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Evaluating the effects of increasing nursing numbers on quality of newborn care in understaffed neonatal units in Kenya: a prospective intervention study

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► Additional supplemental material is published online only. To view, please visit the journal online (https://doi.org/10.1136/bmjqs-2025-019024).

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Received 14 May 2025
Accepted 29 September 2025

To cite: Imam A, English M, Aluvaala J, *et al*. *BMJ Qual Saf* Epub ahead of print: [please include Day Month Year]. doi:10.1136/bmjqs-2025-019024

ABSTRACT

Background Newborn units in resource-constrained low-middle-income countries (LMICs) often have high neonatal mortality rates. Programmes to improve care quality often accept understaffing that directly affects care in these settings as a norm, and the effects of improving staff numbers are not studied. To address a major evidence gap, we examined the effects on quality of care of improving nurse staffing in four intermediate-level Kenyan newborn units.

Methods We introduced three additional nurses to each of four newborn units. We measured nursing care provision using direct bedside observations with a validated structured checklist before and 6 months after intervention. Our primary outcome, changes in nurse-delivered care, was examined using descriptive analysis and multilevel modelling to adjust for confounding. We also examined the pattern of nursing care delivery and intervention fidelity.

Results We observed a total of 1872 hours of care, over 156 nursing shifts for 290 and 300 babies before and after our intervention, respectively, across our four neonatal units. Our intervention increased the nursing hours per patient per shift observed from 34 to 43 min associated with a 4.7% increase in our primary outcome, nurse-delivered care and an 8.4% increase in delivery of 10 tasks nurses prioritise (adjusted B-coefficient 0.047 (95% CI 0.028 to 0.066) and B-coefficient 0.084 (95% CI 0.053 to 0.115), respectively). Intervention strength was reduced by changes in existing nurses' deployment and an increase in workload.

Conclusions In very high workload settings in LMICs where nurses can only deliver a fraction of nursing care, staffing increases improve care delivery more obviously for high-priority tasks. These findings provide much needed evidence that increasing neonatal nurse staffing in under-resourced newborn units improves care quality.

WHAT IS ALREADY KNOWN ABOUT THIS TOPIC

⇒ Available evidence for the role of nurse staffing levels in improving the quality of patient care primarily comes from observational studies in high-income countries.

WHAT THIS STUDY ADDS

⇒ To the best of our knowledge, this study is the first prospective workforce (nursing) intervention study in any setting, and it shows that such interventions are feasible.

⇒ We demonstrate that improving nurse staffing by a fraction in low-resource settings is associated with a measurable increase in the quality of newborn care.

HOW MIGHT THIS STUDY AFFECT RESEARCH, PRACTICE OR POLICY

⇒ This study provides strong evidence for policymakers on the benefits of improving neonatal nursing staff numbers on patient quality of care.

⇒ Our findings are relevant to low-resource neonatal care settings with poor nurse staffing and limited political will for change.

INTRODUCTION

The Global Strategy on Human Resources for Health predicts that by 2030, there will be a need for an additional 18 million health workers, primarily in low-resource settings, to attain universal health coverage.[1] Around 89% of all global nursing shortages occur in low-resource

settings, accounting for a deficit of around 5.3 million nurses.[2]

Research has long established the importance of an adequate number of nurses to ensure patient safety, improve patient outcomes and nurses' experiences, including improved nurse retention.[3–5] Nurses also form the backbone of preventative and curative healthcare services and often serve as a bridge between the patient and other health professionals.[2] The available evidence linking poor nurse staffing or an inappropriate skill mix to poor quality care and adverse patient outcomes in hospitals, however, comes from observational research in high-income countries and not from interventional studies.[5–7] This evidence is used in high-income countries to advocate for minimum acceptable nurse staffing standards in hospitals.[8–10] In many low-resource settings, nurse staffing levels in hospital wards are far removed from these standards, with a single qualified nurse often responsible for as many as 20 or more patients.[7 11 12] This contrasts with ratios ranging from 1 to 1 nursing in intensive care to between 1 to 4 and 1 to 8 in general wards in some higher resource settings.[8] Such poor staffing levels, although widely considered inadequate, have nonetheless been the norm for several years in hospitals in many low-resource settings. This is often linked to a constrained fiscal space for health expenditure characterised by hiring freezes and budget ceilings on health workforce spending.[13] Evidence on the consequences of such poor nurse staffing on nurse-delivered care is sparse, and prospective evaluations examining the effects of workforce interventions are absent.[7] Such evidence is essential to advocate for increased nurse staffing to improve quality and outcomes of care.

