UNIVERSITY OF Southampton

Nurse staffing levels, missed vital signs observations and mortality in hospital wards: modelling the consequences and costs of variations in nurse staffing and skill mix: Retrospective observational study using routinely collected data

Study protocol

Overview

This study will use information about ward and shift level nurse staffing, vital signs observations and patient outcomes that are routinely recorded in all acute general inpatient wards in Portsmouth Hospitals NHS Trust (PHT). Relationships between registered nurse and health care assistant staffing levels and outcomes will be explored using statistical models. These models will be used to estimate staffing required on different wards to achieve satisfactory levels of compliance with vital signs observations

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1.0	PG/ARS	December 2014	No changes to the protocol have been made. However, foot notes have been added to report progress on specific tasks, e.g. Ethics approval to the study.
1.1	PG/ARS	Sept 2015	Expertise and justification of costs section removed
2.0	PG	Jan 2017	Added protocol changes agreed by advisory group before main analysis commenced

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Contents

Nurse staffing levels, missed vital signs observations and mortality in hospital wards: modelling the consequences and costs of variations in nurse staffing and skill mix. Retrospective observational study using routinely collected data

Summary of research

The NHS faces pressure to maintain the quality and safety of care in hospitals at the same or less cost than previously. The quality of nursing care and the potential for inadequate nursing care to do patients harm has emerged as an issue in numerous reports into failings in NHS hospitals in England. Failure to ensure adequate nurse staffing has frequently been cited as a causal factor. [1, 2] This is consistent with many studies showing associations between low levels of nurse staffing and increased mortality. [3, 4] However, because nurse staffing is only one factor affecting mortality, it is difficult to use these findings directly to show the effects of low staffing on nursing care delivery or to guide staffing decisions. The recent NICE draft guidelines on safe staffing highlighted the need for more evidence derived from the UK and for indicators that more directly reflect safe nurse staffing. Recently, studies have begun to explore missed nursing care as a key factor leading to adverse patient outcomes. Missed opportunities to observe and act on deterioration have been implicated in preventable hospital deaths [5, 6] and studies have shown that low staffing levels are associated with nurse reported missed care. [7, 8]

The current study examines the association between registered nurse and care assistant staffing levels, and missed or delayed recording of vital signs using objective measures derived from a clinical information system. The study also explores associations between nurse staffing and adverse patient outcomes: unanticipated ICU admission, cardiac arrest, and mortality. The study will model the costs and consequences of different staffing policies to achieve acceptable rates of observation and assess whether missed observations could be used as a leading indicator of nurse staffing adequacy by testing the extent to which missed observations mediate any relationship between staffing and outcomes.

This retrospective observational study uses routinely collected data on ward and shift level nurse staffing, vital signs observations and patient outcomes in 42 general wards in Portsmouth Hospitals NHS Trust. Data will be derived from a database of records made using the VitalPAC™ system which nurses use to record clinical data on hand held devices at the bedside.

These data will be linked to the following: records of all nursing staff working on a given shift (including bank and agency staff); patient data derived from the hospital patient administration system (PAS); cardiac arrest database; ICU admission database; and hospital laboratory records. Staffing data is available from 2012 onwards, with data from approximately 100,000 shifts available for the

study. Relationships between registered nurse and health care assistant staffing levels and outcomes will be explored using a hierarchical generalized linear mixed model, which allows for clustering of observation in individuals, shifts and wards. We will assess whether there is evidence that missed care mediates any relationship between staffing and adverse outcomes.

Parameters from regression models will be used to estimate staffing required on different wards to achieve specified levels of compliance with vital signs observations. We will assess the economic implications of different staffing models by estimating costs of differing staffing policies to achieve specified 0utcomes, determined through consultation with patients, the public and clinical stakeholders. The study will give guidance on the relative importance and costs of different nursing skill mixes in achieving consistent observations and safe care and determine whether the rate of missed vital signs observations could be used as an indicator of safe staffing.

Background and rationale

What is the problem being addressed?

Having sufficient nurses on duty to provide care safely in a hospital has become a key concern in the NHS. One challenge in assessing whether staffing levels are adequate has been that many of the potential indicators used (e.g., mortality rates, pressure sores, failure to rescue, 'never events') focus on the worst possible, relatively rare outcomes. They are often collated over a long period of time (e.g. annual mortality rates) and reviewed a long time after the care was provided. Nursing care is, at most, only a partial factor in causing variation. Research that has established an association between nurse staffing levels and patient outcomes also identifies the ability of nurses to deliver care on time and completely as a key factor in this relationship. [9-11] Missed or delayed care, if related to adverse outcomes and to staffing levels, may have the potential to provide a more immediate indication of whether a unit is adequately staffed. [7]

This study examines whether and how variation in nurse staffing levels on general hospital wards is associated with omissions or delays in delivering necessary nursing care, with a specific focus on monitoring and acting on vital signs. The monitoring of vital signs is a fundamental component of the 'Chain of Prevention', a structure that describes the interventions necessary to prevent patient deterioration. [6] Secondary outcomes will explore possible impact on patient death, cardiac arrest and unanticipated ICU admissions. The study aims to determine whether there are threshold staffing levels, below which necessary patient observation is substantially compromised, and whether any thresholds are consistent across types of wards and levels of patient need. The results of this study will provide guidance to NHS managers as to when staffing on wards presents a potential risk to patients and, conversely, whether rates of missed observations might provide a measure of underlying problems with staffing levels or other aspects of the nursing team. By determining how the relationships staffing and outcomes variety across different types of wards, it will also help guide

managers to determine appropriate comparators when attempting to benchmark nurse staffing levels against other units and hospitals.

