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Nurse Staffing Level, Length of Work Experience, and Risk of Health Care–associated Infections Among Hospital Patients

A Prospective Record Linkage Study

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Background: Nurse understaffing may have several adverse consequences for patients in hospitals, such as health care–associated infections (HAIs), but there is little longitudinal evidence available on staffing levels and HAIs with consideration of incubation times to confirm this. Using daily longitudinal data, we analyzed temporal associations between nurse understaffing and limited work experience, and the risk of HAIs.

Methods: The study was based on administrative data of 40 units and 261,067 inpatient periods for a hospital district in Finland in 2013–2019. Survival analyses with moving time windows were used to examine the association of nurse understaffing and limited work experience with the risk of an HAI 2 days after exposure, adjusting for individual risk factors. We reported hazard ratios (HRs) with 95% CIs.

Results: Neither nurse understaffing nor limited work experience were associated with the overall risk of HAIs. The results were inconsistent across staffing measures and types of HAIs, and many of the associations were weak. Regarding specific HAI types, 1-day exposure to low proportion of nurses with >3 years of in-hospital experience and low proportion of nurses more than 25 years old were associated with increased risk of bloodstream infections (HR = 1.30; 95% CI: 1.04–1.62 and HR = 1.40; 95% CI: 1.07–1.83). Two-day exposure to low nursing hours relative to target hours was associated with an increased risk of surgical-site infections (HR = 2.64, 95% CI: 1.66–4.20).

Conclusions: Data from time-varying analyses suggest that nursing staff shortages and limited work experience do not always increase the risk of HAI among patients.

Key Words: administrative data, health care–associated infection, nurses, hospital staffing, work experience

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This study was based entirely on administrative register data to which the hospital district permitted access and applied pseudonymised identification numbers for research purposes. Research using such data does not need to undergo review by an ethics committee according to Finnish legislation (Medical Research Act). The consent to participate was not applicable due the secondary use of preexisting register data.

The study protocol was designed and performed according to the principles of the Helsinki Declaration. All methods were carried out in accordance with relevant guidelines and regulations.

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Many European countries face shortages of nursing professionals.[1] This may have several adverse consequences for employees and patients, including an increase in time pressure, job strain, and poor compliance with patient-safety principles among nurses and consequently, a lower quality of care.[2–6] Longitudinal studies have consistently shown that exposure to nurse understaffing is associated with increased mortality risk among hospital patients.[7–9] Another serious adverse consequence of nurse understaffing for patients are health care–associated infections (HAIs),[10] with the prevalence of 7% in European acute care hospitals and 4% in long-term care facilities.[11]

Limited work experience among nurses may also be a risk factor for patient safety. Patient risk might be further exacerbated if understaffing is combined with limited work experience among nursing staff, as greater work experience may be needed to prioritize critical tasks under an excessive workload.[12] However, the few studies on the topic have found inconsistent results. Lower levels of experience have been associated, for example, with both a greater[13] and a lower risk[14] of falls among patients, and mainly not associated with HAIs.[14,15]

Empirical evidence on the associations of nurse staffing levels and limited work experience as risk factors for HAIs has several limitations.[10,15–18] Regarding work experience, prior studies have relied on cross-sectional designs.[14,15] Few studies have considered the temporal associations between nurse staffing levels and the risk of HAIs in detail.[17,19–21] For example, studies have compared average staffing levels and HAI rates at the unit or hospital level, or when measured HAIs at the patient level, have used average staffing levels for the entire admission period before the incident.[17,22,23] For the majority of HAIs, the minimum incubation period is 48 hours, and it has been suggested that a 2- to 4-day incubation period should be considered.[17] A recent US study on administrative data found that exposure to nurse understaffing was associated with an increased risk of HAIs 2 days later.[20] In another study, based on data from Switzerland, the rate of infected patients was associated with the nurse staffing levels in the preceding 2–4 days but not outside of this time window.[19] However, neither study considered actualized hours versus target hours or limited nurse work experience as risk factors for HAIs.

The purpose of this observational study was to address some of these limitations by examining on a daily basis with moving time windows the extent to which nurse understaffing and limited work experience may increase the risk of HAIs in the context of a Nordic welfare state's public hospitals. This study also contributes to the measures of understaffing that have been commonly estimated as nursing hours per patient day in relation to the average or median level in each ward.[7,20,24] Through the utilization of administrative data of working hours obtained via the shift-scheduling system in hospitals, we can estimate nurse understaffing as the share of actualized working hours in relation to the planned working hours. We also examined whether nurse understaffing and limited work experience were associated with specific types of HAIs: bloodstream, *Clostridium difficile*, surgical site, and pneumonia.

METHODS

Study Design

In this longitudinal study, we used register data obtained from one hospital district in Finland. The hospital district included one central university hospital and several regional hospitals with a smaller range of services. The analyses were based on patient and staff data (2013–2019) from 40 units.

Data Sources

We combined information from the employee payroll data register, which includes planned and actual working hours from the shift-scheduling program Titania, and the clinical database Auria,[25] which includes daily information from patient records. Patient and employee data were linked via dates and unit codes. For most of the units, linking was only possible for the period 2013–2019. Most of the 40 units treat both inpatients and outpatients and the services are often organized so that the same personnel treats both patient groups. It was therefore not possible to determine nursing resources targeted to inpatients only. Instead, information on both inpatients and outpatients was included in the unit-level variables described below. However, the treatment of a patient may include inpatient and outpatient visits. In the patient data, we focused on inpatient visits.

