ORIGINAL ARTICLE

Nurse staffing in relation to risk-adjusted mortality in neonatal care

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Objective: To assess whether risk-adjusted mortality in very low birthweight or preterm infants is associated with levels of nursing provision.
Design: Prospective study of risk-adjusted mortality in infants admitted to a random sample of neonatal units.
Setting: Fifty four UK neonatal intensive care units stratified by: patient volume; consultant availability; nurse:cot ratios.
Patients: A group of 2585 very low birthweight (birthweight <1500 g) or preterm (<31 weeks gestation) infants.
Main Outcome Measure: Death before discharge or planned deaths at home, excluding lethal malformations, after adjusting for initial risk 12 hours after birth using gestation at birth and measures of illness severity in relation to nursing provision calculated for each baby's neonatal unit stay.
Results: A total of 57% of nursing shifts were understaffed, with greater shortages at weekends. Risk-adjusted mortality was inversely related to the provision of nurses with specialist neonatal qualifications (OR 0.67; 95% CI 0.42 to 0.97). Increasing the ratio of nurses with neonatal qualifications to intensive care and high dependency infants to 1:1 was associated with a decrease in risk-adjusted mortality of 48% (OR: 0.52, 95% CI: 0.33, 0.83).
Conclusions: Risk-adjusted mortality did not differ across neonatal units. However, survival in neonatal care for very low birthweight or preterm infants was related to proportion of nurses with neonatal qualifications per shift. The findings could be used to support specific standards of specialist nursing provision in neonatal and other areas of intensive and high dependency care.

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Health care in the United Kingdom, in common with many developed countries, is subject to continuing nurse shortages.[1][2] Concerns have been raised about the impact of such shortages on the quality of health care and links made between inadequate nursing provision, increased workload and poor patient outcomes.[3–7] While these views have been echoed in neonatal care, there is little evidence of the impact of nursing levels on infant outcomes. Rather, a number of studies have reported declining mortality in low birthweight and preterm infants associated with technical advances in intensive care and improved obstetric management,[8–10] while others have evidenced increasing demands for neonatal intensive care services.[11–15]

A few studies have attempted to empirically test the relationship between staffing and neonatal outcomes, but they provide us with inconclusive evidence. One study conducted in seven Scottish and two Australian neonatal units suggested that risk-adjusted mortality is independently related to infant:nurse ratios in the first three days after birth with a 79% increase in odds of mortality when more than 1.7 infants were assigned per nurse per shift.[16] However, another Australian study, based in one neonatal unit, reported a decline in risk-adjusted mortality associated with fewer nurses caring for high-risk infants.[17] These counterintuitive findings have been interpreted cautiously and differences in study design and the Australian and UK models of care and emphasised.[18] In the absence of less equivocal evidence, the relationship between neonatal outcomes and nurse staffing warrants further investigation.

Despite the lack of outcome evaluation, the need for more skilled medical and nursing staff has dominated neonatal organisational debates. Several reviews have reported high infant:nurse ratios, variable skill utilisation, diverse nurse staffing policies unrelated to unit size or type and under-provision of

nurses, specifically those with specialist neonatal nursing qualifications.[12][15][19][20] In acknowledging the changing case-mix of infants and increasing technological demands, standards have been produced for neonatal staffing in the UK.[21–23] The most recent used nursing activity studies to recommend nursing levels responsive to infant volume and dependency.[20][22–24] These recommendations were used to assess the adequacy of staffing in neonatal care in this study.

OBJECTIVE

To examine the relationship between nurse staffing input and risk-adjusted mortality in very low birthweight or preterm infants in 54 neonatal intensive care units randomly sampled from all such units in the UK.

METHODS

The study population is a subset of the UK Neonatal Staffing Study (UKNNSS), details of which are given elsewhere.[25] Data collection took place between 1st March 1998 and 2nd April 1999. Workload logs were compiled at each of the 54 selected units twice daily, providing 35 877 shift records of staffing and infants. Data were simultaneously recorded on the characteristics of 13 515 babies admitted (gestational age, gender, birth weight and mortality risk). Of the 35 880 records from the workload logs, information was incomplete or erroneous in 229 records (0.6%) which were coded as missing data. The remaining 35 651 records were used to compute the following nursing indices

- Total number of registered nurses per shift
- Nursing provision ratio per shift

