Nurse staffing levels and hospital mortality in critical care settings: literature review and meta-analysis

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Nurse staffing levels and hospital mortality in critical care settings: literature review and meta-analysis

Aim. This paper reports a review of the literature on the association between critical care nurse staffing levels and patient mortality.

Background. Statistically significant inverse associations between levels of nurse staffing and hospital mortality have not been consistently found in the literature. Critical care settings are ideal to address this relationship due to high patient acuity and mortality, high intensity of the nursing care required, and availability of individual risk adjustment methods.

Methods. Major electronic databases were searched, including MEDLINE, EMBASE, and the Cumulative Index of Nursing and Allied Health Literature.

The search terms included critical/intensive care, quality of health care, mortality/hospital mortality, personnel staffing and scheduling, and nursing staff (hospital). Only papers published in English were included. The original search was conducted in 2002 and updated in 2005.

Results. Nine studies were selected from 251 references screened. All nine were observational. Six were conducted in the United States of America, one in Austria, one in Brazil, and one in Scotland. The unadjusted risk ratio of nurse staffing (high vs. low) on hospital mortality were combined meta-analytically (five studies). The pooled estimate was 0·65 (95% confidence interval 0·47–0·91). However, after adjusting for various covariates within each study, the individually reported associations between high nurse staffing and low hospital mortality became non-significant in all but one study.

Conclusion. The impact of nurse staffing levels on patients' hospital mortality in critical care settings was not evident in the reviewed studies. Methodological challenges that might have impeded correct assessment of the association include measurement problems in exposure status and confounding factors, often uncontrolled. The lack of association also indicates that hospital mortality may not be sensitive enough to detect the consequences of low nurse staffing levels in critical care settings.

Keywords: critical care, hospital mortality, intensive care, meta-analysis, nurse : patient ratios, nursing, systematic literature review

Introduction

The practice of nursing is a critical factor influencing the quality of patient care in hospitals. Nevertheless, demonstrating the impact of high quality nursing care on quantifiable outcomes to make their contribution visible remains a challenge.

Major interest in previous research has been on adverse patient outcomes related to the intensity of care provided by nurses (Flood & Diers 1988, American Nurses Association 1997, 2000). Mortality has the most robust operational definition and has been the most commonly used indicator for the assessment of quality of inpatient care in the past (Pierce 1997, Buerhaus & Needleman 2000), while it has also been criticized for lacking sensitivity as an outcome when assessed by the hospital as a whole (Dubois *et al.* 1987, Jessee & Schranz 1990, Brooten & Naylor 1995). However, as the acuity level of inpatients has increased in recent years, mortality rates may have become more sensitive to the level of care provided in hospital, especially where mortality rate is high.

Among factors affecting the quality of nursing care, staffing levels are believed to be the most basic component with a direct bearing on patient care. Understaffing not only impedes provision of the planned care, but also may introduce human error that jeopardises patient safety (Beckmann *et al.* 1998). Despite long-standing interest in the relationship between nurse staffing and the outcomes of patient care, previous research investigating patient mortality remains inconclusive. A possible link between risk-adjusted mortality ratios and the characteristic, 'no problems in securing adequate nurse staffing', was first indicated by a multi-center study among intensive care patients (Knaus *et al.* 1986). An inverse relationship between the level of nurse staffing and mortality was then documented in a study investigating the attributes of hospital characteristics on the mortality rate (Hartz *et al.* 1989). This association, however, was not found in other studies (Silber *et al.* 1995, Blegen *et al.* 1998, Bond *et al.* 1999, Robertson & Hassan 1999). More recent studies investigating inter-hospital variation in mortality in the United States of America (USA) also failed to find a significant association (Needleman *et al.* 2002, Cho *et al.* 2003), whereas other investigators presented supportive data on the association (Aiken *et al.* 2002, 2003). In the latest systematic review on this topic in acute care hospital settings (excluding intensive care units), in the absence of appropriate adjustments for skill and patient mix, consistent positive effects of richer nurse staffing on mortality were not found (Lang *et al.* 2004). The effect of the level of nurse staffing on patient outcomes, nonetheless, may not be easy to evaluate in randomized controlled trials, due to logistical complexities and ethical concerns. Therefore, exploring this question with a review of observational studies remains the best alternative and provides insights for planning future studies. High patient acuity and mortality rates, high intensity of required nursing care, and availability of standardized methods to adjust individual mortality risk, make the ICU an ideal healthcare setting to address this relationship.

The aim of this paper is to present a review of the literature and meta-analysis of the association between nurse staffing levels and patient mortality during and after critical care.

Search methods

Search strategy for identification of studies

Literature for this review was identified by a combination of electronic searches of core bibliographic databases, retrieval of references cited in available reviews, and hand-searches from in-house reference collections. Databases searched were Cochrane Database of Systematic Reviews (3rd Quarter, 2005), MEDLINE (1966–2005 October week 2), EMBASE (1980–2005 Week 43), the Cumulative Index of Nursing and Allied Health Literature (CINAHL) (1982–2005 October Week 2), and PsycINFO (1985 to October week 3, 2005). The original electronic search was conducted in 2002 and was updated in December 2004 and in October 2005.

