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Costs and cost-effectiveness of improved nurse staffing levels and skill mix in acute hospitals: A systematic review

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ABSTRACT

Background: Extensive research shows associations between increased nurse staffing levels, skill mix and patient outcomes. However, showing that improved staffing levels are linked to improved outcomes is not sufficient to provide a case for increasing them. This review of economic studies in acute hospitals aims to identify costs and consequences associated with different nurse staffing configurations in hospitals.
Methods: We included economic studies exploring the effect of variation in nurse staffing. We searched PubMed, CINAHL, Embase Econlit, Cochrane library, DARE, NHS EED and the INAHTA website. Risk of bias was assessed using a framework based on the NICE guidance for public health reviews and Henrikson's framework for economic evaluations. Inclusion, data extraction and critical appraisal were undertaken by pairs of reviewers with disagreements resolved by the entire review team. Results were synthesised using a hierarchical matrix to summarise findings of economic evaluations.
Results: We found 23 observational studies conducted in the United States of America (16), Australia, Belgium, China, South Korea, and the United Kingdom (3). Fourteen had high risk of bias and nine moderate. Most studies addressed levels of staffing by RNs and/or licensed practical nurses. Six studies found that increased nurse staffing levels were associated with improved outcomes and reduced or unchanged net costs, but most showed increased costs and outcomes. Studies undertaken outside the USA showed that increased nurse staffing was likely to be cost-effective at a per capita gross domestic product (GDP) threshold or lower. Four studies found that increased skill mix was associated with improved outcomes but increased staff costs. Three studies considering net costs found increased registered nurse skill mix associated with net savings and similar or improved outcomes.
Conclusion: Although more evidence on cost-effectiveness is still needed, increases in absolute or relative numbers of registered nurses in general medical and surgical wards have the potential to be highly cost-effective. The preponderance of the evidence suggests that increasing the proportion of registered nurses is associated with improved outcomes and, potentially, reduced net cost. Conversely, policies that lead to a reduction in the proportion of registered nurses in nursing teams could give worse outcomes at increased costs and there is no evidence that such approaches are cost-effective. In an era of registered nurse scarcity, these results favour investment in registered nurse supply as opposed to using lesser qualified staff as substitutes, especially where baseline nurse staffing and skill mix are low.
Registration: PROSPERO (CRD42021281202).
Tweetable abstract: Increasing registered nurse staffing and skill mix can be a net cost-saving solution to nurse shortages. Contrary to the strong policy push towards a dilution of nursing skill mix, investment in supply of RNs should become the priority.

What is already known

- Higher registered nurse staffing levels and skill mix in acute hospitals are associated with improved care quality and patient outcomes, most notably reduced risk of death.

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- Reviews of evidence have supported a causal interpretation of the observed associations.
- Reviews of economic evidence have failed to reach firm conclusions on cost-effectiveness.

What this paper adds

- The preponderance of economic evidence reviewed supports investments in registered nurse staffing and skill mix as a cost-effective solution to staffing shortages.
- Although the risk of bias in many studies is high, a richer registered nurse skill mix may be an economically dominant strategy, providing better outcomes at lower cost.
- More cost-effectiveness evidence is needed, but increases in registered nurse staffing could be highly cost effective with a low cost per quality adjusted-life year.

1. Introduction

Many countries face significant shortages of registered nurse supply, motivating calls for further investment in nurse training or the search for alternative ways of staffing wards, including the creation of new cadres of nursing staff with lower levels of qualifications and increased use of unregistered support staff (Twigg et al., 2016; Van den Heede et al., 2020). There is substantial evidence demonstrating that patients in hospitals with more registered nurses experience higher quality care and have lower risk of complications and death. However, the value of this information for guiding policy and operational decisions has often been questioned (Griffiths and Dall'Ora, 2023). In the face of competing demands for scarce financial and labour resources, economic evaluations are required to inform decision-making.

Several reviews have summarised evidence linking higher registered nurse staffing levels and skill mix to improved patient outcomes and quality, finding hundreds of studies from around the world (Dall'Ora et al., 2022; Kane et al., 2007; Shekelle, 2013; Twigg et al., 2019). The available evidence is almost exclusively observational but careful analysis of the body of evidence as a whole supports a conclusion that the observed associations arise, at least in part, from a causal relationship between nurse staffing and outcomes (Griffiths et al., 2016; Griffiths and Dall'Ora, 2023; Kane et al., 2007). Most evidence relates to reduced risk of death from higher nurse staffing levels or skill mix, but findings also indicate reduced complications, such as infections, and shorter lengths of stay, a major driver of potential cost savings. Findings from hospital level cross-sectional studies are increasingly supported by longitudinal patient level studies showing effects from exposure to low staffing (Dall'Ora et al., 2022). Exposure to low Registered Nurse (RN) staffing (variously defined) on general medical/surgical units typically increases the hazard of death by 2–3% (Dall'Ora et al., 2022).

With nurse staffing comprising a large proportion of the pay bill for hospitals the cost-effectiveness of nurse staffing improvements relative to other potential investments should not be assumed. Existing reviews have found a relatively small number of economic studies, which were hard to synthesise due to the differing methods and measures used (Griffiths et al., 2016; Twigg et al., 2015). The risk of bias in the underlying observational studies used to estimate effectiveness, and the limited economic perspective taken, have been noted as key limitations. Most effectiveness estimates come from cross-sectional studies and few studies consider costs beyond the immediate hospital stay (Twigg et al., 2015). These reviews are now dated and there is significant new evidence. In this paper we aim to provide an up-to-date review of economic studies of variation and change in nurse staffing levels and skill mix in acute hospitals to show the costs and consequences associated with different nurse staffing configurations in hospitals.

2. Methods

2.1. Study eligibility and search strategy

We included economic studies exploring the effect of variation in nurse staffing in acute hospital inpatient settings. We included studies that measured variation in staffing levels (e.g. nurse–patient ratio, nurse hours per patient day), understaffing (e.g. nurse staffing below specified threshold) or skill mix. Nurse staffing levels included any or all staff working as part of a nursing care delivery team in an inpatient unit (including registered nurses, Licensed Practical Nurses and nursing aides/assistants). We considered skill mix based on the mix of all staff considered as part of the nursing teams (e.g. registered nurses, licensed practical nurses, nursing assistants) and included studies that considered the educational level within staff groups (e.g. bachelor's degree qualification, diploma qualification) as well as the mix between staff groups (e.g. proportion of registered nurses in the team). For studies in maternity settings we also included registered midwives, as staffing practices, qualifications and titles of staff vary between countries (e.g. registered midwives vs registered nurse-midwives) and care settings (e.g. the deployment of registered nurses on post-natal wards). We excluded studies conducted in exclusively psychiatric/mental health care, community or long-term care and emergency departments.

We included cost-minimisation, cost-benefit, cost-consequences, cost-effectiveness and cost-utility studies conducted as part of prospective intervention studies (including randomised and quasi-experimental designs), observational studies and secondary modelling studies. Given the variety of economic evaluation approaches we did not limit the study selection in this regard although studies had to provide a direct monetary cost (as opposed to un-costed measure of resource use). Cost-minimisation studies that simply compared staff costs were not considered although studies that compared net costs of different staffing strategies were.

We searched PubMed, CINAHL, Embase, Econlit, Cochrane library (CDSR, CENTRAL, Protocols), Database of Abstracts of Reviews of Effectiveness (DARE), NHS EED and the International Network of Agencies for Health Technology Assessment website up to October 2022. Search terms are provided in Supplementary Material Table A. We considered all eleven studies from two existing systematic reviews (Griffiths et al., 2014; Twigg et al., 2015) and additional relevant texts found in authors' existing reference libraries and in the reference lists of seminal papers. We included peer-reviewed journal articles, theses and conference proceedings. We found no titles/abstracts of non-English papers that might have been considered for full text screening. The review was registered on PROSPERO (reference: CRD42021281202).