Why is this important?

The National Health Service (NHS) in England, like many healthcare systems in the world, is facing intense pressure to maintain or improve the quality and safety of care provided in hospitals at the same or lower cost than in previous years. The quality of nursing care - and the potential for inadequate nursing care to do patients great harm - has emerged as an issue in numerous reports into failings in NHS hospitals in England. The Francis Inquiry examined the reasons why hundreds of patients experienced poor care at the Mid Staffordshire NHS Foundation Trust between January 2005 and March 2009. The Inquiry was instigated when the hospital standardised mortality ratio (case mix adjusted mortality rates) indicated a significantly elevated mortality rate over several years. Failure to ensure adequate nurse staffing was a central factor identified by the independent enquiry and subsequent public enquiry.[1] More recently, the Keogh review of care provided by 14 hospital trusts that had persistently high mortality rates identified inadequate nurse staffing as a significant explanatory factor. [2] Crucially the Keogh report identified deficiencies in staffing on wards that were not apparent from hospital level data.

These reports are consistent with a substantial body of international evidence linking lower levels of nurse staffing to higher hospital mortality rates. This was subject to an extensive systematic review published in 2008. [3] The conclusions were derived primarily from large cross sectional studies in the US. More recently, the RN4CAST study in 300 hospitals across nine European countries (on which PI for this application Griffiths was lead for patient outcome data) showed a 7% increase in the odds of mortality among surgical patients for every additional patient per registered nurse [4]. A further US study showed that every exposure to a shift, where staffing levels were 8 registered nurse hours or more below target levels, increased the hazard of death by 2%. [12] The mechanism for these associations has not been fully explored and although these findings have been used to support policies of mandated patient to nurse ratios in the US and Australia, mortality rates are, at best, an indirect and partial indicator of the adequacy of the nursing workforce to maintain patient safety. The results of the studies generally indicate the possible consequences of variation in staffing at a hospital level and do not identify the level of nurse staffing actually deployed on wards. As the Keogh review and other research has noted, hospital level nurse staffing (for example total nurses per bed or average patients per nurse) may not reflect nursing staff deployed on wards and certainly it not reflect the extensive variation in nurse staffing between wards within hospitals which is typically greater than between hospitals, even when only considering general medical / surgical units. [7, 13] Thus the existing research provides little direct guidance on safe staffing levels on hospital wards.

It has been proposed that the association between nurse staffing and mortality is mediated through the nurse's role in monitoring, observation and initiating actions for patients at risk of deterioration. [10, 14] Investigations into the care of deteriorating patients in the UK and elsewhere support this

possible mechanism with failure to take or to act upon observations cited as an important factor in avoidable deaths. [5] This mechanism is also identified in the 'failure to rescue' hypothesis, which proposes mortality among patients who develop a complication will be particularly sensitive to nurse staffing levels for this reason. [9-11] Using cross-sectional survey data from 2,917 registered nurses working on general medical and surgical wards in England, we showed that nurses on wards with lower staffing, reported more care missed due to time constraints. Nurses working on shifts with the lowest staffing (11.67 patients or more per registered nurse) were twice as likely to report inadequate patient surveillance when compared with those in the best staffed environments (less than 6.14 patients per RN). [7] This finding is consistent with several studies showing that lower RN staffing is associated with reports of more missed nursing care in the US [15-18] and across Europe in our RN4CAST study. [8]

However, these studies have all relied on intermittent surveys and subjective reports of missed nursing care, which may be influenced more by global perceptions of quality rather than directly indicating specific missing care. Furthermore, none have focused on aspects of missed care most likely to link directly to increased mortality. Previous research from our group (DP, GS, PS) shows that scheduled vital signs recording is missed with a relatively high frequency, especially at night. [19] For example only 69% of patients identified as requiring the most frequent observation had another observation recorded in the next six hours at night, while the figure during the day was 87%. Thus far, no studies have examined associations between objective measures of missed observations and staffing levels and between missed observations and adverse events for patients.

One of the recommendations of the Francis report was that NICE should develop guidance on setting safe staffing levels. Applicants PG & JB undertook the evidence review for this guidance. Although there are a number of potential systems for setting nurse staffing levels, the published evidence base for them is weak, largely based on subjective measures of quality or local time and motion studies. [20, 21] Our review concluded that whilst the cumulative evidence pointed strongly to a partly causal relationship between staffing and outcomes, it was limited by its primarily cross-sectional nature, with few studies being able to establish that poor outcomes occurred at the same time or following periods of low staffing. Those outcomes likely to be most directly influenced by nurse staffing, such as rates of pressure ulcers, are highly problematic because there are no well validated risk adjustment models, whereas associations with mortality can only provide indirect evidence to help set nurse staffing levels at ward level.