The search terms used were 1, *critical/intensive care*, *critical/intensive care unit(s)*, or *ICU*; 2, *quality of health care, quality indicators – health care*, or *mortality/hospital mortality*; 3, *personnel staffing and scheduling, nursing staff-hospital*, or *nurse-to-patient ratio*; and 4, *nursing administration research* where appropriate.

Selection criteria

Only studies published in English were considered for this review. Screening of relevant studies for inclusion was conducted independently by two reviewers using titles, publication years, and abstracts. The criteria for considering studies for the review were as follows.

Types of study subjects in appraised studies
Study subjects were critically ill patients who were treated in critical care settings.

Types of outcome measures
The primary outcome measure considered was mortality [ICU, in-patient (hospital), or 30-day mortality].

Types of studies
Randomized controlled trials, controlled trials, and observational studies were included.

Types of exposure (nurse staffing)
The exposure of interest was the level of nurse staffing in critical care settings. The staffing level needed to be clearly defined and described with a quantitative measure such as nurse-to-patient ratio (NPR) or other types of measures. Nursing skill-mix differences were not considered for the current review.

Discrepancies between reviewers related to inclusion of a study were resolved by discussion. The full text of selected publications was then obtained and reviewed to confirm each study's eligibility. A data abstraction form was created to ensure a standardized approach to data abstraction.

Data analysis and synthesis

The information on candidate studies was organized using Reference Manager, version 10 (ISI ResearchSoft 2001), a reference management software, combining the search results from major electronic database searches and hand-searches. Reliability of study inclusion was evaluated using the Kappa coefficient for concordance between reviewers. The quantitative synthesis method was applied to a limited extent due to the limited number of qualifying studies that report comparable outcome measures. The Q-test was performed to evaluate heterogeneity within the identified studies. A Forest plot to describe the range and distribution of effects across studies was presented and parameter estimates such as risk ratios were pooled. Unadjusted risk ratios (RRs) rather than odds ratios (ORs) were chosen to avoid overestimation, as mortality rate in one of the studies was high. Risk ratios were combined using the DerSimonian and Laird random effects model (DerSimonian & Laird 1986). The quality of studies was not formally evaluated or incorporated in the meta-analysis, but several study characteristics were summarized in the table. All analyses were conducted using Stata version 9.1 (Stata Corp 2005).

Results

Study selection

A total of 251 citations were identified from the electronic searches after removal of duplicate entries. Two reviewers screened the titles and abstracts for further review and excluded 228 (90·8%) based on predetermined inclusion criteria. The agreement between reviewers was >96%, with an overall kappa of 0·78 ($P < 0{\cdot}0001$) and a 95% confidence interval of 0·66–0·90. The major reason for disagreement derived from incomplete information in the abstract. Five articles with disputed decisions were excluded after discussion. An additional six citations were identified and added through hand-searches. A study that defined the study population using the specific life-threatening condition [i.e. hospitalized with acute myocardial infarction (AMI)] was included. Of 22 full-text articles, one piece of correspondence and one conference proceeding, a further 12 were excluded on full-text review (Table 1). Therefore, a total of 11 journal articles and one conference abstract remained for data abstraction.

Three were studies on a neonatal intensive care unit (NICU) or intensive care nursery (ICN) (Hamilton *et al.* 2000, Tucker & The UK Neonatal Staffing Study Group 2002, Callaghan *et al.* 2003) while nine were with adult patients who required intensive care. The NICU studies were not included in the review since staffing and demands in NICUs were considered distinct from those in ICUs for adults. These three excluded studies are also listed in Table 1.

Study characteristics

All nine studies used an observational design; none had interventions (Table 2). One study was conducted in Brazil (Bastos *et al.* 1996), one in Scotland (Tarnow-Mordi *et al.* 2000), one in Austria (Metnitz *et al.* 2004) and six in the USA. All but one of the studies used data collected between 1990 and 2000. The median study duration was 36 months, ranging from 10 to 60 months. Eight of nine were multicentre studies including multiple hospitals that ranged from 10 to 6668 beds, with a median of 38. A total of 168,840 patients were included; the number of patients per study ranged from 353 to 118,940. Three studies claimed to have employed prospective data collection on patient outcomes (Bastos *et al.* 1996, Metnitz *et al.* 2004, Shortell *et al.* 1994) and the remaining studies retrieved patient data retrospectively.

Nurse staffing measures

All but one study used NPR aggregated for each participating unit. NPR is usually expressed as 1 : x, where x is the number of patients cared for by a nurse. Two studies used the ratio as a continuous variable in the analysis (Bastos *et al.* 1996, Shortell *et al.* 1994). Four studies dichotomized the NPR: these defined 1 : 3 or 1 : 4 as 'fewer ICU nurses' and 1 : 1 or 1 : 2 as 'more ICU nurses' (Amaravadi *et al.* 2000, Dimick *et al.* 2001, Pronovost *et al.* 2002, Pronovost *et al.* 2001). One study used NPR categorized into quartiles (Person *et al.* 2004).

