The effects of a one to one nurse to patient ratio on the mortality rate in neonatal intensive care: A retrospective, longitudinal, population-based study

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On behalf of the Neonatal Data Analysis Unit (NDAU) and the Neonatal Economic, Staffing, and Clinical Outcomes Project (NESCOP) Group

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ABSTRACT

Objective: To estimate the effect of the provision of a one to one nurse to patient ratio on mortality rates in neonatal intensive care units.

Design: A population based analysis of operational clinical data using an instrumental variable method.

Setting: National Health Service neonatal units in England contributing data to the National Neonatal Research Database at the Neonatal Data Analysis Unit and participating in the Neonatal Economic, Staffing, and Clinical Outcomes Project (NESCOP).

Participants: 43 tertiary level neonatal units observed monthly over the period January 2008 to December 2012.

Intervention: Proportion of neonatal intensive care days or proportion of intensive care admissions for which one to one nursing was provided.

Outcomes: Monthly in-hospital intensive care mortality rate.

Results: Over the study period, the provision of one to one nursing in tertiary neonatal units declined from a median of 9.1% of intensive care days in 2008 to 5.9% in 2012. A ten percentage point decrease in the proportion of intensive care days on which one to one nursing was provided was associated with an increase in the in-hospital mortality rate of 0.6 [95% confidence interval: 1.2, 0.0] deaths per 100 infants receiving neonatal intensive care per month compared to a median monthly mortality rate of 4.5 deaths per 100 infants per month. The results remained robust to sensitivity analyses that varied the estimation sample of units, the choice of instrumental variables, unit classification, and the selection of control variables.

Conclusions: Our study suggests that decreases in the provision of one to one nursing in tertiary level neonatal intensive care units increase the in-hospital mortality rate.
INTRODUCTION

Nurse shortages are a continuing problem for healthcare both in the United Kingdom and elsewhere.[1,2] Nurse to patient ratios have declined in hospitals across many areas of healthcare despite a number of studies providing evidence for an association between increased nurse to patient ratios and a reduction in adverse patient clinical outcomes.[3–5]

A one to one nurse to patient ratio is recommended by the British Association of Perinatal Medicine (BAPM) for all infants receiving neonatal intensive care in the United Kingdom, with a ratio of 1:2 nurses recommended for infants receiving high dependency care and a ratio of 1:4 nurses for infants receiving special care.[6,7] These levels of care are defined according to the care requirements of the infant, with intensive care requiring the most sustained support. Similar recommendations are provided by the American Academy of Pediatrics.[8] Despite this, recent evidence shows that a large number of shifts in neonatal units are understaffed with respect to recommended nurse to patient ratios. Pillay et al. found that 54% of nursing shifts in the six neonatal units they observed in England between October 2008 and February 2009 were understaffed with respect to the 2001 BAPM standards.[9] In 2005, BAPM reported that only 2% of neonatal intensive care units (NICU) met national staffing recommendations.[10,11] Understaffing has also been reported in NICUs in the US.[12] This evidence has led some groups to advocate increased nurse staffing levels in neonatal units.[13]

A recent systematic review[4] of studies that examined nurse to patient ratios in neonatal clinical care settings identified six studies published between 1990 and 2010.[14–19] As far as we are aware, only two further studies on this topic has been published since that time.[20,12] The studies included in the systematic review estimated that higher nurse to patient ratios are associated with a reduction in risk adjusted mortality,[16,18,19] and of adverse events and nosocomial infection,[15,20,12] and with an increase in daily weight gain.[21] Of the identified studies, two were from the United Kingdom:[18,19] results from these two studies, however, are based on the same data from 1998-9, prior to wide, systematic changes in the structure of neonatal care in the United Kingdom from 2003
onwards. The authors of the systematic review concluded that the included studies were too heterogeneous to support any particular nurse to patient ratio.\[4\] Moreover, these studies have not been able to observe specific nurse to patient ratios at the individual patient level nor adequately account for unobserved confounding that may occur due to higher risk patients being more likely to receive more intensive nursing support. This in turn has limited the conclusions that can be made regarding the causal effects of the nurse to patient ratio on patient clinical outcomes.

This study was designed to estimate the effect of one to one nursing on the monthly mortality rate in tertiary level neonatal units in England. We assess whether tertiary level neonatal units – those designated to provide intensive care – that provide a greater proportion of intensive care days with one to one nursing have lower mortality rates using a novel statistical analysis to account for unobserved confounding.

