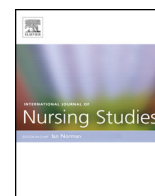




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Nurse staffing, medical staffing and mortality in Intensive Care: An observational study

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ABSTRACT

Objectives: To investigate whether the size of the workforce (nurses, doctors and support staff) has an impact on the survival chances of critically ill patients both in the intensive care unit (ICU) and in the hospital.

Background: Investigations of intensive care outcomes suggest that some of the variation in patient survival rates might be related to staffing levels and workload, but the evidence is still equivocal.

Data: Information about patients, including the outcome of care (whether the patient lived or died) came from the Intensive Care National Audit & Research Centre (ICNARC) Case Mix Programme. An Audit Commission survey of ICUs conducted in 1998 gave information about staffing levels. The merged dataset had information on 65 ICUs and 38,168 patients. This is currently the best available dataset for testing the relationship between staffing and outcomes in UK ICUs.

Design: A cross-sectional, retrospective, risk adjusted observational study.

Methods: Multivariable, multilevel logistic regression.

Outcome Measures: ICU and in-hospital mortality.

Results: After controlling for patient characteristics and workload we found that higher numbers of nurses per bed (odds ratio: 0.90, 95% confidence interval: [0.83, 0.97]) and higher numbers of consultants (0.85, [0.76, 0.95]) were associated with higher survival rates. Further exploration revealed that the number of nurses had the greatest impact on patients at high risk of death (0.98, [0.96, 0.99]) whereas the effect of medical staffing was unchanged across the range of patient acuity (1.00, [0.97, 1.03]). No relationship between patient outcomes and the number of support staff (administrative, clerical, technical and scientific staff) was found. Distinguishing between direct care and supernumerary nurses and restricting the analysis to patients who had been in the unit for more than 8 h made little difference to the results. Separate analysis of in-unit and in-hospital survival showed that the clinical workforce in intensive care had a greater impact on ICU mortality than on hospital mortality which gives the study additional credibility.

Conclusion: This study supports claims that the availability of medical and nursing staff is associated with the survival of critically ill patients and suggests that future studies should

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focus on the resources of the health care team. The results emphasise the urgent need for a prospective study of staffing levels and the organisation of care in ICUs.

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What is already known about the topic?

- There is a growing consensus, supported by several high quality systematic reviews, that the number of nurses available for patient care improves patient outcomes in acute medical and surgical wards, but there is less agreement that this relationship holds in Intensive Care Units.
- Some evidence, mainly from the United States, suggests that the organisation of medical staff in Intensive Care Units is related to patient outcomes.
- A number of other variables affect patient outcomes in ICUs, including, most importantly, the patient's own condition and the workload of the unit. These variables need to be included in the statistical analyses as control variables.

What this paper adds

- This study shows a statistically significant association between the number of nurses and doctors available in Intensive Care Units and patients' chances of surviving their stay in ICU and for up to 30 days after admission to hospital.
- The size of the nursing workforce in ICUs has the greatest effect on the most severely ill patients, whereas the number of doctors seems to be important across the range of patient acuity, i.e. there is no interaction effect between the size of the medical workforce and patient acuity.
- The workload of the unit had an impact on patient mortality in addition to the number of clinical staff on the unit establishment.

1. Introduction

Intensive care units (ICUs) were introduced in the 1950s based on the idea that the lives of severely ill patients could be saved if they were treated in smaller, well staffed units with access to the most technologically sophisticated equipment. Key features of this new organisational form included triage (patients should only be admitted to ICU if their future is uncertain), surveillance (close and continuous observations by highly skilled staff) and organ support, made possible by innovative new technologies. This model of care diffused rapidly throughout the healthcare systems of higher income countries. However, ICUs were, and are, very expensive to run; staff salaries are the most expensive item of expenditure in most health care budgets and ICUs require a much higher staff/patient ratio than general medical and surgical units. The aim of this study is to investigate whether there is a relationship between the number of staff (nurses, doctors and support workers) that are available in ICUs and

patients' chances of survival. To test this relationship we use the best information that is currently available, provided by two national datasets collected in England around March 1998. These datasets allow us to include important control variables in our analyses, including the patient's own condition and the workload of the unit.

1.1. Background

By the late 1990s, the National Health Service (NHS) of the United Kingdom (UK) was spending a large proportion of its budget on intensive care but while the costs were rising, the perceived need for intensive care was not being met. A tragic incident in 1995 when a boy died while being transferred in search of an intensive care bed, followed by a flu epidemic in 1999 drew further attention to the inadequacies in provision leading to sustained media attention, questions in Parliament and vigorous debate among professional groups (Crocker, 2007).

In 1998, the Audit Commission, a body established by the UK government to conduct value-for-money studies across all public services, published a report on ICUs titled "Critical to Success: The place of efficient and effective critical care services within the acute hospital" (Audit Commission, 1999). This investigation showed that the outcomes of care varied widely across ICUs in ways that that were not easily explained by staffing levels or skill mix. In units with similar workloads, the number of nurses varied by 50 per cent and consultant costs by a factor of three. Nursing costs differed by a third between the top and bottom quartiles. Most importantly, mortality was over 50 per cent in some units. While units varied greatly in staffing costs and in patient outcomes, there appeared to be very little relationship between the two. In other words, higher spending on staff did not always result in better chances of survival for patients. The only staffing variable that the Audit Commission team found to be related to patient mortality was the pattern of consultant cover. Lower than expected patient survival was found in units where each consultant worked a set number of days per week compared to units where consultants worked a shift pattern of one week on, two weeks off. None of the nursing variables were found to be related to patient outcomes. However, the analysis conducted by the Audit Commission is not described in detail in the published report and the authors may not have had access to some of the resources and techniques that are available to analysts today, including better methods of risk adjustment, and statistical methods that allow for the simultaneous inclusion of data from more than one level of analysis. Given that the costs of critical care continue to consume expensive resources and that the evidence for linking staffing inputs to patient outcomes in ICUs remains contentious, there are good grounds for reanalysing these data.

1.2. Previous literature

1.2.1. Nurse staffing

There is a large and growing literature on the relationship between nurse staffing and patient outcomes in acute medical and surgical units. Seminal papers by, for example, Aiken et al. (2002), Needleman et al. (2002), Mark et al. (2004) and Tourangeau et al. (2007), conducted mainly in North America, have had a dramatic effect on empirical research on workforce issues and have had a demonstrable influence on policy in many countries. There is international concern about the relationship between nurse staffing and patient outcomes and similar studies have been conducted in several countries, including, for example, Korea (Cho et al., 2008); Belgium (Van den Heede et al., 2009) and Taiwan (Liang et al., 2012). In the UK, where fewer quantitative studies have been conducted, Rafferty et al. (2007) showed that patients in NHS hospitals with the most favourable staffing levels were more likely to survive.