Neonatal units in resource-limited settings, which provide the bulk of care to small and sick newborns, are not spared such nurse staffing shortages.[14 15] These inpatient units are of specific interest as they are the focus of a global drive to improve neonatal outcomes by 'upgrading' facilities through the development and deployment of newborn technologies.[16] These initiatives have not yet directly addressed health workforce numbers or nursing deficits.[17]

In this study, we evaluate the effects of a prospective intervention to modestly increase the number of nurses in resource-constrained newborn units that had poor overall nurse staffing. The hospitals were already part of a programme aiming to upgrade inpatient neonatal care services in other ways.[15] We aimed to evaluate the effect of the intervention on nurse-delivered bedside care as a measure of quality of newborn care.

METHODS

Study design and ethical considerations

We conducted a prospective before-and-after study to examine the effect on bedside nursing care delivery of the addition of nurses to four Kenyan newborn units. This study was part of the Harnessing Innovations in Global Health for Quality Care (HIGH-Q) research programme.[18 19] The HIGH-Q programme aimed to understand how technological interventions being provided as part of a major 'upgrading' initiative (see below) might be affected by the availability of nurse staffing.[20] As part of other objectives, the project investigated how adding ward assistants after adding the extra nurses influenced care and affected nurse and family experiences.[21 22] Our funding body had no role in the study design. This study was approved by two Research Ethics Committees.

Study setting

Our study settings were government-owned neonatal units providing intermediate-level neonatal care in four different counties in Kenya. Being intermediate-level meant they provided specialised but not intensive care, for example providing respiratory support up to Continuous Positive Airway Pressure, but not mechanical ventilation for babies.[23] All study hospitals received a bundle of newborn technologies with support for their maintenance together with staff training and mentorship to conduct quality improvement for at least 1 year before, and during the period, we studied this workforce intervention as part of long-term support for their upgrading.[16] Nurses in these neonatal units oversaw care for all the babies in a whole or one or more specific parts of the neonatal unit depending on the numbers on duty (typically one or two on a shift).[17]

Study population

We recruited babies receiving care on randomly selected nursing shifts. We employed stratified random sampling to identify 12-hour day and night shifts on weekdays and weekends. Within these randomly selected shifts, an observer selected three to four co-located babies to observe their nursing care. Our pilot and previous work have shown this to be logistically feasible.[12] The recruited babies were stratified (to achieve balance) across three illness severity categories: category A requiring vital function support, for example, oxygen support; category B are stable but ill, receiving interventions such as intravenous medication and nasogastric tube feeding; and category C, who were otherwise stable but requiring monitoring and interventions such as oral antibiotics.[24] We also sampled shifts to achieve a 4:2 split across weekday and weekend shifts, as shift type appeared associated with nursing care delivery in earlier research.[25]

Sample size considerations

The study sample size was based on a 5% pre-post difference in mean nurse-delivered care (SD 15%), with α and β of 5% and 80%, respectively, informed by a previous cross-sectional study.[12] We adjusted for clustering using a design effect of 1.5, as data on multiple (3 to 4) babies were usually collected during

each shift observed. The resulting minimum sample size for each data collection period across all neonatal units was 213 babies or 426 babies in total.

The nursing workforce intervention

We added three Kenyan Registered Nurses to each neonatal unit on the same date, for a total of 15 months (table 1), initially alone and after 8 months, with three ward assistants.[18 26] The added nurses had a minimum of 2 years of general nursing experience. Before their introduction, they received the same 1-week intensive neonatal care training provided to hospital staff as part of a separate programme.[27] The current paper assessed the effects of adding extra nurses alone with measurements at baseline and after 6 months. The effect of adding ward assistants is reported elsewhere.[22]

Our intervention was pragmatic, with neonatal nursing ward managers allocating the nurses to work alongside the wider neonatal nursing team on nursing shifts as would ordinarily happen when new nurses reported. We engaged key county, hospital and newborn unit stakeholders and signed a Memorandum of Understanding with hospital authorities that they would maintain the existing staffing complement during the study.[19] We summarise the nursing workforce intervention in table 1 using the Template for Intervention Description and Replication checklist.[28]

Data sources/ measurements

We collected data on bedside nursing care using a structured observation checklist that had previously undergone content and face validity testing in Kenya (online supplemental file 1).[12] Using this checklist, a bedside observer obtained data on patient and nursing numbers on a shift and bedside nursing care processes for observed babies.

Data collection processes

In each round of data collection (pre- and post-intervention), we trained the same set of nutritionists as observers using detailed standard operating procedures and conducted supervised pilot testing in a non-study hospital before each round of data collection. We reasoned that these professionals would have contextual knowledge of the neonatal units but be less influenced by professional loyalties and so retain objectivity. In addition, each observer spent 1-week pre-data collection in the study neonatal unit, piloting data collection processes and familiarising themselves with the ward layout and work schedules. This period of initial engagement likely minimised the Hawthorne effect, which has been shown to decline over time.[29] To further reduce the Hawthorne effect, we spread our data collection over randomly selected 12-hour nursing shifts in 6 weeks. On every shift, observers watched the care of three to four co-located babies of similar illness severity over the 12-hour shift, timing their breaks with the nursing staff. We also collected data across time from neonatal unit nurse staffing rotas and neonatal unit patient numbers from daily bed returns (this reports daily patient numbers after considering both discharges and admissions for the day).