Depending on the research question, nurse staffing measures represented either day shifts, night shifts, day and night shifts, or a decrease of nurse staffing in the evening (yes or no). One study used a composite measure of 'maximum occupancy >6 or not' and 'average nursing requirement per

Table 1 Excluded studies after full-text review

Study	Reasons for exclusion
Adomat and Hewison (2004)	Focus is on new assessment methods of patient category/dependence system
Breslow *et al.* (2004)	No quantitative measures for the nurse staffing was reported
Callaghan *et al.* (2003)	A study in Neonatal Intensive Care Unit (NICU)
Czaplinski and Diers (1998)	Not investigating the association between ICU staffing and mortality but specialized staff nursing and its impact
Aiken *et al.* (2002)	Not a primary study but a review
Adomat and Hewison (2004)	No mortality data but patient falls and injuries only
Hamilton *et al.* (2000)	A study in NICU, a conference abstract without enough details
Iapichino *et al.* (2005)	Proposing a new measurement tool to measure the use of resources regarding nursing care in ICU
American Nurses Association (1997)	Investigating the association between ICU nurse skill-mix and mortality
Knaus *et al.* (1986)	Only qualitative measures of nurse staffing were used (e.g. problems with adequate nurse staffing: none, minor, major)
Miller *et al.* (1999)	Not investigating the association between ICU staffing and mortality but utilization TISS
Solsona *et al.* (1993)	Investigating the association between ICU nurse skill-mix and mortality
Tucker and The UK Neonatal Staffing Study Group (2002)	A study in NICU
Walther *et al.* (2004)	Nursing staff include RNs as well as Nurse's aides, association between nurse staffing and mortality was not investigated in the analysis
Zimmerman *et al.* (1993)	A subgroup analysis of the previously published results

ICU, intensive care unit; NICU, neonatal intensive care unit; TISS, therapeutic intervention scoring system; RN, Registered Nurse.

Table 2 Study characteristics of reviewed studies*

Author, Year	Population	Study period	Study duration (months)	Number of patients	Number of ICUs/ hospitals	Nurse staffing	Outcomes
Metnitz (2004)	Patients admitted to ICU	1998–2000	36	26,186	31	NPR (continuous variable), work-utilization ratio (continuous)	Risk-adjusted hospital mortality per ICU
Person (2004)	Medicare patients hospitalized with AMI	1994–1995	18	118,940	6668	Ratio of full-time equivalent RNs to average daily census	Hospital mortality, 30-day mortality
Dimick (2001)	Adults undergoing hepatic resection	1994–1998	60	556	33	NPR = 1 : 3 or 1 : 4 (Low) vs. NPR = 1 : 1 or 1 : 2 (high) (at night)	Hospital mortality, postoperative morbidity, hospital LOS, total hospital costs
Pronovost (2001)	Adults undergoing abdominal aortic surgery	1994–1996	36	2606	38	NPR = 1 : 3 or 1 : 4 (low) vs. NPR = 1 : 1 or 1 : 2 (high) (during the day)	Hospital mortality rate (crude comparison only), postoperative complications
Amaravadi (2000)	Adults undergoing esophagectomy	1994–1998	32	353	32	Night-time NPR ≥1 : 2 (low) vs. night-time NPR < 1 : 2 (high)	Hospital mortality, hospital LOS, total cost
Tarnow-Mordi (2000)	Adults admitted to ICU (no post cardiac surgery and no some neurosurgery)	1992–1995	48	1025	1	ICU occupancy when admitted ≤6 or >6	ICU mortality, hospital mortality, LOS
Pronovost (1999)	Adults (>30 y.o.) undergoing abdominal aortic surgery	1994–1996	36	2606	39	NPR > 1 : 2 (low) vs. NPR < 1 : 2 (high) during the day, during the evening, or a decreased NPR in the evening	Hospital mortality, hospital LOS, ICU-LOS, complications
Bastos (1996)	Adults admitted to the ICU, consecutive admissions	January 1990 to May 1991	17	1734	10	NPR (continuous)	ICU SMR, hospital mortality
Shortell (1994)	Adults admitted to ICU consecutive admissions	May 1988 to February 1990	Average 10 months (ranged from 3 to 17)	17,440	42	NPR (continuous)	Risk-adjusted mortality (SMR), risk-adjusted LOS, nursing turnover, evaluated technical quality of care, evaluated ability to meet family members needs

ICU, intensive care unit; AMI, acute myocardial infarction; NPR, nurse-to-patient ratio; LOS, length of stay; SMR, standardized mortality ratio.
*Full reference details of the papers reviewed are given in Table 3.

occupied bed >1·6 or not' during the ICU stay for each patient as a proxy for level of ICU staffing (Tarnow-Mordi *et al.* 2000). Only one of the reviewed studies indicated the skill-mix of nursing staff, with the ratio of Registered Nurses (RNs) to Licensed Practical Nurses (LPNs) (Person *et al.* 2004).