As the evidence from single studies of the relationship between nurse staffing and patient outcomes began to accumulate, a number of systematic reviews have attempted to consolidate their findings. For example, based on an analysis of 28 studies, Kane et al. (2007) concluded that higher staffing levels were associated with lower patient mortality in ICUs and in surgical and medical patients. They described an emerging consensus that in acute medical and surgical settings, there is evidence of a "...statistically and clinically significant association between RN staffing and adjusted odds ratio of hospital-related mortality, failure to rescue, and other patient outcomes" (Kane et al., 2007).

A number of systematic reviews have focused specifically on nurse staffing in ICUs. Numata et al. (2006) located nine observational studies of the association between nurse staffing and mortality in ICUs, five of which were included in a meta-analysis (Person et al., 2004; Dimick et al., 2001; Pronovost et al., 2001; Amaravadi et al., 2000; Tarnow-Mordi et al., 2000). The first four studies listed were conducted in the US and the fifth in Scotland. Numata et al. (2006) concluded that there is currently insufficient evidence to support the independent association of nurse staffing levels and the mortality of critically ill patients. However, they highlighted methodological problems in many of the published studies, perhaps most importantly, in their frequent failure to control adequately for the patient's own condition.

A second systematic review of studies of nurse staffing and patient outcomes in ICUs (West et al., 2009) located 15 studies, of which three reported a statistically significant relationship between nursing resources and mortality (Giraud et al., 1993; Robert et al., 2000; Tarnow-Mordi et al., 2000). Each of these studies was conducted in a single unit. However, in seven studies there was insufficient evidence to reject the null hypothesis of no relationship between staffing levels and mortality (Audit Commission, 1999; Bastos et al., 1996; Dimick et al., 2001; Pronovost et al., 1999, 2001; Reis-Miranda et al., 1998; Shortell et al., 1994). Interestingly, these were all multi-unit studies.

A third, more recent review focused on nurse staffing and patient outcomes in ICUs published between 1998 and 2008 (Penoyer, 2010). Of the studies of mortality, six reported an association with staffing (Cho et al., 2008; Stone et al., 2007; Tourangeau et al., 2007; Person et al., 2004; Tucker, 2007; Tarnow-Mordi et al., 2000) while five reported no association (Kiekkas et al., 2008; Metnitz et al., 2004; Dimick et al., 2001; Pronovost et al., 2001; Amaravadi et al., 2000). The conclusions of this review are that the association between nurse staffing and outcomes in ICUs is similar to that reported in studies of the same relationship in general medical and surgical units.

In sum, three relatively recent systematic reviews and meta-analyses do not provide consistent evidence as to how the literature on nurse staffing and patient mortality in ICU should be interpreted. Each review was based on a relatively small number of papers and findings will have been influenced by the inclusion and exclusion criteria. New empirical evidence is also contradictory. Furthermore, although the studies were conducted in many different countries across Europe including, for example, Greece and Austria, as well as Brazil, in addition to the more prolific literature from North America, only one of the studies included in these reviews was conducted in the UK (Tarnow-Mordi et al., 2000). The paucity of studies on the relationship between nurse staffing and mortality in adult ICUs in the NHS is one of the gaps in the evidence base for nursing that this paper seeks to address.

1.2.2. Previous literature on medical staffing

Studies of the medical contribution to patient outcomes in intensive care have focused on the role of the intensivist (a physician specialising in the care of critically ill patients usually working in an ICU) and on the relative effectiveness of "open" and "closed" ICUs. In open units, which predominate in the USA, patients are cared for by their primary physician. Closed units, where an intensivist or team of intensivists provides care, are more common in Europe (Burchardi and Moerer, 2001). A systematic review of the evidence concluded that the closed model tends to achieve better outcomes for patients (Pronovost et al., 2002). These authors argue that "...physicians who have the skills to treat critically ill patients and who are immediately available to detect problems and institute therapies will prevent or attenuate morbidity and mortality." More recently, Kahn et al. (2007) showed that patients receiving prolonged mechanical ventilation, and whose care was primarily the responsibility of an intensivist, were more likely to receive a range of therapies recommended by the Institute for Healthcare Improvement, such as deep vein thrombosis (DVT) and stress ulcer prophylaxis, suggesting that the link between structural variables, such as medical staffing and patient outcomes, might be mediated through process variables relating to the quality of care that is delivered.

Compelling evidence of the benefits of intensivist care reviewed by Pronovost et al. (2002) has led in the US to a call for staffing by intensivists over the entire 24 h. However, Kahn and Hall (2010), caution against this expensive extension to medical coverage of ICUs, arguing

that one reason for the lack of consistent results in empirical studies of the effect of 24 h intensivist staffing is our collective lack of knowledge about why intensivists are good. In other words, we have little knowledge of the mechanisms linking physician staffing to patient outcomes. There are a number of possibilities: care by intensivists might increase the use of evidence based practice, they might facilitate multi-disciplinary care, or they might provide urgent treatment at the bed-side. There is a clear gap in empirical evidence about what intensivists do in ICUs that links their presence to improved clinical outcomes.

Apart from these studies of the organisation of medical work, we have found only one study that investigated whether there was an association between the intensivist-to-bed ratio and patient mortality. [Dara and Afessa \(2005\)](#) studied 2492 patients treated under different staffing ratios (1:7.5, 1:9.5, 1:12.5 and 1:15) in one unit in the US and controlled for demographic variables and patients' APACHE III scores. However, they did not control for the number of nurses or bed occupancy, both of which might mediate the relationship between medical staff and patient outcomes. They found no association between medical staffing ratios and either ICU or hospital mortality but at the highest ratio (1:15), length of stay in the ICU was significantly higher.

More recently, a UK study of 'failure to rescue' (death after a treatable complication) in surgical patients in England (1997–2009) by [Griffiths et al. \(2013\)](#) found that lower rates of failure to rescue were associated both with greater numbers of clinically qualified staff per bed (doctors and nurses) and with higher numbers of doctors relative to nurses. Although failure to rescue has previously been associated with the number of nurses, this study shows that the number of medical staff is also important.

In sum, most of the work on the medical contribution to ICU outcomes has focused on the organisation of work, and has been conducted mainly in the US. Little attention has yet been paid internationally to the size of the medical workforce and to testing whether the number of doctors who are available to provide patient care has an impact on patients' survival chances with the exception of one recent study of surgical patients where "failure to rescue" was the outcome of interest.

1.2.3. Previous literature on workload

One of the criticisms levelled against research on staffing and patient outcomes is the lack of sufficient controls for possible confounding variables, one of which might be workload. A review of the literature on organisational factors in intensive care identified 13 studies under the heading "volume and pressure of work" so the impact of workload is of longstanding international interest ([Carmel and Rowan, 2001](#)).