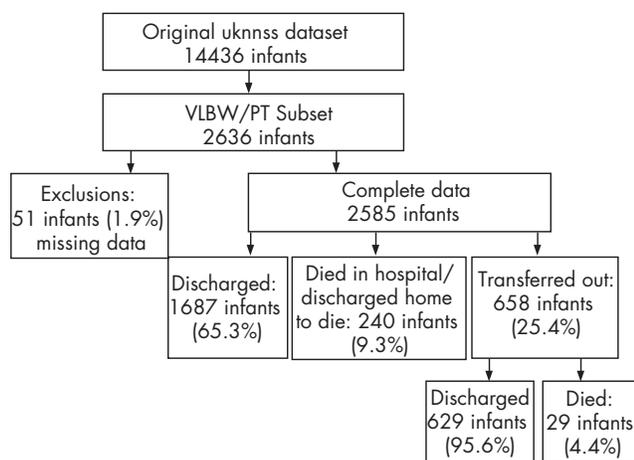**Abbreviation:** UKNNSS, UK Neonatal Staffing Study

Figure 1 Very Low Birthweight/Preterm Infant Data Selection.

A responsive measure of nursing input based on the extent to which a shift meets the recommended minimum number of registered nurses for the number of babies requiring care. The expected number of nurses was defined as a function of the number of babies admitted during the shift (calculated as one half of the intensive care and high dependency babies plus one quarter of the low dependency babies plus one).[23]

- Specialist nursing provision ratio per shift

A responsive index of skilled nursing provision based on the actual and recommended number of nurses with specialist neonatal qualifications (qualified in speciality, QIS) required to care for intensive care and high dependency infants. Specialist neonatal qualifications included neonatal nursing courses such as ENB ''405'', ''904'' or equivalent. It was calculated as one half of the intensive care and high dependency babies plus one.[23]

A value less than 1 indicates that nursing levels are below the recommended nurse staffing guideline.[23]

Units were categorised using three organisational measures from a previous neonatal census.[26] These were: unit volume (high >57, medium 35–57, and low <35 low birthweight infants admitted per year); neonatal consultant availability (greater (high) or less than/equal to (low) the median of 2 clinical paediatricians with more than a 50% commitment in neonatal care) and nursing establishment (similarly defined as

Table 2 Number of shifts where nursing provision ratio is less than 1.0

Understaffing	Type of shift			
	Week day n (%)	Weekend day n (%)	Week night n (%)	Weekend night n (%)
Nurse Provision Ratio <1	6026 (47)	2765 (54)	8239 (64)	3349 (66)
Specialist Nurse Provision <1	2366 (19)	1129 (22)	3502 (27)	1408 (28)

being above or less than/equal to the median of 0.84 nurse to cot ratio).

Patients

From the original UKNNSS cohort of 14 436 infants, data on 2636 infants were selected using the inclusion criteria of birthweight $\leqslant 1500$ g and/or gestation $\leqslant 31$ weeks (fig 1). Observed mortality was defined as in-hospital death or discharged home to die and included all deaths (excluding lethal malformations and deaths post specialist surgery). For risk-adjustment we used a predicted mortality score, derived from the original UKNNSS cohort for 14 436 infants, which incorporated diagnostic information obtained at 12 hours of birth (gestation, size of infant for gestation, sex, mode of delivery, diagnostic category, maternal treatment with antenatal steroids, admission temperature, most extreme partial pressure of carbon dioxide ($PaCO_2$), mean appropriate fraction of inspired oxygen (FiO_2), and lowest base excess).[25] The risk-adjustment model demonstrated good discriminatory power for mortality with the area (SE) under the Receiver Operating Curve of 0.92 (0.009) as compared to 0.88 (0.013) for gestation alone.[27] The predicted mortality derived from this model ranges from 0–1, where a higher value indicates a higher chance of survival.

The study was approved by a regional Multi-centre Research Ethics Committee (MREC) and the Local Research Ethics Committee (LREC) at each participating hospital.

Statistical analyses

Statistical analysis was carried out using SPSS version 10 Software.[28] Individual profiles for each infant were compiled using the nursing variables for each shift that the infant was cared for in the unit from admission to discharge, death or transfer. These were averaged to give three mean nursing provision variables for each infant representing their NICU stay.