Appraisal criteria

The appraisal criteria for study characteristics are listed in Table 3. All nine studies were in peer-reviewed journals published between 1994 and 2004. Although the studies were all observational, one of the authors discussed whether the study had adequate statistical power to detect a difference between the two levels of nurse staffing (Bastos *et al.* 1996). All studies employed multiple regression analysis (i.e. ordinary least square or logistic). Five of eight multi-centre studies used individual patients as the unit of analysis. Among these five, all except one (Dimick *et al.* 2001) aimed to control for a clustering effect by applying the hierarchical modelling or the generalized estimating equations (GEE) method. Investigation of interaction terms and the goodness-of-fit of the chosen model were reported in two studies (Person *et al.* 2004, Tarnow-Mordi *et al.* 2000).

Mortality

All studies used hospital mortality or risk-adjusted hospital mortality as the dependent variable in the main analysis. One study also investigated 30-day mortality as a sensitivity analysis (Person *et al.* 2004). Three reported mean ICU mortality in addition to hospital mortality; however, neither analyzed unit mortality in relation to nurse staffing (Bastos *et al.* 1996, Metnitz *et al.* 2004, Tarnow-Mordi *et al.* 2000). Hence, hospital mortality was chosen as the outcome of interest in our analysis (Table 4). Two studies did not report mean hospital mortality among their multiple study sites, but instead presented the range of mortality data across study sites (e.g. 0–66%). Overall hospital mortality in the remaining seven studies varied from 4·8% to 34%. Three studies calculated an overall standardized mortality ratio (SMR) using the Acute Physiology and Chronic Health Evaluation (APACHE) II or III (Knaus *et al.* 1985, 1991), and these ratios ranged from 0·99 to 1·67. Another study used risk-adjusted mortality ratios based on the Simplified Acute Physiology Score II (SAPS-II) (Le Gall *et al.* 1993). Six reported overall hospital mortality in relation to staffing levels: reported hospital mortality ranged from 7·1% to 39·7% in low nurse staffing conditions while from 2·5% to 23·3% in high nurse staffing conditions.

Impact of high vs. low nurse staffing

Table 4 presents the unadjusted and adjusted odds ratios (ORs) of high vs. low nurse staffing for hospital mortality or coefficients from the linear regression analysis investigating correlation between nurse staffing and hospital mortality. Changes between unadjusted and adjusted ORs were considerable in two studies, suggesting the presence of confounding factor(s) in the multiple regression models. Based on the data reported, unadjusted risk ratios (RRs) of high nurse staffing compared with low nurse staffing were calculated and presented in the Forest plot (Figure 1). Four of five studies showed a statistically significantly reduced risk for hospital mortality among patients with high nurse staffing levels, with an overall risk ratio of 0·65 (0·47–0·91). After adjusting for various covariates in multiple regression models; however, only one study found a statistically significant reduction in mortality associated with higher ICU staffing levels. That statistically significant finding was derived from analysis using a complex, non-dichotomized category for the staffing level (Tarnow-Mordi *et al.* 2000). One recent study with a large sample size delineated the attenuation of the impact of high nurse staffing levels on mortality after adjustment for other covariates by presenting ORs derived from different statistical models (Person *et al.* 2004).

Discussion

This review was conducted to investigate the impact of nurse staffing on patient mortality in critical care settings in the published literature. Nine observational studies were identified, and results from these indicated that there was not enough evidence to support the independent association between nurse staffing levels and critically ill patient mortality during hospital stay. Although the pooled unadjusted risk ratio indicated an inverse association between nurse staffing and hospital mortality (greater nurse staffing is associated with less mortality), this association was not found in eight of the nine studies with adjustment for other factors.

A major limitation of this review is the small number of original studies included. Moreover, four studies came from the same geographical region in the USA (Maryland). Although the patient population differed in two of the four investigations in Maryland, those four studies had a similar methodology. Limitations of these four studies, as acknowledged by the authors, included potential inaccuracy of coding in administrative databases, incomplete risk adjustment for patient mortality, concerns with validity and reliability of nurse staffing measures, and uncontrolled effects of nursing skill-mix and pre- and post-ICU care. Besides,