Patients

We included inpatient periods of patients aged 16 years or older who were treated in the included units, for whom there was complete information on staffing levels during their stay, and who did not die within 2 days of admission (N = 261,067, Fig. 1). In additional analyses, the sample was restricted to patients who had spent at least 2 days in the hospital (N = 232,796).

Measures

Nurse Understaffing and Limited Work Experience

We measured exposure to nurse understaffing and limited work experience using 4 indicators based on the working hours of registered nurses and registered practical nurses. Following the design of Needleman et al[8] and other prior studies,[7,20,24] the aim of this study was to identify days on which nurse staffing levels were low. The first indicator was calculated by dividing actual nursing hours by the planned nursing hours for each unit-day, excluding unit-days with zero planned or zero actual hours. Information on both actual and planned hours of each shift were recorded for the calendar day according to the starting day of the shift. We categorized unit-days for which this proportion was <90% of the annual unit median as having low nursing hours relative to planned hours. To study the robustness of our findings, we repeated the main analyses using an alternative lower cutoff threshold of 85% and an alternative higher cutoff threshold of 95% in sensitivity analyses.

The second indicator was calculated by dividing the total nursing hours for each unit and calendar day by the number of patient days (1 patient day corresponds to 24 h spend by a single patient in a unit).[26] Nursing hours were calculated based on the start and ending times of each actualized shift, and the numbers of patient days were calculated based on the start and ending times of each admission and outpatient visit. The inpatient hours were accurate, but the ending times of outpatient visits are approximations as outpatients may be checked out as a group at specific times or the visits may be automatically recorded to end at 12 PM if not previously closed. Most of the outpatient visits were recorded to end between 5 PM and 12 PM, suggesting that the outpatient hours in the unit might have been overestimated.

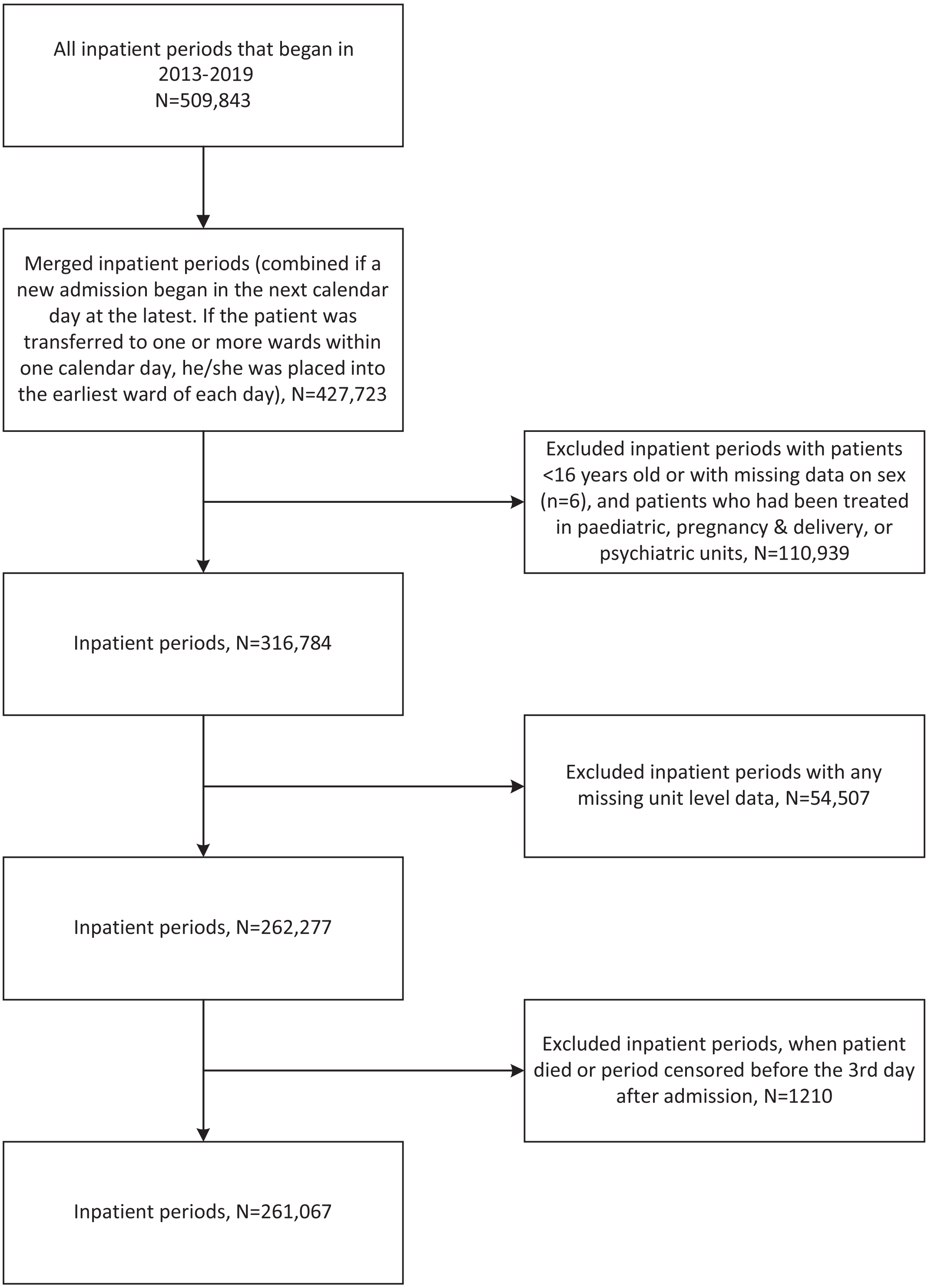

FIGURE 1. Inclusion criteria of the sample.

