Associations between adverse outcomes for surgical admissions and nurse understaffing – a longitudinal study

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**Abstract**

Background: Nurses play a crucial role in maintaining the safety of surgical patients. Few nurse staffing studies have looked specifically at surgical patients to examine the impact of exposure to low staffing on patient outcomes.

Methods: A longitudinal patient analysis was conducted in four organisations in England using routine data from 213,910 admissions to all surgical specialties. Patients’ staffing exposures were modelled as counts of understaffed registered nurse (RN) and nurse assistant (NA) days in their first five inpatient days. Understaffing was identified when staffing per patient day was below the mean for the ward. Cox models examined mortality within 30 days of admission and readmission within 30 days of discharge. Generalised linear models examined length of stay and occurrence of hospital-acquired conditions.

Results: Increased exposure to RN understaffing was associated with longer length of stay and increased risk of deep-vein thrombosis, pneumonia and pressure ulcers. This was also true for NA understaffing but the effect sizes tended to be smaller. In the Cox models, there were similarly increased hazards of death for RN understaffing (HR 1.092, 95% CI 1.066,1.118) and NA understaffing (HR 1.103, 95% CI 1.077, 1.129), whereas the effect size of RN understaffing for readmission (HR 1.023, 95% CI 1.019, 1.028) was greater than that seen with NAs (HR 1.014, 95% CI 1.010, 1.019).

Conclusion: Understaffing by both RNs and NAs is associated with increased risks of a range of adverse events and generally larger effects are seen with RN understaffing.

# Introduction

It is estimated that a third of the global burden of disease can be addressed by surgical care(1)  and over 300 million surgical procedures are carried out each year worldwide(2). The Global Patient Safety Action Plan aims to achieve the maximum possible reduction in avoidable harms associated with healthcare(3). There are growing concerns about the quality of care received by adult patients undergoing surgery(4,5)  and the rising cost of avoidable complications, prolonged hospitalisations and readmissions(6,7).

Patients in surgical units and intensive care units are more likely to experience preventable harm than those in medical settings(8). The safety of surgery has come under scrutiny, with never events and serious incidents being tracked as key measures of safety(9,10). Many advances have been made in perioperative care, such as the widespread use of the surgical safety checklist(11), but preventable harms still occur. In a stratified meta-analysis, the pooled prevalence of preventable harm was 10% for patients in surgical settings, and incidents relating to surgical procedures accounted for 23% of all harm incidents(8). It has been estimated that 55% of surgical site infections are preventable(12). Many safety interventions have focused on implementing checklists, staff training and improving teamwork(13). However, leaving the onus on frontline staff to prevent harms without addressing shortfalls in nurse staffing levels is a persistent barrier to patient safety(14).

Variation in nurse staffing levels have been linked to patient safety consequences(15). Hassen *et al.*(16) conducted a Delphi study of international patient safety experts who were asked to rank seventeen factors contributing to care quality and safety on surgical wards. Nurse staffing was among the highest scoring factors in this consensus generating activity. A systematic review including 44 studies(17) found higher nurse staffing levels were associated with lower 30-day mortality among surgical patients, however, 39 of these studies were cross-sectional in design using aggregated or sampled measures of nurse staffing(18–21). Amiri *et al.*(22) studied the relationship between nurses’ density and surgical complications in a panel analysis in 21 countries. They found that an increase in nurse staffing levels was significantly associated with reductions in deep vein thrombosis, pulmonary embolism, post-operative sepsis and wound dehiscence.

This study was a multi-centre longitudinal observational study in which daily variation in staffing was linked to individual patients to explore the relationship between nurse staffing levels, and outcomes for surgical patients. Outcomes of interest were mortality, readmissions, length of stay and the potentially avoidable clinical events of deep-vein thrombosis, pneumonia and pressure ulcers.
Methods

This research is a sub-cohort analysis forming part of a study approved by the Health Research Authority (ref IRAS 273185) in England with ethical review undertaken by the faculty research ethics committee at the University of Southampton (ref ERGO 52957).

Patient and staffing data sets were provided for the period April 2015 to February 2020 by three hospital trusts in the English National Health Service (NHS) and from April 2019 to Feb 2020 by the fourth. All data was supplied to researchers in a pseudonymised form, with dates of birth replaced by 5-year age groups. The patient data was sourced from patient administration systems and the staffing data was sourced from electronic roster systems.