**METHODS**

**Data Source and Study Population**

Data were extracted from the National Neonatal Research Database (NNRD) for tertiary level neonatal units participating in the Neonatal, Economic, Staffing, and Clinical Outcomes Project (NESCOP). We utilised self-reported unit classifications reported to the National Neonatal Audit Programme (NNAP) in 2010 to identify tertiary units.\[22\] The NNRD comprises data extracted from the electronic patient records of all infants admitted to all 173 neonatal units in England with units joining the NNRD from 2006 onwards and not all units contributing in all years. Approval for data collection is provided by the national research ethics service (reference REC 10/H0803/151) as well as the Caldicott Guardians of each National Health Service (NHS) Trust. NESCOP included 43 tertiary level centres (of 165 centres overall) providing perinatal care that provided agreement for the inclusion of their data in the NNRD in 2011. NESCOP was able to utilise data from 30 tertiary units in 2008 (of 146 total units), 34 in 2009 (of 150), 41 in 2010 (of 164), 42 in 2011 (of 165), and 41 in 2012 (of 162). We extracted data on all infants who were admitted to a participating tertiary level unit over the period 1\textsuperscript{st} January 2008 to 31\textsuperscript{st} December 2012. Two units changed classification during the
study period. We therefore examined the robustness of our results to these classifications by additionally utilising unit classifications reported to NNAP in 2008 and 2012.

**Outcomes**

The data were aggregated to neonatal unit level by calendar month. Mortality data were derived from the extracted NNRD data. The outcome was specified as the monthly in-hospital intensive care mortality rate and specified as the number of deaths per 100 infants receiving intensive care per month in each neonatal unit.

**One to one nursing**

The NNRD records a binary variable indicating receipt of one to one nursing for each care day provided to each infant. We validated whether this variable represented whether an infant did receive, as opposed to should have received, one to one nursing on the indicated care day, by conducting a number of validation checks. First, we asked staff members at three different neonatal units what information they entered for this variable; second, we compared reported one to one nursing provision with clinical guidelines; third, we compared infant risk of mortality with one to one provision; and, fourth, we compared one to one nursing ratios with average nurse to patient ratios using data from a survey of neonatal units participating in NESCOP. The results of these validation checks are presented in Appendix A. For the analysis at neonatal unit level, the one to one nursing variable was specified in two ways: (i) the proportion of intensive care days on which one to one nursing was provided; and (ii) the proportion of infants receiving intensive care who were provided with at least one day of one to one nursing. Data were not available on cot numbers or overall staffing levels over the course of the study period.

**Covariates**

Following our previous work modelling mortality on neonatal units using NNRD data, and based upon a review of previous prediction models,[23] we included a number of covariates in our statistical models that a) were significant predictors of mortality, b) were available in our dataset and of high quality, and c) not confounded by the provision of neonatal care. These were: gestational age at birth, birth weight z-score (birth weight standardised by gestational age week), the monthly neonatal unit
volume (to capture nurse workload), and the following indicators: whether the mother received a full or partial course of antenatal steroids, infant sex, infant year of birth (to capture trends in mortality over time), and calendar month (to capture any seasonal trends in mortality). In addition, a neonatal unit indicator (fixed effect) was included (see Appendix B).

**Statistical Methods**

One to one nursing is assigned only to the sickest infants receiving neonatal intensive care, who will have the highest risk of mortality. This will generally lead us to underestimate the benefit, or even to predict an adverse effect of one to one nursing due to the effect of unobserved confounding if infant health is not perfectly observed. We aggregated data to unit level for each calendar month in the sample so that unobserved heterogeneity at the infant level was not a confounding factor. A neonatal unit level model was also arguably appropriate to inform neonatal unit level policy. Nonetheless, there are two issues that may affect the analyses: (i) unobserved confounding at neonatal unit level, and (ii) reverse causality from the risk of mortality to one to one nursing due to the increased provision of intensive nursing to sicker infants (i.e. ill health causing one to one provision).

A linear regression model was specified with controls for unobserved characteristics (unit fixed effects) to account for the neonatal unit level unobserved confounding. The model was then estimated using ordinary least squares (OLS). To account for reverse causality, we utilised an instrumental variables estimator. This instrumental variables estimator involves the use of a variable, termed an “instrument” that in this context fulfils two criteria: (1) it should be strongly correlated with the one to one nursing ratio in a particular month; and (2) it should not be correlated with the outcome of interest conditional on observed covariates, including one to one nursing. For the instruments, we utilised lagged values of the one to one nursing ratio (i.e. previous months’ values for one to one nursing ratios for the respective neonatal unit) since: (1) a particular month’s one to one nursing ratio should be correlated with previous monthly ratios at a unit level given the availability of nursing staff and local nursing practices; and (2) the previous monthly ratios should be uncorrelated with unobserved confounders during the month of analysis. The number of lagged values included was determined by sequential testing (see Appendix B). To test the first condition we conducted an F-test for the
significance of the lagged values, and to test the second condition we conducted a Hansen J test.[24] The standard errors were adjusted for clustering within units. Analyses were conducted in Stata version 12.