The draft NICE guidance specifically highlighted *"…There is a lack of evidence from UK data that allows the effects of actual nursing staff that are present … to be readily determined…"* and *"…There is a lack of good quality research on the indicators that are most sensitive to numbers of available nursing staff…"*

More research is needed to develop direct and objective indicators of adequate staffing if any approach to determining nurse staffing levels is to be properly validated. The evidence cited above suggests that missed care may serve as a leading indicator of nursing service quality that is more sensitive to variation in nurse staffing than are outcomes, thereby providing a better guide to determining staffing requirements at a ward level. However current measures of missed care are problematic because they rely on intermittent survey and a subjective report. The current study will be the first to use an objective measure of missed vital signs observations, a key nursing function assuring patient safety, to explore the relationship between staffing levels, missed care and adverse outcomes for patients.

Aims and objectives

This retrospective observational study will use data derived from clinical and workforce databases to explore the relationship between nurse staffing levels on hospital wards and vital signs observations taken by nurses and care assistants. This project will use a unique clinical database of vital signs observations that are recorded using hand-held devices running the VitalPAC software [22] to provide an objective measure of timely provision of care that is key to maintaining patient safety. The study will link these data to shift level ward staffing data (from an e-rostering system) and use multi-level regression models to explore associations between nurse staffing and missed care in the clinical micro-system of most direct relevance – the hospital ward. The study will also examine the relationship between ward nurse staffing and adverse events, assessed in terms of cardiac arrest, unanticipated ICU admission and death. By examining non-linear relationships, the study will identify if there are threshold staffing levels where risk of missed care is substantially increased, and the extent to which any relationships and thresholds are specific to particular types of wards or types of patients.

Crucially this study will add significantly to the body of evidence on associations between nurse staffing and outcomes because it will:

i) Determine that variation in the presumed causal factor (nurse staffing) precedes the presumed effect (adverse outcomes)
ii) Explore an intervening care process (vital signs observation) that is a direct result of actions by nurses
iii) Provide evidence that is directly relevant to the UK context

Thus the study aims to provide a basis for identifying the nurse staffing levels and skill mix required to ensure adequate patient surveillance and assess whether rates of missed vital signs observations can be used to identify when or where care is falling below accepted standards and putting patients at risk.

In order to do this we will:

- develop a database linking individual patient details, vital signs observation records and ward level nurse staffing records
- model the relationship between the available nursing workforce on a shift and missed or delayed observations, in order to identify (a) the association between registered nurse staffing levels and delayed or missed observations and (b) the association between health care assistant staffing levels and delayed or missed observations
- determine whether any relationship is linear or whether performance deteriorates beyond a threshold of staffing level.
- assess the potential for missed vital signs observation to be an indicator of safe nurse staffing
- determine whether any thresholds are similar in similar wards
- determine whether the strength of any relationships are similar in similar wards
- model the relationship between nursing workforce and adverse events to assess whether patients exposed to periods of low staffing are at increased risk of death, cardiac arrest or unanticipated ICU admission
- model the relationship between missed vital signs and adverse outcomes
- assess whether any relationship between staffing and adverse outcomes is mediated by missed observations
- organise stakeholder (clinicians, patients, public) events to identify staffing policies (e.g. different skill mixes) and target levels of vital signs observation compliance to be considered in economic models
- use coefficients from the regression models to identify staffing policies that are associated with desired outcomes and model the staffing costs associated with these policies.
- assess how modelled staffing requirements and outcomes vary by time of day and between wards

Research Plan / Methods

Method

This is a retrospective observational study using routinely collected data on ward and shift level nurse staffing, vital signs observation and patient outcomes.

Setting

The study will take place in all acute inpatient general wards (approx. 32 wards and 800 beds) in Portsmouth Hospitals NHS Trust (PHT), a large acute care general hospital trust. PHT employs 6,300 whole-time equivalent staff and provides acute services to approximately 650,000 people across Portsmouth, South East Hampshire and West Sussex. Planned daytime staffing varies between wards, from 8 patients per registered nurse (identified as a risk threshold by NICE) to 4 or fewer patients per nurse (reflecting recommended safe staffing levels from other countries). [23] Actual

staffing is more variable. These ratios suggest that the trust is typical when compared to the range observed in England in our RN4CAST study. [24] In 2012-2013 PHT had a hospital standardised mortality ratio (HSMR) of 99.54, placing it near the middle of the range observed in England (86/141). Similarly it's Summary Hospital-level Mortality Indicator (SHMI), at 104.52 is ranked 91/141. ICU mortality, rates of cardiac arrest and survival after cardiac arrest are also close to national averages. Indicators of health for people living in Portsmouth are generally worse than the England average (NHS Health profile). It has 19.5% of people living in in areas categorised as among the 20% most deprived in England (national average 19.9%). Portsmouth has a diverse community with approximately 14% coming from black and ethnic minority communities. The largest minority group is Bangladeshi (approximately 8%).

Sample / data sources

Data for the study will be derived from a database of records made using the VitalPAC system, which enables nurses to record clinical data on hand held devices at the bedside. The database includes records of vital signs observations, nutritional assessments and assessments of the risk of venous thromboembolism. The frequency of vital signs observations required is determined by a national protocol based on the National Early Warning Score (NEWS) [25], which identifies when the next observation is due. These data will be linked to the following: records of all nursing staff working on a given shift (e-rostering); records of bank and agency staff working on the ward; patient data derived from the hospital patient administration system (PAS), cardiac arrest database, ICU admission database and hospital laboratory records. VitalPAC has been hospital wide since 2010. It contains approximately 1,000,000 complete observation sets on approximately 44,000 episodes of care per year. Previous research from this group shows that scheduled vital signs recording is missed with a relatively high frequency, especially at night. For example only 69% of patients identified as requiring the most frequent observation had another observation recorded in the next six hours at night while the figure during the day was 87%. [19] Local audit data show that these figures vary widely between wards.