2.2. Data extraction

The initial search, deduplication and title/abstract screening were conducted by one reviewer. Potentially relevant studies were kept, and two reviewers reviewed full texts independently. Disagreements were resolved by discussion with the entire review team. Data extraction was undertaken by one reviewer and checked by a second. We extracted author(s), year, country and setting, study design, sample size, staff group(s), source of staffing data, measure of staffing levels/skill mix, natural variation/planned change, level of aggregation at which staffing measured and analysed, economic perspective, time horizon over which the consequences of nurse staffing variations are evaluated, costs and relevant outcomes. We extracted both costs and consequences when they were reported in a disaggregated fashion.

Where data was available to do so we calculated incremental cost per life saved. We translated these estimates into US$ and a common year for ease of comparison, first converting to 2021 costs using country specific inflation, then converting to equivalent costs in US$ using

Organisation for Economic Cooperation and Development (OECD) purchasing power parity tables (OECD, 2022). As there is no universally accepted threshold to show cost-effectiveness, we tabulated mortality-based incremental cost-effectiveness estimates against the relevant country's per capita gross domestic product (GDP).

2.3. Quality appraisal

We assessed the risk of bias in the underlying studies using a framework based on that used for the development of National Institute for Health and Care Excellence (NICE) public health guidance (Griffiths et al., 2014; National Institute for Clinical Excellence, 2012). Because most studies used routine administrative data for resource use and clinical outcomes, we focussed our assessment on items related to the underlying study design; sample size; representativeness of patient, hospital and staff samples in relation to the target populations for inference from the study; and control for confounding. Cross-sectional designs were rated as weak (high risk of bias) unless accompanied by additional features such as matching/propensity. Longitudinal studies and studies using individual patient exposure measures rated as strong (low risk of bias). As no power calculations were given and there was no consistent basis for determining precision in the face of varying staffing measures we classified studies as small <1000, medium < 10,000, or large 10,000+ based on the number of patients and assigned a risk of bias accordingly. Studies with no adjustment for variation in patient level risk were rated as weak (see Supplementary Appendix 1). We did not calculate summary scores, but we gave overall assessments based on the lowest scoring item. Risk of bias assessments were undertaken by two reviewers with disagreements resolved with reference to a third.

We additionally used Henrikson's framework, which brings together common domains from three economic reporting checklists (Henrikson and Skelly, 2013). We focussed particularly on assessing the comprehensiveness of cost/resource use, including the cost perspective, time horizon, and tests for sensitivity to key assumptions about costs, linked to precision and underlying bias of staffing outcome association estimate. We classified costs included as direct staff costs, general consequential (due to changes in length of stay), additional treatment costs, post-discharge care costs and societal costs. We gave a summary of the relative comprehensiveness of costs by summing the areas of cost covered. We classified the strength of the approach to economic analysis for decision making, ranging from lowest (cost-minimisation) low (cost-consequences) moderate (cost-effectiveness) to high (cost-utility/cost-benefit).

The diversity of the evidence made a formal assessment of publication bias unfeasible, but the issue and likely biases were addressed in narrative discussion. Similarly, we did not formally assess overall of strength of evidence/recommendations using GRADE (Guyatt et al., 2008) but used it to shape our discussion.

2.4. Synthesis & analysis

We considered statistical meta-analysis but heterogeneity in terms of interventions, range of costs considered and health economies amongst the studies we found led us to focus on qualitative reporting for synthesis. We performed a narrative synthesis, considering patterns of results. To support this we developed graphical displays based on a hierarchical matrix to summarise findings of economic evaluations, as described by Nixon et al. (2001). Constellations of results (increases/decreases in costs, improvements/decline in outcomes) are organised by the economic decisions that arise. In a classic health economic decision-making framework, where costs are increased and health outcomes are not improved, or if costs are unchanged and outcomes are worsened then an intervention should be rejected on economic grounds. Conversely if outcomes are improved and costs are not increased, the intervention should be accepted.

Other results, typically where improved outcomes are associated with increased costs, need an incremental cost-effectiveness analysis to inform decision making about whether an intervention should be accepted. A cost of 1 X the per capita gross domestic product per quality adjusted life year (QALY) is sometimes used as a threshold for defining cost-effectiveness, although many consider that this may be excessive (Claxton et al., 2015; Marseille et al., 2014). Therefore, we used the per capita gross domestic as a reference point, providing an upper bound for potential cost-effectiveness, considering the likely number of quality adjusted life years gained from averted deaths. If increases in staffing yield a cost per quality adjusted life year more than the per capita gross domestic product it is unlikely to be considered cost-effective by any criteria, although other benefits such as avoided complications, improved experiences preferences for reduced hospitalisation are not considered in such an analysis.

3. Results

We found 6783 studies from database searches and fourteen from other sources. 68 were retained after title and abstract screening and we included 24 papers reporting on 23 studies, which included one additional paper published in 2021 identified during the peer review process. See Fig. 1 for PRISMA flow chart and Table 1 for details of the studies.

3.1. Study characteristics

Most studies (17) addressed staffing on general medical and/or surgical units whilst the rest addressed specific surgical specialties or procedures (Behner et al., 1990; Kim et al., 2016; Li et al., 2011; Pang et al., 2019; Ross et al., 2021) or maternity care (Clark et al., 2014; Cookson et al., 2014). Publications were from 1990 to 2022 although data in some studies were considerably earlier than publication year. Most studies (16/23) were conducted in the United States of America (USA), three (reported in four papers) in the United Kingdom (UK) (Cookson et al., 2014; Griffiths et al., 2018, 2020b, 2021), and one each in Australia (Twigg et al., 2013), Belgium (Van den Heede et al., 2010), China (Pang et al., 2019) and South Korea (Kim et al., 2016). In total, data came from over 5900 hospitals and 42 million patients. See Table 1.

All studies were observational or sourced parameters and data for modelling from observational studies. Most studies used estimates of effects based on natural variation in registered nurse or midwife staffing expressed as a staff to patient ratio (or vice versa), using staffing outcome associations to model the effect of various changes in staffing levels. Three used parameters from natural variation to model the effects of planned change across health systems (Dall et al., 2009; Needleman et al., 2006; Van den Heede et al., 2010), typically increasing staffing to the 75th centile. Two studies used a mathematical simulation model to explore the effects of different approaches to determining staffing levels on achieved staffing (Griffiths et al., 2020b, 2021). In two studies the observed variation in staffing was associated with implementing a method to determine staff requirements which led to increased staffing levels (Twigg et al., 2013), or a minimum nurse to patient ratio staffing policy (McHugh et al., 2021).

3.2. Study quality and risk of bias

Overall, nine studies were rated as moderate risk of bias with the remaining rated as having a high risk of bias (see Table 2 & supplementary b). Because of large sample sizes and risk adjustment, most studies were assessed as low risk of bias related to power and control of confounders but the intrinsic design limitations of cross-sectional studies meant that only two studies (reported in three papers) were rated as strong for internal validity (Griffiths et al., 2018, 2020b, 2021), but the overall risk of bias was assessed as moderate because these were single site studies. A further seven were rated as moderate risk of bias in terms of internal

