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Nurse Staffing and Healthcare Associated Infection, Unit-level Analysis

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Abstract

Objective: To examine whether healthcare associate infections (HAIs) and nurse staffing are associated using unit-level staffing data.

Background: Previous studies of the association between HAIs and nurse staffing are inconsistent and limited by methodological weaknesses.

Methods: Cross-sectional data between 2007 and 2012 from a large urban hospital system were analyzed. HAIs were diagnosed using the Centers for Disease Control and Prevention's National Healthcare Safety Network definitions. We used Cox proportional-hazards regression model to examine the association of nurse staffing (2 days before HAI onset) with HAIs after adjusting for individual risks.

Results: Fifteen percent of patient-days had 1 shift understaffed, defined as staffing below 80% of the unit median for a shift, and 6.2% had both day and night shifts understaffed. Patients on units with both shifts understaffed were significantly more likely to develop HAIs 2 days later.

Conclusions: Understaffing is associated with increased risk of HAIs.

Healthcare associated infections (HAIs) are a serious but often preventable problem resulting in high morbidity and mortality and increased healthcare costs. A multi-state survey recently found that approximately 4% of patients had 1 or more HAIs during their hospital stay [1], and these HAIs contribute to billions of additional healthcare costs annually [2]. In addition to their medical and financial impacts, HAIs also have

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psychological and social consequences for patients such as depression, anxiety, disability, and job loss [3].

The Department of Health and Human Services has prioritized elimination of HAIs as a major component of its action plan to build a safer and affordable health care system [4]. In 2008, Medicare stopped payment to hospitals for 3 HAIs (catheter associated urinary tract infection (CAUTI), vascular catheter associated infection CLABSI), and surgical site infection (SSI)) [5]. Centers for Medicare and Medicaid Services (CMS) 2016 Value Based Purchasing Program also included these HAIs as safety measures in evaluating hospital performance [6]. Hence, reducing HAIs is a top priority to improve quality of care and reduce hospital costs.

Nurses play a critical role in the prevention of HAIs. In addition to providing bedside care, nurses often act as coordinators of the multidisciplinary health care team in the work of infection control and prevention. A 2008 systematic review found substantial but inconsistent evidence that better nurse staffing is related to lower rates of HAIs [7]. Among the reasons for the inconsistent findings: were reliance on highly aggregated measures of staffing; inability to determine the staffing level individual patients experienced; lack of adequate controls for patient-level risk; use of International Classification Diagnosis (ICD) codes in discharge data that may be incomplete and do not match the Centers for Disease Control and Prevention (CDC)'s National Healthcare Safety Network (NHSN) definition for HAIs; and failure to consider the incubation period for the development of an HAI [8].

To address the limitations of prior research and provide new evidence, we examined the association between unit-level nurse staffing and HAIs. Staffing on each unit for each shift was identified through hospital payroll data in the subject organizations. Patients were tracked through their stays, identifying the unit on each day and the shift, allowing direct measure of their exposure to staffing levels. Infections were identified for individual patients from institutional datasets that use CDC/NHSN definitions, and a robust patient-level risk adjuster was implemented.

Methods

Setting

The study was conducted in a hospital system with 3 campuses located in a large, metropolitan US city (2 tertiary/quaternary hospitals and 1 community hospital) with more than 2,000 beds and over 100,000 patient discharges annually. Columbia University Medical Center and Weill Cornel institutional review boards approved the project.

Datasets

Multiple electronic data sources were used. Nurse staffing data were extracted from hospital payroll data, which provided detailed information on individual bedside nurse staffing on each unit by shift. Patient information was obtained from 3 databases: 1) administrative data providing patient demographic information as well as admission/discharge dates, admission resources, and all diagnoses; 2) clinical data warehouse (CDW) integrating data from more than 20 clinical electronic sources, providing information on patient location, laboratory

results, medication, and medical procedures; and 3) electronic health record system including physician orders and nurses' notes. These 3 datasets were linked through each patient's unique medical account number. The merged patient data were then linked to the staffing data using the location code and date.