**Sensitivity Analyses**

A number of sensitivity analyses were conducted to determine the robustness of the results to the statistical methods, the set of included covariates, and assumptions of the models. In particular, we tested the sensitivity of our results to: (i) including only neonatal units that provided data for all months of the analysis; (ii) exclusion of any outlying units identified from a graphical inspection of the data; (iii) inclusion of non-tertiary units that provide an average monthly level of intensive care at least as large as the smallest tertiary unit; (iv) re-estimating the models with no covariates, except for unit level indicators and the one to one nursing variable; (v) using a different number of lagged values for the instruments; (vi) using 2008 and 2012 reported unit classifications; and, (vii) removing data from 2008 when large decreases in one to one nursing were observed that were not observed in subsequent years.

**RESULTS**

**Summary Statistics**

Overall, data from 43 unique tertiary neonatal units were included in our primary analyses. Of the remaining 122 neonatal units in NESCOP, 82 reported as being level two and 40 as level one in 2010.[25] Table 1 shows summary statistics for the sample; the top panel shows sample aggregate statistics, whilst the lower panel shows neonatal unit median values. The median annual proportion of intensive care days on which one to one nursing was provided in tertiary neonatal units in the sample declined from 9.1% in 2008 to 5.9% in 2012. Similarly, the proportion of infants admitted to intensive care receiving any one to one nursing during their care declined from 39.4% to 35.7% over the same period. The median [interquartile range] in-hospital intensive care mortality rate was 4.5 [0.0, 8.3] deaths per 100 infants receiving intensive care per month.
Regression Results

Estimated effects of one-to-one nursing on the in-hospital intensive care mortality rate are reported in Table 2 for both OLS and the instrumental variables estimator. The OLS results revealed a positive association between the one to one nursing ratio and the in-hospital intensive care mortality rate, suggesting that a ten percentage point decrease in the proportion of intensive care days on which one to one nursing was provided was associated with an decrease in the mortality rate of 0.6 deaths per 100 infants receiving intensive care per month (95% confidence interval (CI): [0.1, 1.2]).

After adjusting for possible reverse causality, the instrumental variables estimator results showed strong evidence of an increase in the mortality rate was associated with a higher one to one nursing ratio. A ten percentage point decrease in the proportion of intensive care days on which one to one nursing was provided was associated with an increase in the mortality rate of 0.6 deaths per 100 infants receiving neonatal intensive care per month (95% CI: [-1.2, -0.0]). Where one to one nursing was measured as the proportion of infants who received at least one day of one to one nursing care, a ten percentage point decrease in one to one nursing led to an increase of 0.4 deaths per 100 infants receiving neonatal intensive care per month (95% CI: [-0.7, -0.0]).

Sensitivity analyses

The results from the sensitivity analyses are presented in Appendix C, tables C1-C4. In all cases, the estimated coefficients were negative and were qualitatively similar to the main results. Removal of neonatal units that did not contribute data in all months of the analysis and removal of one outlying unit generally resulted in an increase in the magnitude of the estimated coefficients while reducing precision of the estimates (tables C1 and C3). Varying the lag length of the instrumental variables used had small effects on the magnitude of the estimated coefficients of interest and standard errors as was expected (tables C2 and C4). For one to one nursing measured as a proportion of intensive care days, the inclusion of extra lagged months as instrumental variables had little qualitative effect on the estimated coefficient, while reducing the number of lagged months reduced the magnitude of the coefficient. For one to one nursing measured as a proportion of admissions, the inclusion of extra lagged months increased the magnitude of the estimated coefficient, while reducing the number of
lagged months had little qualitative effect on the estimated coefficient. The choice of lag length used as instrumental variables therefore affects the point estimates of the effect of one to one nursing suggesting there is a fair amount of uncertainty about the effects of one to one nursing on the mortality rate; however, these changes did not affect the general conclusions drawn from the results that an increase in the provision of one to one nursing was associated with a reduction in the mortality rate. Variations in reported unit classifications over the study period did not affect the results. Removal of data from 2008, given the trend observed in this period, did not affect the magnitude of the estimate but did reduce its precision.