To reduce any bias resulting from deviating recordings, we identified outliers in the measure "nursing hours per patient day" using a predefined Tukey boxplot method.[27] We excluded 5.5% of the unit-days in which the number of nursing hours per patient day was exceptionally low or high, that is, lower than the annual unit 25% percentile minus 1.5 times annual unit interquartile range or higher than 75% percentile plus 1.5 times the interquartile range. We categorized days for which nursing hours per patient day were < 80% of the annual unit median as low staffed and used alternative cutoff points of 75% and 85% in sensitivity analyses.

Third, limited nurse experience was based on the proportion of nurses with >3 years of work experience in each unit-day, based on calendar years they had nonzero working hours in the hospital district, for example, excluding contracted years during which employees were on parental leave. As the data cover 2008 onwards and our analysis is restricted to 2013–2019, we can assume the variable covers at a minimum the employees' most recent work experience under the current employer. The fourth indicator was based on the proportion of nurses more than 25 years old in each unit-day. We categorized unit-days for which the share of nurses with >3 years of in-hospital experience and more than 25 years old was <90% of the annual unit median as having a limited nurse experience. We used alternative lower and higher cutoff points of 85% and 95% in sensitivity analyses.

Patient-level Covariates

For each inpatient period, we adjusted for patient age, sex, comorbidities, and certain diagnoses and medical procedures that may increase the HAI risk.[5,20,28,29] The comorbidity index was based on the Charlson score.[30,31] We adjusted for specific diagnoses partly as in a prior study[5] and created separate variables to indicate whether a patient had undergone any specific operation during their follow-up periods (see Table 1 and Table S1, Supplemental Digital Content 1, http://links.lww.com/MLR/C610 for operation codes).

Health Care–associated Infection

In Finland, the law requires that HAIs be monitored in health care settings.[32] For the hospital district from which the data were collected, the classification of HAIs is a modified version of the definitions provided by the Centers for Disease Control and Prevention (CDC). The main outcome was the first incident of any HAI. HAIs are typically defined as infections that occur 48 hours after hospital admission at the earliest and may be detected within a single admiss ion or during a subsequent admission or a polyclinical operation.[33,34] To take an incubation period into account, we only considered HAIs that occurred between the third day of each inpatient admission and 2 days of discharge. In addition, we considered 4 specific HAIs as outcomes: bloodstream, *C. difficile*, surgical site, and pneumonia.

Statistical Analysis

We first describe the patients' characteristics across the whole sample and compare those who contracted an HAI with those who did not. We also describe the distributions of the main exposure variables.

Survival analyses with moving time windows were used to examine the ways in which exposure to nurse understaffing and limited work experience were associated with the risk of an HAI. As an HAI takes some time to develop, the risk was predicted in relation to exposure to nurse understaffing and limited work experience measured within a single day 2 days earlier (=a 1-d exposure) with the time window moving forward with the patients' hospital stay until 2 days postdischarge. In additional analyses, we predicted the risk of an HAI as the cumulative sum of exposure variables measured within 2 days, that is, in 2 and 3 days earlier (=a 2-d exposure). To be able to calculate the exposure within 2 days, in these analyses, the sample was restricted to patients who had spent at least 2 days in the hospital.

Separate models were applied for the 4 factors used to indicate exposure to nurse understaffing and limited work experience. We also analyzed interactions between exposure to nurse understaffing and limited work experience, and with respect to 1-day exposure, we analyzed different combinations of nurse understaffing and limited work experience and their associations with HAIs. In other analyses, we restricted the data to those patients, who had not been treated in intensive care unit (ICU) where exposure to understaffing and limited work experience was less likely and baseline HAI rates higher compared with other units. To examine whether including both inpatient and outpatient data is a potential source of error, we performed a sensitivity analysis in which we included only the 12 units in which the median daily share of inpatient hours of all patient hours was $>90\%$.

In all analyses, sex, age, comorbidities, and the presence of specific risk diagnoses were included mainly as time-independent variables according to the information available for each admission. For cases in which consecutive admissions were combined, comorbidities and diagnosis could also vary over time. Medical procedures were included as time-varying covariates and they were expected to increase the risk of HAI until the end of each follow-up period (ie, time in hospital and postdischarge period), hence these values changed from 0 to 1 on the day of the first occurrence of a given procedure for a given period. The year was also controlled for. As the staffing practices and patient characteristics may vary between hospitals, hospital divisions, and units, we adjusted the models for the type of hospital division so that the units of the regional hospitals formed one group and the divisions of the central hospital formed several separate groups. Unit codes were included as a random effect in the models. We conducted parametrical survival analyses with Stata, version 17 using the mestreg-command, assuming a Weibull distribution for the baseline hazard function.

RESULTS

The final data included 261,067 inpatient admissions. Half of the inpatients were men, 74.5% were in the age group of 51–90 years old and 74.1% had no comorbidities according to the Charlson Comorbidity Index (Table 1). In total, 4.6% of the inpatients had diabetes, while the prevalence of all other diagnoses was lower. The most common procedures were surgical (18.5%) and minor surgical operations (7.1%). Inpatients with HAIs were more likely to be men, older, have comorbidities in the Charlson index, lymphomas, leukemia or myeloma, transplantation, surgical or minor surgical operations, or treatment in an ICU.