In a study of one UK hospital, [Tarnow-Mordi et al. \(2000\)](#) found that patients who were treated when workload was high were about twice as likely to die as those who were admitted during relatively quiet periods. Three measures of workload were particularly important: peak occupancy, average nursing requirement (as defined by the UK Intensive Care Society) per occupied bed per

shift, and the ratio of occupied to appropriately staffed beds. Although this was a study of only one unit, it was conducted over 4 years and meets many of the criteria of a high quality study ([West et al., 2009](#)).

Both [Unruh and Fottler \(2006\)](#) and [Evans and Kim \(2006\)](#) in the US have argued that patient turnover, defined as number of admissions, transfers and discharges, increases the demands on nurses and so affect patient outcomes. This idea was tested in a recent US study of nurse staffing and inpatient mortality, using models that included measures of day-to-day, shift-to-shift variations in nurse staffing and patient turnover ([Needleman et al., 2011](#)). This large study included nearly 200,000 admissions in 43 units in one institution that had a good staffing record and low mortality rates. Using Cox proportional hazards estimation, they found that there was a significant association between mortality and exposure to shifts when there were fewer nurses than the target number (set by a well calibrated commercial system for determining nurse staffing levels) and high turnover (admissions, transfers and discharges). They found that "...the risk of death increased by 2 per cent for each below-target shift and 4 per cent for each high turnover shift to which a patient was exposed." The authors argue that staffing decisions might best be taken on a shift-by-shift basis as workload can fluctuate rapidly and is a potential threat to patient safety.

In summary, interest in the effect of workload on patient outcomes is long-standing. Some good evidence exists that workload, variously defined and measured, might have a direct effect on patient mortality as well as being an important mediating variable in a model linking staffing levels to patient outcomes.

1.3. Hypotheses

What are the mechanisms linking staffing levels to patient mortality? In the nursing literature, the concept of "surveillance", that is the close and continuous observation provided by skilled nursing staff, plays a key role (e.g., [Clarke and Donaldson, 2008](#); [Kutney-Lee et al., 2009](#)). Because nurses are with patients for longer periods of time than any other member of the team, they are more likely to see early warning signs, such as increasing pallor, breathlessness or a change in vital signs that indicate deterioration in a patient's condition. More nurses on the unit should mean that patients will be more closely observed; nurses can respond more rapidly when patients need life saving interventions and nurses can mobilise the resources of the hospital to meet their needs. This leads to the following hypothesis:

H1. Higher numbers of nurses on the ICU establishment will be associated with lower rates of patient mortality.

Historians claim that in the 1950s and 1960s, the demands of intensive care in the US meant that nurses and doctors had to evolve a new kind of relationship, one which gave nurses more autonomy and independence and forged links among all the team members ([Sandelowski, 2000](#)). An ethnographic study conducted in a UK ICU describes nurses and doctors as performing very similar roles ([Carmel, 2006](#)), arguing that "while medicine is

undoubtedly the dominant occupation, the relationship between medicine and nursing in intensive care is characterised more by convergence and incorporation than competition...". This author describes observing working relationships characterised by informality and mutual respect suggesting that ICUs might come closer to the ideal of a multi-disciplinary team than many other health care settings. This makes it all the more surprising that so many studies have adopted a uni-professional focus. It seems reasonable to suggest that if nurses and doctors are working closely together, and indeed if there is some overlap in their functions, we need to include some measure of medical staffing, leading to the following hypothesis:

H2. Higher numbers of consultants in an ICU will be associated with lower mortality rates.

Few studies have tested whether the numbers of support staff, that is staff who provide administrative, clerical and technical support to the Unit, are related to patient outcomes. Although not involved directly in patient care, the presence of support staff should, through relieving them of administrative duties as well as technical and scientific tasks, increase the amount of time that nurses and doctors are able to spend with patients. The hypothesis then is that:

H3. Higher numbers of support staff in an ICU will be associated with lower mortality rates.

The framework developed above is based on the idea that additional resources lead to better outcomes. However, there is an important mediating variable: the amount of work that has to be done. Units vary greatly in key workload indicators including admissions, bed occupancy and turnover rates so that the same number of nurses and doctors, even when standardised by the number of beds, may mean very different things in busy rather than quiet ICUs.

H4. The higher the workload of the unit, the less likely individual patients are to survive.

In summary, we have developed a simple input, throughput, output model linking human resources and patient outcomes in ICUs. When there are more members of the clinical staff available to provide surveillance and to intervene when required and holding constant the workload of the unit, more patients are likely to survive. From this conceptual framework and based on previous empirical research four hypotheses have been derived based on the assumption that the factors underlying these four hypotheses have independent effects, detectable in multivariable analysis.

2. Methods

2.1. Study design

This is an observational study where statistical controls are used to assess the relationship between the key independent variables of interest and the dependent

variable. This study seeks to understand the relationship between the size of the clinical workforce (nurses and doctors), as well as the number of support staff (administrative, clerical, technical and scientific), and patients' chances of survival. Although we have hypothesised that there will be a relationship between these variables, we expect that the patient's own condition—age, number of diagnoses, severity of the illness and co-morbidities—will contribute more than any other factor to the outcome. This means that we need to take their risk of dying due to their own condition into account, as well as any other variables that contribute to the outcome, in order to get unbiased estimates of the key variables of interest.

2.2. Data sources/measurement

The Intensive Care National Audit & Research Centre (ICNARC) Case Mix Programme is the national clinical audit of patient outcomes from ICUs in England, Wales and Northern Ireland. Participation is voluntary; however the participating units are representative of the population in terms of geographical spread, unit size and hospital teaching status (university vs. non-university). Data for the six months before and after March 1998, which had been collected prospectively, were merged onto organisational data on 65 ICUs surveyed by the Audit Commission. The matched dataset contained information only on ICUs in England. We use two dichotomous dependent variables: whether or not the patient survived their stay in ICU and whether or not the patient survived their stay in the acute hospital. Most previous studies have used the latter measure of mortality and this is an attractive option in our study for a number of reasons. First, it facilitates comparability with prior research. Second, the risk adjustment variable we use is based on this outcome. Third it is possible that people are transferred out of ICU when death is thought to be inevitable, or when the workload of the unit is too high. On the other hand, it could be argued that staffing levels in ICU should not be expected to affect the chances of mortality outside the unit, especially when the key mechanism linking staffing levels and mortality is argued to be "surveillance". Therefore, we analyse both outcomes to explore the idea that staffing in an ICU will have the greatest impact on ICU mortality and, although the effect will carry over into the hospital, it will be attenuated.