The inclusion criteria for admissions were that they: a) had a surgical treatment function code on admission as defined in the NHS data dictionary(24), excluding children’s special services, b) included an overnight stay in an inpatient area, thus day surgery patients who didn’t stay overnight were excluded, c) included a stay in a unit other than maternity and paediatrics, d) were for patients in the age group of 15-19 or above.

**Exposure, outcomes and case-mix adjustment**

Daily nursing staffing levels were obtained from records of worked shifts which included temporary assignments to wards but excluded absences, with details of the ward, pay band and the shift fulfilment source (substantive contract, bank or agency) but no staff demographics. Nursing staff were categorised as registered nurse (RN) or nurse assistant (NA) according to their pay band with RNs having an NHS pay band of 5 or more. Daily ward staffing levels were calculated by job type (RN or NA) in hours per patient day (HPPD) relative to the mean for the ward. Daily patient occupancy in a ward was calculated from patient movement records. Data cleaning resulted in the removal of less than 2% of ward day records from the dataset, see the appendix for details. Based on previous research(25) exposures that occurred during the first five days of the hospital stay were used, accounting for most of the stay for most patients. A sensitivity analysis was performed using exposures occurring during the first three days and ten days for comparison. Another sensitivity analysis adjusted the models for weekend admissions to test whether the differences in staffing of other occupational groups at weekends altered the effects of nurse understaffing.

Since a change in ward use would affect its staffing, a ward rebasing exercise was undertaken prior to calculating ward mean staffing levels. Where changes in a ward’s case-mix were identified, the ward study period was split into two at the change, with each sub-period given its own identifier. Each ward sub-period resulting from the split was then treated separately when calculating the expected staffing levels.

The outcomes were death from all causes within 30 days of admission, non-elective readmission within 30 days of discharge, length of stay, and the coding of three conditions which are not expected to be present in surgical admissions (pneumonia, deep vein thrombosis and pressure ulcers). These three conditions were selected after considering those nursing-sensitive outcomes from an umbrella review of research(26) which could feasibly be identified in the available data. Death was determined either from a recorded discharge method of “death” or, in the case of those discharged alive, from the date of death recorded posthumously on patient records via the national patient demographic service. Hence the outcome was not limited to in-hospitals deaths. Readmission within 30 days of discharge was assigned to patients with a non-elective admission to the same trust within 30 days of discharge. Length of stay was the duration of continuous care in the trust as an inpatient and was calculated in hours from admission and discharge dates and times. Length of stay for admissions which ended in discharge rather than death was modelled. Pressure ulcers, pneumonia and deep vein thrombosis (DVT) were identified from the ICD-10 diagnosis coding on the administrative record(27).

To account for patient-level risk factors, a predicted risk of mortality using the published Summary Hospital Mortality Indicator (SHMI) model(28) was calculated. This uses clinical and demographic factors (including age, method of admission, primary diagnosis and comorbidity) to calculate a predicted risk of death. These risk factors are also known to be predictive of readmission and length of stay. The SHMI risk coefficients from the April 2019 model (version 1.30) were used in the risk calculation.

**Statistical Models**

Admissions were regarded as being independent in the main analysis, however a sensitivity analysis was performed using only patient index admissions in the dataset. Dataset construction and all analyses were performed using R Statistical Software (v4.3.2; R Core Team 2023); further details of the software and packages used can be found in the supplementary material. Table 1 summarises the regression models used. Effect sizes were calculated as hazard ratios, odds ratios and linear multipliers along with their 95% confidence intervals. There were no pre-planned hypotheses tests.

The mortality survival analysis modelled the hazard using patient day observations and measured exposure to staffing by means of cumulative time-dependent covariates. This approach has been taken elsewhere(25,29). Counts of understaffed days by job type were constructed with understaffing identified as a day where observed HPPD fell short of the expected (mean) HPPD. The model included the ward as a random effect to capture unspecified ward characteristics. If a patient day included a ward transfer, the ward at the start of the day was used as the clustering ward. In our patient-period formatted survival analysis records, a previous day’s staffing values were carried forward in the case of missing values. The assumption of proportional hazards was examined with graphs of scaled Schoenfeld residuals and was seen to be reasonable for the staffing measures.