Study variables

Main exposure variable

The primary exposure variable for this study was the change in nursing numbers across recruitment period (pre- or post-intervention).

Outcome variable

Our outcome variable was the nursing care index (NCI), a patient-level aggregate score expressed as the proportion of expected nursing tasks completed for a baby by a nurse, which quantifies nurse-delivered

Table 1 Nursing workforce intervention described using the template for intervention description and replication (TIDieR) checklist and guidance

TIDieR component	Intervention
Brief name	Nursing workforce intervention to improve nurse staffing numbers.
Why	Improving neonatal nursing staff numbers is likely to lead to increased nurse available time for patient care and ultimately increase nurse-delivered care.
What	Three additional nurses who had ordinary diplomas and who received additional intensive newborn training using the neonatal Emergency Triage Assessment and Treatment +(ETAT+) were added to each neonatal unit.
How	A pragmatic approach with neonatal unit nurse managers deploying added nurses to improve nurse staffing as they deem fit.
Where	Additional nurses were placed in level 2 newborn units, which served as referral neonatal units from the community.
When and how much	Additional nurses were added for 15 months, with evaluations happening at baseline and then 6 months after the intervention.
Tailoring	Each neonatal nurse manager utilised extra nurses as they deemed fit to increase the number of shift-level nursing staff.
Intervention modifications	None
How well	Stakeholder engagement and a memorandum of understanding were signed to promote intervention fidelity. I assessed intervention fidelity using changes in available nursing time.

bedside care over the 12-hour observation period.[12] For this score, a conducted task is given a score of 1, while a missed task is scored 0. An unweighted combined score of observed care is then expressed as a proportion of expected care. Expected tasks are based on minimum nursing tasks per baby that reflect their illness severity category (eg, sicker babies require more monitoring) and the individual's expected medical interventions on observed shifts.[24] The NCI was thus calculated with a value specific to each baby and combined multiple individual indicators of the nursing process into a single metric.[12] It is based on agreed standards of care proposed by senior members of the nursing profession, nursing regulators and the Ministry of Health in Kenya and has been content and face validated in Kenya[24] and has also been shown to be sensitive to nurse staffing changes in earlier work.[12 17]

In this study, we employed two aggregate NCI metrics as outcome measures –

1. Nurse-delivered care, our primary outcome measure, directly measures the proportion of expected nursing care delivered by a qualified nurse or a nursing student or a mother who is directly supervised by a nurse.
2. The prioritised nursing care, our exploratory outcome, measures the ten most prioritised nursing tasks from our baseline data, excluding tasks that were almost always done by nurses (performance >90% at baseline) and therefore had no room for improvement.

While the nurse-delivered care directly measured the effect of the intervention on the work nurses do, the prioritised nursing care explored the influence of existing norms on any intervention effect, that is, does adding extra nurses mean nurses keep focusing on tasks they already consider as high value and prioritise?

Potential confounders

We noted key variables as potential confounders in the relationship between additional nurse staffing and increased nursing care delivery from literature searches.[25] These were nursing shift type (weekday, weekend, night or day), patient severity and the number of nursing students present on a nursing shift. We used these variables for model building and adjusted for their potential confounding effects.

Magnitude of intervention

We postulated that our intervention would increase nurse-delivered care by increasing the nursing time available per patient, measured as the nursing hours per patient per shift (NHPPS) and the nursing hours per patient per day (NHPPD). The NHPPS sums up all actual nursing hours available on a standardised 12-hour shift, divided by the number of patients resident on the neonatal unit on the same shift.[30] The NHPPD differs in that it sums up all planned nursing care hours available on a specific day, divided by the number of patients resident on the neonatal unit on the same day.[30] We used the NHPPD to examine the effect of intervention on nursing care hours over time using unit nursing rotas and patient numbers from daily bed returns between October 2021 and December 2022. This period was at least 6 months before and after the workforce intervention. In this way, we were able to explore changes in nurse staffing hours and thus the magnitude of intervention over time.

Statistical methods and data analysis

We describe baby and shift-level characteristics in pre- and post-intervention periods using frequencies, percentages, medians and IQRs.

We use a time series line graph to explore week-to-week changes in the NHPPD and use interrupted time series analysis to model changes in this nursing metric following our intervention. We also examined changes in NHPPS using medians and interquartile ranges. We handled missing data using complete case analysis.