2.3. Variables

2.3.1. Risk adjustment

There are a number of risk prediction models for use with critical care patients. Recently, ICNARC developed a new model (the ICNARC model) using data from the Case Mix Programme, which we adopt. The purpose of this variable is to control for the great influence that the patients' own health status will have on the outcome of their hospital stay. The ICNARC model was developed specifically to underpin comparative studies of risk-adjusted outcomes for adult critical care in the UK. To this end, it specifically avoids factors related to treatment and quality of care, focussing entirely on patient factors

only. Details of the model are provided by Harrison et al. (2006, 2007), but briefly, the ICNARC score is based on a physiology model, including blood pressure, respiratory rate, oxygenation, and acid base disturbance, along with a range of other factors known to be associated with mortality, including age, past medical history, and source of admission to an ICU. The model has been validated and shown to perform better than other risk adjustment models, such as APACHE II and APACHE III.

2.3.2. Human resource variables

Data on several independent variables came from the Audit Commission's survey of all ICUs in England and Wales, on which the report *Critical to Success* (1999) was based. Key explanatory variables derived from this dataset are described below.

Number of nurses per bed: This variable counts the number of full-time equivalent nurses on the permanent staff of the ICU on one specific date (the date of the Audit Commission survey). The question on the survey asked for separate information on registered nurses and health care assistants. The variable used in these analyses is a count of the registered nurses at different grades who were in post on the census date. It is important to note that this is not the number of nursing staff available for duty when any particular patient is admitted. We were able to break the number of nurses per bed into two separate variables: the number of direct care nurses and the number of supernumerary nurses. This was made possible by the fact that survey respondents were asked to specify how many of the nurses in post on the census date were designated as supernumerary. We analyse the effect of the number of direct care nurses as they are potentially more relevant to the concept of "surveillance" than the supernumerary nurse who contribute to the unit in other ways.

Number of consultant Notional Half Days (NHDs) per bed: Units reported to the Audit Commission the total number of weekly fixed notional half days for critical care clinical sessions. To those that were reported as "shared with other units" we gave a weighting of half as the data did not specify how much time was allocated to each unit.

Intensivist: The AC survey asked whether one or more consultants worked all the time in the ICU (and related critical care units) with no other clinical commitments. This is a dummy variable, coded 1 for units that had a dedicated consultant (intensivist).

Support Staff: This variable was the summation of several different categories of staff including administrative and clerical staff (e.g., business or service manager, secretary, ward clerk, audit assistant) and technical and scientific staff (ICU technician, ECG technician). This variable does not include professions allied to medicine, such as pharmacists, dieticians, occupational therapists and physiotherapists.

Workload variables: We used several variables to measure the pressure of work experienced by the staff of the ICU. The first three are drawn from the ICNARC dataset, whereas the second two are derived from the Audit Commission dataset.

1. Proportion of beds in the ICU that were occupied at the time of each patient's admission.
2. Mean ICNARC model predicted log odds of acute hospital mortality of other patients in the unit at the time of admission (a measure of how seriously ill the other patients were).
3. Average length of stay of patients in the ICU, measured in hours.
4. Admissions to the unit, per bed per day.
5. The number of transfers in from another Trust to the unit, per bed, per week.

The first stage of this analysis was hypothesis testing but we also conducted further exploratory analysis which included interactions between the number of nurses and the number of consultants and the predicted log odds of acute hospital mortality from the ICNARC model to see whether the impact of staffing differs depending on the degree of severity of the patient's illness.

2.4. Statistical methods

Multilevel logistic regression was used to perform all the analyses (Guo and Zhao, 2000; Gelman and Hill, 2006). All our analyses were carried out using the lmer function that is part of the lme4 package in R version 3.0 (R Development Core Team, 2013; Bates et al., 2013). Multilevel regression is used for these analyses because it would be inappropriate to consider patients treated in the same ICU as being independent observations.

The basic model that we used can be represented by the following equation:

$$\log\left(\frac{p_{ij}}{1-p_{ij}}\right) = b_0 + \sum_k b_k x_{ijk} + u_j,$$

where i indexes patients, j indexes ICUs, there are k explanatory variables in the model, $p_{ij} = \Pr(y_{ij} = 1)$ is the probability of death, and the following conditions are assumed:

$$E[u_j] = 0,$$

$$\text{var}(u_j) = \sigma_u^2,$$

$$\text{and cov}(u_j, u_{j'}) = 0 \quad \text{for all } j \neq j'.$$

It will be noted that this is essentially a standard logistic regression model with the addition of a separate random effect, u_j , for each hospital trust. This can be considered to control for unmeasured factors that vary across units but are constant over time. The assumptions regarding the variance and covariances of the random effects are conventional for this type of analysis. The estimates of the effects of the explanatory variables (b_k) are interpreted in the same way as standard logistic regression estimates, and confidence intervals for these estimates are also interpreted in the usual way. When we report estimated log odds ratios we use the mean values of explanatory variables as shown in Table 1.

Table 1
Descriptive statistics of the explanatory variables.

	Mean	Standard deviation
IM log odds	-1.41	1.92
Proportion beds occupied	0.83	0.20
Admissions per bed per day	0.18	0.061
Transfers in per bed per week	0.090	0.073
Total support staff per bed	0.25	0.23
Direct care nurses per bed	4.97	1.29
Clinical notional half days per bed	1.04	0.75
Unit length of stay in hours	100.0	27.0

3. Results

3.1. Descriptive statistics

The Audit Commission gathered data from 69 ICUs in total. We were able to merge data from the two sources (Audit Commission and ICNARC) on 65 ICUs. Four units were dropped from the analyses because the number of beds they reported differed by more than three in the two datasets, which cast doubt on the reliability of the information about them. The merged dataset had information on 38,168 admissions. The number of patients was

reduced in some of the multivariable analyses by missing data; numbers of cases in each analysis are shown in the relevant tables.

Of the 38,168 patients in this study, 6413 (16.8 per cent) died in the ICU where they were being treated. A further 4397 (11.5 per cent) died in hospital after leaving the initial ICU, with 579 (1.5 per cent) patients being lost to follow up (see Figs. 1 and 2). The observed crude mortality rates in the units varied between 8.1 per cent and 33.9 per cent, while the hospital mortality rates were between 16.9 per cent and 47.9 per cent. This variation could not be entirely explained by variation in patient risk factors. The correlation between the ICU and hospital mortality rates was 0.90.

The distribution of nurses per bed (whole time equivalents) across different units is shown in Fig. 3. Only a small minority of units in the UK had seven or more nurses per bed on their permanent payroll, the number generally accepted as being required to maintain a one patient per nurse ratio over three shifts, with allowance for sickness and holiday leave. The number of consultant notional half days per bed is also shown in Fig. 3. Descriptive statistics and correlations among the variables used in the analysis are shown in Tables 1 and 2, respectively.