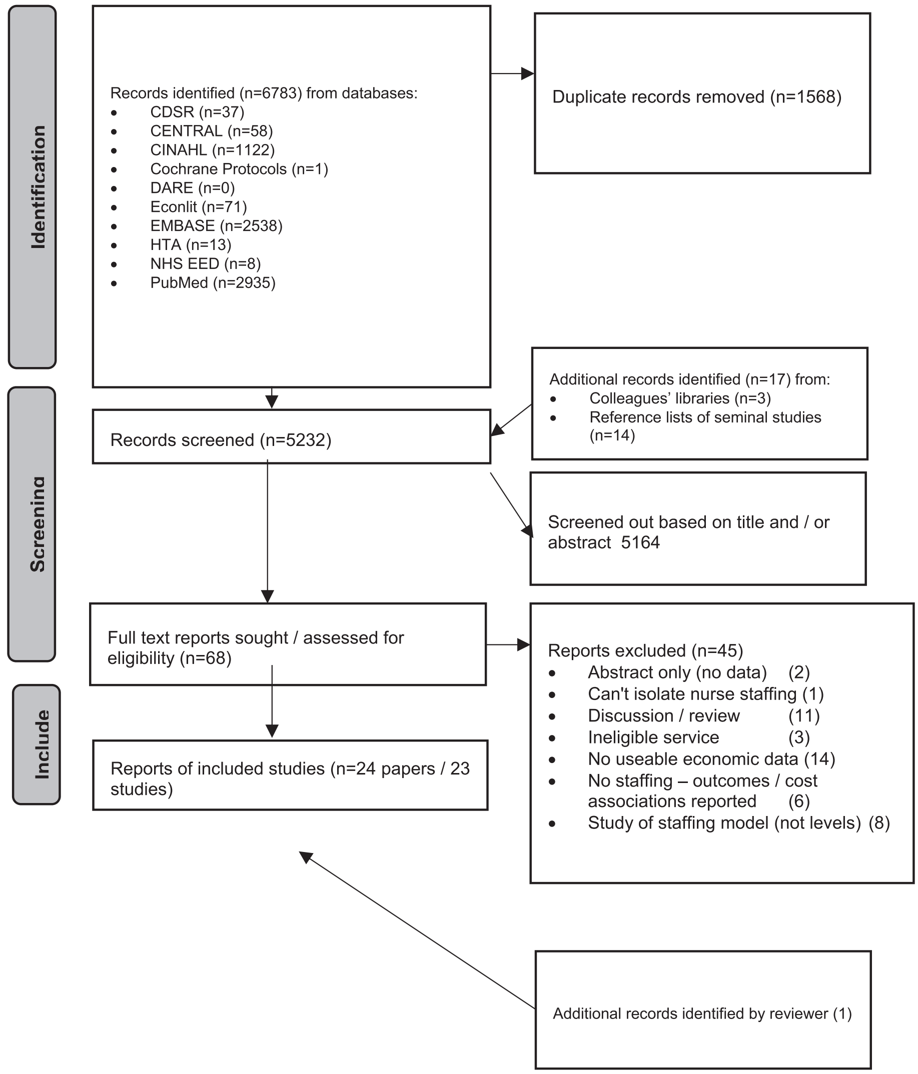

Fig. 1. PRISMA flow diagram.

validity (Lasater et al., 2021a, 2021b; Li et al., 2016; McHugh et al., 2021; Shamliyan et al., 2009; Twigg et al., 2013; Yakusheva et al., 2014).

Most studies (18) used estimates for the effect of nurse staffing that were cross-sectional in the sense that staffing levels are aggregated over a large unit (typically a hospital) over time (typically a year) and linked with outcomes of patients admitted over that period. Of these, four use potentially stronger matched cohort designs (Lasater et al., 2021a, 2021b; Li et al., 2016; Martsolf et al., 2014). Four studies provide (or use) estimates of staffing/outcome associations that directly link patients to staffing at a day or shift level (or equivalent) (Behner et al., 1990; Griffiths et al., 2020b, 2021; Yakusheva et al., 2014), one compared outcomes before and after a planned change in staffing (Twigg et al., 2013) and one derived estimates of effect with changes associated with implementing minimum staffing legislation (McHugh et al., 2021). Despite the preponderance of large multi-hospital studies, only seven studies were rated as potentially strong for external validity (Cookson et al., 2014; Dall et al., 2009; Li et al., 2011; Martsolf et al., 2014; Needleman et al., 2006; Shamliyan et al., 2009; Van den Heede et al., 2010) with a number of large studies down-graded to moderate risk of bias because there was a mismatch between the patient sub-group providing outcomes and the patient population served by the staff included.

We were unable to judge the likely direction of bias consistently, although the most pervasive likely source of bias is simultaneity, as staffing may be increased in response to risk. This bias is likely to lead to an underestimate of the effect of staffing increases (Dall'Ora et al., 2022; Griffiths et al., 2016). However, studies that assess associations with variation in staffing between hospitals potentially over-estimate nurse staffing effects, because the effect of staffing by other groups of staff and other hospital level resources, often strongly correlated with nurse staffing, is not considered (Dall'Ora et al., 2023).

The economic analysis in most studies was a disaggregated cost consequences analysis with a range of consequences reported – typically restricted to some or all of mortality rates, adverse incidents, length of stay and readmissions (see Table 2). The economic perspective was that of the hospital in most studies and in five studies only staffing costs were considered (Clark et al., 2014; Cookson et al., 2014; Li et al., 2011; Pang et al., 2019; Van den Heede et al., 2010). The remainder considered at least some consequential costs ranging from costs of extended stays, treatments of adverse events, readmissions and, in two cases, societal costs in terms of lost earning or productive capacity (Dall et al., 2009; Shamliyan et al., 2009). Whilst most studies took an immediate perspective on both outcomes and cost, two took a lifetime perspective on outcomes (Twigg et al., 2013; Van den Heede et al., 2010), estimating life expectancies, whilst two (Dall et al., 2009, Shamliyan et al., 2009) considered lifetime future earnings/productivity. We were able to extract or calculate a cost-effectiveness ratio related to death as an outcome from 9 studies (see Table 4) and one study provided cost–benefit analysis in terms of a ratio of staff costs to financial benefits arising from care cost savings and future productivity (Shamliyan et al., 2009). Whilst many studies undertook some form of

Table 1
Characteristics of included studies.

Paper	Country	Patient group	Study design	Source of variation	Level of aggregation for staffing	Hospitals	Patients	Economic analysis
Behner et al., 1990	USA	Back and neck procedures	Retrospective observational study	Natural variation	Patient stay	1	132	Cost-consequences (disaggregated) & net cost of avoiding low (20% below standard) staffing
Clark et al., 2014	USA	Maternity – induction of labour	Retrospective cross-sectional observational study	Natural variation	Hospital	110	101,377	Cost-consequences (disaggregated) of providing universal 1:1 midwifery care
Cookson et al., 2014	UK	Maternity	Retrospective cross-sectional observational study	Natural variation	Hospital	157	5,753,551	Cost-effectiveness (1 additional midwife per 100 deliveries)
Dall et al., 2009	USA	General med/surg	Secondary modelling (data from cross-sectional studies)[a]	Simulated change	Hospital	610	5,400,000	Cost-(monetary) benefits (disaggregated) and consequences of increased RN staffing
Griffiths et al., 2018	UK	General med/surg	Retrospective longitudinal observational	Natural variation	Patient day	1	138,133	Cost-effectiveness per additional RN hour per patient day and increasing skill mix to establishment
Griffiths et al., 2020b	UK	General med/surg	Simulation model (parameter data from retrospective longitudinal study)[b]	Simulated change	Shift	4	NA	Cost-consequences (low staffing) and effects of different baseline staffing policies
Kim et al., 2016	South Korea	Hip & knee surgery	Retrospective cross-sectional observational	Natural variation	Hospital	222	22,289	Care Cost (charges) consequences (disaggregated) of different patient:RN ratios in hospitals
Lasater et al., 2021a	USA	General med/surg (select)	Retrospective cross-sectional observational	Natural variation	Hospital	116	417,861	Cost-consequence (disaggregated) of changed patient:RN ratio
Lasater et al., 2021b	USA	General surg (select)	Matched cohort/retrospective cross-sectional observational	Natural variation	Hospital	306	125,430	Cost-effectiveness of composite nursing resource (staffing, skill mix, BSN mix and nurse reported work environment)
Lasater et al., 2021c	USA	General med (select)	Matched cohort/retrospective cross-sectional observational	Natural variation	Hospital	306	148,090	Cost-effectiveness of composite nursing resource (staffing, skill mix, BSN mix and nurse reported work environment)
Li et al., 2011	USA	General med/surg	Retrospective cross-sectional observational	Natural variation	Unit	125	110,646	Costs of additional nursing hour and increased RN skill mix
Li et al., 2016	USA	Cardiac surgery	Propensity matched cohort/retrospective cross-sectional observational	Natural variation	Hospital	1887	439,365	Cost-consequence (disaggregated) of hospital above median staffing (RN HPPD ≥ 7.07) vs below (HPPD < 7.07)
Martsolf et al., 2014	USA	General med/surg	Matched cohort/retrospective cross-sectional observational	Natural variation	Hospital	421	18,474,860	Cost-consequence (disaggregated) of additional nurse (RN/LPN) per 1000 admissions and higher RN/Licensed skill mix
McHugh et al., 2021	Australia	General med/surg	Quasi experimental panel	Natural variation and policy implementation	Hospital	55	489,155	Cost-consequences of implementing minimum nurse to patient ratios
Needleman et al., 2006	USA	General med/surg	Secondary modelling (data from cross-sectional studies)[a]	Simulated change	Hospital	799	5,075,969	Cost-consequences (disaggregated) of different staffing levels/configurations (HPPD)
Pang et al., 2019	China	Neurology/neuorsurgery	Prospective cross-sectional observational	Natural variation	Hospital	1	5091	Cost-consequence (disaggregated) of care in 6 wards with different proportion of RNs.