Using multilevel modelling, we explored the intervention's impact on nurse-delivered care as a primary outcome and its impact on prioritised nursing care as an exploratory outcome. Model building was done sequentially, adding pre-determined covariates until we determined the best-fit model using Akaike's Information Criteria, Bayesian Information Criteria and likelihood ratio tests. Additional covariates that we added sequentially were nursing shift type, patient severity and the number of nursing students present on a nursing shift (confounders mentioned above).

In further exploratory analysis, we examine changes in individual nursing tasks between pre- and post-intervention periods to identify any changes in the pattern of care. All our data analysis was conducted in STATA V.18. Our multilevel model specification is shown in online supplemental file 2).

RESULTS

Across all four intervention neonatal units, we observed 80 12-hour nursing shifts and 290 babies between February and March 2022 (before our intervention) and 76 12-hour nursing shifts and 300 babies between October and December 2022 (after the intervention).

The case mix of recruited babies was similar in pooled data in the pre- and post-intervention periods in the four neonatal units (table 2). However, the average number of babies admitted to the neonatal units increased in the post-intervention period (table 2).

The four neonatal units (H1, H2, H3 and H4) employed 11, 17, 8 and 10 nurses at baseline, respectively. Adding three extra nurses to each unit increased the total nursing numbers by between 17.6% and 37.5%. We employed 12 nurses across the four units for 15 months at a total cost equivalent to 17 797 488 Ksh (equivalent to 137 538.99 US dollars as of 14 July 2025). This included training costs for nurses and administration related to employment. This was equivalent to $9170 per nurse and $27 509 for three nurses per neonatal unit per year.

Table 2 Participant and nursing shift characteristics across pre- and post-intervention periods

Participant characteristics	N	Pre-intervention (%)	N	Post-intervention (%)
Gender	290		300	
Male		139 (47.9)		150 (50.0)
Female		151 (52.1)		150 (50.0)
Patient illness severity	290		300	
Category A		101 (34.8)		102 (34.0)
Category B		88 (30.3)		98 (32.7)
Category C		101 (34.8)		100 (33.3)
*Neonatal unit of recruitment**	290		300	
H1		75 (25.9)		79 (26.3)
H2		75 (25.9)		75 (25.0)
H3		66 (22.8)		73 (24.3)
H4		74 (25.5)		73 (24.3)
Recruitment shift type	290		300	
Weekday day		93 (32.1)		90 (30.0)
Weekday night		101 (34.8)		116 (38.7)
Weekend day		47 (16.2)		57 (19.0)
Weekend night		49 (16.9)		37 (12.3)
Nursing shift characteristics	**n†**	**Pre-intervention Median (IQR)**	**n†**	**Post-intervention Median (IQR)**
Patient numbers on a nursing shift	80	27 (21.5 to 50)	76	33 (25 to 49)
Patient numbers by intervention on a nursing shift	80		76	
Continuous Positive Airway Pressure (CPAP)		0 (0 to 1)		0 (0 to 1)
Oxygen		6 (4 to 10)		4 (2 to 6)
Intravenous therapy		17 (12 to 25)		18 (10 to 24)
Phototherapy		2 (1 to 5)		4 (3 to 6)
Nasogastric and orogastric tube feeding		11 (7 to 16)		8 (5 to 12)
Incubator care		7 (4 to 9)		4 (2 to 9)
Kangaroo mother care		3 (0 to 5)		3 (2 to 6)
Nurse student numbers	80	5 (3 to 9)	76	5 (3 to 11)
Total nursing hours per 12-hour shift‡	80	20.7 (12.0 to 24.1)	76	24.1 (24.0 to 29.4)

Category A patients are unstable babies, category B babies are those that are stable but still ill, while category C babies are stable babies on the neonatal unit.
*H1 to H4 represent individual neonatal units.
†Nursing shift characteristics are based on data from 156 observed nursing shifts (80 pre-intervention and 76 post-intervention). There were 590 patient observations across 156 nursing shifts.
‡Combined nursing care hours provided by the nursing team across all nursing shifts.

Following the intervention, we observed a moderate but significant level change in NHPPD. This amounted to 0.86 hours (51.6 mins) per patient per 24 hours in the first week (β-coefficient: 0.86 (95% CI 0.58 to 1.15), p value <0.001) but was followed by a statistically significant declining trend in the 6 months after the intervention (figure 1; β-coefficient −0.02 (95% CI −0.03 to −0.01), p value <0.001). Despite this declining trend, median (IQR) NHPPD in the 6 months post-intervention (median: 1.79 hours (IQR 1.65 to 1.97)) was higher than in the 6 months pre-intervention (median: 1.48 hours (IQR 1.43 to 1.67)).