Table 3 Appraisal criteria for study characteristics

Author, year	Main analytical methods	Unit of exposure	Unit of analysis	Clustering effect controlled?	Covariates adjusted in multiple regression model	Interaction investigated	Goodness of fit	Involvement of statistics specialist	Reference information
Metnitz (2004)	Multiple linear regression	ICU	ICU	Not applicable	No details	Not reported	Not reported	NSD	*Intensive Care Medicine* (2004) More interventions do not necessarily improve outcome in critically ill patients. 30, 8: 1586–1593
Person (2004)	Generalized estimating equation modeling	Hospital	Patient	GEE with exchangeable correlation structure	Age, gender, race, severity of illness (cardiac arrest on admission, congestive heart failure, systolic BP,s-creatinine, WBC count, anterior or lateral AMI), hospital volume, rural/urban, teaching status, technology index, receipt of key prescribing therapy for AMI	Important two-way interactions were investigated	Akaike information criterion	NSD	*Medical Care*. (2004) Nurse staffing and mortality for Medicare patients with acute myocardial infarction 42, 1: 4–12
Dimick (2001)	Multiple logistic regression	Hospital	Patient	Not controlled	Age, race, gender, low hospital volume, type of admission, type of procedure	Not reported	Not reported	NSD	*American Journal of Critical Care* (2001) Effect of nurse-to-patient ratio in the intensive care unit on pulmonary complications and resource use after hepatectomy. 10, 6: 376–382
Pronovost (2001)	Multiple logistic regression	Hospital	Patient	Multi-level hierarchical model	Age, race, gender, low hospital volume, 10 comorbid diseases, severity of illness, hospital volume, surgeon volume	Not reported	Not reported	NSD	*Effective Clinical Practice*. (2001) Intensive care unit nurse staffing and the risk for complications after abdominal aortic surgery. 4, 5: 199–206
Amaravadi (2000)	Multiple logistic/ linear regression	Hospital	Patient	Multi-level hierarchical model	Age, gender, race, procedure, nature of admission, hospital volume, surgeon volume	Not reported	Not reported	NSD	*Intensive Care Medicine*. (2000) ICU nurse-to-patient ratio is associated with complications and resource use after esophagectomy. 26, 12: 1857–1862
Tarnow-Mordi (2000)	Multiple logistic regression	Patient	Patient	Not applicable	APACHE II during the first 24 hours of admission	All-first order interactions examined	Hosmer-Lemeshow GOF chi-square: satisfactory	NSD	*Lancet*. (2000) Hospital mortality in relation to staff workload: a 4-year study in an adult intensive-care unit. 356, 9225: 185–189
Pronovost (1999)	Multiple logistic regression	Hospital	Patient	Multi-level hierarchical model	Age, race, gender, comorbid diseases, severity of illness, hospital volume, surgeon volume, ICU characteristics	Not reported	Not reported	NSD	*Journal of American Medical Association*. (1999) Organizational characteristics of intensive care units related to outcomes of abdominal aortic surgery. 281, 14: 1310–1317

Table 3 (*Continued*)

Author, year	Main analytical methods	Unit of exposure	Unit of analysis	Clustering effect controlled?	Covariates adjusted in multiple regression model	Interaction investigated	Goodness of fit	Involvement of statistics specialist	Reference information
Bastos (1996)	Simple linear regression for SMR	Hospital	Hospital	Not applicable	Not applicable	Not reported	Not reported	NSD	*Intensive Care Medicine*. (1996) The importance of technology for achieving superior outcomes from intensive care. Brazil APACHE III Study Group. 22, 7: 664–669
Shortell (1994)	Multiple linear regression for SMR	Hospital	Hospital	Not applicable	APACHE III on the day of admission, primary disease category, length of stay, location prior to ICU admission, surgery type (elective or emergency)	Not reported	Not reported	NSD	*Medical Care*. (1994) The performance of intensive care units: does good management make a difference? 32, 5: 508–525

NSD, not specifically described; BP, blood pressure; APACHE, acute physiology and chronic health evaluation; GOF, goodness-of-fit; SMR, standardized mortality ratio.

limitations within individual studies, inconsistencies in definitions of nurse staffing measures and variations in sets of variables used in the analysis limited numerical integration of the results.

As an approach to investigating the impact of nurse staffing, we focused on a specific healthcare setting such as critical care. Since nursing care assignments need to reflect the level of demands from the patients, variability in nurse staffing across specialties is inevitable. It is reasonable to restrict the unit setting so that patient populations are similar across studies, as well as within each study, in terms of nursing care needs. The severity of illnesses among ICU patients, for example, often requires one-to-one nursing, and mortality among these patients is high. Hence, the relationship between nurse staffing level and mortality rate is more likely to be detected among those patients with life-threatening conditions. Aiken *et al.* (2003) reported that each additional patient per nurse was associated with a statistically significant 7% increase in the likelihood of dying within 30 days of admission to acute care settings, where the statistical mode of number of patients per nurse was five and overall mortality rate was 2·0%. The impact of additional patients per nurse must be larger in critical care units, where both NPR and patient's survival are among the lowest in acute care.

Restricting the unit type also helps to measure exposure levels more accurately. In practice, nurse-staffing decisions are made on a unit basis. Hospital-wide measures of nurse staffing (rather than unit basis) may be too crude without distinguishing bedside nurses who have direct contact with the inpatients from all other nurses within the organization. Although attempts to overcome this problem were made in recent studies (Aiken *et al.* 2002), it may not be completely adjustable and aggregation of the staffing levels across various units can obscure the association of interest.

Furthermore, because of higher patient acuity levels, most ICUs and other critical care areas remain staffed by RNs with minimum assistive nursing staff (Blegen & Vaughn 1998). Thus, limiting the setting to the critical care settings where RNs are frequently hired almost exclusively would reduce, to some extent, the potential confounding effect of nurse skill-mix.

Lastly, data on case mix adjustment are often available in such settings. As case mix has a major influence on patient prognosis as well as staffing demands, it is crucial to control its influence adequately. Use of standardized instruments such as APACHE II or III (Knaus *et al.* 1985, 1991), Mortality Predictive Model (MPM) (Lemeshow *et al.* 1987), SAPS-II (Le Gall *et al.* 1993) or equivalent allows investigators to perform patient risk adjustment in the analysis.