A Cox mixed-effects survival model was used to model time to readmission after discharge with fixed covariates. A patient’s exposure to staffing shortfall was calculated as the proportion of patient days below the mean ward staffing level for each job type over the 5-day exposure period. The denominator count of exposure patient days was adjusted for missing values. The time origin was the day of discharge and the discharge ward was included as a random effect. Graphs of scaled Schoenfeld residuals showed that the assumption of proportional hazards was reasonable for each predictor.

Length of stay (LOS) is an outcome which exhibits a right-skewed distribution with mode near zero and heavy tails. Therefore the gamma distribution was used in a generalised linear regression model using the same summary staffing measures as the readmissions model. The discharge ward was included as a random effect.

The diagnoses ICD-10 codes for the patient condition outcomes are listed in the supplementary methods as Table S1. The outcomes were identified from recorded ICD-10 codes for the hospital stays but since precise dates and times were not available, logistic regression rather than time to event models were used with a random effect for the ward occupied after the first night. As with the readmission and LOS analysis, proportions of understaffed days represented the staffing exposures with adjustment for missing values.

# Results

A breakdown of the admissions by treatment function code for each of the four hospital trusts can be found in Table 2. The most frequent admission specialties are Trauma & Orthopaedics, General Surgery and Urology and these account for more than half of the admissions. Small admission numbers relating to oral, dentistry, burns, ophthalmic and bariatric surgery have been grouped into “other surgery” for this description. The 213910 surgical admissions in the dataset pertained to 162598 patients, a ratio of 1.32 admissions per patient.

The summary descriptives of the admissions overall, by death within 30 days of admission and by emergency readmission within 30 days of discharge are shown in Table 3. The modal 5-year age group was 70-74, 55% of admissions were emergency admissions, 49% of admissions were recorded as female, the median length of stay was 3.2 days and 34% had a Charlson Comorbidity Index greater than five(30). The overall 30-day mortality was 2.1% and, of those discharged, the readmission rate within 30 days was 10.6%.

Summary descriptive statistics for patient days with regards to the hours of care received from RNs and NAs during the first five days of their admissions are shown in Table 4. The distributions of care hours received are right-skewed such that 57% of patients days are exposed to below mean levels for the ward.

The results of the regression models showing the associations of below mean staffing levels with the patient outcomes are shown in Table 5. The relative risk of mortality was increased by 9.2% (HR 1.092, 95% CI 1.066 to 1.118) with each day of low RN staffing and by 10.3% (HR 1.103, 95% CI 1.077 to 1.129) with each day of low NA staffing. Whilst the readmissions model is also a survival analysis, the coefficients are not directly comparable since the staffing exposure variables are different and measure the proportion of low staffed days rather than being accumulated counts of low staffed days. However, a 10% increase in the proportion of low staff days can be interpreted as a change in the staffing level for one 12 hour shift from above mean staffing to below mean staffing during a 5 day exposure period. Such an increase in RN understaffing increases the relative risk of readmission by 2.3% (HR 1.023, 95% CI 1.019 to 1.028) and by 1.4% for NA staffing (HR 1.014, 95% CI 1.010 to 1.019). The odds of the incidence of each of the three diagnosed conditions of DVT, pneumonia and pressure ulcers increased by 4.8%, 5.7% and 6.4% respectively for each 10% increase in the proportion of days of low RN staffing, and correspondingly by 2.9%, 5.1% and 2.9% respectively for each 10% increase in days of low NA staffing.

The coefficients for the length of stay model show an increased length of 6.3% for each 10% change in the proportion of days of low RN staffing (95% CI 1.061 to 1.065) and a 5.4% increase for the same change in days of low NA staffing (95% CI 1.052 to 1.055).