We will also use data from PAS and hospital laboratory records to determine rates of mortality and to adjust for patient level variation in risk. The group has developed risk models of in-hospital mortality using laboratory data (biochemistry and haematology data) with ROC c statistics up to 0.85 [26-28], indicating good discrimination. These models compare favourably with those typically observed for the widely used HSMR method. [29] We will use both these approaches as the basis of our risk adjustment for mortality and determine which approach to use based on overall model fit.

E-rostering data is available from 2012 onwards, with data from approximately 100,000 shifts available for the study. The database contains records of shifts worked, hours worked (dates, start and end time), ward and grade for all nurses employed by the hospital. A second database records all bank and agency shifts worked in a similar format.

The data have a complex hierarchical structure and are drawn from several sources (see table 1 and additional document 'data structure'). The team has considerable expertise in dealing with such data. We have scrutinised the staffing databases and trialled data extraction. Members of the research team have already successfully linked PAS data to the vital signs data collected by VitalPAC [22] and to the hospital laboratory records (biochemistry and haematology databases). [28] Their work led to the development of the first validated Early Warning Score [30] from which the National Early Warning Score (NEWS) was developed. [25, 31].

Table 1. Data structure & sources

Data (source) **Ward (trust administration)**	**Nurse Staffing (ESR / bank and agency)**	**Missed care (VitalPAC Database)**	**Patient (PAS, Pathology, Cardiac arrest, ITU databases)**
Type of data (level)			
Descriptive profile of ward (ward)	Record of nurse hours worked daily (ward / shift / time period)	Record of observation taken (patient, repeated measure)	Record of patient details & events during stay (patient)
Link variables			
Ward	Ward	Ward	
		Patient ID (pseudonymised)	Patient ID (pseudonymised)
	Date & time	Date & Time	Date
	Nurse ID (not used)	Nurse ID 2 (not used)[1]	
Data (exemplars)			
Ward specialties	Nurse grade	Nurse role	Demographics (age, sex etc.)
Beds	Start date/ time	Vital signs	Admission / discharge date
Case mix	End date / time	MUST assessment & others	speciality
	End time	(derived)	Date / place of death
	Shift	Time when next obs. due	ICU admission / date
		NEWS value	
			Cardiac arrest / date
			Lab results / date
			Diagnosis (ICD)
			Procedure (OPCS)
			HRG

[1] The nurse ID on the VitalPAC database cannot currently be linked to the ESR as different identifiers are used. In order to maintain confidentiality we do not propose using nurse IDs in this study because we currently have no mechanism for extracting them with pseudonymised IDs to allow linkage

Outcomes

The primary outcome for the study will be missed vital signs observations. A missed observation is defined as an observation that is not performed before the next observation is due. The planned frequency of observations is determined from a national protocol based on NEWS values, which identifies risk of adverse outcome. [25]

Secondary outcomes will include:

- Rate of missed observations in high risk sub-groups, defined by elevated NEWS score (e.g. where required frequency is less than every 4 hours)
- Absolute delay (time from observation becoming due until an observation is taken)
- Relative delay (time from observation becoming due until an observation is taken expressed as a proportion of the scheduled observation frequency in minutes)
- Deaths
- Cardiac arrests
- Unanticipated ICU admissions
- Records of other assessments (e.g. the MUST Nutritional assessment) in VitalPAC

Staffing variables

We will consider nurse staff variables in the following ways

i) Nursing Hours per patient day. We will sum all nursing hours on the ward for each day and divide by average patient census for that day.
   a. Total Nurse hours (RN + HCA) per patient day
   b. RN Hours per patient day
   c. HCA Hours per patient day
   d. Skill mix (RN Hours / total hours)

ii) Shift level staffing (early / late / night). Average patients on ward on the shift / average number of nurses over the shift
   a. Patients per nurse
   b. Patients per RN
   c. Patients per HCA
   d. Skill mix (RN / RN+HCA)

iii) Granular level staffing – by 30 and 60 minute intervals – at the time when observations are done (patients / nurses present)

iv) Periods where staffing falls substantially below the planned establishment for the ward or where staffing levels fall below the 20th centile staffing level for that ward.

Data management

Data will be provided by Portsmouth Hospitals Trust to the University of Portsmouth in its original form, except with patient identification being pseudonymised. The data will be stored in the University of Portsmouth clinical data repository, which is subject to additional security checks. Access to the database will be limited to members of the research team.

From the repository, particular datasets will be generated that address particular aspects of the analysis. Cleaning of the data, adjusting or excluding missing values will be done at this stage. Where convenient / required for analysis, synthetic categorisation (relating date/time to shift for example) will be performed. These data will be shared with the remainder of the analysis team. All transfers of individual patient data will use secure data transfer protocols.