Table 4 Mortality results*

Author, year	Mortality rate (overall or by sub-group)	Low-intensity ICU nurse staffing death/patients %/*n* (95% CI)	High-intensity ICU nurse staffing death/patients %/*n* (95% CI)	Unadjusted OR (95% CI)/coefficient	Unadjusted (*P*-value)	Adjusted OR (95% CI) A: adjusted for other covariates B: adjusted for individual risk of mortality AB: both	Conclusion (after adjustment)
Metnitz (2004)	Group A–C: 10·2–14·6% O/E mortality ratio: Group A: 0·88 (0·84–0·92) Group B: 0·83 (0·80–0·87) Group C: 0·99 (0·96–1·02)	Not reported	Not reported	Not reported	Not reported	Not significant OR not reported	No association
Person (2004)	By quartile: In hospital: 17·4–20·1% 30-day: 20·5–23·3%†	In-hospital: 19·2%† 30-day: 22·5%†	In-hospital: 17·6%† 30-day: 21·0%†	In-hospital: 0·89 (0·86–0·92)† 30-day: 0·92 (0·89–0·94)†	$P < 0·001$† $P < 0·001$†	A Q4 vs. Q1 0·91 (0·86–0·97) Q3 vs. Q1 0·94 (0·88–1·00) Q2 vs. Q1 0·96 (0·90–1·02)	Not reported if the staffing variable as a group (three dummies) was significant
Dimick (2001)	4·8%	7·1	2·5	0·34 (0·15–0·49)*	$P = 0·01$	AB 0·49 (0·18–1·29)	No association
Pronovost (2001) Amaravadi (2000)	Ranged from 0% to 66% 8·1%	8·4 (6·0–11·2) 15	7·0 (6·0–8·1) 5·6	0·82 (0·57–1·18)† 0·34 (0·16–0·73)†	$P = 0·43$† $P = 0·005$	Not reported A 0·7 (0·3–2·0)	No association No association
Tarnow-Mordi (2000)	32·9% SMR 1·17	High workload (C): 129/285 Intermediate (E1): 71/241 Intermediate (E2): 95/279 Moderate (E3): 42/245 Dichotomized‡: 113/486 vs. 224/564‡		(C):1·0 (E1): 0·6 (0·4–0·9) (E2): 0·5 (0·4–0·7) (E3): 0·3 (0·2–0·4) Dichotomized‡: 0·6 (0·5–0·7)§	$P < 0·001$†	B (C): 1·0 (E1): 0·5 (0·3–0·8) (E2): 0·5 (0·3–0·8) (E3): 0·3 (0·2–0·5) Reversed by definition	Association 'the higher staffing, the less mortality'
Pronovost (1999)	Ranged from 0% to 66%	Not reported		Not-decreased NPR compared with decreased NPR in the evening: 0·52 (0·33–0·83)§	Not reported but significant	Not significant OR not reported	No association
Bastos (1996)	ICU mortality = 29%; hospital mortality = 34% (21–57%); SMR = 1·67 (1·01–2·30)	Not reported		Not applicable coefficient, β = 0·32	$P = 0·12$	Not reported	No association

Table 4 (*Continued*)

Author, year	Mortality rate (overall or by sub-group)	Low-intensity ICU nurse staffing death/patients %/*n* (95% CI)	High-intensity ICU nurse staffing death/patients %/*n* (95% CI)	Unadjusted OR (95% CI)/coefficient	Unadjusted (*P*-value)	Adjusted OR (95% CI) A: adjusted for other covariates B: adjusted for individual risk of mortality AB: both	Conclusion (after adjustment)
Shortell (1994)	Mean actual mortality rate = 16·6% (6·2–40%); SMR 0·99 (SD 0·15) (0·67–1·26)	Not reported	Not reported	Not applicable coefficient β = −0·17	Not reported	Not reported	No association

OR, odds ratio; O/E, observed-to-expected; CI, confidence interval; OR, odds ratio; SMR, standardized mortality ratio; C, control/reference group; E1–E3, exposure groups.
*Full reference details of the papers reviewed are given in Table 3.
†Proportions, ORs, and 95% CI were calculated by the reviewer based on the information given in the article.
‡Dichotomized using maximum occupancy > 6 vs. ≤6 reported in Table 3 in the original article by Tarnow-Mordi, 2000.
§Odds ratios were reversed by definition.

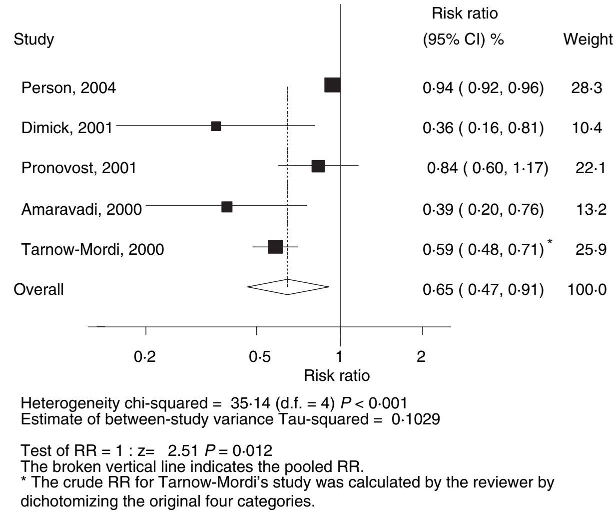

Figure 1 Forest plot with the estimated risk ratios (RR) of hospital mortality with 95% confidence intervals (CIs).