**DISCUSSION**

We examined the effect of one to one nursing in neonatal intensive care on the monthly mortality rate in neonatal intensive care units for infants admitted to neonatal units in England. The key finding was an increase in the mortality rate in tertiary level neonatal units when a decreased proportion of intensive care days was provided with one to one nursing. The results from the OLS results showed the opposite effect, which provides evidence that sicker infants were more likely to be provided with one to one nursing thereby confounding the standard analysis. The results from analyses where an alternative measure of one to one nursing, along with the results from a wide variety of robustness checks, were all qualitatively similar, supporting the main instrumental variables estimator findings.

The methods utilised in this study enabled us to account for a number of sources of unobserved confounding so that our results can be arguably interpreted as causal effects in the absence of a randomly assigned one to one nurse to patient ratio. This study employed an instrumental variable method, which has been widely applied in other healthcare evaluations.[26] However, we are only aware of two previous studies incorporating this method in perinatal settings, including one study utilising NNRD data previously conducted by the authors.[27,28] Our findings can be compared with three previously conducted studies that found a reduction in risk adjusted mortality with higher nurse to patient ratios in neonatal healthcare.[14,18,19] One previous study did find an increase in mortality.[14] However, none of the cited earlier studies took into account the various sources of
unobserved confounding and the possibility of reverse causality, and all examined the effects of an average nurse to patient ratio in cross-sectional contexts at the baby level without being able to examine within unit changes to nurse to patient ratios over time. The difference between our OLS and instrumental variable estimator results suggest that there is significant reverse causality from one to one nursing to mortality which may be caused by unobservable differences in patient case mix or by differences or changes over time to the technology in use by neonatal units.

The results presented in this study could serve as inputs into models that estimate the incremental cost per life saved associated with increased provision of one to one nursing. As an illustrative example of this, consider the case of a hospital providing 180 intensive care days per month. If it is assumed that infants who receive intensive care at a ratio of two to one rather than one to one, then an increase in the one to one nursing rate of ten percentage points requires an additional nine days of nursing labour, which would have the effect of reducing the mortality rate by 0.6 percentage points, equivalent to 1.08 deaths. The unit costs for an hour of face-to-face specialist nursing was estimated at £64 in 2014.[29] This would result in an incremental cost of £12,800 per life saved, which would generally be considered cost-effective by decision-making bodies such as the National Institute of Health and Care Excellence in England and Wales.[30] We recognise that this calculation is illustrative rather than proscriptive, and further research is required to incorporate considerations of staff position, qualifications, experience, and other factors.

We acknowledge limitations to our study. Our study is only able to identify the ‘marginal’ effects of the one to one nursing ratio on the in-hospital intensive care mortality rate; the effects of large increases in one to one nursing provision remain unknown. Even with 100% one to one nursing provision to infants during neonatal intensive care, the mortality rate will not be zero. Thus, while these findings support an increase in one to one nursing provision on tertiary level neonatal units, they do not inform us whether a one to one nurse to patient ratio for all intensive care days would have a beneficial effect. We are furthermore not able to identify the optimal nurse to patient ratio given that we only observe whether an infant received one to one nursing or not; for example, it is possible that a greater than one to one nurse to patient ratio has additional beneficial effects. Further research is
required to determine the optimal levels of nurse staffing to best improve infant clinical outcomes. This would involve infant level, daily observations of nursing support for infants receiving care in a neonatal unit.

One further weakness of our study is that we are not able to determine whether nurses should be re-allocated from other nursing tasks in neonatal units to one to one nursing in neonatal intensive care. Time-use studies were conducted in the early 1990s to determine nurse to patient ratios recommended by BAPM.[31,32] A more recent study re-affirmed these results and suggested required nursing time had increased.[33] New time-use studies are therefore an important area for future research.

Our study is also not able to suggest when during an infants’ care one to one nursing would achieve its optimal effects. Increasing one to one nursing provision is assumed to reduce preventable nursing errors that may lead to mortality. In the first hours of life this effect may be small as the underlying medical condition may have a larger effect. Many errors may not be prevented by increasing the nurse to patient ratio but through other quality improvements. We have assumed that increases in the provision of one to one nurses are indicative of increases in the overall nurse to patient ratio. Nevertheless, we have provided evidence that increases in one to one nursing provision for neonatal intensive care leads to a reduction in mortality. Further research is required both to establish how this is achieved in practice and to find other quality improvements that may reduce mortality. We also note that given the complexities involved in neonatal care and potentially large differences in practice between countries, these results may not be generalizable to other countries or health care systems.