The NHPPS that reflects staffing on observed shifts (over a 6-week period) changed from a median nursing time available per baby for patient care of 0.56 hours (33.6 min) before the intervention to 0.72 hours (43.2 min) after the intervention (a 28.5% increase in median shift nursing time per patient, (online supplemental file 3).

At baseline, the median (IQR) nurse-delivered care and prioritised nursing care were 0.33 (0.28–0.41) and 0.38 (0.29–0.50), respectively (online supplemental file 4). The intervention resulted in a statistically significant 4.7% increase in nurse-delivered care (B-coefficient: 0.047 (95% CI 0.028 to 0.066, table 3)) in the pooled post-intervention shifts observed compared with the pre-intervention shifts observed. The additional nurses, however, resulted in an 8.4% increase in the metric exploring delivery of the 10 prioritised nursing tasks (B-coefficient 0.084 (95% CI 0.053 to 0.115), table 3)). These prioritised tasks are shown in the online supplemental file 5).

Further exploratory analyses showed that more technical nursing tasks were completed for a greater

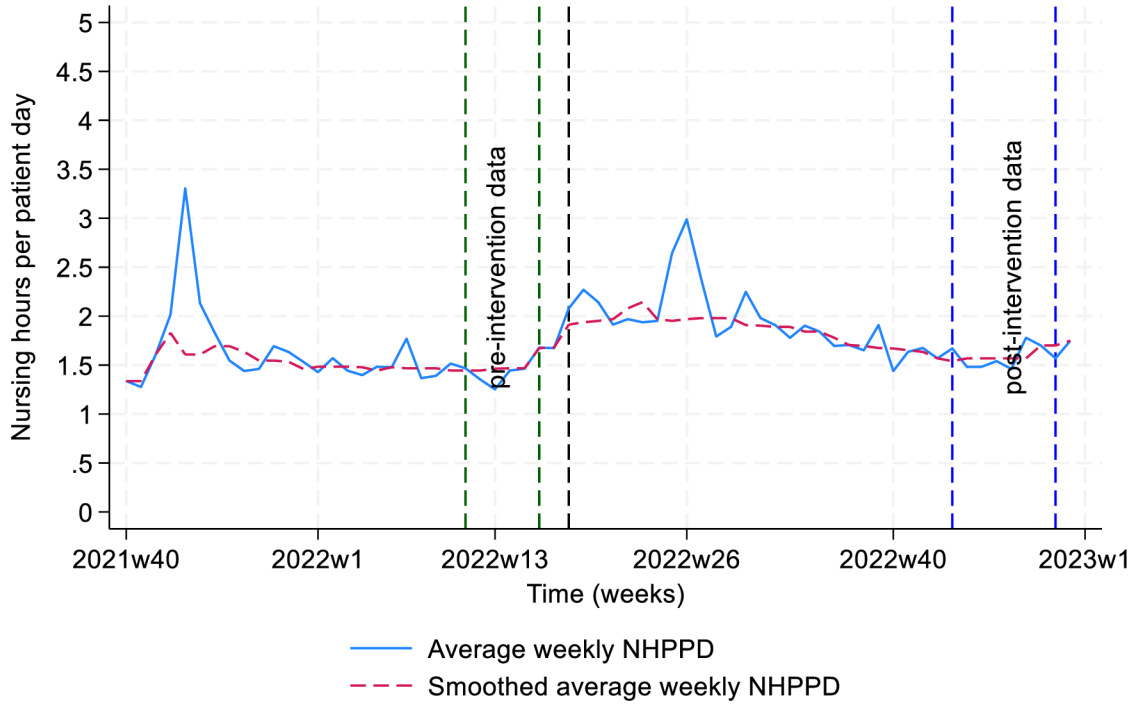

Figure 1 Time series line graph showing the change in nursing hours per patient per day (NHPPD) before and after the workforce intervention plotted as actual weekly data points (blue line graph) and 9 week moving averages (dotted red line graph). The period between the vertical dark-green dotted lines represents the pre-intervention data collection period. The vertical black dotted line represents the intervention week (2022), week 18. The period between the blue dotted lines is the post-intervention data collection period. The spike in the pre-intervention period is linked to a drop in patient numbers in one of the neonatal units due to COVID-19, while the smaller spike in the post-intervention period is linked to a drop in neonatal admissions across to neonatal units.

proportion of babies in the post-intervention period (table 4). For example, nurses attended more ward rounds (11.0% increase), conducted patient assessments before ward rounds (19.9% increase) and checked incubator settings (15.6% increase). They continued to demonstrate little involvement in less technical tasks, for example, feeding (0% change), cord care (0.7% increase) and patient monitoring (<5% increase). These tasks remained largely the role of nursing students and mothers who had no supervision in the neonatal units.