We used 6 years of data, from 2007 through 2012, excluding patients from pediatric, labor and delivery, mental health, and inpatient rehabilitation units. We also excluded patients who had surgery during the hospitalization because data for surgical site infections were not complete in the datasets.

We identified the unit on which each patient was located on a daily basis, merged with nurse staffing of that unit on a shift-by-shift basis. We excluded unit-shifts with extreme staffing levels, which may have been caused by data error, including unit-shifts with patient-to-nurse ratios higher than 4 for intensive care units (ICUs), 8 for medical and medical/surgical units, and 6 for step-down units.

Study variables

Healthcare Associated Infections—The HAIs included in the analysis were urinary tract infection (UTI), bloodstream infection (BSI), and pneumonia (PNU). Following the surveillance definitions from the CDC/NHSN (http://www.cdc.gov/nhsn/about.html) for HAIs [9–11], rigorous algorithms were developed and tested to identify HAIs [12, 13] after combining multiple clinical information such as microbiologic results and urine microscopy results. We identified 3 types of HAI – UTI, BSI and PNU and then developed a composite HAI measure by combining these HAIs together. Consistent with CDC/NHSN HAI definitions, we only selected infections that occurred on or after the 3rd calendar day of hospital admission, where day of admission is the 1st calendar day. That is, if a patient developed any of the 3 types of infection on or after the 3rd day of hospital admission, he/she was identified as having a HAI.

Nurse staffing—Individual nursing staff members' daily time in and out data were aggregated to unit-shift level nursing hours for each type of nursing staff based on the location code. Because there were very few licensed practiced nurses (LPNs) in the 3 hospitals, we combined the LPNs with nurse assistants, and categorized them as nursing supporting staff (NS). For each of the registered nurses (RNs) and NSs, we divided the unit-shift level nursing hours by the total number of patients in the unit on that day to generate a shift-based nursing hours per patient days (NHPPD) variable. We used the day (7am-7pm) and night (7pm-7am) shifts, corresponding to the normal 12-hour shift adopted by most units.

Following an approach used in a prior study [14], each shift on each unit was characterized as understaffed or not. We chose to dichotomize the staffing because previous analysis found a nonlinear relationship between staffing levels and patient outcomes; clinicians suggested that small differences in staffing below target could be better accommodated than larger differences in staffing below the target. Because target staffing levels were not available for each shift on each unit, we used the median hours per patient for each unit for day or night shifts as the standard staffing on the unit and characterized the shift as understaffed if

staffing was below 80% of the unit median for a shift. For each patient, we generated a categorical staffing variable for each day ranging from 0 to 2, with 0 representing no shift understaffed, 1 representing 1 of the day or night shifts understaffed, and 2 representing both day and night shifts understaffed. The categorical variable was created for both RN and NS staffing.

Patient-level Measures—To account for individual risk, we controlled for a number of patient-level covariates. From the hospital administrative dataset, we obtained patients' demographics such as age and gender, whether the patient had a skilled nursing facility stay prior to the current admission, and coexisting medical conditions such as diabetes mellitus (DM), cancer, transplantation, and HIV. We calculated a Charlson Comorbidity Index for each patient using ICD-9 codes [15]. From the CDW and electronic health record, we obtained information on medical procedures or treatments during the hospitalization that had a potential relationship with HAIs including insertion of feeding tube, urinary catheters, central venous catheters, cardiac catheters, being placed in a mechanical ventilation, having a coronary angioplasty or a catheter angiography, taking high risk medications that would impair the immune system such as chemotherapy, and receiving antibiotics before the infection onset.

Statistical Analysis

Statistics describing patient demographics, comorbidities, and medical procedures were calculated and compared for patients with and without HAIs using t-tests for continuous variables and chi-square tests for categorical variables. For each type of nursing unit, we calculated the mean level of RN and NS staffing, 80% of the median staffing, and the proportion of shifts with staffing below 80% of the median.