The sensitivity analysis using only patient index surgical admissions in the dataset yielded effect estimates within the 95% confidence intervals of those shown in Table 5, and the results are available as Table S2 in the supplementary material. The sensitivity analysis comparing model coefficients for the low staffing predictors when the exposure was measured over different periods, the first three days, five days and ten days of the admission, are displayed in Table S3 in the supplementary material. The coefficients for the outcomes of mortality, readmission and length of stay were similar for the three different exposure periods. The effect sizes for three diagnosed patient conditions however became larger with an increase in length of the measured exposure period. For a 10-day measured exposure, the odds of the incidence of each of DVT, pneumonia and pressure ulcers increased by 6.2%, 7.7% and 9.0% respectively for each 10% increase in the proportion of days of low RN staffing, and increased by 4.1%, 6.5% and 4.5% correspondingly for changes in the proportion of days of low NA staffing. The sensitivity analysis which adjusted for weekend admissions (Table S4 in the supplementary material) showed very little change in the coefficients of the low staffing variables, although the weekend admission covariate was significant for mortality, length of stay, pneumonia and pressure ulcers.

# Discussion

In this longitudinal study of linked individual patient data, the exposure to understaffing by either RNs or NAs was found to be associated with a wide range of detrimental outcomes for patients admitted for surgery. The effects were larger for understaffing by RNs in most of the outcomes studied but low NA staffing was still associated with increased risks. In the UK, RNs have graduate level formal training and 2300 training hours of clinical placements before they can register with the professional council. In contrast NAs, commonly with the job title “healthcare support worker”, can be employed on probation with no formal training but must complete a basic care certificate which includes competencies in fluids and nutrition, infection prevention and control, and basic life support(31). Only registered staff create care plans and administer medications, infusions and other treatments. NAs work under the guidance of RNs and support them in the delivery of nursing services. It is likely that NA understaffing results in an increased workload for RNs which may in turn mean that some care tasks are delayed or left undone.

The cost of readmissions and avoidable events is significant. Increased length of stay is the primary cost associated with healthcare acquire infection (HCAI)(32) and adult inpatient HCAIs in general and teaching hospitals were estimated in 2016/17 to cost NHS England £2.1 billion annually(33). Treatment costs for morbidity, and the potential reduction to length and quality of life would be added to this burden. This is one of the first studies that has used a longitudinal design for exploring nurse staffing levels and a large range of outcomes in surgical patients.

Previous studies of surgical populations have also found associations between RN understaffing and mortality(34–37). When the subset of surgical patients were examined in the RN4CAST study, authors found that increasing a nurse’s workload by one patient was associated with a 16% increased odds of death(38). However in the RN4CAST study, in common with many others, the staffing levels were based on estimates of hospital level averages over long periods, and did not specifically estimate staffing on surgical units. Our study has measured staffing at a more granular level using ward rosters and the individual patients have been followed up longitudinally. The strength of this approach is that exposures have been calculated more accurately, patients have been followed over time, and more detailed case-mix adjustment was undertaken.

The longitudinal study by Griffiths et al.(25) also found that the hazard of death was increased for every day a patient was exposed to understaffing by RNs in a mixed medical and surgical population. The picture for NAs is less clear in the literature. Most studies suggest there is a hazardous effect of higher nursing assistant staffing(37,39,40) but one study found a non-linear relationship between the hazard of death and differing NA levels(25) where harm associated with both low and high levels.

The observed associations between higher staffing and reduced mortality and morbidity are important. There has been limited progress in improving patient safety outcomes despite intense interest in this area. High profile campaigns, cultural shifts, training and interventions have not yet offered significant and sustainable benefits(14). Recent cost-effectiveness studies have suggested that investment in RNs can lead to a reduced net cost, although more evidence is needed(41). This study adds to the evidence that staffing levels merit more attention.

The method of measuring exposure for the first 5 days of each admission does not find all associations between understaffing and adverse events which occur later in admissions since the understaffing may have occurred after the 5 days. This might be the case with hospital acquired conditions such as pressure ulcers, pneumonia and deep-vein thrombosis as demonstrated by the results in Table S3 in the supplementary material which show larger effects for understaffing with longer measured exposure periods. Overall, the 5-day exposure period is effective in finding variations in staffing which can be associated with subsequent adverse events. Longer exposure periods have less daily variation in staffing levels. There is scope for methods research to identify measures of understaffing which best associate the staffing exposure with the outcome for different kinds of adverse event in longitudinal studies. A limitation of the dataset was that there was no visibility of hospital acquired conditions manifesting themselves after discharge unless they resulted in readmission.