DISCUSSION

In high-dependency neonatal units with very low baseline staffing, our modest intervention, adding three extra nurses to each unit resulted in an average increase in NHPPS observed from a median of 33.6 min to 43.0 min (9.4 min (28.5%) increase). In line with our hypothesised pathway to effect, pooled data indicated the intervention was associated with a 4.7% increase in nurse-delivered care and a greater increase (8.4%) in the delivery of care that nurses prioritised. These findings are consistent with existing literature linking better nurse staffing with positive effects on care delivery and patient care outcomes, although from typically observational research in very different high-income country settings[31–35] and addressing the absence of such research in low-middle-income county (LMIC).[7] To the best of our knowledge, this is the first study that has evaluated the specific effect of a prospective increase in ward-level nurse numbers on the quality of patient care within a hospital.

The magnitude of improvement in nurse-delivered care may seem small. However, the absolute increase in NHPPS of 9.4 min per baby, to reach an average of 43 min per baby, should be contrasted with the 119 min or 84 min required to carefully initiate Continuous Positive Airway Pressure (CPAP) or nasal cannula oxygen respectively, and the 4 min it takes to carefully conduct one set of vital signs measures in one sick child.[36] In comparable high-income settings, the NHPPS is reported to be 5.43 hours (325.8 min),[30] almost 10-fold higher than the baseline staffing in our study settings. The scale of our intervention was driven largely by cost considerations, and we were cautious in our request to funders. Similar to the NHPPS, which was measured when shifts were observed over 6 weeks (pre-intervention and post-intervention), our longitudinal fidelity measures the NHPPD which estimated staffing based on nursing rotas up to 6 months before and after the intervention demonstrated higher mean values in the 6 months post-intervention compared with pre-intervention. The NHPPD demonstrated a significant rise immediately after the addition of extra nurses, with a slow declining trend across time highlighting challenges with maintaining our intervention fidelity over time, together with an increase in patient volumes over time. A specific process evaluation of

Table 3 Multilevel models comparing nurse-delivered care between the pre-intervention and post-intervention periods

	Nurse-delivered care (primary outcome)			Priority nursing care delivered		
	Model 1	Model 2	Model 3*	Model 1	Model 2	Model 3*
Characteristics	**B-coefficient (95% CI)**	**B-coefficient (95% CI)**	**B-coefficient (95% CI)**	**B-coefficient (95% CI)**	**B-coefficient (95% CI)**	**B-coefficient (95% CI)**
Recruitment period						
Post-intervention period	0.042 (0.021, 0.064)	0.043 (0.024, 0.063)	**0.047 (0.028, 0.066**)	0.078 (0.041, 0.115)	0.07 9 (0.045, 0.114)	**0.084 (0.053, 0.115**)
Pre-intervention period	Reference	Reference	Reference	Reference	Reference	Reference
Patient category						
Category A			Reference			Reference
Category B			−0.066 (-0.089, to 0.042)			−0.184 (-0.223, to 0.146)
Category C			−0.012 (−0.035, 0.011)			−0.193 (−0.231, to 0.156)
Number of nursing students			−0.004 (−0.006, to 0.002)			−0.005 (−0.008, to 0.002)
AIC	−720.68	−784.19	−826.95	−63.14	−129.75	−241.36
BIC	−711.92	−766.67	−796.29	−54.38	−112.23	−210.69
LRT (P value comparing model to a linear model)		<0.001	<0.001		<0.001	<0.001
Variance						
Hospital level		0.002 (0.001, 0.009)	0.003 (0.001, 0.011)		0.007 (0.002, 0.029)	0.007 (0.002, 0.031)
Baby level		0.015 (0.013, 0.017)	0.014 (0.012, 0.015)		0.045 (0.040, 0.051)	0.037 (0.033, 0.042)
Intraclass correlation coefficient		0.125 (0.032, 0.379)	0.160 (0.043, 0.447)		0.130 (0.034, 0.389)	0.168 (0.046, 0.460)

Model one is a linear regression model, model two is an unadjusted multilevel regression model based on a two-level random intercept model (level 1 baby and level 2 is hospital) and model 3 is the two-level model adjusted for patient illness severity and number of nursing students on a shift.
Emboldened coefficients are those from the best-fit model. Prioritised nursing care delivered is based on a set of 10 most performed nursing tasks at baseline.
*Best fit model for each outcome.
AIC, Akaike's Information Criteria; BIC, Bayesian Information Criteria; LRT, likelihood ratio tests.