(continued on next page)

Table 1 (*continued*)

Paper	Country	Patient group	Study design	Source of variation	Level of aggregation for staffing	Hospitals	Patients	Economic analysis
Ross et al., 2021	USA	Pulmonary lobectomy	Retrospective cross-sectional observational study	Natural variation	Hospital	NA	16,944	Cost-consequence (disaggregated) of different staffing levels (RN FTEs per 1000 patient days)
Rothberg et al., 2005	USA	General med/surg	Secondary modelling (data from cross-sectional studies)[c]	Natural variation	Hospital	799	5,075,969	Cost-effectiveness per unit reduction in patient to nurse ratio
Shamliyan et al., 2009	USA	General med/surg	Secondary modelling (data from cross-sectional studies)[d]	Natural variation	Hospital	NA	NA	Net benefit and Cost-Benefit arising from avoided deaths (and adverse events – not reported) corresponding to a 1 FTE RN per 1000 patients increase
Twigg et al., 2013	Australia	General med/surg	Retrospective observational study	Implementation of new staffing levels	Hospital	3	214,261	Cost-effectiveness of implementing a NHPP method to guide nurse staffing
Van den Heede et al., 2010	Belgium	Cardiac surgery	Secondary modelling (data from cross-sectional studies)	Simulated change	Ward	28	9054	Cost-effectiveness of increasing nurse staffing to the 75th centile
Weiss et al., 2011	USA	General med/surg	Prospective cross-sectional observational	Natural variation	Ward	4	1892	Cost consequences (disaggregated) of increasing non overtime RN staffing
Yakusheva et al., 2014	USA	General med/surg	Retrospective observational study	Simulated change	Patient stay	1	8526	Cost consequences (disaggregated) of increasing % BSN qualified RN staffing

FTE – Full time equivalent, HPPD – Hours per patient day, LPN – Licensed Practical Nurse, Med – Medical, NA – Not applicable, RN – Registered Nurse, Surg – Surgical, BSN – Bachelors Science Nursing, UK – United Kingdom, USA – United States of America.
Studies providing effectiveness estimates:
[a] Needleman et al. (2001, 2002).
[b] Griffiths et al. (2018).
[c] Aiken et al. (2002).
[d] Kane et al. (2007).

sensitivity analysis, estimates of economic parameters did not reflect underlying uncertainty (e.g. 95% confidence intervals).

3.3. Costs and cost-effectiveness

For details of the main economic results see Table 3. In almost all studies the staffing level considered was professional nurses – either registered nurses or midwives alone or registered and licensed practical nurses (or equivalent) although the groups in one study were undefined (Behner et al., 1990) whilst one included both registered nurses and nurses' aides in staffing levels. In all cases, simple increases in staff led to increased staffing costs, as did increases in skill mix. Seventeen studies provided estimates of net costs associated with staffing increases, considering other costs/savings that might result from staff changes. Of these, five found that increases in registered nurse staffing levels in general medical/surgical or other surgical specialities led to reduced costs overall (Behner et al., 1990; Kim et al., 2016; McHugh et al., 2021; Shamliyan et al., 2009; Weiss et al., 2011). All but two of these studies were rated as high risk of bias. Of the studies with moderate risk of bias one found that economic benefits to society, including losses to productivity avoided, exceeded costs with a benefit to cost ratios for each additional registered nurse between 1.27 and 2.51 (Shamliyan et al., 2009). One additional registered nurse per 1000 surgical patients in US hospitals costs $923,832 but yielded a benefit of $1,646,190. For medical and intensive care, costs of an additional registered nurse per '000 patients ($982,800/$589,680) were also less than benefits ($1,244,061/$1,479,933). A second study rated as moderate risk of bias estimated that implementing mandatory minimum staffing levels in Australia (McHugh et al., 2021) also yielded net financial benefits with cost savings from reduced hospital stays and readmissions exceeding the costs of the increased staffing required to meet the mandatory minimums by a factor of two.

Two studies in US general medical/surgical patients found no statistically significant difference in net cost from staff increases (Lasater et al., 2021b; Martsolf et al., 2014) whilst the remaining ten found net cost increases (Dall et al., 2009; Griffiths et al., 2018, 2020b, 2021; Lasater et al., 2021a; Li et al., 2016, 2011; Needleman et al., 2006; Ross et al., 2021; Rothberg et al., 2005). In all but one study, there was evidence of improved health outcome associated with increased staffing. Clark et al. (2014) found increased costs but no statistically significant evidence of reduced complications from increased nurse staffing to achieve 1 to 1 staffing during induction of labour in US maternity settings.

For change of skill mix, all four studies that considered net costs found that a skill mix that was richer in registered nurses was associated with reduced net costs overall (Griffiths et al., 2018; Li et al., 2011; Martsolf et al., 2014; Needleman et al., 2006). Three studies found improved health outcomes from increasing the proportion of RNs in the nursing team in medical/surgical settings (Griffiths et al., 2018; Needleman et al., 2006; Pang et al., 2019) whilst a fourth found that increasing the proportion of bachelors educated RNs was associated with improved outcomes (Yakusheva et al., 2014). Of these studies two were assessed as moderate risk of bias with one rated as low risk of bias based on internal validity, although both were single site studies (Griffiths et al., 2018; Yakusheva et al., 2014).

Table 2
Assessment of economic study quality.

Study	Economic perspective	Discounting/time horizon?	Staff cost	Consequential	Treatment cost	Post-discharge cost	Societal costs	Sensitivity analysis	Range of costs[a]	Level of economic analysis[b]	Risk of bias in underlying study
Behner et al., 1990	Hospital	n/i	Salary	Hospital stay	AE			No	Moderate	Moderate	High
Clark et al., 2014	Hospital	n/i	Salary					No	Limited	Moderate	High
Cookson et al., 2014	Hospital	n/i	Employment					Yes	Limited	Moderate	High
Dall et al., 2009	Societal	y/life	Employment	Hospital stay	AE	Follow-up care	Productive value	No	Extensive	Moderate	High
Griffiths et al., 2018	Hospital	n/i	Employment	Hospital stay				Yes	Moderate	Moderate	Moderate
Griffiths et al., 2020b	Hospital	n/i	Employment	Hospital stay				Yes	Moderate	Moderate	Moderate
Kim et al., 2016	Hospital	n/i	Charges	Hospital stay				Yes	Moderate	Moderate	High
Lasater et al., 2021a	Hospital/patient	n/i	Hospital costs			Readmission		No	Moderate	Moderate	High
Lasater et al., 2021b	Hospital/patient	n/i	Employment	Hospital stay		Readmission		No	Moderate	Moderate	Moderate
Lasater et al., 2021c	Hospital/patient	n/i	Employment	Hospital stay		Readmission		Yes	Moderate	Moderate	Moderate
Li et al., 2011	Hospital	n/i	Hospital costs					Yes	Limited	Low	High
Li et al., 2016	Hospital	n/i	Hospital costs	Hospital stay	AE			Yes	Moderate	Moderate	Moderate
Martsolf et al., 2014	Hospital	n/i	Hospital costs	Hospital stay	AE			Yes	Moderate	Moderate	High
McHugh et al., 2021	Hospital	n/i	Salary	Hospital stay		Readmission		No	Moderate	Moderate	Moderate
Needleman et al., 2006	Hospital	n/i	Salary	Hospital stay	AE			No	Moderate	Moderate	High
Pang et al., 2019	Hospital	n/i	Employment					No	Limited	Moderate	High
Ross et al., 2021	Hospital	n/i	Hospital costs	Hospital stay				No	Moderate	Moderate	High
Rothberg et al., 2005	Hospital	n/i	Salary	Hospital stay				Yes	Moderate	Moderate	High
Shamliyan et al., 2009	Societal	y/life	Employment	Hospital stay	AE		Future earnings	Yes	Extensive	High	Moderate
Twigg et al., 2013	Hospital	y/life	Employment		AE			Yes	Moderate	Moderate	Moderate
Van den Heede et al., 2010	Hospital	y/life	Salary					Yes	Limited	Moderate	High
Weiss et al., 2011	Hospital/payer	n/i	Employment			Readmission		No	Moderate	Moderate	High
Yakusheva et al., 2014	Hospital	n/i	Salary			Readmission		Yes	Moderate	Moderate	Moderate

AE - adverse events, i - immediate, n - no, y - yes.
[a] Limited - 1 cost domain, Moderate - 2 or 3 cost domains, Extensive - 4 or 5.
[b] Low - cost only study, Moderate - cost consequences or cost effectiveness, High - cost utility or cost benefit.