To assess the association of RN and NS staffing with HAIs, we used survival analysis. We estimated a Cox proportional-hazards regression model with hospital day as the time scale and the composite HAIs as the outcome. Hazard ratios were calculated and reported. The hazard ratio, commonly used in survival analysis, is an expression of the hazard or chance of events occurring (i.e., HAI) in 1 condition (i.e., understaffing) as a ratio of the hazard of the events occurring in another condition (i.e., normal staffing) [16]. To account for the temporal relationship between nurse staffing and HAIs and the infection incubation period, daily nurse staffing information 2 days before the onset of an HAI was used as a time varying covariate. The model controlled for patient individual factors as described previously; unit type, year, and patient turnover were calculated as the number of unit admissions, transfers, and discharges divided by the total number of patients on that unit on a daily basis. We also added unit random effect to control for the clustering effects in multi-level data. All medical procedures and treatment variables were treated as time-varying covariates.

Results

The final sample included 100,264 patients with 448,826 patient-days from 34 units, including ICUs, medical, medical/surgical combined, and step-down units. Of 100,264 patients in the final sample, 4,390 (4.34%) developed an HAI during the hospitalization, including 2,594 (59.1%) UTIs, 1,198 (27.3%) BSIs, and 751 (17.1%) PNUs. Table 1

summarizes the characteristics of the total study sample and those with and without a HAI. On average, the patients were 61 years old and half were female. About 3% of patients had stayed in a skilled nursing facility before the hospital admission. About a quarter of patients had DM, were on high risk medications, and had indwelling urinary catheters placed during the hospitalization. About 20% of patients had a history of cancer or had an ICU stay during the hospitalization, and about 12% had a central venous catheter placed during hospitalization. Patients who had a HAI during the hospitalization were significantly older and were more likely to be female, more likely to have had a stay in a skilled nursing facility prior to admission, had more comorbidities, and had more medical procedures and treatments than those without HAIs. While those with a HAI were more likely to have a history of cancer, transplantation, and HIV, there was no difference in rates of DM, with about 27% of patients having history of DM for patients with HAIs and without HAIs.

Of a total of 66,871 unit shifts, 27,331 (40.9%) were in ICUs, 18,793 (28.1%) were in medical units, 10,016 (15.0%) were in medical/surgical combined units, and 10,731 (16.1%) were in step-down units (Table 2). The RN staffing on average for the day shift was 11.5 hours per patient in ICUs, 3.8 in step-down units, 3.4 in medical units, and 2.6 in medical/surgical units. The RN staffing levels were consistent across day and night shifts for all units, with the staffing per patient on day shifts slightly higher than on night shifts. The NS staffing on day shifts was on average 2.3 hours per patient in ICUs, 1.5 in step-down units, 1.8 in medical units, and 2.0 in medical/surgical units. The same pattern was observed for NS staffing levels, as day shifts had slightly higher staffing than night shifts. Approximately 19% of shifts in ICUs were understaffed (below 80% of the median unit staffing per patient) for RNs and about 32% were understaffed for NSs during both day and night shifts. In general, there were more understaffed shifts in ICUs than other unit types, and units were more likely to be understaffed for NSs than for RNs (Table 2). RN understaffing was observed on 22% of patient-days, with about 15% of patient-days having 1 shift understaffed and 6.2% patient-days having both day and night shifts understaffed.

Hazard ratios for HAIs associated with exposure to low staffed shifts are presented in Table 3. Controlling for patients' demographics, comorbidity, medical procedures, treatment, patient turnover, and unit type, we found significant associations between HAIs and RN and NS understaffing. Hazard rate of HAIs, or risk of HAIs in any given time, in patients on units with RN understaffing on both shifts two days prior to infection onset were 15% higher than for those staying in units with both day and night shifts staffed at or above 80% of the unit median (HR = 1.15, 95% CI = 1.02, 1.30). Likewise, Hazard rate of HAIs in patients on units with NS understaffing on both shifts 2 days before infection onset were 11% higher than for those staying in units with both day and night shifts adequately staffed with NSs (HR = 1.11, 95% CI = 1.01, 1.21). We observed no significant association between HAIs and understaffing when only 1 of the 2 shifts was understaffed.