The average length of follow-up periods (from the third day of the admission period until the end of the 2-d post-discharge period) was 4.4 days, of which 1.4% (n = 3754) ended in an HAI. The most common infections were

TABLE 1. Descriptive Information on Patient Observations (N = 261,067)

Patient characteristics	n (%) Patients without HAI	Patients with HAI	All patients
Sex			
Women	129,569 (50.4)	1742 (46.4)	131,311 (50.3)
Men	127,744 (49.6)	2012 (53.6)	129,756 (49.7)
Age groups (y)			
16–30	19,237 (7.5)	132 (3.5)	19,369 (7.4)
31–50	41,392 (16.1)	448 (11.9)	41,840 (16.0)
51–70	99,413 (38.6)	1608 (42.8)	101,021 (38.7)
71-90	92,081 (35.8)	1500 (40.0)	93,581 (35.8)
> 90	5190 (2.0)	66 (1.8)	5256 (2.0)
Charlson Comorbidity Index			
0	190,957 (74.2)	2439 (65.0)	193,396 (74.1)
1	14,369 (5.6)	133 (3.5)	14,502 (5.6)
2	42,917 (16.7)	962 (25.6)	43,879 (16.8)
≥ 3	9070 (3.5)	220 (5.9)	9290 (3.6)
Diagnoses			
Diabetes*			
No	245,565 (95.4)	3573 (95.2)	249,138 (95.4)
Yes	11,748 (4.6)	181 (4.8)	11,929 (4.6)
Diagnosis related to lower immune response†			
No	246,225 (95.7)	3615 (96.3)	249,840 (95.7)
Yes	11,088 (4.3)	139 (3.7)	11,227 (4.3)
Lymphomas, leukemia, myeloma‡			
No	251,223 (97.6)	3460 (92.2)	254,683 (97.6)
Yes	6090 (2.4)	294 (7.8)	6384 (2.4)
Burns§			
No	256,965 (99.9)	3745 (99.8)	260,710 (99.9)
Yes	348 (0.1)	9 (0.2)	357 (0.1)
Diseases of the liver and pancreas‖			
No	255,578 (99.3)	3725 (99.2)	259,303 (99.3)
Yes	1735 (0.7)	29 (0.8)	1764 (0.7)
Transplantation¶			
No	255,375 (99.2)	3612 (96.2)	258,987 (99.2)
Yes	1938 (0.8)	142 (3.8)	2080 (0.8)
Operations			
Surgical operation			
No	209,686 (81.5)	2972 (79.2)	212,658 (81.5)
Yes	47,627 (18.5)	782 (20.8)	48,409 (18.5)
Minor surgical operation			
No	239,334 (93.0)	3297 (87.8)	242,631 (92.9)
Yes	17,979 (7.0)	457 (12.2)	18,436 (7.1)
Transluminal endoscopy			
No	246,471 (95.8)	3644 (97.1)	250,115 (95.8)
Yes	10,842 (4.2)	110 (2.9)	10,952 (4.2)
Investigative procedure connected with surgery			
No	255,574 (99.3)	3724 (99.2)	259,298 (99.3)
Yes	1739 (0.7)	30 (0.8)	1769 (0.7)
Procurement of organs or tissue for transplantation			
No	257,295 (100.0)	3754 (100.0)	261,049 (100.0)
Yes	18 (0.0)	0 (0.0)	18 (0.0)
Radiologic operation			
No	253,912 (98.7)	3710 (98.8)	257,622 (98.7)
Yes	3401 (1.3)	44 (1.2)	3445 (1.3)
Respiratory support			
No	257,307 (100.0)	3754 (100.0)	261,061 (100.0)
Yes	6 (0.0)	0 (0.0)	6 (0.0)
Dialysis			
No	255,172 (99.2)	3708 (98.8)	258,880 (99.2)
Yes	2141 (0.8)	46 (1.2)	2187 (0.8)
ICU stay			
No	249,763 (97.1)	2789 (74.3)	252,552 (96.7)
Yes	7550 (2.9)	965 (25.7)	8515 (3.3)

The table shows the proportions of patients who had had a given operation until the occurrence of first HAI (or until the end of the follow-up period for those who did not contract an HAI).

*E10–E14.

†Immunodeficiency disorders D80–D89; Rheumatic disorders I01, I02, I05–I09, M05, M06, M08, M12, M13, M33, M45, M79; Thyroid disorders E00-E07; Adrenal gland insufficiency E27.1–E27.4, E89.6; Autoimmune hemolytic anemia D59.0, D59.1, Vitamin B12 deficiency anemia D51, Idiopathic thrombocytopenic purpura D69.3, Myasthenia gravis G70.0, P94.0, Human immunodeficiency virus (HIV) disease B20–B24.

‡C81–C85, C88, C96, C91–C95, C90.

§T20–T31, T95, M61.3.

‖K70, K74, K76, P78.80, P78.81.

¶Z94.

HAI indicates health care–associated infection; ICU, intensive care unit.

respiratory tract (27.4%), urinary tract (20.5%), sepsis and bloodstream infections (13.7%), and surgical-site and organism-specific infections (14.9%).