Table 4 Percentage of babies who had a specific neonatal nursing task carried out by nurses along with cluster-adjusted 95% confidence compared between pre-intervention and post-intervention periods (n=590)

Domains	Subdomains	Pre-intervention N	Pre-intervention Nurse* (95% CI)	Post-intervention N	Post-intervention Nurse* (95% CI)	Absolute change in percentage of care delivered by nurses†
Routine nursing care	Patient handover	290	100.0 (-)	300	99.7 (92.9,100.0)	- 0.3
	Patient assessment before a shift	289	76.1 (11.3, 98.8)	300	96.0 (75.2, 99.5)	+19.9
	Hand washing	290	70.7 (11.3, 97.9)	296	79.4 (8.8, 99.4)	+8.7
	Ward round attendance	83	14.5 (10.9, 18.9)	55	25.5 (3.8, 74.6)	+11.0
	Patient communication	289	42.2 (7.5, 86.8)	294	51.4 (12.5, 88.7)	+9.2
Routine newborn care	Cord care	167	0.0 (-)	138	0.7 (0.0, 13.4)	+0.7
	Cleaning baby	178	0.6 (0.0, 16.3)	153	0.7 (0.0, 14.0)	+0.1
	Diaper change	290	0.7 (0.0, 14.4)	299	1.7 (0.4, 7.5)	+1.0
	Linen change	174	1.7 (0.4, 7.9)	245	1.6 (0.3, 8.8)	+0.1
	Checking incubator settings	32	46.9 (2.3, 97.1)	48	62.5 (1.7, 99.4)	+15.6
Feeding	Nasogastric tube feeding	99	0.0 (-)	90	0.0 (-)	0.0
	Cup feeding	73	2.7 (0.4, 16.9)	74	1.4 (0.1, 19.9)	−1.3
Vital sign monitoring	Measuring pulse oximetry	290	22.4 (15.2, 31.6)	295	21.4 (1.9, 79.4)	−1.0
	Measuring pulse rate	290	16.6 (5.2, 41.9)	300	21.0 (1.7, 80.3)	+4.4
	Measuring respiratory rate	290	15.9 (5.2, 39.5)	299	19.1 (1.2, 82.6)	+3.2
	Measuring temperature	290	14.8 (3.9, 42.8)	300	19.3 (2.4, 69.7)	+4.5
Physical turning of baby	Turning	289	1.0 (0.1, 7.2)	300	5.7 (0.6, 39.6)	−4.7
Medication	Oral medication	18	11.1 (2.6, 37.2)	32	18.8 (2.2, 70.5)	+7.7

Values in brackets after percentages are cluster adjusted 95% CIs.
*Percentage of babies who had a specific task carried out by a nurse (the numerator is the number of babies for which the expected task was conducted by a nurse, while the denominator is the total number of babies for which the task was expected).
†%Difference between the percentage of specific tasks carried out by a nurse in the post and pre-intervention for all babies recruited during the period.

how hospitals managed the additional staff provided and existing staff during our intervention will be reported elsewhere.

We also show that when nurses have little time, they target efforts to more technical tasks (delegating others) consistent with the wider missed nursing care literature.[25 37] The tasks nurses prioritise or informally delegate are likely driven by established norms within these low-resource neonatal units.[38] Our direct observations confirm that delegated tasks are conducted by mothers and students. These individuals are given little direct training with practices predominantly informed by their peers and are not directly supervised.[17] When delegation includes tasks such as nasogastric feeding of preterm babies with respiratory distress, this may put babies' safety at risk and result in poor training and mentorship of novice professionals, which may perpetuate bad practices.[17] Nurse-delivered care thus represents an important process-based measure of quality of care that assesses key quality of care dimensions, including safety and delivery of evidence-based practices.[39]

While ambitions to scale up access to neonatal technologies such as CPAP, phototherapy machines and pulse oximeters are gaining traction as technology costs fall, our findings suggest that their benefits will not be realised without improving nurse staffing numbers and capacity. These findings are in keeping with those of studies in which staff recruited to support research conduct in facilities also directly support clinical care contributing to the success of technology interventions.[40] We noted limited CPAP use, with often one or no patients being on CPAP during an observation shift. This is linked in part to a view that CPAP was a complicated technology to be started by only consultants and also a limited know-how of setting up CPAP properly by nursing staff.[41]

Ultimately, in Kenya and other LMICs, our findings demonstrate the need to increase human resources for health spending. Few LMICs have mandatory staffing norms for neonatal nursing to guide such investments. In South Africa, the Limpopo Initiative for Neonatal Care spells out specific standards of 1 to 1 nursing for intensive care, at most one professional nurse to three babies for intermediate level care (equivalent to those in category A and B in our study) and 1 nurse to six babies to cover standard care and KMC units (equivalent to those in category C). Some LMICs are now enacting bold policies. For example, Rwanda has committed to the 4×4 health reform, which is aimed at quadrupling