Whilst this study demonstrated an association between nurse understaffing and negative outcomes, we are unable to recommend an optimal level of staffing based on this. There are further unanswered questions as data on medical staff or other support staff such as physiotherapists was not accessible. Higher staffing levels across the wider multidisciplinary team, including medical and allied health professional staff, have also been associated with improved outcomes(42). However, the effects of nurse understaffing in our models would only be altered were there to be a correlation of nurse understaffing with understaffing in the other staff groups. The sensitivity analysis with “weekend admissions” as a covariate showed little change in the nurse understaffing coefficients suggesting that nurse understaffing is largely independent of understaffing in other occupational groups.

This study was conducted in four acute NHS trusts in England and this sample was heterogeneous, representing a range of catchments, socioeconomic groups, patient demographics, population health indicators, trust sizes and services. However, it is an observational study without matching controls and the data related to a number of years so it is possible that there were organisational changes and service improvements occurring during the period which might have affected patient safety.

**Conclusion**

Measures to correct low nurse staffing on surgical wards could lead to widespread benefits, as understaffing was associated with higher mortality and preventable morbidity. Focussing on avoiding low RN staffing is predicted to give more benefits than avoiding understaffing by NAs. Recruitment and retention of RNs ought to be the priority.

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**Appendices**

**Data Cleaning**

Unrealistic staffing levels on patient days were replaced by missing values in the dataset. Likewise any gaps in staffing records after matching to ward days were filled with missing values. This amounted to around 1.64% of patient days with missing RN staffing levels and 1.86% days with missing NA levels.

When analysing length of stay, small numbers of admissions with a length of stay of 180 days or more were trimmed from the dataset. Occurrences of this were more likely to indicate a late closure of the admission record than a genuine stay exceeding that interval.

**Admission numbers by specialty**

Table 2. Admission numbers by treatment function code.

Table 1. Regression models used for each study outcome.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Outcome** | **Outcome type** | **Regression** | **Random effect** | **Effect type** |
| All-cause mortality within 30 days of admission | Binomial | Cox proportional hazards mixed effects regression with time varying covariates | Ward for each patient day | Hazard ratio |
| Emergency readmission within 30 days of discharge | Binomial | Cox proportional hazards mixed effects regression with fixed covariates | Discharge ward | Hazard ratio |
| Length of stay | Days count | Gamma GLMM\* | Discharge ward | Linear multiplier |
| Deep Vein Thrombosis diagnosis | Binomial | Binomial GLMM | Ward after first night | Odds ratio |
| Pneumonia diagnosis | Binomial | Binomial GLMM | Ward after first night | Odds ratio |
| Pressure Ulcer diagnosis | Binomial | Binomial GLMM | Ward after first night | Odds ratio |

\* Generalised Linear Mixed Model

Table 2. Admission numbers by treatment function code.

|  |  |
| --- | --- |
| **Total N (%)** | **213910 (100.00)** |
| Trauma and Orthopaedics | 54608 (25.53) |
| General Surgery | 34453 (16.11) |
| Urology | 27771 (12.98) |
| Ear Nose and Throat | 14906 (6.97) |
| Colorectal Surgery | 13794 (6.45) |
| Neurosurgery | 11885 (5.56) |
| Plastic Surgery | 9430 (4.41) |
| Upper Gastrointestinal Surgery | 9199 (4.30) |
| Spinal Surgery | 6386 (2.99) |
| Vascular Surgery | 5624 (2.63) |
| Hepatobiliary & Pancreatic Surgery | 3961 (1.85) |
| Thoracic Surgery | 3850 (1.80) |
| Cardiac/Cardiothoracic Surgery | 3573 (1.67) |
| Breast Surgery | 3494 (1.63) |
| Maxillofacial Surgery | 3465 (1.62) |
| Transplant Surgery | 2242 (1.05) |
| Other surgery\* | 5269 (2.46) |