The distributions of the exposure variables in each unit are shown in Table S2 (Supplemental Digital Content 1, http://links.lww.com/MLR/C610). On average, 95.7% of planned daily nursing hours were realised and the mean nursing hours per patient day was 6.6. The average proportion of nurses with > 3 years of in-hospital experience was 79.2%, and the average proportion of nurses more than 25 years old was 91.3%.

In total, nursing hours were low relative to planned hours on 10.3% of unit-days, and on 16.7% of unit-days, nursing hours per patient day were low (Table 2). The average proportion of days with a low share of nurses with > 3 years of in-hospital experience was 19.3%, and the proportion of days with a low share of nurses more than 25 years old was 10.8%.

One- or 2-day exposures to nurse understaffing or limited work experience were not associated with an overall incidence of HAI (Table 3). However, patients exposed to limited work experience had increased risk of bloodstream infections compared with patients not exposed to limited work experience. Regarding 1- and 2-day exposures to a low share of nurses with > 3 years of in-hospital experience, the hazard ratio (HR) was 1.30 (95% CI: 1.04–1.62) and 1.40 (95% CI: 1.05–1.86), respectively. Considering 1-day exposure to a low share of nurses aged more than 25 years old, the HR was 1.40 (95% CI: 1.07–1.83), while 2-day exposure did not reach statistical significance (HR = 1.23, 95% CI: 0.83–1.82). One-day exposure was also related to a lower risk of pneumonia (HR = 0.70, 95% CI: 0.51–0.97).

Nurse understaffing, in turn, measured as low nursing hours relative to target hours was associated with an increased risk of surgical-site infections. Concerning 1-day exposure, the HR was 1.34 (95% CI: 0.97–1.85), but only statistically significant when assessed with 2-day exposure (HR = 2.64, 95% CI: 1.66–4.20).

In the analyses based on lower and higher cut points in the exposure variables, some HRs were lower and some higher than in the main analyses, and apart from one exception, were unrelated to the overall risk of HAIs (Table S3, Supplemental Digital Content 1, http://links.lww.com/MLR/C610). Interactions between nurse understaffing and limited work experience were not statistically significant, and 1-day exposure to combinations of nurse understaffing and limited work experience were not associated with an increased risk of HAIs (Table S4, Supplemental Digital Content 1, http://links.lww.com/MLR/C610). In the analyses restricted to patients without an ICU stay, the HRs for the overall risk of HAIs and specific HAIs were mainly similar as in the main analyses. In the analyses restricted to patients from the 12 inpatient units, the findings largely replicated those in the main analysis although the 95% CIs were wider due to a smaller number of infection cases. These results suggest that mixing inpatient and outpatient data is an unlikely source of major bias (Tables S5, S6, Supplemental Digital Content 1, http://links.lww.com/MLR/C610).

DISCUSSION

Using 7-year daily administrative data from one hospital district in Finland, this study examined the associations of nurse understaffing and limited work experience with the risk of HAI among patients. The results were inconsistent across staffing measures and specific types of HAIs, and many of the associations were weak. Neither nurse understaffing nor limited work experience were associated with the overall risk of HAI. Regarding specific HAI types, limited work experience among staff was associated with an increased risk of bloodstream infections but a lower risk of pneumonia, while nurse understaffing was associated with a higher risk of surgical-site infections. Combinations of

TABLE 2. Proportion of Days With Nurse Understaffing or Limited Work Experience According to Hospital Divisions in Unit-days (N = 79,335)

	Nurse understaffing		Limited work experience	
Hospital type and divisions	**Low nursing hours relative to planned hours***	**Low nursing hours per patient day†**	**Low share of nurses > 3 y of in-hospital experience‡**	**Low share of nurses > 25 y old§**
Regional hospitals (4 hospitals, 7 units)	13.9	19.8	21.3	9.1
Divisions of the central hospital				
Division 1	11.6	21.4	12.5	8.5
Division 2	0.6	7.4	14.8	3.3
Division 3	6.4	19.8	20.8	11.5
Division 4	11.7	17.1	21.0	8.4
Division 5	11.6	15.8	22.3	14.5
Division 6	8.6	12.2	21.6	10.5
Division 7	12.6	18.7	19.9	14.1
Intensive care unit	1.1	8.0	0.8	0.0
Whole sample	10.3	16.7	19.3	10.8

*The share of nursing hours relative to planned hours is <90% of the annual unit median.
†Nursing hours per patient day is <80% of the annual unit median.
‡The share of nurses with > 3 years of in-hospital experience is <90% of the annual unit median.
§The share of nurses more than 25 years old is <90% of the annual unit median.

TABLE 3. Exposure to Nurse Understaffing and Limited Work Experience and the Risk of Any HAI and 4 Specific HAIs