Table 3
Summary of results.

	Country	Patient group	Main results
General medical/surgical			
Dall et al., 2009	USA	Med/surg	Employment costs of each additional RN $83,000 yield economic benefit (through reduced treatment costs and increased productivity) of $60,000. Net cost $23,000 ∗ 133,000 to save 5900 lives from increasing all hospitals to 75th centile
Griffiths et al., 2018	UK	Med/surg	Staff cost £65,092 (net cost £47,376) per life saved (1 RN HPPD increase). Staff cost £26,351 (net saving £486) from skill mix change +0.3 RN/−0.3 NA HPPD.
Griffiths et al., 2020b	UK	Med/surg	Staff cost only: standard staffing [achieved RN HPPD 3.6] vs low [achieved staffing 3.2 RN HPPD] baseline £ 19,437 per life saved. High staffing (achieved staffing 3.9 RNHPPD) £21,766 per life saved vs standard. Net cost per life saved £13,117/£8653
Lasater et al., 2021a	USA	Med/surg (select)	Moving all hospitals to a 4:1 average patient to RN ratio (current mean 6.3) lead to 4370 lives saved (ARR 1%) and $720 million saved in shorter lengths of stay (0.5 days per patient) and avoided readmissions (ARR 1.4%). Costs of increased staffing not included.
Lasater et al., 2021b	USA	Surg (select)	Better resourced hospitals (Mean 4.3 patient per nurse, 85% RN skill mix, 68% BSN nurse, PES 3.01) cost $203,500 per life saved vs worse resourced (Mean 5.8 patient per nurse, 78% RN skill mix, 43% BSN PES 2.68)
Lasater et al., 2021c	USA	Med (select)	Better resourced hospitals (Mean 4.3 patient per nurse, 85% RN skill mix, 68% BSN nurse, PES 3.01) had lower 30 day mortality (16.1 vs 17.1%) shorter stays (5.38 vs 5.66) more Intensive Care admissions (5.38 vs 5.66%) fewer readmissions (32.3 vs 33.6%) vs worse resourced (Mean 5.8 patient per nurse, 78% RN skill mix, 43% BSN PES 2.68) Costs (net) were similar ($18,848 vs 18,671 NS).
Li et al., 2011	USA	Med/surg	Surgical admissions, + 1 HPPD (RN, Licensed Practical/Vocational & assistant nurses) cost $261.45 (NS $p = 0.095$) + 1% skill mix cost $27.54 (NS $p = 0.253$) per admission. Medical admissions, + 1 HPPD cost $164.49 ($p < 0.001$) & + 1% skill mix cost saved $2.73 (NS $p = 0.704$)
Martsolf et al., 2014	USA	Med/surg	Additional licensed nurse (RN/LPN) per 1000 inpatient days associated with a −0.25% reduction in adverse events 0.033 reduction in length of stay and a $166.5 increase in cost (NS -$35 to $368.1 95% CI). 1% increase in percentage of licensed nurses that are RNs is associated with $87 reduction in cost.
McHugh et al., 2021	Australia	Med/surg	167 FTE needed to meet ratio requirements for RN/enrolled nurses at a cost of $33,000,000 would prevent 145 deaths, avoid 29,222 days of stay and 255 readmissions at a net cost of $33,000,000 AU$ saving $67,561,264 from LoS and AU$1,589,594 from readmissions
Needleman et al., 2006	USA	Med/surg	Raising the number of licensed nurse hours nationally to the 75th centile (10.23 HPPD) cost $7538 (staff) $5819 (net) million, avoids 1801 deaths, 10,813 adverse outcomes and 2,598,339 hospital days. Raising the proportion of RNs in licensed hours to the 75th percentile (0.94) cost $811 (staff) saves- $242 million (net), avoids 4997 deaths, 59,938 adverse outcomes and 1,507,493 hospital days. Raising the proportion of RNs and the number of licensed hours to the 75th percentile cost $8488 (staff) $5716 (net) million nationally and avoids 6754 deaths, 70,416 adverse outcomes and 4,106,315 hospital days.
Rothberg et al., 2005	USA	Med/surg	Incremental cost per life saved moving from Patient to RN ratio of 8:1 to 7:1 $45,900 (staff)/$24,900 net. Moving from 5:1, a ratio of 4:1 incremental cost per life $142,100 (staff) $70,700 (net).
Shamliyan et al., 2009	USA	Med/surg	1 additional RN per additional 1000 admissions in intensive care cost $589,680 vs societal benefit $1,479,933, benefit/cost ratio 2.51. Surgical $923,832/$1,646,190/1.79. Medical $982,800/$1,244,061/1.27
Twigg et al., 2013	Australia	Med/surg	Pre to post net 12% increase in RN hours: Staff cost per life year AU$13,575, net AUD$8907.
Weiss et al., 2011	USA	Med/surg	Increasing RN (non-overtime) staffing by 1 standard deviation (0.75 h per patient day) led to staffing cost $145.74 with a net -$409.59 saving (due to reduced readmissions). Reducing RN overtime staffing by 1 standard deviation (0.07 h per patient day) lead to reduced staff cost of $8.18, net saving $19.16 per patient.
Yakusheva et al., 2014	USA	Med/surg	Increasing the BSN-educated staff to 80%/100% cost between $1,843,266 & $3,446,106 with $5,653,022.97 cost savings from shorter stays (−0.03 days) and readmission rate (−1.7%)
Maternity			
Clark et al., 2014	USA	Induction of labour	Staff cost of universal 1:1 midwifery staffing $97,000,000 (1618 FTE staff) no evidence of benefits in terms of complications
Cookson et al., 2014	UK	General labour	Incremental cost effectiveness ratio £85,560 per 'healthy mother' (staff) £193,426 per delivery with bodily integrity from one additional midwife per 100 births.
Other			
Behner et al., 1990	USA	Surg (back and neck)	Days of low nurse staffing (20%+ below standard) reduce staff cost (−$13,600) CONSEQUENCE 34% absolute increase in risk of complications NET cost +$17,200 ($130 per patient). Nurse staffing undefined
Kim et al., 2016	South Korea	Surg (hip & knee)	Patients in hospitals with high staffing by RNs and nurse aides (beds/nurse ratio ≤ 2.0) are charged $US 1142.2 less than those with the lowest nurse staffing level (beds/nurse ratio ≥ 6.0) and have shorter stays (13 vs 25)
Li et al., 2016	USA	Surg (cardiac)	Hospitals with higher RN staffing had higher mean costs $2123, a 10% to 25% reduction in Healthcare Acquired Infections, a 6% reduction in mortality and 0.3 day reduction in mean LOS.
Pang et al., 2019	China	Med/surg (neuro)	Compared with 100% RNs: 75% RNs is associated with a decrease in staff costs of CN¥573 (22%) an increase in urinary tract infection (1.503 OR, 1.189–1.900 95% CI, $p = 0.001$), fewer medication errors (0.684 OR, 0.499–0.936 95% CI, $p = 0.018$) and successful ventilator weaning (0.677 OR, 0.592–0.775 95% CI, $p < 0.001$). Other outcomes NS.
Ross et al., 2021	USA	Surg (pulmonary lobectomy)	Compared to low staffed hospitals (≤3.5 RN FTEs per 1000 patient days) hospitals with ≥5.6 had $4388 increased costs, 0.37-day shorter stays & 36% lower odds of mortality (OR = 0.64, $p = 0.014$), compared to ≤3.5.
Van den Heede et al., 2010	Belgium	Surg (cardiac)	On average, increasing RN staffing to the 75th percentile, additional 0.8 FTE per unit costing total €1,211,022, €26,372 per life saved, €2639 per life-year gained

BSN – Bachelors Science Nursing, CI – Confidence Interval, FTE – Full time equivalent, HPPD – Hours per patient day, NS – Not significant, RN – Registered Nurse, RR – Relative risk, OR – Odds ratio, PES – Practice Environment Scale.