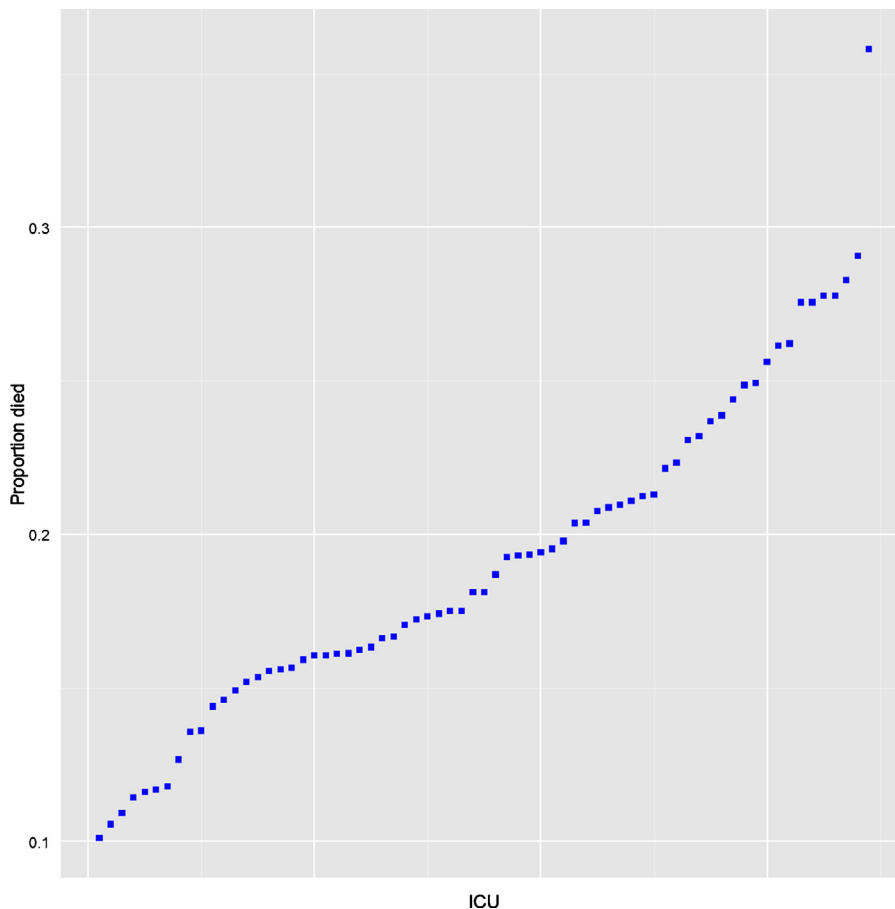


Fig. 1. Proportion of patients who died in the ICU in which they were being treated. Each point on the graph represents an ICU.

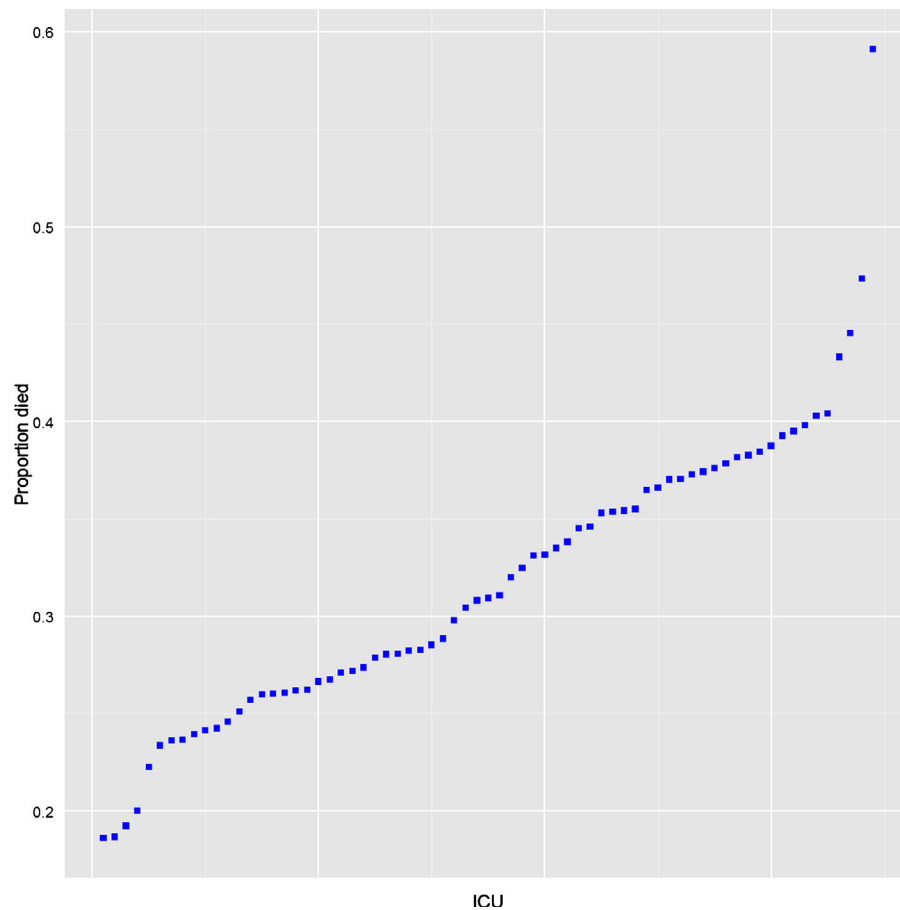


Fig. 2. Proportion of patients who died in the hospital in which they were being treated. Each point on the graph represents a hospital.

3.2. Multivariable analyses

The results of our multivariable analyses are shown in Table 3 (ICU mortality) and Table 4 (hospital mortality). The first column in each table shows the results for the tests of Hypotheses 1 to 4.

Considering first the impact on ICU mortality, shown in Table 3, we can see that the risk of mortality is significantly increased by the severity of the patient's own condition (ICNARC model predicted log odds of acute hospital mortality) and by our measures of workload (hypothesis 4). The risk of mortality increases when a higher proportion of beds in the unit are

occupied and when there are a large number of transfers into the unit. The number of nurses and the number of consultants both significantly reduce the risk of mortality (Hypotheses 1 and 2). The hypothesis that the number of support staff would affect patient mortality is not supported.

Further, as we believe that the effect of staffing might depend on the severity of a patient's illness; in the second column we add an interaction between the number of nurses and predicted log odds of mortality, while in column 3 we add an interaction between the number of consultants and predicted log odds of mortality. Here we are exploring the relationship between staffing and

Table 2
Correlation matrix of the explanatory variables.