	All infections		Bloodstream		*Clostridium difficile*		Surgical site		Pneumonia	
Exposure variables	**HR**	**95% CI**	**HR**	**95% CI**	**HR**	**95% CI**	**HR**	**95% CI**	**HR**	**95% CI**
One-day exposure (reference: 0 d)										
Low nursing hours relative to target hours	1.02	0.88–1.17	0.69	0.44–1.07	0.90	0.56–1.44	1.34	0.97–1.85	0.94	0.69–1.29
Low nursing hours per patient day	0.94	0.85–1.03	0.95	0.73–1.24	1.09	0.79–1.49	1.08	0.87–1.33	0.95	0.80–1.14
Low share of nurses with > 3 y of in-hospital experience	1.00	0.91–1.09	**1.30**	**1.04–1.62**	1.03	0.77–1.39	1.03	0.82–1.30	0.88	0.72–1.07
Low share of nurses > 25 y old	1.04	0.92–1.17	**1.40**	**1.07–1.83**	0.94	0.64–1.38	1.11	0.82–1.50	0.82	0.62–1.09
No. cases	3754		491		302		599		968	
No. admission periods = 261,067										
Two days of exposure (reference: 0 d)										
Low nursing hours relative to target hours										
1 d	1.00	0.88–1.14	0.94	0.66–1.33	0.84	0.54–1.32	1.00	0.70–1.43	1.00	0.76–1.32
2 d	1.12	0.88–1.43	0.47	0.17–1.27	0.63	0.23–1.70	**2.64**	**1.66–4.20**	1.46	0.88–2.42
Low nursing hours per patient day										
1 d	0.99	0.90–1.08	1.03	0.81–1.32	0.82	0.58–1.16	1.16	0.94–1.44	1.02	0.86–1.21
2 d	0.99	0.84–1.15	0.93	0.59–1.47	1.38	0.87–2.19	1.11	0.77–1.59	0.95	0.70–1.28
Low share of nurses with > 3 y of in-hospital experience										
1 d	0.99	0.89–1.10	1.19	0.90–1.56	1.16	0.83–1.61	0.84	0.63–1.14	0.83	0.66–1.05
2 d	0.99	0.87–1.12	**1.40**	**1.05–1.86**	1.00	0.67–1.49	0.96	0.69–1.34	0.89	0.68–1.16
Low share of nurses > 25 y old										
1 d	0.90	0.78–1.04	1.08	0.78–1.50	1.30	0.89–1.88	0.95	0.67–1.36	**0.70**	**0.51–0.97**
2 d	1.01	0.84–1.21	1.23	0.83–1.82	0.87	0.49–1.53	0.97	0.59–1.58	0.84	0.55–1.28
No. cases	3195		430		264		501		851	
No. admission periods = 232,796										

Separate models for the 4 exposure variables. Adjusted for age, sex, comorbidities, specific diagnoses and medical procedures, hospital divisions, year, and unit random effect.
HAI indicates health care–associated infection; HR, hazard ratio.
Statistically significant HR with 95% CI are shown in bold.

understaffing and limited work experience were unrelated to HAI.

We measured nurse understaffing by nursing hours in relation to planned hours which has not previously been investigated. The findings partly align with the previous reviews on the topic,[10,18] including a recent study based on a similar design using time-varying measurements of exposure to nurse understaffing.[20] In the latter study, patients who were exposed to understaffing during both day and night shifts were more likely to have contracted an HAI 2 days later, while in our study a 2-day exposure but not a 1-day exposure to nurse understaffing increased the risk of surgical-site infections. Unlike the previous study, we did not calculate exposure to nurse understaffing during day and night shifts separately. However, in our study, the exposure was obtained via the automatized shift-scheduling system in hospitals, controlling for unit-level differences in staff requirements. Another difference is that in the previous study, a larger proportion of patients had stayed in an ICU or had certain specific diagnoses that may have made them more vulnerable to HAIs than in our study. In our study, a 2-day exposure to nurse understaffing was based on a sample of admission periods lasting at least 2 days. Patients subject to a 2-day stay may in general be more vulnerable to HAIs than those who are only subject to a 1-day stay.

Limited work experience—indicated by a low share of nurses with > 3 years of in-hospital experience in the same hospital district and a low share of nurses more than 25 years old—was associated with an increased risk of bloodstream infections. In one prior cross-sectional study, limited work experience was associated with urinary tract infection rates,[35] while the other few studies on the topic have not found any associations with HAI.[14,15]

Furthermore, there was no association with HAI when analyzing cumulative risk, that is, both nurse understaffing and limited work experience or interactions between these exposures. This is in line with a prior study that found no interaction between nurse staffing and training levels in relation to ventilator-associated pneumonia.[21]

As the results were inconsistent, this evidence suggests that a shortage of nursing staff and lack of experienced nurses in hospital units does not always increase HAIs in patients. These factors were related to a higher risk of surgical-site and bloodstream infections only. Nurse staffing and experience levels are also interrelated, as understaffing may increase work strain and turnover in hospitals.

The strengths of this study include the use of a large, administrative data set covering 7 years and various health care specializations, and the inclusion of multiple kinds of HAIs as outcomes. While health care staff are expected to record all HAIs, the accuracy of these records may vary. In this hospital district, following the national guidelines, specific attention is given to monitoring 3 specific HAIs; bloodstream, *C. difficile*, and surgical-site infections. We, therefore, focused on these specific HAIs, as well as pneumonia, as separate outcome variables. Nurse understaffing was associated with a higher risk of surgical-site infection, while limited work experience was related to bloodstream infections. Neglecting infection-control principles, and especially poor hand hygiene are the crucial links between extensive workload and HAIs[6,36] and may increase the risk of these types of infections in particular. It is also possible that especially surgical-site infections are more accurately recorded as HAIs once a patient has been discharged. Nurse understaffing and limited work experience were not associated with an increased risk of *C. difficile* infections and pneumonia. Regarding pneumonia, this may partly be explained by poorer monitoring of this type of HAI. Rather than nurse understaffing or limited work experience, antibiotic treatment increases the risk of *C. difficile* infection and may partly explain the lacking associations with staffing indicators.