Fig. 2 summarises results of those studies that provided estimates of both outcomes and costs in a hierarchical matrix (Nixon et al., 2001). In total six studies provided results that clearly supported increased registered nurse staffing when using net costs, with a combination of no statistically significant cost change but improved outcomes (Lasater et al., 2021b, Martsolf et al., 2014) or reduced costs and improved outcomes (Behner et al., 1990; McHugh et al., 2021; Shamliyan et al., 2009; Weiss et al., 2011) in medical and/or surgical wards. Of these, three studies were rated as moderate for the underlying risk of bias (Lasater et al., 2021b; Martsolf et al., 2014; McHugh et al., 2021). However, most studies showed both increased costs and improvements in health outcomes, where incremental (cost-effectiveness) analysis is required

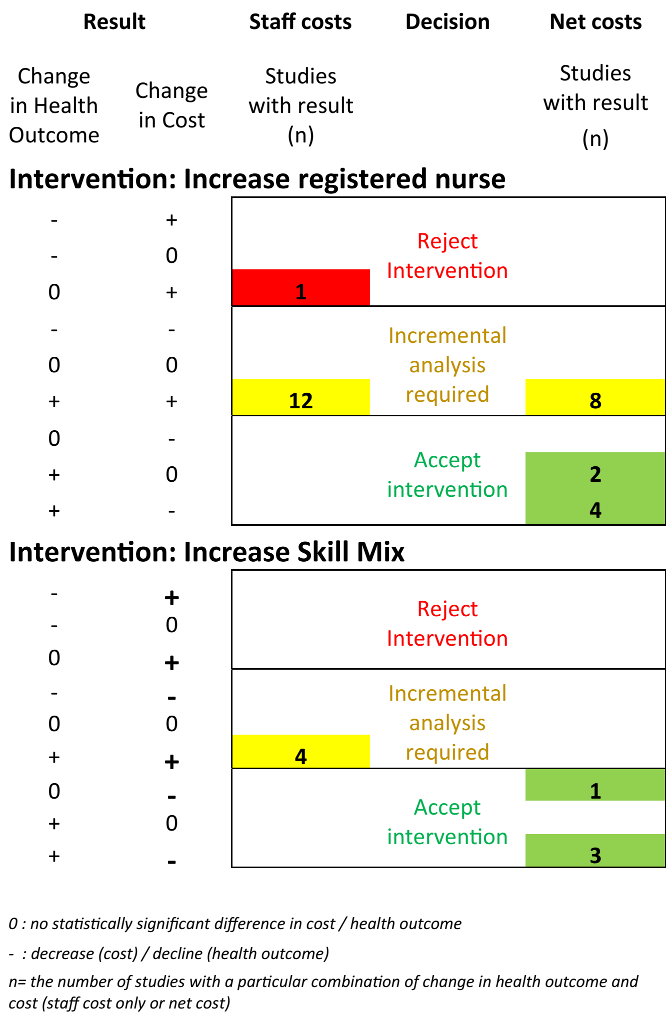

Fig. 2. Hierarchical matrix to summarise findings & economic conclusions from economic studies of nurse staffing/skill mix increase.

to inform the economic decision. A single study gave results that clearly reject staffing increases, but this used limited cost data and was at high risk of bias (Clark et al., 2014). All four studies that considered net costs supported a decision to increase skill mix (Griffiths et al., 2018; Martsolf et al., 2014; Needleman et al., 2006; Yakusheva et al., 2014), although if using staff costs alone the results of four studies with improved outcomes and increased costs mean that incremental analysis is required for decision making.

In Table 4, cost-effectiveness estimates are summarised, alongside the 2021 per capita gross domestic product of the country providing the estimate. Twigg et al. (2013) & Van den Heede et al. (2010) provide cost per life year for nurse staffing increases in Australian general medical/surgical units and Belgium cardiac units respectively. In both cases the cost per life year is far below per capita gross domestic product and adjustment for loss of utility (quality) is unlikely to substantively alter the conclusions that the staffing increases are likely to be cost-effective at a gross domestic product-based threshold. McHugh et al. (2021) found net cost savings from staff increases due to a mandatory minimum staffing policy and so the policy dominates the economic decision (better outcomes at reduced cost), largely due to savings from reduced length of hospital stay. For four studies in US and UK general medicine/surgery settings, the ratio between per capita gross domestic product/cost per life saved ranged from 0.3 (Lasater et al., 2021b) to 3.2 (Lasater et al., 2021a), although both the US studies provided estimates for a 'combined' intervention, implying both increased registered nurse staffing and additional changes in skill mix beyond that which would result from the staff increases. Even the higher end of this range is potentially cost-effective if each 'life saved' gains 3.2 quality adjusted life years. Other US studies require that each life saved yield more than 12 quality adjusted life years (Dall et al., 2009) or, in the case of Needleman et al. (2006) nearly 70 quality adjusted life years to achieve the gross domestic product based threshold.

4. Discussion

We have identified economic evaluations of change in the size and/or composition of the nursing midwifery staff in hospitals and have found additional evidence not considered in previous inconclusive reviews. The evidence is extensive, with twenty-three studies using data

Table 4
Costs per life saved from studies of increased staffing.

Paper	Country	Patient group	Intervention	Cost per life (*life year) saved (2021 equivalent)	Cost per life (*life year) saved (2021 US$ PPPE)	2021 per capita GDP (in US$)
Dall et al., 2009	USA	General med/surg	Increasing RN staffing in all hospitals to 75th centile	US$839,930	$839,930	$69,287
Griffiths et al., 2018	UK	General med/surg	Increase of 1 RN Hour per patient day	GB£54,009	$77,957	$47,334
Griffiths et al., 2020b	UK	General med/surg	Standard staffing policy [achieved RN HPPD 3.6] vs low staffing [achieved staffing 3.2 RN HPPD]	US$14,560	$21,016	$47,334
Lasater et al., 2021b	USA	General surg (select)	Better resourced hospitals (Mean 4.3 patient per nurse, 85% RN skill mix, 68% BSN nurse) vs worse resourced (mean 5.8 patient per nurse, 78% RN skill mix)	US$221,815	$221,815	$69,287
Lasater et al., 2021c	USA	General med (select)	Better resourced hospitals (Mean 4.3 patient per nurse, 85% RN skill mix, 68% BSN nurse) vs worse resourced (Mean 5.8 patient per nurse, 78% RN skill mix, 43% BSN)	US$18,127	$18,127	$69,287
McHugh et al., 2021	Australia	General med/surg	Increase staffing to meet specified ratio policy	AU$0 (-AU$227,586)	US$0 (−$158,158)	$59,934
Needleman et al., 2006	USA	General med/surg	Raising the number of licensed hours nationally to the 75th centile	US$4,840,377	$4,840,377	$69,287
Twigg et al., 2013	Australia	General med/surg	Implementation of RN hours per patient day staffing model – net 12% increase in RN hours.	AU$12,114*	$8418*	$59,934
Van den Heede et al., 2010	Belgium	Cardiac surgery	Increasing staffing to the 75th percentile (additional 0.8 FTE per unit)	€3510*	$4726*	$51,768

BSN – Bachelors Science Nursing, FTE – Full time equivalent, GDP – Gross domestic product, HPPD – Hours per patient day, Med – medical, PPPE – Purchasing power parity equivalent, RN Registered Nurse, Surg – surgical.

from many millions of patients over many countries. The largest body of evidence relates to registered nurse staff levels in adult medical and/or surgical wards with a smaller number of studies addressing skill mix. Most studies found that staffing increases provided results consistent with cost-effectiveness based on a per capita gross domestic threshold for cost per quality adjusted life year. In many cases staffing increases were consistent with cost-effectiveness at a considerably lower threshold. In some cases a decision to increase staffing was economically dominant because net costs were reduced or unchanged and outcomes improved. In studies exploring skill mix, increased skill mix (higher proportion of RNs or increased qualification of RNs) was an economically dominant strategy based on consideration of net costs, which were reduced. However, evidence came from diverse contexts and evaluated a range of different interventions and the quality of the underlying observational studies had, at best, a moderate risk of bias.