\* oral, dentistry, burns, ophthalmic and bariatric surgery

Table3. Admissions cohort descriptives with mortality and readmission outcomes.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   | **All1** |  | **Alive** | **Died** |  | **No readm2** | **Readmitted** |
| **Total N (%)** | 213910 (100.00) |  | 209378 (97.88) | 4532 (2.12) |  | 187791 (89.38) | 22309 (10.62) |
| **Sex Ratio (M:F)** | 508:492 |  | 507:493 | 542:458 |  | 505:495 | 528:472 |
| **Emergency admission** | 118158 (55.24) |  | 114090 (54.49) | 4068 (89.76) |  | 99633 (53.06) | 15072 (67.56) |
| **Age group** |  |  |  |  |  |  |   |
| 15-19 | 5277 (2.47) |  | 5260 (2.51) | 17 (0.38) |  | 4902 (2.61) | 360 (1.61) |
| 20-24 | 8644 (4.04) |  | 8628 (4.12) | 16 (0.35) |  | 7869 (4.19) | 758 (3.40) |
| 25-29 | 8752 (4.09) |  | 8731 (4.17) | 21 (0.46) |  | 7844 (4.18) | 890 (3.99) |
| 30-34 | 9106 (4.26) |  | 9088 (4.34) | 18 (0.40) |  | 8162 (4.35) | 922 (4.13) |
| 35-39 | 9241 (4.32) |  | 9200 (4.39) | 41 (0.90) |  | 8228 (4.38) | 980 (4.39) |
| 40-44 | 9742 (4.55) |  | 9677 (4.62) | 65 (1.43) |  | 8709 (4.64) | 983 (4.41) |
| 45-49 | 12829 (6.00) |  | 12736 (6.08) | 93 (2.05) |  | 11542 (6.15) | 1208 (5.41) |
| 50-54 | 15709 (7.34) |  | 15566 (7.43) | 143 (3.16) |  | 14013 (7.46) | 1586 (7.11) |
| 55-59 | 17263 (8.07) |  | 17083 (8.16) | 180 (3.97) |  | 15423 (8.21) | 1693 (7.59) |
| 60-64 | 17739 (8.29) |  | 17484 (8.35) | 255 (5.63) |  | 15832 (8.43) | 1689 (7.57) |
| 65-69 | 20587 (9.62) |  | 20204 (9.65) | 383 (8.45) |  | 18232 (9.71) | 2023 (9.07) |
| 70-74 | 23245 (10.87) |  | 22672 (10.83) | 573 (12.64) |  | 20378 (10.85) | 2395 (10.74) |
| 75-79 | 20307 (9.49) |  | 19708 (9.41) | 599 (13.22) |  | 17598 (9.37) | 2207 (9.89) |
| 80-84 | 17336 (8.10) |  | 16588 (7.92) | 748 (16.50) |  | 14602 (7.78) | 2091 (9.37) |
| 85-89 | 11523 (5.39) |  | 10801 (5.16) | 722 (15.93) |  | 9318 (4.96) | 1589 (7.12) |
| 90-120 | 6610 (3.09) |  | 5952 (2.84) | 658 (14.52) |  | 5139 (2.74) | 935 (4.19) |
| **Charlson Index** |  |  |  |  |  |  |  |
| [0] | 104771 (49.21) |  | 104734 (50.02) | 601 (13.26) |  | 95997 (51.12) | 8817 (39.52) |
| [1-5] | 35736 (16.79) |  | 35374 (16.89) | 362 (7.99) |  | 31711 (16.89) | 3726 (16.70) |
| [>5] | 72396 (34.00) |  | 68833 (32.87) | 3564 (78.64) |  | 59702 (31.79) | 9708 (43.52) |
| (Missing) | 442 (0.21) |  | 437 (0.21) | 5 (0.11) |  | 381 (0.20) | 58 (0.26) |
| **% SHMI risk** | 2.50 (5.76) |  | 2.24 (5.17) | 14.53 (13.45) |  | 2.12 (5.04) | 3.60 (6.77) |
| **Median Length of Stay (IQR)** | 3.24 (1.50 to 7.09) |  | 3.21 (1.49 to 6.97) | 6.31 (2.71 to 12.19) |  | 3.16 (1.46 to 6.63) | 4.01 (1.90 to 9.08) |

1. Values are number(%) unless otherwise specified,

2. Discharged and not readmitted (excludes in-hospital deaths)

Table 4. Staffing levels experienced during the first 5 days of patient stays.

