours relative to the unit-shift mean.

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Discussion

POAF is the most common complication of cardiac surgery. Although prior research has identified several important risk factors for its occurrence, and many preventive interventions have been proposed, the incidence of POAF has not declined over the past several decades, indicating that new interventions must now be identified and investigated. In this study, we explored whether 4 postoperative nurse staffing practices, which can be modified by nursing managers, were associated with the occurrence of POAF.

We found that higher RN understaffing over the first 6 postoperative days was associated with higher odds of POAF occurrence, a finding consistent with that of a growing number of studies that linked RN staffing levels to several surgical outcomes.[18,27,46] Moreover, to the best of our knowledge, the present investigation is the first multisite longitudinal study to measure RN understaffing over the time window during which POAF is most likely to occur. This methodological characteristic, along with our finding of an association of the same magnitude in 2 administratively distinct UHCs, strengthens the likelihood that RN understaffing contributes to the incidence of POAF.

Although the exact mechanism by which POAF develops is not fully understood,[1] sympathetic nerve activation through a variety of postoperative symptoms (eg, pain, anxiety), physiologic instabilities (eg, hypovolemia, anemia, hypoglycemia),[1,47] and electrolyte disturbances (eg, magnesium and potassium deficiencies) could contribute to its incidence.[47] Because they are present day and night at the bedside, RNs are well positioned to assess and monitor patients for these postoperative conditions, as well as to intervene when required. Understaffing could thus influence the effectiveness of this postoperative surveillance system by reducing the amount of time available for adequate patient monitoring and interventions by RNs,[18,22] a hypothesis that warrants further investigation.

In addition, we noted that, aside from the effect of RN understaffing, higher RN experience at UHC B had a protective and independent effect against POAF occurrence, a finding that was not observed at UHC A or in the analysis combining data from both sites. Although some previous studies have found that a greater level of RN experience is related to better patient outcomes, the results across studies (and settings) have been inconsistent, and the reasons for such inconsistencies are still being debated.[15,18] Our findings suggest that more-experienced RNs at UHC B may have developed, over time, better patient surveillance skills and interventions, which could contribute to reducing the occurrence of POAF. However, one may wonder why a similar phenomenon did not occur at UHC A, and we cannot exclude the possibility that some other site-specific variables are at play. For instance, RNs at UHC A could have received extensive training and orientation prior to their employment in postsurgical nursing units, as well as regular continuing education, which could have levelled the effect of RN experience at this site. Whether this hypothesis holds true will require additional research work. Further research is also necessary to examine whether alternative but less commonly available measures of RN expertise, such as the proportion of RNs holding specialty certifications in cardiology, would provide similar or different results.

Moreover, we found no evidence that RN education at the baccalaureate degree level or non-RN skill mix were related to POAF occurrence. Although variability in the use of these staffing practices was observed, both within and across UHCs, it is possible that the threshold at which they correlate with POAF occurrence was not reached in this study. Alternatively, RN education and the non-RN skill mix may simply not affect whether POAF develops. Given that no prior study has examined whether these staffing practices are associated with POAF occurrence, and inconsistent associations with several other postoperative cardiac events as reported in recent systematic reviews,[15,18] it appears advisable to recommend further investigations in other settings and jurisdictions.

Overall, our results suggest that preventing RN understaffing in the immediate postoperative period could act as a protective factor against the incidence of POAF in cardiac surgery patients. Despite being potentially modifiable, addressing RN understaffing will represent a challenge for hospital managers. With an international shortage of RNs that is expected to increase in the near future,[48,49] national-level policies may be required to further increase the availability of RNs (eg, through higher immigration and graduation rates) and their retention in the profession (eg, with higher wages and better working conditions).[49,50] In addition, better staffing levels could also be achieved through minimum nurse-to-patient ratio mandates, as currently implemented in Queensland (Australia) and in California (US), which have been linked to better patient outcomes and a good return on investment.[46] Last, hospital-based managers could also opt for evidence-based strategies, such as those found in "magnet hospitals"—a group of hospitals with organizational features (eg, flexible self-scheduling, increased career opportunities and professional autonomy, decentralized decision-making) that not only attract and retain RNs at the bedside but also are associated with better patient outcomes.[17,51]

Study limitations

First, although the results of this multicentre cohort study suggest that RN understaffing contributes to POAF occurrence, causation cannot be inferred from the observed associations, and confounding remains a possibility. For instance, we had no data on the availability and qualifications of physicians and other healthcare professionals, aside from the nursing staff, or on the postoperative policies and procedures that were in place at the participating sites (eg, type and duration of monitoring, medication use), all of which might have influenced nurse staffing practices and POAF occurrence. Second, although the accuracy of our risk adjustment model is comparable to that of other commonly used risk scores, the reported c-statistics are somewhat low, and residual confounding could be at play. Third, although we used a validated measure of POAF occurrence,[28] its accuracy was not perfect, and measurement errors may have influenced the estimated effects of the nurse staffing exposures in either direction.

Fourth, because our outcome measure is based on discharge diagnostic codes, the timing of POAF occurrence could not be determined. Consequently, although the nurse staffing exposures were measured over the time window during which POAF is most likely to occur, a true time-to-event analysis was not feasible in this study. To mitigate this limitation, investigators could apply machine learning and/or natural language–processing techniques to electronic electrocardiogram reports,[52,53] which have the advantage of being date- and time-stamped. However, at the time of this study, electronic electrocardiograms were not available at the participating sites.

Fifth, our measure of RN understaffing was relative to unit-shift mean values observed over the study period, an approach that may under- or overestimate patient requirements for nursing care. Although this measure could be improved by using a validated patient classification system that specifies the required number of RN hours per unit-shift, as in most hospitals, such a system was not in use at either of the study sites. Sixth, our measure of RN understaffing was calculated using both regular and overtime hours. However, several studies suggest that overtime use is, by itself, a staffing practice associated with adverse patient outcomes.[18,54] Exploring the associations of RN overtime with POAF occurrence thus represents an interesting avenue for future studies.

Seventh, this study was conducted in 2 tertiary-care centres, which typically employ greater numbers of physicians and nurses, benefit from trainees, treat more complex cases, and have access to more sophisticated technology. Therefore, further research is required to determine whether our results can be reproduced in other types of centres. Last, further research is required to determine if our observations hold for other types of postoperative adverse events among cardiac surgery patients.

Conclusion

In this patient-level, multicentre study, we found evidence that higher RN understaffing during the first 6 postoperative days is associated with increased POAF occurrence among cardiac surgery patients. This finding suggests that hospital managers should pay greater attention to assessing the frequency of understaffed shifts in the postoperative period, and that ongoing efforts to further increase the availability of RNs at the bedside should be pursued.

Funding Sources

Disclosures

The authors have no conflicts of interest to disclose.

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Supplementary Material

To access the supplementary material accompanying this article, visit *CJC Open* at https://www.cjcopen.ca/ and at https://doi.org/10.1016/j.cjco.2021.08.013.