Analysis

We will use hierarchical generalized linear mixed models to model associations between staffing and outcomes. This is currently the most appropriate approach in repeated measurement data analysis of clustered data. Such models differentiate variation within and between subjects and support inference about the personal trajectory of each subject. They provide a flexible strategy to account for complex correlation structures in the analysis of repeated measurements. Since the available data are in the form of repeated measurements on different subjects, clustered into shifts belonging to several wards, the hierarchical structure of the data is taken into account by including cluster effects at the different levels of the hierarchy. A random term is included for every shift and ward. In order to determine whether the relationship between staffing and outcomes is the same in all wards and at all times, we will assess the need to include interactions between staffing and these random effects. As a key element of the model, we specify the relationship between the mean response (e.g., average rate of missed observations) and a set of available covariates, associated with fixed effects (to be estimated).

As possible covariates to be included in the linear predictor, we will consider the ratio of patients to nursing staff present on the ward at the time the observation was due. We will use age and NEWS values of all patients present on the ward at the time and the number of admissions / discharges recorded on a shift to adjust for variation in workload over and above number of patients. Analyses will consider total nursing staff (registered nurse or health care assistant) and each individual staff group. We include the grade mix by modelling the proportion of staff in various nursing grades and add quadratic terms for the staffing variables to the model to determine non-linear effects and to identify possible thresholds where observed relationships start or end.

Because the likelihood and significance of missed observations for an individual may be related to the planned observation frequency, we will undertake a sub group analysis considering only patients with a high NEWS value (therefore requiring frequent observation). We will explore for lagged effects (effect of staffing at a given point in time on missed observations at later points in time) and whether the grade of staff taking observations (HCA or RN) has any impact.

We will assess whether exposure to periods of low staffing increases the subsequent risk of an adverse event. To explore associations between staffing levels and patient death, we will use Cox proportional-hazards models with adjustment for characteristics of patients, based on risk validated risk models using laboratory data from admission and / or the HSMR method.[26-28] For ICU admission and cardiac arrest we will use NEWS value 24 hours before the event to control for patient level risk.

In the context of hierarchical generalized linear mixed models, the choice of the model structure is a crucial aspect of the model selection process. The prevailing approaches which have been adopted to balance model fit and parsimony are based on information criteria, obtained through penalizations of the maximum log-likelihood. We will use the Akaike information criterion and the Bayesian information criterion to assess model fit. The first one is known as an estimator of the (Kullback-Leibler) discrepancy between the data generating model and the fitted model. The Bayesian information criterion provides an approximation of the Bayesian posterior probability of the candidate model. These criteria have the advantage, compared to methods based on the likelihood ratio test between nested models, of not requiring a bootstrap resampling procedure.

We will look for evidence that missed observations mediate the relationship between staffing and adverse outcomes. Our approach is based on Baron and Kenny. [32] A mediator variable is a variable that accounts (in whole or in part) for the relationship between the independent and dependent variables. [33] Firstly, we hypothesise that low staffing levels reduce the ability of nurses to undertake timely vital signs observations. Secondly, we hypothesise that timely vital signs observation is a mechanism by which nurses can reduce the risk of death. Thus, we hypothesise that the relationship between nurse staffing levels and mortality is mediated by timely vital signs observation. If this is the case there must be a significant relationship between the independent variable of interest (nurse staffing levels) and the dependant variable, mortality (after controlling for other confounders such as patient age and comorbidity). There must also be a significant relationship between the proposed mediator variable (vital signs observation) and the independent variable (staffing levels). When both the independent variable (staffing) and the mediator (vital signs observation) are included in the regression model the relationship between the independent variable (staffing) and the dependant (mortality) is significantly reduced or, in the case of full mediation, eliminated. Because timely vital signs observation is not the only mechanism by which nurses can reduce the risk of death, nor is it in itself sufficient, we hypothesise that mediation will be partial.

We will address this issue in a number of ways. Actions taken in response are difficult to track and link to the extremely large number of patients involved in this study because they are not explicitly linked to nursing actions (i.e. calls for assistance) in administrative data. However, these actions can be inferred from response patterns in the project data.

Specific actions following high NEWS values (7+)

NEWS values of 7+ are expected to result either in active therapy (e.g., rapid resolution of abnormal physiology or ICU admission) or managed limitation of active treatment (e.g., DNACPR decisions or end-of-life care). A failure to ensure appropriate handling of a patient with a high NEWS value (with at least one of the above) is a potential indicator of inadequate response due to (a) no call for help; (b) no response

Missed observations following an elevated NEWS value (5+) (unless there is ICU transfer)

As the NEWS value indicates need for attention and frequent monitoring, omission or delay of the next set of nursing observations indicates a direct failure to respond adequately in whole or part.

Sequence of NEWS values of 5 or above that is either constant or rising

This is a potential indicator of inadequate response due to (a) no call for help; (b) no response or (c) ineffective response.

We will explore for these patterns and describe the frequency of their occurrence. This process will also be modelled as follows. Taking mortality counts as outcome, a latent variable is constructed which, within the arm of non-missed observation, stands for increased versus diminished mortality risk. This variable can be proven to exist or not to exist via a likelihood-based clustering approach. Its interpretation as 'failure to act' is likely albeit with ambiguity and can be tested by associations with the response patterns outlined above.