	1	2	3	4	5	6	7	8	9
ICNARC model log odds for each patient	1	1							
Number of direct care nurses per bed	.069	1							
Proportion beds occupied at the time of admission	.044	.14	1						
Admissions per bed per day	-.038	.36	.033	1					
Transfers in per bed per week	.029	.34	-.006	-.10	1				
Support staff per bed	-.043	.067	.13	.12	.07	1			
Number of consultant NHDs per bed	-.04	.014	.12	.21	-.018	.54	1		
Mean IM log odds (other patients in unit)	.083	.11	.040	-.064	.043	-.012	-.029	1	
Average ICU length of stay	.10	.20	.072	-.51	.30	.020	-.18	.14	1

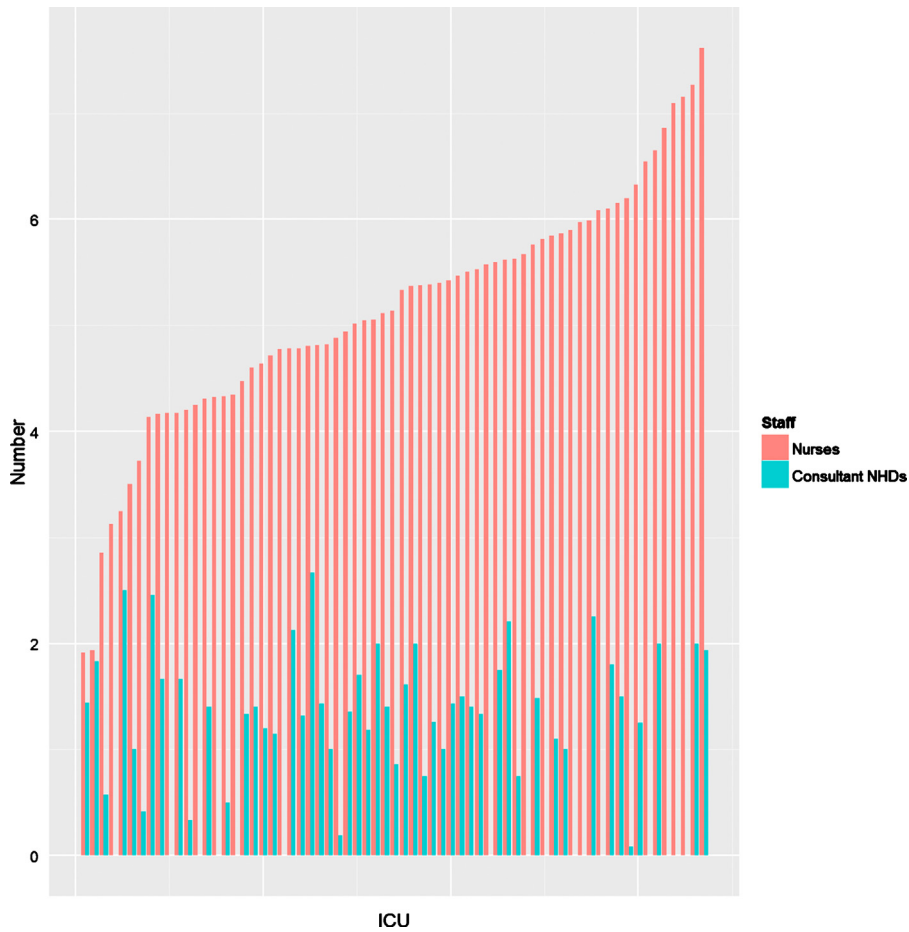


Fig. 3. Bar plot showing the numbers of direct care nurses (WTEs) and consultant NHDs per bed in each ICU.

Table 3

Mortality in the ICU. Odds ratios from multilevel logistic regression models, with 95 per cent confidence intervals.

	1	2	3
ICNARC model log odds of patient mortality	2.62 [2.56,2.69]	2.97 [2.70,3.27]	2.97 [2.68,3.29]
Mean IM log odds of patient mortality ^d	0.95 [0.91,0.99]	0.95 [0.91,0.99]	0.95 [0.91,0.99]
Average ICU length of stay (h) ^d	1.54 [1.11,2.13]	1.53 [1.11,2.12]	1.53 [1.11,2.12]
Proportion beds occupied ^d	1.24 [1.03,1.48]	1.23 [1.03,1.48]	1.23 [1.03,1.48]
Admissions per bed per day ^d	1.66 [0.35,7.96]	1.65 [0.35,7.89]	1.66 [0.35,7.90]
Transfers in from another trust per week per bed ^d	5.06 [1.47,17.4]	5.17 [1.50,17.8]	5.17 [1.50,17.8]
Support staff per bed ^c	1.16 [0.81,1.68]	1.15 [0.79,1.66]	1.15 [0.79,1.66]
Intensivist	0.97 [0.79,1.19]	0.98 [0.80,1.21]	0.98 [0.80,1.21]
Number of direct care nurses per bed ^a	0.90 [0.84,0.97]	0.90 [0.83,0.97]	0.90 [0.83,0.97]
Number of consultant NHDs per bed ^b	0.85 [0.76,0.95]	0.85 [0.76,0.95]	0.85 [0.76,0.95]
IMlo * Number of nurses per bed		0.98 [0.96,0.99]	0.98 [0.96,0.99]
IMlo * Number of consultant NHDs per bed			1.00 [0.97,1.03]
Intercept	-1.38	-1.36	-1.36
Standard deviation of random effect	0.28	0.28	0.28
Deviance	23,293	23,286	23,286
Number of admissions	38,168	38,168	38,168
Number of units	65	65	65

^a Hypothesis 1.
^b Hypothesis 2.
^c Hypothesis 3.
^d Hypothesis 4.