|  |  |  |
| --- | --- | --- |
|  | **RN1 Staffing** | **NA2 Staffing** |
| Hours per Patient Day, Mean(SD) | 5.36 (4.82) | 2.80 (1.40) |
| Hours per Patient Day, Median(IQR) | 3.95 (3.05-5.62) | 2.56 (1.88-3.42) |
| Days below mean staffing, N (%) | 465653 (57.16) | 466408 (57.25) |
| Days at or above mean staffing, N (%) | 335662 (41.20) | 333062 (40.88) |
| Days of unknown staffing | 13336 (1.64) | 15181 (1.86) |

1–Registered Nurse, 2-Nurse Assistant

Table 5. Staffing levels and outcome associations from the adjusted models

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Outcome** | **Low RN** | **Low NA** | **SHMI (Risk)** | **Ward random effect (SD)** |
| Mortality | 1.092 (1.066-1.118) | 1.103 (1.077-1.129) | 1.084 (1.082-1.086) | 0.972 |
| Readmission | 1.023 (1.019-1.028) | 1.014 (1.010-1.019) | 1.018 (1.016-1.020) | 0.558 |
| Length of stay | 1.063 (1.061-1.065) | 1.054 (1.052-1.057) | 1.054 (1.052-1.055) | 0.967 |
| Deep-vein thrombosis | 1.048 (1.020-1.077) | 1.029 (1.002-1.056) | 1.016 (1.006-1.026) | 0.762 |
| Pneumonia | 1.057 (1.048-1.066) | 1.051 (1.042-1.059) | 1.065 (1.062-1.067) | 1.020 |
| Pressure ulcers | 1.064 (1.043-1.085) | 1.029 (1.009-1.049) | 1.052 (1.046-1.057) | 0.879 |

95% confidence interval limits given in brackets;

Associations between adverse outcomes for surgical admissions and nurse understaffing – a longitudinal study

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**Supplementary Materials - Index**

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**Supplementary Methods**

All analyses were performed using R Statistical Software (v4.3.2)1 in the RStudio integrated development environment (v2023.12.1.402)2. The tidyverse R package (v2.0.0)3 was used for data wrangling. The survival analysis data set used to model mortality and readmission was constructed with the survival R package (v3.5.8)4 and analysed with the coxme R package (v2.2.18.1)5. The length of stay gamma regression modelling and patient conditions logistic modelling were undertaken with the lme4 R package (V1.1.35.1)6. Descriptive statistics used the finalfit R package (v1.0.7)7. The rmarkdown R package (v2.25)8 was used to format output in the preparation of this paper.

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**Supplementary Figures and Tables**

Table S1: ICD-10 Codes identifying the patient condition outcomes

| **Patient outcome** | **ICD-10 Code and Description** |
| --- | --- |
| Pneumonia | **Diagnosis codes** "J13 Pneumonia due to Streptococcus pneumoniae","J14 Pneumonia due to Haemophilus influenzae","J15 Bacterial pneumonia, not elsewhere classified","J16 Pneumonia due to other infectious organisms, not elsewhere classified","J18 Pneumonia, organism unspecified". |
| Deep venous thrombosis | **Diagnosis codes** “I80.1 Phlebitis and thrombophlebitis of femoral vein”, “I80.2 Phlebitis and thrombophlebitis of other deep vessels of lower extremities”, “I80.3 Phlebitis and thrombophlebitis of lower extremities, unspecified”. Matthews, A and Bhaskaran, K (2018). Clinical code list - Deep Vein Thrombosis. [Data Collection]. London School of Hygiene & Tropical Medicine, London, United Kingdom. <https://doi.org/10.17037/DATA.00000733> |
| Pressure ulcer | **Diagnosis codes** “L89.2 Stage III decubitus ulcer”, “L89.3 Stage IV decubitus ulcer”, “L89.9 Decubitus ulcer and pressure area, unspecified ie without mention of stage” |

Table S2: Staffing levels and outcome associations from the adjusted models for patient index admissions