Nonetheless, although there are limitations in the evidence, we judge that there is moderate certainty that our findings in relation to nurse staffing levels and skill mix in general hospitals are correct. There is considerable degree of consistency in results, especially in relation to improvements in outcomes. The effects on mortality across these economic studies, mostly based on cross-sectional associations, are consistent with those observed in longitudinal studies which are, in general, at much lower risk of bias (Dall'Ora et al., 2022). Although there are mechanisms that can bias estimates in both directions, the most pervasive likely source of bias is when staffing is increased in response to higher risk. This bias is likely to lead to an underestimate of the effect of staffing increases and so an over-estimate of the cost of staffing required to achieve improvements (Dall'Ora et al., 2022; Griffiths et al., 2016). Most studies considered a limited range of costs, in many cases considering the cost of extended stays only. Therefore, decisions based on these cost-effectiveness estimates could be regarded as 'conservative' in the sense that cost per life saved is likely to be lower than that estimated in the studies.

Both the cost-effectiveness of nurse staffing increases and decisions based on such evidence are contingent, and evidence from local contexts is desirable. Nonetheless all evidence from countries other than the USA gave results that are compatible with cost-effectiveness at a per capita GDP per quality adjusted life year-based threshold. In the simplest case, a blanket 1 h per patient per day increase in registered nurse staffing in the UK costs $77,957 per life saved (2021 US$ equivalent) (Griffiths et al., 2018). In the context of a per capita GDP of $47,334, this would be cost-effective if each life saved gained 1.6 quality adjusted life years. Discounted quality adjusted life expectancy for an 80–90 year old with comorbidities in the UK is estimated to be over 2 years (Briggs et al., 2021), with over 6 years estimated for a population similar to the inpatient population at risk (Briggs et al., in press). Thus, it seems likely that the staffing change is cost-effective at this high threshold and possible that it would remain cost-effective if a much lower threshold is applied.

Other cost-effectiveness estimates were based on more complex staffing changes, such as bringing all hospitals up to a defined level of staffing, improved staffing and skill mix combined or changed baseline staff establishments to meet varying need. In general, these results were more favourable to increased staffing (i.e. lower cost per life or life year saved). Such evidence is consistent with cost-effectiveness of staffing increases being enhanced by targeted intervention, focussed on areas with greater deficit or guided by validated staffing tools. However, evidence for the validity of currently used patient classification systems and other staffing systems to determine staffing requirements is extremely limited and so the evidence base to guide targeting decisions is equally limited (Griffiths et al., 2020a).

Per capita GDP is a high threshold for cost-effectiveness and may not reflect a society's willingness to pay. Substantially lower thresholds have been proposed as the basis for a decision to invest in a health technology and treatments. In a resource constrained system, consideration must be given to the opportunity costs when considering whether or not the health benefits gained are greater than the health that is likely to be lost because resources are not deployed elsewhere (Claxton et al., 2015). In the UK context, the National Institute for Health and Care Excellence, the body charged with assessing evidence to inform health care provision in the publicly funded health system, identified £10,000 per QALY ($15,572 2021 US$ equivalent) as representing '*exceptional value for money*', meaning that a drug could be fast-tracked for availability in the National Health Service (National Institute for Health and Care Excellence (NICE), 2017). In most cases it seems likely that staff increases could be cost-effective at this lower threshold. To this must be added the weight of six studies where staff increases were associated with improved outcomes and reduced net costs, where the decision to increase staffing dominates.

The major exception to a conclusion of likely cost-effectiveness comes from two US studies where costs per life saved from registered nurse staffing increases in general medical surgical units are many multiples of per capita GDP (Dall et al., 2009; Needleman et al., 2006). Other US studies suggest that even at this level there may be net societal benefit once lost productivity is considered (Dall et al., 2009; Shamliyan et al., 2009). Whilst this societal perspective is important, it may have less influence on those providing or paying for services if immediate costs far outweigh immediate benefits. A recent US study may shed some light on this apparent difference between US studies and those from other countries. A panel study of over 2000 US hospitals found complex interactions and non-linear relationships between staffing level, outcomes, and costs. In simple terms, increases in staffing were initially associated with reduced costs and improved outcomes. As staffing levels increased, both associations were subject to tipping points so further increases in staffing became associated with increased costs and (at a higher level) no further improvements in outcomes (Peng et al., 2022). We found very limited evidence about staffing in maternity settings. Although one US study found increased costs and no evidence of benefit, the context was very specific and both outcomes and costs considered were limited.

Across all countries, including the USA, the economic arguments for increasing the proportion of Registered Nurses are more compelling than the argument for absolute increases. Although the findings about changes in skill mix are consistent, the limited sensitivity analyses around economic parameters mean that it is unclear how sensitive conclusions might be to wage differentials between staff groups or differently qualified or experienced staff.

4.1. Limitations

The mortality-based outcomes considered for cost-effectiveness here are not the only value that can be delivered from increased staffing. Whilst long term health gains might best be reflected in quality adjusted life years, these are insensitive measures and may not reflect important but less tangible benefits, for which individual healthcare consumers and society in general would still be willing to pay. Some of these benefits may be represented by improved patient experience and patient satisfaction, which are also associated with increased nurse staffing in several studies (e.g. Aiken et al., 2002; Bridges et al., 2019). Specific conclusions about cost-effectiveness cannot be generalised, although a degree of consistency in results does give an indication of likely outcomes in other contexts. In summarising cost effectiveness estimates we treated 'null' results (i.e. not statistically significant) as 0 effect/cost difference. Because most studies were very large and confidence intervals were narrow, the range of possible effects was small and close to 0, and so this simplifying assumption seems warranted, although we did not formally determine minimally important differences.

Our searching was extensive, but the imprecise terminology and large number of potential studies mean it is possible that some studies were missed. We were unable to assess publication bias but selective non-reporting of results that are less favourable to higher nurse staffing or skill mix is a possibility. However, it would require several studies with materially different results to change our conclusions. Our risk of bias assessment led most cross-sectional studies to be downgraded to a high risk of bias. Whilst this is broadly correct, because there are intrinsic limitations to such designs that can never be fully resolved and uncertainty that cannot be quantified, this downgrading does mean that the relative strengths of some large well conducted studies may not be fully recognised. Paradoxically, studies with a high risk of bias could still produce unbiased estimates and the general agreement between the results of longitudinal studies and those of cross-sectional studies is evidence that this may be the case.

4.2. Conclusions

Whilst there may be residual uncertainty around the cost-effectiveness of registered nurse staffing increases, the evidence of this review lends no support to policies that maintain or increase the size of the nursing workforce through skill mix dilution. In absolute terms the evidence is limited but the conclusions are clear. Increasing the proportion of registered nurses is associated with improved outcomes and, potentially, reduced net cost. Conversely reducing skill mix could increase costs and make outcomes worse. Limitations of current evidence could bias estimates of both effect and relative costs of registered nurse staffing increases in either direction, but the evidence shows that increased registered nurse staffing is potentially highly cost effective. Local economic evaluations using methods that minimise bias are needed to show incremental cost-effectiveness to inform decisions.

Studies of nurse staffing-outcome associations continue to be published without any estimates of costs and cross-sectional studies routinely fail to consider staffing by other professional groups. The marginal utility of studies with such limitations is low and the priority for future research should be the use of more robust designs and the inclusion of economic evaluation using measures such as quality adjusted life years. As it seems likely that cost-effectiveness can be maximised by targeting staffing increases to areas of greatest need, more research is required to validate staffing tools, including patient classification systems, to guide such decisions, as current evidence is limited.