PPI / Stakeholder events to inform modelling

In order to undertake economic modelling we need to determine a target level of compliance with vital signs observations and to consider the range of staffing models that might be considered acceptable and plausible. For example, regression coefficients might indicate that HCAs could substitute for RNs in achieving vital signs observations. However, because of other responsibilities of the RN role, it is unlikely to be acceptable to consider (and model) the costs of a 100% HCA workforce. While 100% compliance with vital signs observations might seem desirable, it may be that there are reasonable exceptions or that there are other reasons why a lower level might be an acceptable target. In order to explore these issues we will convene one or more joint stakeholder events including clinical professionals (nurses, HCAs and medical practitioners as well as ward managers) and former patients and carers with recent inpatient hospital experience. We will present any emerging findings and ask participants to reflect on possible scenarios and identify limitations of any scenarios to be modelled. In order to ensure participation of a wide range of stakeholders we will explore the possibility of holding these events in a virtual (online) environment and the use of social media channels to facilitate dialogue. Records of the events will be used to inform decisions on modelling. In addition we will convene a final event to consider the implications of our emerging findings and to identify priorities for future research. These events will be facilitated by a member of the research team (AdI) as a lay researcher and JEB as expert on staffing levels.

Economic modelling

We will identify the costs and consequences (in terms of reduced rates of missed observations and adverse events) of a range of staffing mixes. The staffing mix in each ward for an average shift (examining day and night separately) will be described, and variations between and within wards will be explored. Costs of staffing will be estimated and valued using Unit Costs of Health and Social Care [34] in order to ensure they are based on an agreed methodology and are nationally representative. We will examine variations in staffing costs and any associations with average patient acuity (as measured using the NEWS value) and patient comorbidities (using an appropriate comorbidity measure such as the Charlson or Elixhauser index). We will assess whether ward-level staff costs are associated with missed observations and adverse events.

We will model the costs and consequences of changes in staffing levels and various staffing 'policies'. Scenarios to be considered and modelled and desirable thresholds for observation compliance will be informed by our stakeholder events including PPI members and clinicians. We will use the coefficients derived from multi-level models to calculate staffing levels and costs predicted to reduce missed care or to maintain levels of missed care below threshold levels (e.g. average 95% observations undertaken on time). For example, we will explore the marginal costs of adding a registered nurse and/or a health care assistant to each ward and shift, and estimate the marginal consequences of this, in terms of missed care avoided and any effects on patient outcomes. We will explore whether there is scope for substitution between RNs and HCAs and what the costs / savings might be. Mixed models will be specified based on the rate of missed observations (dependent variable) given a range of independent variables. The independent variables will include RN and HCA staffing levels (as fixed effects), but also accounting for various patient-level and ward-level variables (as random effects).

We also aim to assess the extent to which particular staffing policies would be feasible. For example, to what extent can a fixed establishment for a given ward or speciality efficiently meet need? To do this we would identify fixed staffing levels required to meet or exceed predicted staffing requirements (say) 95% of the time (threshold to be informed by our stakeholder events) and calculate the associated costs compared to a policy where staffing was allowed to vary according to the estimated requirement and compared to current average staffing.

We will undertake sensitivity analyses to assess the extent to which conclusions are sensitive to differences in costs between staff groups and the strength of any observed relationships.

Approach to causal inference and generalisation

We will take a cautious epidemiological approach to assessing causality of the exposure-outcome relationship via the so-called epidemiological proof, including the following elements: the strength of association between exposure and outcome; the temporal sequence between exposure and outcome; the dose response relationship between exposure and outcome; and the reproducibility of the association. Our primary outcome, missed observation, is a direct consequence of actions by nurses. Therefore, although this study is observational, there is an *a priori* basis on which to consider causality (a plausible mechanism). Secondly, our study will be able to establish temporal associations – that is that the presumed cause (low nurse staffing levels) precedes or is simultaneous with the adverse outcomes (missed observation, mortality). Thirdly, our analyses will pay close attention to the shape of any relationship, and will consider whether there is evidence of a 'dose response' relationship between nurse staffing and outcomes.

The aspect of reproducibility will be approached by investigating the relationship in a diversity of wards. We will consider the consistency of the relationship across the multiple wards in the study. The use of random effects models allows the gradient of the relationship to vary across wards but we would expect that it would be consistent in its direction. We will look for evidence that supports our hypothesised mechanism of cause by assessing whether missed observations mediate the relationship between staffing and outcomes.

We are able to adjust for potential confounders at the patient level and have established risk models for mortality, which have been shown to perform well. Because we do not have comparable staffing data for medical teams, it is not possible to directly consider medical staffing levels (or indeed other staff) as a potential confounding variable in the analyses. However, we will scrutinise the results in order to see if there are patterns that might be consistent with confounding by medical staffing levels. We will explore whether nurse staffing levels vary with periods where there are known variation in medical staffing levels (for example evenings and weekends). Assuming this to be the case, all our analyses will include time of day and weekday / weekend as variables and we will undertake sensitivity analyses using staffing levels from weekdays only, to determine whether the strength and nature of the relationship between nurse staffing and outcomes are altered.

While the availability of data at Portsmouth creates a unique opportunity for this team to undertake a more detailed analysis of staffing / outcomes relationships than has hitherto been possible in England, we recognise that it is a single centre and so there must also be a cautious approach to generalisation. Each hospital in England is different, but as outlined above, PHT is, many respects, 'typical'. Numerous studies have noted that there tends to be more variation in staffing between shifts and wards within hospitals than there is between hospitals [e.g.7, 13]. The costs used in this study will be based on national reference costs rather than local costs.