Table 1 Nurse staffing per shift by unit organisational type

	Registered nurses	Nurse provision ratio	Specialist nurse provision ratio
	Median (IQ range)	Median (IQ range)	Median (IQ range)
Total	4 (2)	0.92 (0.36)	1.33 (1.0)
Unit Volume Type			
High	6 (2)	0.93 (0.34)	1.33 (1.0)
Medium	4 (2)	0.92 (0.35)	1.33 (1.0)
Low	3 (2)	0.91 (0.36)	1.20 (1.2)
	p ⩽ 0.001*	p ⩽ 0.001*	p ⩽ 0.01*
Unit Consultant Availability			
High	4 (3)	0.93 (0.36)	1.33 (1.1)
Low	3 (1)	0.91 (0.36)	1.33 (1.0)
	p ⩽ 0.001†	p ⩽ 0.001†	P = 0.06†
Unit Nursing Establishment			
High	4 (2)	0.96 (0.36)	1.33 (1.0)
Low	4 (2)	0.89 (0.33)	1.33 (1.0)
	p ⩽ 0.001†	p ⩽ 0.001†	P = 0.07†

Statistical Test: * Kruskal Wallis Test, †Mann Whitney U Test

Table 3 Indicators of infant illness severity and infant nurse staffing for duration of unit stay by unit organisational type

	Birthweight mean (SD)	Gestation mean (SD)	Predicted mortality score median (IQ range)	Registered nurses median (IQ range)	Nurse provision ratio median (IQ range)	Specialist nurse provision ratio median (IQ range)
Cohort	1231.7 (359)	29.3 (2.6)	0.98 (0.08)	4.6 (2.5)	0.92 (2.5)	1.35 (0.6)
Unit volume type						
High	1176.4 (344)	29 (2.6)	0.98 (0.12)	6 (1.1)	0.93 (0.21)	1.41 (0.47)
Medium	1257.3 (356)	29.3 (2.5)	0.99 (0.06)	4.3 (2.3)	0.94 (0.22)	1.33 (0.75)
Low	1270.5 (373)	29.5 (2.5)	0.99 (0.06)	3.5 (1.4)	0.87 (0.23)	1.26 (0.63)
	p≤0.01*	p≤0.01*	p≤0.01°	p≤0.001°	p≤0.001°	P≤0.001°
Unit consultant availability						
High	1228.9 (351)	29.2 (2.6)	0.99 (0.05)	5.5 (2.6)	0.94 (0.22)	1.35 (0.62)
Low	1234.6 (368)	29.3 (2.6)	0.98 (0.08)	4 (2.2)	0.89 (0.25)	1.35 (0.58)
	p=0.69*	p=0.82*	p=0.29†	p≤0.001†	p≤0.001†	p=0.42†
Unit nursing establishment						
High	1230 (355)	29.3 (2.6)	0.99 (0.08)	4.8 (2.8)	0.95 (0.21)	1.32 (0.55)
Low	1234 (364)	29.3 (2.6)	0.98 (0.09)	4.4 (2.2)	0.87 (0.21)	1.39 (0.67)
	p=0.78*	p=0.72*	p=0.83†	p≤0.001†	p≤0.001†	p≤0.01†

Statistical tests: *one way ANOVA, ˚Kruskal Wallis, †Mann Whitney U test

These were then fitted as potential explanatory variables, along with unit organisational type, with risk-adjusted mortality as the dependent variable and the infant as the unit of analysis using logistic regression techniques on multivariate analysis.

RESULTS
Nurse staffing
Data describing characteristics of the nursing shifts are shown in table 1. The overall median nursing provision ratio was 0.92 (mean, 0.96; SD 0.31) indicating that the average shift was understaffed. In total 20380 shifts (57%) were understaffed and 35 units (65%) had an average ratio of less than one. Each unit had understaffed shifts, ranging from 90% shifts in the ''worst'' staffed to 13.4% in the ''best'' staffed units (both large units). The median specialist nursing provision ratio was 1.3 (mean, 1.42; SD 0.78). Eight (14.8%) units had an average specialist nursing provision ratio less than one. In total 8405 (23.6%) shifts were understaffed for specialist nurse provision with wide variation ranging from 0.7% in the ''highest'' to 65.1% in the ''lowest'' staffed neonatal unit. For nursing and specialist nursing ratios, the frequency of understaffed shifts increased for night shifts (table 2).

Infant variables
Table 3 shows the descriptive data for the infant cohort according to unit organisational type. Larger units had significantly smaller and more immature infants. Predicted mortality scores ranged from 0.002 to 0.998 and were skewed to the right with a mean of 0.89 (SD 0.206; median 0.98), indicating that on average the infants had an 89% chance of

survival according to variables measured at 12 hours of age. Infants who died had a mean mortality score of 0.513 (SD 0.31) versus 0.939 (SD 0.13) for those who survived. Predicted mortality differed significantly across neonatal units grouped by size, with the larger units treating sicker infants than medium and low volume units (table 3).