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Outcome** | **Low RN** | **Low NA** | **SHMI (Risk)** | **Ward random effect (SD)** |
| **Mortality** | 1.088 (1.059-1.119) | 1.092 (1.062-1.122) | 1.085 (1.083-1.088) | 1.012 |
| **Readmission** | 1.023 (1.017-1.029) | 1.019 (1.013-1.025) | 1.020 (1.018-1.022) | 0.540 |
| **Length of stay** | 1.062 (1.059-1.064) | 1.055 (1.053-1.058) | 1.057 (1.055-1.058) | 1.356 |
| **Deep-vein thrombosis** | 1.065 (1.032-1.099) | 1.026 (0.996-1.058) | 1.011 (0.999-1.024) | 0.749 |
| **Pneumonia** | 1.056 (1.046-1.067) | 1.053 (1.043-1.063) | 1.065 (1.062-1.068) | 1.051 |
| **Pressure ulcers** | 1.070 (1.044-1.096) | 1.041 (1.017-1.065) | 1.054 (1.048-1.061) | 0.867 |

95% confidence interval limits given in brackets;

Table S3:. Comparison of model staffing coefficients for different periods of measured staffing

|  |  |  |
| --- | --- | --- |
|  |  | **Measured exposure period** |
| **Outcome** | **Staffing predictor** | **3 days** | **5 days** | **10 days** |
| **Mortality** | **Low RN** | 1.095 (1.057-1.135) | 1.092 (1.066-1.118) | 1.083 (1.067-1.100) |
|  | **Low NA** | 1.121 (1.082-1.162) | 1.103 (1.077-1.129) | 1.080 (1.064-1.096) |
| **Readmission** | **Low RN** | 1.023 (1.018-1.028) | 1.023 (1.019-1.028) | 1.026 (1.021-1.031) |
|  | **Low NA** | 1.015 (1.010-1.019) | 1.014 (1.010-1.019) | 1.015 (1.010-1.020) |
| **Length of Stay** | **Low RN** | 1.063 (1.061-1.065) | 1.063 (1.061-1.065) | 1.076 (1.074-1.079) |
|  | **Low NA** | 1.055 (1.053-1.057) | 1.054 (1.052-1.057) | 1.064 (1.062-1.066) |
| **Deep-vein thrombosis** | **Low RN** | 1.031 (1.006-1.056) | 1.048 (1.020-1.077) | 1.062 (1.032-1.093) |
|  | **Low NA** | 1.024 (1.000-1.049) | 1.029 (1.002-1.056) | 1.041 (1.012-1.070) |
| **Pneumonia** | **Low RN** | 1.029 (1.021-1.037) | 1.057 (1.048-1.066) | 1.077 (1.067-1.087) |
|  | **Low NA** | 1.028 (1.020-1.035) | 1.051 (1.042-1.059) | 1.065 (1.056-1.074) |
| **Pressure Ulcer** | **Low RN** | 1.034 (1.015-1.052) | 1.064 (1.043-1.085) | 1.090 (1.067-1.114) |
|  | **Low NA** | 1.013 (0.995-1.031) | 1.029 (1.009-1.049) | 1.045 (1.024-1.067) |

95% confidence interval limits given in brackets;

Table S4: Staffing levels and outcome associations from the adjusted models with weekend admission predictor

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Outcome** | **Low RN** | **Low NA** | **Wke\_adm\*** | **SHMI (Risk)** | **Ward random effect (SD)** |
| **Mortality** | 1.091 (1.065-1.118) | 1.101 (1.075-1.127) | 1.247 (1.165-1.335) | 1.084 (1.082-1.086) | 1.012 |
| **Readmission** | 1.023 (1.019-1.028) | 1.014 (1.010-1.019) | 1.021 (0.986-1.058) | 1.018 (1.016-1.020) | 0.540 |
| **Length of stay** | 1.063 (1.061-1.065) | 1.054 (1.052-1.057) | 1.081 (1.063-1.099) | 1.053 (1.052-1.054) | 1.356 |
| **Deep-vein thrombosis** | 1.048 (1.020-1.076) | 1.028 (1.002-1.056) | 1.083 (0.883-1.328) | 1.016 (1.006-1.026) | 0.749 |
| **Pneumonia** | 1.057 (1.048-1.066) | 1.051 (1.042-1.059) | 1.141 (1.072-1.215) | 1.065 (1.062-1.067) | 1.051 |
| **Pressure ulcers** | 1.064 (1.043-1.085) | 1.029 (1.009-1.049) | 1.165 (1.008-1.346) | 1.052 (1.046-1.057) | 0.867 |

\* Weekend admission: hospital admission on Saturday or Sunday