In an era of registered nurse scarcity, our results strongly favour investment in registered nurse supply as opposed to using lesser qualified staff as substitutes. Our analysis gives support for increases in nurse skill mix and shows that policies that lead to a reduction in the proportion of registered nurses in nursing teams could give worse outcomes at increased costs. Although more evidence on cost-effectiveness is still needed, increases in absolute numbers of registered nurses in general medical and surgical wards have the potential to be highly cost effective, especially where baseline staffing is low.

Other contributors

Paul Schmidt of Portsmouth Hospitals University NHS Trust and Francesca Lambert of the University of Southampton both contributed to acquiring funding for the study. Francesca also supported the author team throughout by giving advice and asking questions from a lay perspective in her role as patient and public involvement and engagement lead. She also provided administrative support. Bruna Rubbo (University of Southampton) supported the project.

CRediT authorship contribution statement

Peter Griffiths: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Christina Saville:** Writing – review & editing, Writing – original draft, Validation, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Jane Ball:** Writing – review & editing, Methodology, Funding acquisition, Data curation, Conceptualization. **Chiara Dall'Ora:** Writing – review & editing, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Paul Meredith:** Writing – review & editing, Validation, Investigation, Funding acquisition, Data curation, Conceptualization. **Lesley Turner:** Writing – review & editing, Validation, Investigation, Formal analysis, Data curation, Conceptualization. **Jeremy Jones:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

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Erratum regarding missing declaration of competing interest statements in previously published articles

The IJNS has a long-standing policy that when editors publish in the journal, they are not involved in making decisions about papers which:

- They have written themselves.
- Have been written by family members or colleagues.
- Relate to products or services in which they have an interest.

This policy has been in place for some time and the names of the editorial team are published in every issue of the journal. However we have not consistently recorded the relationship with the journal as a potential conflict of interest on the papers themselves. We apologize for the omission and would like to acknowledge the potential conflict for the articles listed below. We would like to assure readers that members of the editorial team are never involved in the review process of papers for which they are authors.

1. "The association between nurse staffing and quality of care in emergency departments: A systematic review" [International Journal of Nursing Studies, May 2024; Volume 153, 104,706] https://doi.org/10.1016/j.ijnurstu.2024.104706
2. "Costs and cost-effectiveness of improved nurse staffing levels and skill mix in acute hospitals: A systematic review" [International Journal of Nursing Studies, November 2023; Volume 147, 104,601] https://doi.org/10.1016/j.ijnurstu.2023.104601
3. "Nurse staffing levels and patient outcomes: A systematic review of longitudinal studies" [International Journal of Nursing Studies, October 2022; Volume 134, 104,311] https://doi.org/10.1016/j.ijnurstu.2022.104311
4. "Integral leadership in nursing: Development and psychometric validation of a Korean version of the Integral Nursing Leadership Scale" [International Journal of Nursing Studies, April 2024; Volume 152, 104,697] https://doi.org/10.1016/j.ijnurstu.2024.104697
5. "Enhancing skin health and safety in aged care (SKINCARE trial): A cluster-randomised pragmatic trial" [International Journal of Nursing Studies, January 2024; Volume 149, 104,627] https://doi.org/10.1016/j.ijnurstu.2023.104627
6. "Skin assessments and interventions for maintaining skin integrity in nursing practice: An umbrella review" [International Journal of Nursing Studies, July 2023; Volume 143, 104,495] https://doi.org/10.1016/j.ijnurstu.2023.104495
7. "Body listening in the link between symptoms and self-care management in cardiovascular disease: A cross-sectional correlational descriptive study" [International Journal of Nursing Studies, August 2024; Volume 156, 104,809] https://doi.org/10.1016/j.ijnurstu.2024.104809
8. "Patterns of self-care decision-making and associated factors: A cross-sectional observational study" [International Journal of Nursing Studies, February 2024; Volume 150, 104,665] https://doi.org/10.1016/j.ijnurstu.2023.104665
9. "The effectiveness of self-care interventions in chronic illness: A meta-analysis of randomized controlled trials" [International Journal of Nursing Studies, October 2022; Volume 134, 104,322] https://doi.org/10.1016/j.ijnurstu.2022.104322
10. "The handling of hazardous medications by nurses and midwives: A retrospective cohort study" [International Journal of Nursing Studies, December 2024; Volume 160, 104,889] https://doi.org/10.1016/j.ijnurstu.2024.104889
11. "The relationship between nursing home staffing and resident safety outcomes: A systematic review of reviews" [International Journal of Nursing Studies, February 2024; Volume 150, 104,641] https://doi.org/10.1016/j.ijnurstu.2023.104641
12. "Work-schedule management in psychiatric hospitals and its associations with nurses' emotional exhaustion and intention to leave: A cross-sectional multicenter study" [International Journal of Nursing Studies, October 2023; Volume 146, 104,583] https://doi.org/10.1016/j.ijnurstu.2023.104583
13. "Care coordination in homecare and its relationship with quality of care: A national multicenter cross-sectional study" [International Journal of Nursing Studies, September 2023; Volume 145, 104,544] https://doi.org/10.1016/j.ijnurstu.2023.104544
14. "Increasing implicit rationing of care in nursing homes: A time-series cross-sectional analysis" [International Journal of

DOIs of original article: https://doi.org/10.1016/j.ijnurstu.2022.104256, https://doi.org/10.1016/j.ijnurstu.2022.104322, https://doi.org/10.1016/j.ijnurstu.2023.104641, https://doi.org/10.1016/j.ijnurstu.2023.104583, https://doi.org/10.1016/j.ijnurstu.2024.104706, https://doi.org/10.1016/j.ijnurstu.2024.104889, https://doi.org/10.1016/j.ijnurstu.2022.104283, https://doi.org/10.1016/j.ijnurstu.2023.104601, https://doi.org/10.1016/j.ijnurstu.2023.104495, https://doi.org/10.1016/j.ijnurstu.2023.104665, https://doi.org/10.1016/j.ijnurstu.2022.104311, https://doi.org/10.1016/j.ijnurstu.2023.104544, https://doi.org/10.1016/j.ijnurstu.2023.104669, https://doi.org/10.1016/j.ijnurstu.2024.104697, https://doi.org/10.1016/j.ijnurstu.2023.104627, https://doi.org/10.1016/j.ijnurstu.2024.104809, https://doi.org/10.1016/j.ijnurstu.2022.104320, https://doi.org/10.1016/j.ijnurstu.2021.104093, https://doi.org/10.1016/j.ijnurstu.2023.104494.

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Nursing Studies, October 2022; Volume 134, 104,320] https://doi.org/10.1016/j.ijnurstu.2022.104320
15. “Voice, silence, perceived impact, psychological safety, and burnout among nurses: A structural equation modeling analysis” [International Journal of Nursing Studies, March 2024; Volume 151, 104,669] https://doi.org/10.1016/j.ijnurstu.2023.104669
16. “Adapting the Geriatric Institutional Assessment Profile for different countries and languages: A multi-language translation and content validation study” [International Journal of Nursing Studies, October 2022; Volume 134, 104,283] https://doi.org/10.1016/j.ijnurstu.2022.104283
17. “Assessing the influence of patient language preference on 30 day hospital readmission risk from home health care: A retrospective analysis” [International Journal of Nursing Studies, January 2022; Volume 125, 104,093] https://doi.org/10.1016/j.ijnurstu.2021.104093
18. “Should I stay or should I go?” Nurses' perspectives about working during the Covid-19 pandemic's first wave in the United States: A summative content analysis combined with topic modeling” [International Journal of Nursing Studies, July 2022; Volume 131, 104,256] https://doi.org/10.1016/j.ijnurstu.2022.104256
19. “Feasibility and effectiveness of artificial intelligence-driven conversational agents in healthcare interventions: A systematic review of randomized controlled trials” [International Journal of Nursing Studies, July 2023; Volume 143, 104,494] https://doi.org/10.1016/j.ijnurstu.2023.104494