The nurse provision calculated for each infant for the duration of their unit stay (table 3) shows that in each group infants in the higher volume category had more registered nurses than those in the lower volume category units. The median nurse provision ratio for the infant cohort was 0.91 and 69% (n = 1784) of infants had an understaffed nurse provision ratio for their neonatal stay. The median specialist nurse provision ratio/shift for each infant's neonatal stay was 1.3 (mean 1.4; SD 0.49). However, 19% of the cohort infants (n = 497) had a specialist nurse provision ratio less than one.

Infant mortality
Observed mortality was 10.4% (n = 269) and was significantly lower for infants treated in low compared to high volume units (table 4). Risk-adjusted mortality (using the predicted mortality scores) is also shown by unit organisational type, relative to the high category units, with no difference across these categories.

On multivariate analysis, a stepwise model was fitted for each infant (table 5). The criteria for inclusion in this conditional model was set at a significance level of ≤0.05. Birthweight, unit organisational characteristics (size, consultant availability, nursing establishment levels), number of nurses per shift and nurse provision ratio per shift were excluded in the final risk-adjusted mortality model. Mortality

Table 4 Observed and risk-adjusted mortality by unit organisational type

		Crude mortality		Risk-adjusted mortality	
Unit type	Died n (%)	p Value	OR (95% CI*)	p Value	OR (95% CI*)
Unit volume type					
High	111 (11.7)	Referent category		Referent category	
Medium	93 (11.2)	0.73	0.95 (0.71 to 1.27)	0.44	1.18 (0.77, 1.8)
Low	65 (8.1)	0.01	0.66 (0.48 to 0.91)	0.63	0.89 (0.56 to 1.41)
Unit consultant availability					
High	146 (11.1)	Referent category		Referent category	
Low	123 (9.7)	0.22	0.85 (0.66 to 1.10)	0.43	0.86 (0.6 to 1.24)
Unit nursing establishment					
High	133 (9.7)	Referent category		Referent category	
Low	136 (11.3)	0.19	1.18 (0.92 to 1.52)	0.16	1.3 (0.9 to 1.9)

*The odds ratios and 95% confidence intervals are derived using logistic regression modelling with an odds ratio <1 indicating a decrease in odds relative to high volume/consultant/nursing units.

was significantly related to gestation, predicted mortality and the specialist nurse provision ratio aggregated for each infants' unit stay (OR 0.63; 95% CI 0.42 to 0.96).

In order to determine linearity of the relationship between risk-adjusted mortality and specialist nursing, four categories of ratio were entered into a logistic regression model (table 6).

There was no difference in risk-adjusted mortality for infants with a specialist nurse provision ratio between 1.0 and 1.2 compared to those with a ratio less than one (understaffed). The median specialist nursing provision ratio for this cohort was 1.3 and the odds of mortality decreased by 48% (odds ratio: 0.52, 95%CI: 0.33,0.83) when the ratio was increased from <1 to ⩾1.3. The predictive accuracy of the combined probabilities from the regression model (risk-adjusted mortality and qualified in speciality nurse provision) is represented by the area under the Receiver Operating Curve (SE) which was 0.92 (0.01).

DISCUSSION

Specific recommendations for nurse staffing enabled comparisons between units and an examination of levels of nursing provision in relation to risk-adjusted mortality in neonatal care.

Adjustment was made for infant illness severity using gestational age and a 12 hour probability model.[25] Although larger units tended to have more immature and sicker infants than smaller units, risk-adjusted mortality was not related to the size or type of neonatal unit. Other studies, including the UKNNSS have detected no difference in risk-adjusted outcomes by unit size.[11 25 29 30]

Over half of the nursing shifts were understaffed, while nearly a quarter did not have the minimum number of nurses with specialist neonatal nurse qualifications to care for intensive care and high dependency infants. There was wide variation in nursing provision, consistent with previous studies of neonatal nurse staffing.[19 20 26] Similarly variation in staffing levels by time of day and day of week corroborates the findings of an earlier UK survey.[19]

Using logistic regression specialist nursing provision was inversely related to risk-adjusted mortality and subgroup analysis indicated that increasing the ratio to greater than 1.2 decreased the probability of mortality by 48%. In other words, providing more than the minimum recommended number of nurses with specialist neonatal qualifications significantly increased the chance of survival in this cohort.

The possibility that the relationship between risk-adjusted mortality and specialist nursing provision could be attributed to confounding variables that were not examined in this study cannot be excluded. However, the probability is small as the approach included two primary methods of stratification not previously utilised. The first included organisational stratification by unit type and thus an attempt was made to separate the relative contributions of unit size and staff interaction. Secondly, analysis was based on infant profiles using individually determined risks, initially of illness severity and subsequently of workload demands and nurse provision representative of that infant's neonatal stay.