Despite all these advantages, we did not find a consistent inverse association between nurse staffing levels and mortality in critical care. Reasons for this finding can be understood in the light of the methodological challenges inherent in this type of research. Problems of reliability and validity in measuring nurse staffing levels, lack of variation in nurse staffing measures, lack of advanced statistical analysis methods required for a certain study design, and confounding factors that are difficult to quantify and/or not properly controlled for may have impeded detection of an association and thus may have discouraged researchers from investigating this research question further.

There appears to be no standardized operational definition for nurse staffing level. NPR was the most common measure used in the reviewed studies. However, this ratio, usually presented as a static figure, may not fully capture nurse staffing conditions that are dynamic in nature. NPR may fluctuate between work shifts (i.e. day and evening/night) as well as between weekdays and weekends. Several NPR measures were used in the reviewed studies (e.g. NPR during either day or night shift, averaged across all shifts or whether there is a decrease in the NPR in the evening). The rationale for investigating nurse staffing at night is an increased importance of nursing care while medical and other staffing levels are decreased. The choice of the NPR during the day as a pertinent staffing measure, on the other hand, was based on the correlation between NPR during the day and hospital length of stay (LOS) (Pronovost *et al.* 1999). The question of the best measure for nurse staffing level in terms of timing appears to merit future research.

Another concern with the nurse staffing measurement is how this measure was dealt with in the analysis. Four studies used dichotomized categories for the NPR, while three used NPR as a continuous variable. Dichotomization may be due in part to the lack of variability in this measure and/or lack of an odds-linear or linear association between multiple exposure levels and the outcome. One study justified the use of categorized nurse staffing levels with an unmet linearity assumption (Person *et al.* 2004). Setting a cut-off ratio for 'high' vs. 'low' staffing level is arbitrary, and no fixed value has yet been universally advocated (Lang *et al.* 2004). Pooling the NPR from more than two original categories into fewer levels presumes that there is a little heterogeneity within the pooled categories in regard to the impact on mortality. Confirmation of this assumption with given data would have assured appropriateness of the chosen cut-off values.

Except for three studies, the study periods spanned longer than 32 months, with a maximum of 5 years. The suitability of assigning a single fixed measure of nurse staffing level in a relatively long study might be questioned. Moreover, applying an aggregated unit-level measure to individual patients may introduce bias, known as the ecological fallacy. The process of aggregating data inevitably conceals variations among patients within the unit. It is worth noting that the only study that found an independent association between ICU staffing and mortality after adjusting other covariates was a single-centre study assigning the staffing levels individually to each patient (Tarnow-Mordi *et al.* 2000).

With regard to analytical methods, multi-level hierarchical modelling or GEE method was applied in four of five multi-centre studies that used the patient as the unit of analysis. It is reasonable to assume that patients are clustered within hospitals; thus, such analytical techniques should be applied in all investigations in multi-centre studies to avoid the effect of artificially decreased variance estimates.

In addition, the validity of multivariate modelling depends on the extent to which the selected model fits the data. If statistical modelling is employed in the analysis, fit of the selected model as well as suitability of statistical assumptions need to be reported. Only two studies presented results from such investigations.

Influence of unmeasured and/or uncontrolled confounding factors cannot be underestimated. In multi-centre studies, comparability among ICUs except for nurse staffing needs to be assured, or more practically, critical differences in potential confounding factors, which are associated with both nurse staffing and patient mortality, should be accounted for in the analysis. One such confounding factor may be the intensity of medical staffing. This factor was confirmed to be independently associated with hospital mortality in patients treated in the ICU (Pronovost *et al.* 2002). If high-intensity physician staffing (i.e. mandatory intensivist consultation or closed ICU) is related to nurse staffing levels, the association of interest may have been confounded unless adjusted. Although this might not have been the case in the reviewed studies, if hospitals with high intensity medical staffing had low nurse staffing levels and medical staffing factors were not adjusted in the analysis, the association between nurse staffing and mortality could be falsely described in the opposite direction. In addition, the impact of other staff contributions cannot be ignored. Interdisciplinary collaboration in the care of critically ill patients in ICUs is normative in current practice. Shortages of nurses may have been compensated by additional ICU staffing in other healthcare disciplines such as respiratory therapists and other allied healthcare professionals. The degree of contribution or work sharing by various disciplines is likely to vary by unit. The staffing of other professionals can be more difficult to quantify than that of nurses; hence, it might have remained unmeasured and uncontrolled. It is also worth noting that the study that reported a statistically significant independent association was the one investigating mortality in relation to level of staffing not exclusive to nursing staff (Tarnow-Mordi 2000).