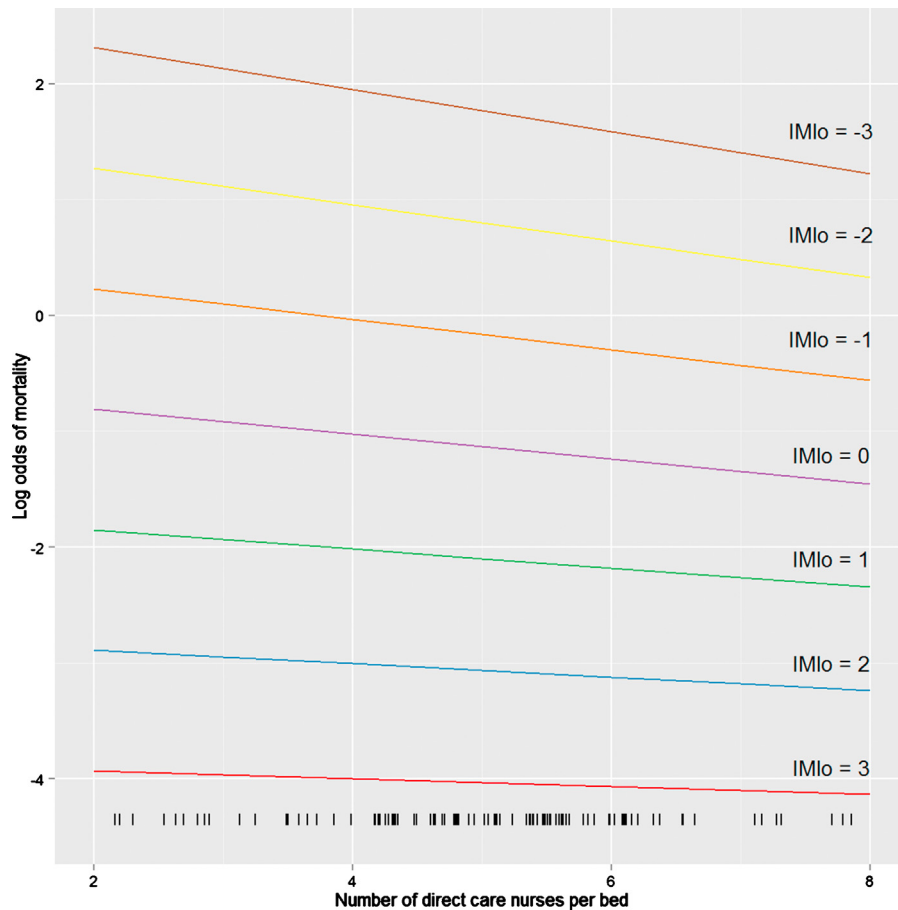


Fig. 4. Estimated effect on the odds of mortality in the ICU of the number of direct care nurses in the unit for patients at different levels of risk as measured by the ICNARC model, with a rug plot showing the distribution of observed values. Other explanatory variables are set at the mean values shown in Table 1, with units assumed to have an intensivist. IMlo means ICNARC Model log odds of mortality.

Table 4

Mortality in acute hospital. Odds ratios from multilevel logistic regression models, with 95% confidence intervals.

	1	2	3
IM log odds of patient mortality	2.61 [2.56,2.67]	2.72 [2.50,2.96]	2.64 [2.42,2.89]
Mean IM log odds of patient mortality ^d	0.96 [0.93,0.99]	0.96 [0.93,0.99]	0.96 [0.93,0.99]
Average ICU length of stay (h) ^d	1.26 [0.95,1.68]	1.26 [0.95,1.68]	1.26 [0.95,1.68]
Proportion beds occupied ^d	1.22 [1.05,1.43]	1.22 [1.04,1.43]	1.22 [1.04,1.43]
Admissions per bed per day ^d	1.04 [0.27,4.04]	1.04 [0.27,4.02]	1.05 [0.27,4.06]
Transfers in from another trust per bed per week ^d	11.7 [3.93,34.7]	11.7 [3.93,34.6]	11.6 [3.91,34.5]
Support staff per bed ^c	1.08 [0.78,1.49]	1.08 [0.78,1.49]	1.08 [0.78,1.49]
Intensivist	0.99 [0.83,1.19]	0.99 [0.83,1.19]	0.99 [0.83,1.19]
Number of direct care nurses per bed ^d	0.92 [0.87,0.98]	0.92 [0.86,0.98]	0.92 [0.86,0.98]
Number of consultant NHDs per bed ^b	0.89 [0.81,0.99]	0.90 [0.81,0.99]	0.91 [0.82,1.00]
IMlo * Number of nurses per bed		0.99 [0.98,1.01]	0.99 [0.98,1.01]
IMlo * Number of consultant NHDs per bed			1.03 [1.00,1.06]
Intercept	-0.22	-0.19	-0.21
Standard deviation of random effect	0.24	0.24	0.24
Deviance	30,335	30,334	30,330
Number of admissions	37,590	37,590	37,590
Number of units	65	65	65

^a Hypothesis 1.

^b Hypothesis 2.

^c Hypothesis 3.

^d Hypothesis 4.

mortality as there is no previous literature on which to base a hypothesis.

Column two shows that the interaction variable is negative and significant, implying that the reduction in mortality risk from having more nurses is larger for patients who are the most severely ill. In the third column, however, we can see that the equivalent interaction is not significant when it involves the number of consultants. Fig. 4 is an effect plot, based on the results in column 2 of Table 3, to illustrate how the influence of nurse staffing varies with condition severity. By way of example, we can calculate that the effect of increasing the number of nurses per bed from four to six is to reduce the probability of mortality for patients with a predicted log odds of mortality of -3 from .017 to .016. This represents approximately one extra death for every 1000 patients. However, the real importance of these results is that this effect is so much larger for those patients who have a high risk of death. If we look at patients with a predicted log odds of mortality of 2, then the reduction in the probability of mortality in going from four to six nurses is from .72 to .65, or about seven extra deaths per 100 patients. About 5 per cent of ICU admissions in this dataset have a predicted log odds of mortality at least this high, so this represents a significant number of patients. These results suggest that the most severely ill patients are a sub-group that is most vulnerable to low nurse staffing levels.

In Table 4 we see a broadly similar pattern of results for the effects on hospital mortality. Again, the number of nurses and the number of consultants per bed have a negative association with the risk of mortality. The estimated magnitude of these effects is similar to the corresponding estimates of their effects on the risk of mortality in the ICU. However, although both main effects are statistically significant, this is not true of either of the two estimated interaction effects. The main effect of ICU staffing is on the outcome of the patients' stay in ICU. Although we can show an effect on hospital mortality, the interaction effect between nurse staffing and patient acuity is not significant.

4. Discussion

4.1. Key results

This study investigated whether the size of the clinical workforce—the number of nurses and doctors—was associated with the survival chances of critically ill patients both in the intensive care unit and in the hospital. The most significant findings are that, controlling for patient characteristics and the workload of the unit, higher numbers of nurses per bed on the unit's establishment and higher numbers of consultants per bed were both associated with higher survival rates. Nurses and doctors do seem to make a difference to patient outcomes in ICU. We found no evidence that the number of support staff working on the unit improves patients' survival chances even though their presence on the unit might have the effect of releasing clinical staff to care for patients. In this study, clear support emerged for the effect of workload. High workload, measured in a number of different ways, was associated with higher mortality.

There was also a statistically significant interaction between the number of nurses and patient's risk of mortality, suggesting that nursing staff availability has the greatest impact on those at greatest risk of death. This is consistent with the claim that nursing surveillance is one of the key mechanisms linking nursing numbers to patient outcomes. The fact that the interactions between the size of the clinical workforce and the patient's risk of mortality were statistically significant in estimates of ICU mortality but not in the case of hospital mortality also lends support to the suggestion that the effects are due to the key surveillance role of nurses in ICUs.