This study also has several limitations. Many hospital units in our study treated both inpatients and outpatients. Due to a lack of relevant data, we were unable to distinguish the share of nursing hours targeted to inpatients only. This may introduce bias to estimates of nursing effort for inpatients, potentially underestimating the associations between understaffing, limited work experience, and HAI, and widening the 95% CIs. In particular, the measure of nursing hours per patient day is affected by the inclusion of outpatients and imprecise recording of discharge times, limiting comparisons of our findings to those reported in other studies. In addition, the rate of HAIs was low in our data reducing statistical power to detect weak associations.

In the hospital district, staff scheduling is planned for periods of 3 or 6 weeks using an automatized shift-scheduling system,[37] which allowed us to take into account staff requirements in each unit and calculate both planned and actual working hours. Except for intensive care, there are no hospital or national standards for the nurse-to-patient ratio in specialized health care, but the working hours of each employee are regulated by national legislation and collective labor agreements.[37] Low nursing hours relative to planned hours can result from several factors. Unexpected absences of employees and last-minute changes of work duties due to variation in patient flow may result in a lack of nursing resources on specific days. In contrast, the planned nursing hours indicated by the shift-scheduling system may be low in the first place if there are not enough employees in the unit. In addition, low daily working hours can result from last-minute cancellation of treatments, although in that case, an under-target staffing levels are not an indicator of increased workload. Inaccuracies in the measurement might have affected our findings on the effects of actual versus planned working hours, but any bias is likely to be small. The reliability and quality of the data from the shift-scheduling system is considered high,[37] and a suitable way to collect objective information on increased workloads in hospitals. Regarding nurse work experience, future studies on the topic should clarify the role of unit-tenure and overall work experience as a nurse in patient outcomes, such as HAIs.[38]

Prior studies[20,26] have commonly measured the numbers of registered nurses and nurse assistants/practical nurses separately, whereas this study combines both registered nurses and practical nurses together. In Finland, practical nurses are registered as health professionals and carry out treatments and procedures that may increase the risk of infection.[39] The average share of registered nurses of all nurses was also very high, 82%. Thus, distinguishing between registered and practical nurses may not be that critical.

The indicators of nurse understaffing and low levels of work experience were based on artificial cutoff points, and we performed sensitivity analyses with alternative cutoff thresholds. With higher cutoff points, the difference with days with adequate staffing and experience levels is narrower while with lower cutoff points, fewer unit-days are defined as understaffed/having limited experience, which leads to larger 95% CIs. Importantly, in both cases, the point estimates were close to those obtained from our main analysis. This strengthens the validity of our findings. To account for the incubation period, we estimated the risk of HAI for exposure variables measured 2 days earlier (a 48-h lag period) using a moving time window. As our follow-up extended 2 days postdischarge, 1-day hospital stays were possible to include in the analysis (Fig. S1, Supplemental Digital Content 1, http://links.lww.com/MLR/C610). It is possible that the lag period for infection is less than or more than 48 hours, and that these incubation times are different for different HAIs, although varying incubation times were not considered in this study.

CONCLUSIONS

We found partial support for previous smaller-scale research suggesting that nursing staff shortages increase the risk of HAI among patients. Our evidence suggests that a shortage of nursing staff and a lack of experienced nurses in hospital units does not always increase HAIs in patients.

REFERENCES

1. McGrath J. *Analysis of Shortage and Surplus Occupations 2020*. Publications Office of the European Union; 2020.
2. Griffiths P, Recio-Saucedo A, Dall'Ora C, et al. The association between nurse staffing and omissions in nursing care: a systematic review. *J Adv Nurs*. 2018;74:1474–1487.
3. Jimmieson NL, Tucker MK, White KM, et al. The role of time pressure and different psychological safety climate referents in the prediction of nurses' hand hygiene compliance. *Saf Sci*. 2016;82:29–43.
4. Shin S, Park JH, Bae SH. Nurse staffing and nurse outcomes: a systematic review and meta-analysis. *Nurs Outlook*. 2018;66:273–282.
5. Virtanen M, Kurvinen T, Terho K, et al. Work hours, work stress, and collaboration among ward staff in relation to risk of hospital-associated infection among patients. *Med Care*. 2009;47:310–318.
6. Vaismoradi M, Tella S, A. Logan P, et al. Nurses' adherence to patient safety principles: a systematic review. *Int J Environ Res Public Health*. 2020;17:2028.
7. Griffiths P, Maruotti A, Recio Saucedo A, et al. Nurse staffing, nursing assistants and hospital mortality: retrospective longitudinal cohort study. *BMJ Qual Saf*. 2019;28:609–617.
8. Needleman J, Buerhaus P, Pankratz VS, et al. Nurse staffing and inpatient hospital mortality. *N Engl J Med*. 2011;364:1037–1045.
9. Rochefort CM, Beauchamp ME, Audet LA, et al. Associations of 4 nurse staffing practices with hospital mortality. *Med Care*. 2020;58:912.
10. Mitchell BG, Gardner A, Stone PW, et al. Hospital staffing and health care–associated infections: a systematic review of the literature. *Jt Comm J Qual Patient Saf*. 2018;44:613–622.
11. Suetens C, Latour K, Kärki T, et al. Prevalence of healthcare-associated infections, estimated incidence and composite antimicrobial resistance index in acute care hospitals and long-term care facilities: results from two European point prevalence surveys, 2016 to 2017. *Euro Surveill*. 2018;23:1800516.
12. Ausserhofer D, Zander B, Busse R, et al. Prevalence, patterns and predictors of nursing care left undone in European hospitals: results from the multicountry cross-sectional RN4CAST study. *BMJ Qual Saf*. 2014;23:126–135.
13. Stalpers D, de Brouwer BJM, Kaljouw MJ, et al. Associations between characteristics of the nurse work environment and five nurse-sensitive

patient outcomes in hospitals: a systematic review of literature. *Int J Nurs Stud*. 2015;52:817–835.