An important consideration is the omission of the neonatal unit as a predictive variable in the regression equation, and the independence of workload variables, calculated for each infant, which could potentially overestimate the significance of the association between specialist nurse provision and risk-adjusted mortality. This possible effect could be determined by modelling for the 54 neonatal units. However, the ability to do so was limited by the raw event rate, which, in 15% of units, was zero. Conversely, by using data for the whole duration of infant stay, not simply the most critical period of intensive or high dependency care, it could be argued that there was a dilution of the effects of inadequate staffing.

Table 5 Multivariate analysis of infant mortality

Variables	p Value	Odds Ratio (95% CI)
Gestation	<0.001	0.745 (0.67 to 0.83)
Predicted mortality	<0.001	0.008 (0.003 to 0.019)
Specialist nurse provision ratio/shift	0.031	0.63 (0.42 to 0.96)

Table 6 Risk-adjusted mortality and specialist nurse provision ratio categories

Specialist nurse provision ratio	p Value	Odds Ratio (95% C.I.*)
<1.0	0.03	Referent Category
1.0–1.2	0.105	0.63 (0.37 to 1.10)
1.3–1.8	0.006	0.52 (0.33 to 0.83)
>1.8	0.08	0.57 (0.31 to 1.08)

*The odds ratios and 95% confidence intervals are derived using logistic regression modelling with an odds ratio <1 indicating a decrease in odds relative to high volume/consultant/nursing units.

The method for adjusting for illness severity used a probability model based on twelve-hour data from birth, which is independent of subsequent therapeutic decisions. Although closely related to the validated and widely used CRIB score, the logistic model derivation process is designed to maximise predictive power, but runs the risk of over-fitting the idiosyncrasies of this dataset. Thus both the probability model and the final model of risk-adjusted mortality and specialist nurse provision, while having a good discriminatory power, lack support from independent validation.[25 29 30] Adjustment for clustering, for example by use of generalised estimating equations, may have increased the confidence interval around the observed estimates of risk adjusted mortality, but is unlikely to have changed the direction of apparent effect.

This study used recommendations published in 1996 to measure adequacy of nursing levels. More recent recommendations in the UK suggest higher ratios of nursing staff for intensive care and high dependency infants.[22 31] However, a survey of UK neonatal units conducted in 2005 showed that of 143 neonatal units, only three (2%) met the new recommendations for nurse staffing establishments and 20% were below those made earlier.[23 32] Thus the analysis using earlier recommendations is appropriate.

The measure of specialist nursing used in this study is the ratio of nurses who have undergone specialist neonatal training, in relation to the number of intensive care and high dependency infants. It reflects the ability to meet the demands for trained neonatal nursing and supports claims that quality of care may be impaired if the availability of trained staff is too low.[15] In the current nursing shortage, increasing nurse: patient ratios will be difficult. In America and Australia, one controversial initiative has been to mandate ratios for adult and paediatric care.[33 34] Optimisation of workload planning, by developing improved workload predictors from patient characteristics is also possible.[35 36] In neonatal care, mechanisms that allow more efficient staffing, that is the ability to flex up and flex down in the face of volume changes, are also key in addressing variable demand.[37] This study adds weight to previous calls for the collection of more detailed nurse staffing data in conjunction with more reliable measures of patient acuity to better match nurse staffing and patient need.[38 39] More effective workforce planning, perhaps involving networked care, are crucial to ensure that nursing levels match infant demands.

What is already known on this topic

- Shortages in nurse staffing in adult care have been linked with impaired patient outcomes.
- Most UK neonatal units do not meet levels of medical and nursing staffing recommended by professional bodies.
- Neonatal studies to date have provided inconclusive evidence of any relationship between nurse staffing, skill mix and infant outcomes.

What this study adds

- Risk-adjusted mortality is related to specialist nursing input.
- Increasing the ratio of specialist nurses to intensive care and high dependency infants may increase chance of survival in very low birthweight and preterm infants.

CONCLUSION

Reports of nursing in neonatal care have created an image of a workforce stretched by excessive infant volume workloads and technical demands of highly dependent infants with a possible deleterious effect on outcomes. The study devised a model to explore this issue, by investigating whether exposure of small and premature infants to different levels of nurse provision, aggregated for each infant for the duration of neonatal care, is related to survival, after adjusting for initial illness severity. The results show nurse understaffing in relation to infant demands across all neonatal units and an inverse relationship between risk-adjusted mortality and provision of nurses with specialist neonatal qualifications for this population of babies.

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