4.2. Interpretation

Taken together these findings suggest the need to study the whole team in ICU. There is a large literature on the nursing contribution to patient outcomes which focuses on the size and level of qualifications of staff. There is also a large literature on the medical contribution to ICU outcomes. We argue that future studies need to consider these two groups at the same time. Nurses and doctors, in particular, may in some clinical settings be substitutes for each other, so that units that are short of doctors, for example, may compensate by hiring more nurses. This is supported by ethnographic evidence of how closely clinicians from different professional backgrounds work together in this setting (Carmel, 2006). Further empirical support for the importance of team working is provided by a recent US study (Kim et al., 2010) which showed a link between daily rounds by a multi-disciplinary team (physicians, nurses, respiratory therapists, clinical pharmacists, social workers and others) and lower mortality among medical ICU units, especially when this was combined with high intensity physician staffing (mandatory care by an intensivist or mandatory consultation). This study did not control for the size of the clinical workforce but does suggest that further work on the contribution of the team as a whole will be justified.

Future studies also need to need to control adequately for workload. The nurse-to-patient or physician to bed ratio does not make sense without including controls for the throughput of the unit as well as amount of care that each patient needs. Further research on the workforce is urgently required to guide decisions about safe staffing levels in a variety of health care settings to ensure patient safety as well as equity and cost-effectiveness across the whole system.

This study, which tests a simple model of human resources, demonstrates a relationship between those inputs and perhaps the most important measure of a hospital's performance—whether or not patients survive. The baseline model we have produced will be useful in testing more complex models of, for example, the impact of team members level of education and experience, quality of team work or processes of care in ICUs.

4.3. Strengths and weaknesses of the study

The use of two high quality national data sets is one of the strengths of this study. Data from the Intensive Care

National Audit and Research Centre (ICNARC) enabled us to estimate models of ICU and hospital mortality using sophisticated methods of risk adjustment, and to control for important sources of workload; the proportion of beds that were occupied at the time the patient was admitted and the level of acuity of the other patients that were in the unit. Data on characteristics of the unit collected by the Audit Commission in 1998 and a merged dataset with information on 65 units and 38,168 patients was constructed and multilevel logistic regression was used to analyse the outcomes of their admission. The large number of units and patients analysed in this study, as well as the use of appropriate methods for the structure of the data are additional strengths of this study. The study may also be important theoretically, because it is consistent with the operation of mechanisms, such as surveillance and the adoption of evidence-based practice, proposed as key mechanisms linking staffing inputs and patient outcomes in ICU. These results will hopefully be developed in future qualitative and quantitative research.

But this study also has weaknesses. The data are cross-sectional which limits the extent to which causal claims can be made. If longitudinal data were available, recording the effects of changes in staffing levels and patient acuity over time, we would be able to produce more robust evidence about the impact of staffing levels on patient outcomes. The data are also several years old. This is acceptable to us because we set out to investigate a relationship between human resources and organisational performance which is not temporally or geographically bounded. If there were more recent data of this quality, then it would be difficult to justify this investigation, but such data do not yet exist. Changes in the distribution of staff across units since the data were collected will mean that the results are probably less useful for practical purposes such as workforce planning, but strongly suggest that managers and policy makers need to consider human resources as key to quality and safety in UK ICUs. There are other weaknesses in the data. Key variables derived from the Audit Commission Survey on staffing and work load are measured for the ICU as a whole not at the patient level and there is no direct patient level measure of workload. Ideally, we would like to be able to measure the number of nurses, doctors and the activity of the ICU for each patient, shift-by-shift; some studies in the US are now based on data of this quality. The results of this study then underscore the need for a prospective study in the area, given the crucial importance of staff costs in the NHS.

Since 2000 there has been a process of modernisation in critical care, including the formation of 29 geographically based networks (several hospitals working together to common protocols and standards); the integration of critical care into the range of adult services in hospitals (outreach and response teams), and a planned approach to workforce development. The Department of Health (2000) also proposed that critical care should be based on severity of illness, rather than the location of the patient within a designated unit and that patient dependency, rather than bed numbers, should be the basis of staffing allocations. So the boundaries around critical care as a unit of analysis

may be less clear. Increased funding was also made available to develop services and there was a rise in the number of, mainly high dependency, beds, which may have led to a diminution of the average level of acuity of patients who are now receiving critical care. The modernisation agenda pursued since 2000 does seem to have produced improvements overall in the effectiveness and cost-effectiveness of critical care, although it is difficult to attribute these to one or more of the changes that have taken place (Hutchings et al., 2009). It is possible that the modernisation agenda has decreased the amount of variation in staffing levels and patient mortality from unit to unit, which was a source of great concern when Audit Commission data were published in 1998, or that the organisational changes to the service have changed the relationship between staffing numbers and patient outcomes. However, this remains an empirical question which will require the formulation of new theoretical models and the collection of new data that will enable us to test the relationship between staffing levels and patient mortality in the current organisational context.

5. Conclusions

This is one of the few studies that show a significant relationship between the size of the clinical workforce and patient's chances of survival in ICU. This study therefore makes a contribution to the international literature. At the same time, this study is particularly important because so few studies in this research tradition have been conducted in the UK. While the international evidence about nursing numbers has been extremely influential in shaping debates about resources, this study should have additional impact on policy and practice because it shows that the relationship between nursing numbers and patient mortality also holds in the context of the NHS.

This study has also produced some new knowledge. It is the first study to include nurses, doctors and support staff in one analysis and to control for the impact of workload on patients' survival chances. Although there is a growing international literature on nurse staffing, few studies have investigated the importance of other professional groups. It is also the first analysis to test whether there is an interaction effect between the number of nurses and number of doctors and the severity of the patients own illness. It seems reasonable to argue that skilled nurses, who have the time to observe patients closely, to intervene or mobilise the team if they begin to deteriorate, would be most important to patients who are at the greatest risk. This study is the first to produce evidence that this is the case.

The results suggest the need to study the effects of the whole team that is available to care for patients, or more radically, that we shift our focus away from professional groups and onto the skills that are required in ICU. In a recent paper, Needleman et al. (2011) call for further research to try to understand "...the complex interplay among nurse staffing, patient preferences, and other factors, including staffing levels for physicians and other non-nursing personnel, technology, work processes and clinical outcomes." This is clearly the agenda for a

programme of work that will inform policy and practice to improve patient care.

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Ethical approval: London School of Hygiene and Tropical Medicine ethics committee.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.ijnurstu.2014.02.007>.

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