14. Wang L, Lu H, Dong X, et al. The effect of nurse staffing on patient-safety outcomes: a cross-sectional survey. *J Nurs Manag*. 2020;28: 1758–1766.
15. Audet L-A, Bourgault P, Rochefort CM. Associations between nurse education and experience and the risk of mortality and adverse events in acute care hospitals: a systematic review of observational studies. *Int J Nurs Stud*. 2018;80:128–146.
16. Driscoll A, Grant MJ, Carroll D, et al. The effect of nurse-to-patient ratios on nurse-sensitive patient outcomes in acute specialist units: a systematic review and meta-analysis. *Eur J Cardiovasc Nurs*. 2018;17: 6–22.
17. Shang J, Stone P, Larson E. Studies on nurse staffing and health care–associated infection: methodologic challenges and potential solutions. *Am J Infect Control*. 2015;43:581–588.
18. Dall'Ora C, et al. Nurse staffing levels and patient outcomes: a systematic review of longitudinal studies. *Int J Nurs Stud*. 2022;134: 104311.
19. Hugonnet S, Chevrolet JC, Pittet D. The effect of workload on infection risk in critically ill patients. *Crit Care Med*. 2007;35:76–81.
20. Shang J, Needleman J, Liu J, et al. Nurse staffing and healthcare associated infection, unit-level analysis. *J Nurs Adm*. 2019;49:260.
21. Hugonnet S, Uçkay I, Pittet D. Staffing level: a determinant of late-onset ventilator-associated pneumonia. *Crit Care*. 2007;11:1–7.
22. Bae SH, Brewer CS, Kelly M, et al. Use of temporary nursing staff and nosocomial infections in intensive care units. *J Clin Nurs*. 2015;24: 980–990.
23. Daud-Gallotti RM, Costa SF, Guimarães T, et al. Nursing workload as a risk factor for healthcare associated infections in ICU: a prospective study. *PLoS ONE*. 2012;7:e52342.
24. Needleman J, Liu J, Shang J, et al. Association of registered nurse and nursing support staffing with inpatient hospital mortality. *BMJ Qual Saf*. 2020;29:10–18.
25. Auria Clinical Informatics. High quality data for researchers. 2022. Accessed Feburary 17, 2022. https://www.auria.fi/tietopalvelu/en/index.html
26. Dall'Ora C, Maruotti A, Griffiths P. Temporary staffing and patient death in acute care hospitals: a retrospective longitudinal study. *J Nurs Scholarsh*. 2020;52:210–216.
27. Nejim BJ, Wang S, Arhuidese I, et al. Regional variation in the cost of infrainguinal lower extremity bypass surgery in the United States. *J Vasc Surg*. 2018;67:1170–80. e4.
28. Ferreira E, Pina E, Sousa-Uva M, et al. Risk factors for health care–associated infections: from better knowledge to better prevention. *Am J Infect Control*. 2017;45:e103.e7.
29. Rodríguez-Acelas AL, de Abreu Almeida M, Engelman B, et al. Risk factors for health care–associated infection in hospitalized adults: systematic review and meta-analysis. *Am J Infect Control*. 2017;45: e149–e156.
30. Charlson ME, Pompei P, Ales KL, et al. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *J Chronic Dis*. 1987;40:373–383.
31. Quan H, Li B, Couris CM, et al. Updating and validating the Charlson Comorbidity Index and score for risk adjustment in hospital discharge abstracts using data from 6 countries. *Am J Epidemiol*. 2011;173: 676–682.
32. Amendments to Communicable Diseases Act. Laki tartuntatautilain muuttamisesta 935/2003. Accessed March 24, 2022. https://www.finlex.fi/fi/laki/alkup/2003/20030935
33. European Centre for Disease Prevention and Control. *Point Prevalence Survey of Healthcare-associated Infections and Antimicrobial use in European Acute Care Hospitals—Protocol Version 53*. ECDC;; 2016.
34. Revelas A. Healthcare–associated infections: a public health problem. *Niger Med J*. 2012;53:59.
35. Kendall-Gallagher D, Blegen MA. Competence and certification of registered nurses and safety of patients in intensive care units. *Am J Crit Care*. 2009;18:106–113.
36. Allegranzi B, Pittet D. Role of hand hygiene in healthcare-associated infection prevention. *J Hosp Infect*. 2009;73:305–315.
37. Härmä M, Ropponen A, Hakola T, et al. Developing register-based measures for assessment of working time patterns for epidemiologic studies. *Scand J Work Environ Health*. 2015;41:268–279.
38. Bartel AP, Beaulieu ND, Phibbs CS, et al. Human capital and productivity in a team environment: evidence from the healthcare sector. *Am Econ J Appl Econ*. 2014;6:231–259.
39. Paivi Lavander R, Suhonen M, Turkki L, et al. How practical nurses, registered nurses and nurse managers view practical nurses' work activities. *Int J Caring Sci*. 2018;11:23–35.