Another major confounding factor to be adjusted for is the risk of mortality of the patient. Use of administrative databases did not allow highly reliable measures for the severity of patient conditions. ICUs that have more nursing staff may be those where the most severely ill patients with high mortality risk are treated. Therefore, without properly adjusting for the patient risk, high staffing ICUs are likely to indicate higher mortality even though the opposite may be true. Risk-adjusted mortality derived from a systematic scoring system was used in only three of the nine reviewed studies. The rest used several proxy variables retrospectively retrieved from the administrative or project databases and adjusted in multiple regression analysis. Since even non-systematic measurement errors in confounding variables (i.e. inaccurate assessment of patient risk) can bias the association in either direction (Rothman & Greenland 1998), risk adjustment using the crude measure of patient mortality risk can be a serious problem.

Furthermore, as hospital mortality rather than ICU mortality was chosen as the main outcome in all reviewed ICU studies, the care patients received outside ICU could be another confounding factor. While a few acknowledged that 30-day mortality is considered a standard for hospital mortality, the choice of in-hospital mortality was based on its relevance to the nursing care provided during patients' hospital stay. Treatments/care that patients received within and outside the critical care settings were not fully distinguished or accounted for in any of the reviewed studies. Not

What is already known about this topic

- Several recent large-scale studies have failed to find an association between nurse staffing levels and patient mortality.
- Whether levels of nurse staffing are associated with patient mortality has not been conclusively established when the setting was a hospital as a whole.

What this paper adds

- In relation to critical care settings, of the nine studies found, five had a common parameter to permit a meta-analysis.
- A positive impact of high nurse staffing levels on patient mortality in critically ill patients was not evident.
- Methodological challenges in the studies reviewed include difficulties in measuring nurse staffing levels, various unaccounted confounding factors, and possible lack of sensitivity of outcome measures.

using ICU mortality as a patient outcome in the studies of ICUs appears to be justified, as decisions to discharge patients from the ICU greatly influence the outcome. However, if pre-ICU or post-ICU treatments/care were different by unit and related to the levels of nurse staffing in a systematic way among study sites for any reason, not accounting for these factors might have biased the association.

Finally, while we considered issues of nursing skill-mix are not critical with restriction of the study setting to critical care only, this relies on an assumption that all nurses can equally provide quality care. One of the studies examined the impact of RN : LPN ratio as well as LPN : patient ratio on patient mortality since the authors thought that these factors were potentially relevant to their study population. In that study, an association between LPN staffing levels and hospital mortality, independent from the impact of RN staffing levels, was indicated. The magnitude of that association was, however, attenuated after adjustment for other variables. The RN : LPN ratio was not found to be statistically significant in any of the reported models (Person *et al.* 2004). The nursing work force is comprised of nurses with different lengths of clinical experience. In practice, such varied experience levels are incorporated into staff scheduling. Therefore, not finding a statistically significant impact of nurse staffing levels on mortality may be inherent to the use of simplified measures for nurse staffing.

Assessment of outcomes in critical care has traditionally focused on mortality. The advantages of using mortality include availability of the date and its not socially conditioned definition. Problems of underreporting or errant reporting are unlikely. While other proposed outcomes including ‘failure to rescue’ and adverse events are considered more sensitive to nurse staffing levels among certain patient populations (Unruh 2003), our review suggests that mortality may not be sensitive enough to capture the impact of nurse staffing levels. Establishing patient outcome measures with sufficiently robust definitions and with feasible data collection procedures across various facilities is imperative. Furthermore, beyond mortality and adverse events, outcomes that reflect positive influences of high intensity nursing care need to be explored in the critical care setting (Brooks *et al.* 1995, Hayes *et al.* 2000, Black *et al.* 2001).

The lack of robust research addressing the association between nurse staffing and mortality may reflect methodological challenges, as well as a lack of resources for this type of research in current healthcare systems. There is an urgent need to conduct adequately planned studies to address quality of patient care from the perspective of nursing as well as other health care disciplines’ staffing. Randomized controlled trials and prospective multi-centre cohort studies would be ideal if valid and reliable measures of nurse staffing and all related covariates were established, and if data were reliably collected across all participating sites. Meanwhile, well-conducted single-centre studies remain valuable. There was only one such single-centre study in our review. If such studies were conducted in multiple sites with various unit structures in different countries, the evidence gathered could be convincing. Reliable workload measures that address physical numbers of nurse staffing, nursing care demand levels, and nursing skill (knowledge and experiences) will be invaluable for any future studies. Such efforts have been observed in newly proposed measurements in several recent studies (Adomat & Hewison 2004, Junger *et al.* 2004, Iapichino *et al.* 2005). It may be expected more studies investigating the impact of nurse staffing levels will emerge in future.

Conclusion

This appraisal identified methodological challenges in the type of studies reviewed: problems in measurement of nurse staffing levels, unmeasured, imprecisely measured, and/or uncontrolled confounding factors, and potential lack of sensitivity of the selected outcome measure (mortality). Until investigators overcome these issues and conduct studies with sufficient scientific rigour, an unbiased estimate of the effect of nurse staffing on patient outcomes cannot be determined.

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Author contributions

YN, MS, RV, JG, PS, EB and JMF were responsible for the study conception and design and drafting of the manuscript. YN and MS performed the data collection and data analysis. RV, PS and JMF obtained funding and provided administrative support. MS provided statistical expertise. YN, MS, PS, EB and JMF made critical revisions to the paper. MS, RV and JG supervised the study.

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