Discussion

Using the CDC/NHSN definition of HAIs, we found that 4.3% of non-surgical patients had at least 1 of the 3 types of infections during their 30-day hospital stay, which is consistent with the infection rate of 4.0% reported by Magill in the 2010 multistate point-prevalence

survey [1]. Our study strengthens the existing evidence regarding an association between HAIs and nurse staffing by addressing the multiple challenges faced by previous researchers. First, the rich clinical data for individual patients contained in the CDW allowed for a more precise diagnose of HAIs and better risk adjustment, which are often missing in studies using administrative data [17–19]. Second, linking nurse payroll data to patient data made it possible to examine staffing at the unit-shift level for each patient, which is deemed a more precise staffing measure by researchers [20]. Third, the standardized nurse staffing measure used in our study by comparing the unit-shift staffing with the median staffing for the unit addresses the concern raised in studies with different unit types [21]. Fourth, researchers criticized that the traditional hours per patient day measures overestimate the RN staffing and understate the workload without adjustment of patient turnover [22]. Our models addressed this issue by adjusting for patient transfers. Finally, our examination of the staffing level 2 days before infection onset made it possible to test the temporal relationship between staffing and HAIs and consider the infection incubation period. We are aware of 2 other studies which have examined the nurse staffing level before HAI onset and its impact on HAIs [23, 24]. However, these studies were limited by small sample sizes, focused on certain unit types, and lacked control for covariates.

Our findings of an association between unit nurse understaffing and HAI confirms the findings of previous studies[7] but with better data and a stronger design. Nurses, the largest workforce in hospitals, play a vital role in preventing and controlling HAIs by providing bedside care and helping to coordinate multidisciplinary team work. When a unit is understaffed, in our study, meaning staffing was below 80% of unit median, nurses in the unit experienced excessive workloads. These heavy workloads may compromise infection prevention practices and surveillance activities for early recognition of signs and symptoms of infection. The effect of understaffing in 1 shift may be temporary as nurses may still manage to maintain patient surveillance. However, continuous understaffing throughout the day will undermine nurses' wellbeing, cause job-related stress, and negatively affect patient care. As indicated by our finding that patients in units understaffed for both day and night shifts were more likely to have HAIs, a break of continuous care due to nurse understaffing will directly affect patient outcomes. In addition, a continuous unit staff shortage may also indicate an underlying issue with the working environment. Nurse administrators need to implement effective solutions to ensure adequate nurse staffing and provide safe and reliable care to acutely ill hospitalized patients.

Our study has limitations. The study sample included only 3 urban hospitals: 1 community hospital and 2 tertiary/quaternary care hospitals; although this included a diverse patient population, generalizability may be limited. The available data sources did not allow us to examine the underlying situation leading to the continuous understaffing in these units and specific care processes. Future studies may include these components (e.g., infection control practices such as aseptic technique and hand hygiene) to better understand how nurse staffing may affect HAIs.

In summary, our study addressed a few methodological limitations by using CDC/NHSN definition of HAI and more precise staffing measure. The unit-level data structure and linking staffing 2 days before infection onset allowed us to examine the temporal relation

between unit nurse staffing and HAI. Our study findings demonstrated that hospital units experienced nurse shortage for both day and night shifts; and this shortage lead to adverse patient outcomes. When addressing the understaffing issue, hospital administrators need to pay close attention to the units with continuous understaffing.

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Table 1.

Descriptive characteristics of study patients [a]