If our analysis gives some confidence that the relationships observed are causal, there is no *a priori* basis to suppose that similar relationships do not apply elsewhere. Our analysis will give the opportunity to ascertain whether the strength (and direction) of relationships vary between wards. The extent of variation observed will give an indication of the likelihood that coefficients observed in this study might be applied to other wards with a similar case mix, although we will be unable to model additional, hospital level, random variation.

Dissemination and projected outputs

The research outputs from this project will be of interest to a wide audience. We anticipate a number of potential papers for academic peer review journals that will contribute to the emerging literature on the mechanisms of the link between nurse staffing and patient outcomes. The 'core' papers that we anticipate are:

i) What is the relationship between nurse staffing, vital signs observations, and adverse events?
ii) Does missed care mediate any relationship between adverse events and nurse staffing?
iii) The costs / consequences of different staffing policies.

We will prioritise journals that are read by a broad audience of health researchers and professionals and which have options for gold / green open access. Our ability to deliver these papers will be partially determined by editorial policies in relation to the publication of results in the NIHR HS&DR journal, although we anticipate peer review papers preceding this publication. In addition to these peer review papers we are committed to dissemination to a wider audience of health service managers and will aim to disseminate summaries of findings and implications via journals such as the HSJ and Nursing Times, and networks such as the Health Services Research Network, NHS employers and organisations working in the field of the deteriorating patient. Our PPI and service representatives on the project steering group will guide us in developing a dissemination strategy for these audiences as findings emerge. We will work closely with the University media team and ensure that members of the project team are given full support and training in dealing with media enquiries.

Additionally we will present findings at key national and international conferences with likely candidates being the US Academy Health annual research meeting, International Forum on Quality and Safety in Healthcare, RCN International Research Conference, Annual Conference of the International Society for Rapid Response Systems as well as conferences targeted at NHS managers.

Plan of investigation and timetable

Month	Pre project (Year -1)	Year 1	Year 2
1		Project start up meet. Project Advisory Group meet Literature review / background for papers (to month 3)	Advisory Group Meet
2		Specification for data extraction	Economic cost / consequences modelling (to month 4) Mediation analysis (to month 4)
3		Data extraction (to month 6)	Draft papers 1-3 (to month 19)
4		Draft background for papers 1-3 & final report (to month 9) PPI and reference panel event re outcomes & scenarios to be modelled - what level of missed observation is acceptable & under what circumstances?	Review and revise analyses
5		Data extraction continues Report prep	Papers continue
6		Build database & data cleaning (to month 8) Interim report Project Advisory Group meet	PPI and reference panel event to review draft findings and identify future research priorities / needs Report to NIHR
7	Initiate ethics application	Data cleaning contd.	Review analyses in the light of stakeholder events / feed back
8		Complete database	Review and finalise drafts / submit papers
9		Pass data to stats team / report of descriptive data PPI and reference panel even re economic models - what factors should be considered and what scenarios modelled?	Prepare final report to NIHR
10		Model missed observations (to month 11)	Prepare final report to NIHR / revise papers
11	Initiate appointments (if required)	Model Mortality (to month 12)	Prepare final report to NIHR
12		Model Cardiac arrest & other outcomes (to month 13) Pass regression coefficients to economics team Report to NIHR	Month 24 Final report to NIHR

Project management

The project will be overseen and managed by PG with day-to-day project management provided by senior RF. JSB will deputise in the case of unforeseen periods of absence. The work of the project will be organised into 5 work streams with senior leads. Project management and dissemination (PG), data management (JSB), statistical analysis (DB) economic modelling (AM) and stakeholder engagement (PG / ADI). Leads will hold regular research management group meetings (+ other team members as appropriate) to review and coordinate progress on each work stream. Project progress against key milestones will be monitored monthly. Because of the complexities of the data set and the associated analyses, we have allowed significant periods of time for analysis and for write up following the building of the database. This timescale also gives some degree of contingency should

we experience delays in accessing data or building the database. However, given the familiarity and experience of team members with using and linking these data, we do not anticipate such delays.

Strategic oversight and advice will be provided by a project advisory group. The group will meet four times. The group will comprise senior academics, NHS and other stakeholders and patient and public representatives. Mark Stafford Watson has agreed to participate as a PPI representative. Healthwatch Dorset & Hampshire and The Patients Association have expressed an interest and will be asked to nominate members (Steve Taylor, Healthwatch Hampshire Manager & Katherine Murphy, Patients Association, confirmed).

We have also sought / will seek agreement in principle to participate in this group from:

Carl May, Prof of Healthcare Innovation, University of Southampton (independent chair); Graham Cookson, Prof Economic and Public Policy, University of Surrey; Mohammed Mohammed, Professor of Healthcare Quality and Effectiveness, University of Bradford; Ruth May, Regional Chief Nurse for NHS England (Midlands and East), Member of the Nursing and care Quality Forum with responsibility for the nursing workforce work stream of the "Compassion in Practice" strategy.; John DePury, Head Health Policy, Universities UK; Anne Marie Rafferty, Prof Nursing Policy, King's College London; DH, Rosemary Chable, Associate Director of Nursing, University Hospital Southampton;

Approval by ethics committees

The project draws data from individual patient records where explicit consent has not been gained from participants. All patient data used for the project will be pseudonymised in order to maintain confidentiality while allowing the necessary records to be linked. We will not seek individual identifiers on nurse staffing data for this project. As per standard procedures for maintaining confidentiality when using these data we will supress small numbers when reporting and avoid the use / presentation of constellations of data that can potentially be used to reveal identities. Because of the high level of aggregation used in the analyses we propose, we do not anticipate significant issues in this regard.