the health and nursing workforce by 2030.[42] Internationally, the WHO is working on a newborn norms document that will provide guidance on nurse to newborn ratios at different levels of care for LMICs. In settings like those we studied with between 500 (low volume) to 1500 or more (high volume) neonatal admissions per year where one nurse typically cares for 20 babies, the cost of employing three additional nurses was approximately $27 500 per annum.[43] To ensure one additional nurse on every 12-hour shift across a full week (and with cover for holiday, study and sick leave) might require six nurses at approximately $55 000 per annum. Adding three or six nurses in one neonatal unit might therefore cost between $18 to $55 or $37 to $110 per newborn admission in higher and lower volume newborn units, respectively. Even if the investment was $110 per newborn admission, and if extra staffing only averted 1 disability-adjusted life year (DALY) per baby admitted, then the cost per DALY averted would be $110 which is below a commonly used threshold for cost-effectiveness for interventions in LMIC of less than $200 per DALY averted. Averting one DALY per baby admitted would be achieved if six or seven babies' lives were saved among 500 admissions annually because there were more nursing staff or if some babies' lives were saved and fewer babies were discharged with severe physical or neuro-cognitive disability. Improved nurse staffing by improving care quality may have local and wider health system benefits too, for example, by reducing hospital acquired infections and reducing hospital stay costs. Moreover, investments in human resources are likely to result in broader benefits for parents through better family-centred care, for the existing newborn unit staff who may suffer less burnout and for local economies through increased employment.[44 45]

Strengths and limitations

Our study used direct observations as an objective assessment of nurse-delivered care; previous research in this area has largely relied on nurse self-reports of missed care.[25 37] Our pre-post study design included no contemporaneous controls linked to budgetary constraints and the ethical challenge of withholding additional staffing from control hospitals.

We employed repeated cross-sectional data collection over 6-week periods which may not accurately represent changes across the full intervention period. Post-intervention assessments were conducted at 6 months, when it was thought that the added nurses would be fully integrated, and our tracking of nurse staffing across the whole period reassures us that findings are likely to represent effects over the whole post-intervention period.

We recognise that our measure of quality of care, nurse-delivered care, is process-based. Linking the individually assessed NCI to individual patient mortality or major morbidity would be extraordinarily difficult given the numbers of patients that would need to be studied. Furthermore, sick newborns stay multiple days, but the NCI is measured for one 12-hour period making it more difficult to establish a causal relationship. Nurse-delivered care is, however, upstream on our intervention causal pathway and is likely to be sensitive to a change in nurse staffing than more downstream outcome measures.

We also worked towards the sustainability of our intervention, engaging with counties and hospital administration from the intervention outset to support the need for extra nurses. While the importance of extra nurse staffing was appreciated, by the end of our intervention, only one out of four of the intervention newborn units retained the added nursing staff. This was linked in part to limited funding available to employ additional nurses.

Our data were pooled from four neonatal units with varying contexts. While we are limited by how much variation in context we can measure quantitatively, employing multilevel modelling is likely to adjust our estimates for any difference arising from clustering of our observations.

CONCLUSION

We show that in neonatal units with severe workforce deficits, where most expected nursing tasks are not delivered by qualified nurses, modest increases in nurse staffing are associated with more nurse-delivered care. Our findings suggest, however, that large increases in nurse staffing at the shift level will be needed before qualified nurses can deliver or directly supervise the delivery of most of the expected care to sick babies. Our findings have major implications for programme efforts to scale up more advanced neonatal care, often linked to the introduction of technologies. In settings where nurses care for large numbers of babies, these programmes should consider establishing minimum, safe staffing levels to help achieve health impacts.

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Contributors ME, FW, DG and MM were responsible for gaining funding for this work. AI together with DG, MM, JA and ME conceptualised the idea for this manuscript. All authors contributed to the methods for the paper. AI, VK

and OO oversaw data collection with oversight provided by DG, MM, JA, FW, SF, KK and ME. AI analysed the data with support from DG, MM, JA and ME. AL worked on the economic evaluation of the workforce intervention with support from AI, DG and ME. AI drafted the manuscript with significant contributions from all authors and under the supervision of DG, MM, JA and ME. All the authors reviewed all versions of the manuscript and agreed on a final version for submission. AI and ME are guarantors of this manuscript.

Funding This research was funded by the NIHR (project references: NIHR130812) using UK international development funding from the UK Government to support global health research. The views expressed in this publication are those of the author(s) and not necessarily those of the NIHR or the UK government. A Wellcome Trust core award to the KEMRI-Wellcome Trust Research Programme (#092654) also enabled this research. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Competing interests None declared.

Patient consent for publication Not applicable.

Ethics approval This study involved human participants and was approved by the Kenyan Medical Research Institute (KEMRI) Scientific and Ethics Review Unit (KEMRI/RES/7/3/1) and the University of Oxford Research Ethics Committee (26–21). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer-reviewed.

Data availability statement Data are available upon reasonable request. The dataset that was generated for this study, including anonymised individual data that were analysed, is available upon reasonable request and a written protocol.

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