Characteristics	Total Sample (n = 100,264)	Patients without HAIs (n = 95,874)	Patients with HAIs (n = 4,390)	P value
Demographics				
Female	50,703 (50.6)	48,356 (50.4)	2,347 (53.5)	<0.001
SNF stay	3,048 (3.0)	2,845 (3.0)	203 (4.6)	<0.001
Age – mean (S.D.)	60.8 (18.7)	60.6 (18.7)	65.1 (17.6)	<0.001
Comorbidity				
Charlson Index – mean (S.D.)	2.3 (2.4)	2.2 (2.4)	3.3 (2.8)	<0.001
Diabetes Mellitus	26,569 (26.5)	26,535 (26.5)	1,188 (27.1)	0.386
Cancer	15,799 (15.8)	14,630 (15.3)	1,169 (26.7)	<0.001
Transplantation	2,094 (2.1)	1,965 (2.1)	129 (2.9)	<0.001
HIV	2,534 (2.5)	2,362 (2.5)	172 (3.9)	<0.001
Medical procedures				
Intensive Care Unit stay	16,668 (16.6)	14,508 (15.1)	2,160 (49.2)	<0.001
Mechanical ventilation	3,553 (3.5)	2,417 (2.5)	1,136 (25.9)	<0.001
Feeding tube	878 (0.9)	562 (0.6)	316 (7.2)	<0.001
Dialysis	3,524 (3.5)	3,198 (3.3)	326 (7.4)	<0.001
High risk medication	24,645 (24.6)	22,640 (23.6)	2,005 (45.7)	<0.001
Urinary catheter	26,895 (26.8)	23,807 (24.8)	3,088 (70.3)	<0.001
Central Venous catheter	11,599 (11.6)	9,717 (10.1)	1,882 (42.9)	<0.001
Antibiotics	4,035 (4,0)	1,413 (1.5)	2,622 (59.7)	<0.001
Cardiac catheter	5,333 (5.3)	5,052 (5.3)	281 (6.4)	0.001
Coronary angioplasty	2,293 (2.3)	2,214 (2.3)	79 (1.8)	0.027
Catheter angiography	8,624 (8.6)	8,039 (8.4)	585 (13.3)	<0.001

Note:

[a] unless indicated, all statistics are presented as n (%), HAI: Healthcare associated infection, SNF: Skilled nursing facility, S.D.: Standard Deviation.

Table 2:

Level of Nurse Staffing by Unit Type and Shift [a]

Variable	ICUs	Medical Units	Med/Surg Units	Step-Down Units
Day Shift				
No. of Shifts	27,331	18793	10016	10731
Registered Nurses (RN)				
RN nursing hours/patients (mean (S.D.))	11.5 (6.6)	3.4 (2.2)	2.6 (2.1)	3.8 (1.6)
80% of RN staffing median	8.0	2.2	1.8	2.9
Understaffed shifts by the definition (%)	19.40%	13.20%	11.70%	15.60%
Nursing supporting staff (NS)				
NS nursing hours/patients (mean (S.D.))	2.3 (2.3)	1.8 (1.0)	2.0 (1.3)	1.5 (0.8)
80% of NS staffing median	1.44	1.28	1.44	1.12
Understaffed shifts by the definition (%)	32.40%	20.90%	23.30%	27.80%
Night Shift				
No. of Shifts	27,331	18793	10016	10731
Registered Nurses (RN)				
RN nursing hours/patients (mean (S.D.))	11.1 (6.6)	3.2 (2.1)	2.4 (2.0)	3.7 (1.5)
80% of RN staffing median	7.6	2.08	1.68	2.8
Understaffed shifts by the definition (%)	19.40%	11.60%	9.10%	13.80%
Nursing supporting staff (NS)				
NS nursing hours/patients (mean (S.D.))	1.9 (2.1)	1.5 (1.0)	1.6 (1.2)	1.3 (0.7)
80% of NS staffing median	1.2	1.04	1.2	1.04
Understaffed shifts by the definition (%)	32.70%	23.80%	22.80%	27.70%

Note:

[a]Understaffing is defined as the nursing staff is lower than 80% of the shift median for each unit type and each type of nursing staff, S.D.: Standard Deviation.

Table 3:

Association of nurse staffing and HAIs (n = 448,826) [a]

Variables	Hazard Ratio (95% CI)	P value
RN Understaffing [b] (0 as reference group)		
1	1.00 (0.92, 1.09)	0.98
2	1.15 (1.02, 1.30)	0.024
NS understaffing (0 as reference group)		
1	1.05 (0.97, 1.12)	0.226
2	1.11 (1.01, 1.21)	0.031

Notes:

[a] Model is controlled for patient individual risks such as demographics, comorbidity, medical procedures and treatments, unit patient turnover, unit types, and data year.

[b] Understaffing & skill mix are both calculated by comparing with 80% of median in the unit and shift, 0 = neither day nor night shift was understaffed, 1= one of the shift was understaffed, & 2 = both shifts were understaffed.

RN: Registered nurse, NS: Nursing support staff including nursing assistants and a small number of licensed practiced nurses.