We will initiate an application to NRES for a research database that would include the research activities detailed in this project but would also provide future opportunities to use the database for other research projects in the future, thus building capacity. This application will be commenced immediately after submission of this proposal and will proceed irrespective of funding.[2]

Patient and Public Involvement

[2] Favourable opinion to conduct the study from the NRES Committee East Midlands – Northampton Ref: 15/EM/0099 was granted on the 24th February 2015. Documentation regarding the application and decision can be provided upon request.

Safe staffing in hospitals is a major area of public concern following the Francis Inquiry and other reports. This proposal has been developed with this concern in mind and has been specifically shaped by conversations and meetings with members of Healthwatch Dorset, Healthwatch Hampshire, Katherine Murphy (Chair of The Patients Association), Mark Stafford Watson (a local person with experience of frequent hospitalisations linked to asthma and who is actively involved in developing the patient and Public Involvement Strategy of the NIHR Wessex CLAHRC) and Anya de Iongh, who also has experience as a patient. These discussions affirmed the importance of the topic, identified a number of issues and challenges that have shaped the proposal (including how patient need can dynamically shape nursing workload) and confirmed the importance of observation as a primary outcome for the study, recognising its intrinsic value and indeed potential priority relative to measures of psychosocial care which are not routinely available for the current study. Anya has joined us as a Co-investigator and contributed to the further development of the proposal, including the development of our approaches to consulting with stakeholders (patients, public and clinicians) about parameters to be used in economic modelling.

Mark Stafford Watson will participate as a member of the project advisory group. Both Anya and Mark are members of, and have access to, wider networks of patients, carers giving them both broader insight into patient experience and issues, and providing opportunities to further involve patients and carers in this work. Representatives from Healthwatch and the Patients Association will also join the project advisory group.

All PPI representatives will have a key role in developing the dissemination strategy and shaping messages / materials designed for a wider (non-professional) public audience. As a CI, Anya will participate in all aspects of the research and be a member of our research management group, which will be the key forum for decision-making. She will contribute to the analysis, interpretation and reporting of findings and co-lead our stakeholder engagement work stream. Aspects of the research including the economic modelling will draw on the results of PPI / clinical stakeholder consultation events. We will also convene a stakeholder event including public / patient participants to explore emerging results and identify future research priorities. Training requirements will be assessed and support provided as required, drawing on the expertise and facilities provided by the local RDS and the NIHR CLAHRC Wessex

Protocol Changes

Inevitably in a project such as this where much of the data has not been used for research previously there are iterative elements to the analysis which result in changes to the approach. Wherever possible these changes were made following discussion with our advisory group. Below we list key changes that were made before analysis commenced or at an early stage.

Shift modelling

Because of the variety of shift patterns in use across wards we propose to create 4 6 hour 'pseudo-shifts' for consideration in the model 7am-1pm, 1pm-7pm, 7pm-1am, 1am-7am (TBC). These approximately match start and finish times of the widely deployed 12-hour shifts while also picking up variation in staffing levels associated with a 3 shift system. Advisory group agreed that this was sensible and useful to service.

Patient groups.

Because a small number of patients aged 16 to 18 are cared for on adult wards and thus the wards in our study, contributing to the ward workload, we propose including them in our sample

Mortality risk modelling.

In our proposal, we planned using the Hospital Standardised Mortality Ratio (HSMR) method to adjust for risk of death. However, the HSMR method excludes significant numbers of patients and furthermore requires the use of data relating to socio-economic status, which we are unable to access as part of our study data. We had also considered using a risk modelling approach based on laboratory data on admission but this also excluded a large number of patients where lab results were not available (generally because bloods were not taken in the ED or early during an elective admission). We thus reviewed alternatives and determined that an approach based on the Summary Hospital-level Mortality Indicator (SHMI), which gives results that correlate highly with HSMR at a hospital level (https://www.sheffield.ac.uk/polopoly_fs/1.51777!/file/SHMI_Final_Report.pdf) would provide an equally valid basis for our approach. Because coefficients derived from a National Model are available for the SHMI, we propose assigning each patient a risk score based on these coefficients to control for individual variation in risk of death. The use of the nationally derived coefficients also allows us to estimate risk of death in patients where the diagnosis is infrequent in our data and so this approach is in many respects superior to that which we originally proposed.

Missed observations

We originally defined a missed observation as one which was not competed by the time the next observation was due. Discussion with stakeholders and among the project team revealed problems with this approach because timing of observations are not 'perfect' and an observation which was due but not taken until (for example) 1 minute before the next observation was due would be counted as 'late' whereas, in reality, it is approximately on schedule, with the previous observation missed. Therefore, we have slightly revised our definition of missed and late observations: late 1/3 or more after the time until the next observation is due and missed 2/3 or more until the next observation is due.

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