This study provides evidence to support the claim that tertiary level neonatal units with higher levels of one to one nursing provision have reduced mortality rates. Further research is clearly warranted on the best way to achieve this. Furthermore, the benefits of increasing the nurse to patient ratio may be underestimated in this study since common neonatal morbidities are not considered, and previous studies have shown an increased nurse to patient ratio is associated with a reduction in the risk of diseases such as infection, bronchopulmonary dysplasia, and intra-ventricular haemorrhage.[15,16,21] This would be an important extension to these analyses in future. We believe the results in this study provide some evidence in support of a one to one nurse to patient ratio in neonatal intensive care in
England, in line with BAPM guidelines, and therefore provide evidence in support of increased
nursing labour provision on neonatal units in England.
WHAT IS ALREADY KNOWN ON THIS TOPIC

Higher nurse to patient ratios in neonatal units are associated with reduced risk of adverse clinical outcomes.

Many shifts on neonatal units in England are understaffed with respect to recommended nurse to patient ratios

A one to one nurse to patient ratio is recommended by the British Association of Perinatal Medicine for infants receiving intensive care

WHAT THIS STUDY ADDS

Provision of a one to one nurse to patient ratio for infants receiving intensive care declined between 2008 and 2012

Neonatal units that provided one to one nursing on a greater proportion of neonatal intensive care days had a lower mortality rate

Provision of a one to one nurse to patient ratio may be cost-effective for infants receiving intensive care however further research is required
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CONTRIBUTORS

SIW conceived the study; SIW, WA, and SP contributed to developing the statistical methodology for the study; SIW prepared the data for analysis; SIW, WA, SP, NMa, AM, ED, and NMo contributed to covariate selection and interpretation of the results; SIW prepared the first draft of the paper; this and all subsequent drafts were reviewed and revised by all authors; all authors approved the final version submitted.

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COMPETING INTERESTS

None declared.

ETHICAL APPROVAL

This study was carried out with the National Neonatal Research Database (REC 10/H0803/151) as part of NESCOP undertaken with permission from NHS Trust Caldicott Guardians.
DATA SHARING STATEMENT

No additional data available. Statistical code is available from the corresponding author.


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Tables

Table 1 Characteristics of tertiary neonatal units in the sample

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<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
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<td>34</td>
<td>41</td>
<td>42</td>
<td>41</td>
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</table>

Summary statistics for whole sample

<table>
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<tr>
<th>Variable</th>
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<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total intensive care days</td>
<td>63,036</td>
<td>70,256</td>
<td>75,400</td>
<td>89,893</td>
<td>97,681</td>
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<tr>
<td>Total one to one care days</td>
<td>9,415</td>
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<td>6,085</td>
<td>7,080</td>
<td>7,474</td>
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<tr>
<td>Percentage of intensive care days on which one to one nursing was provided</td>
<td>14.9%</td>
<td>8.7%</td>
<td>8.1%</td>
<td>7.9%</td>
<td>7.7%</td>
</tr>
<tr>
<td>Percentage of infants receiving intensive care and at least one day of one to one nursing</td>
<td>38.4%</td>
<td>38.6%</td>
<td>37.0%</td>
<td>37.6%</td>
<td>36.4%</td>
</tr>
<tr>
<td>Monthly intensive care mortality rate (%)</td>
<td>4.5%</td>
<td>4.9%</td>
<td>6.5%</td>
<td>6.0%</td>
<td>5.4%</td>
</tr>
</tbody>
</table>

Monthly median [IQR] values of neonatal units in the sample reported by year

<table>
<thead>
<tr>
<th>Variable</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly intensive care days provided</td>
<td>181 [121.5,235.5]</td>
<td>176 [112.237]</td>
<td>151.5 [100.2,233.5]</td>
<td>139 [114.249]</td>
<td>178.5 [120,272.2]</td>
</tr>
<tr>
<td>Percentage of intensive care days on which one to one nursing was provided</td>
<td>9.1 [3.8,17.5]</td>
<td>6.1 [2.6,11.7]</td>
<td>6.2 [3.2,11.8]</td>
<td>6.5 [3.4,11.2]</td>
<td>5.9 [3.1,10.8]</td>
</tr>
<tr>
<td>Percentage of infants receiving intensive care and at least one day of one to one nursing</td>
<td>39.4%</td>
<td>37.5% [26.1,36.8]</td>
<td>36.8 [25.0,37.5]</td>
<td>37.5 [25.0,35.7]</td>
<td>35.7 [25.0,37.5]</td>
</tr>
<tr>
<td>Monthly intensive care mortality rate (%)</td>
<td>4.0 [0.0,7.7]</td>
<td>4.4 [0.0,7.7]</td>
<td>5.3 [0.0,9.1]</td>
<td>5.3 [0.0,9.5]</td>
<td>4.5 [0.0,8.3]</td>
</tr>
</tbody>
</table>

Tertiary units were identified as those reporting tertiary level classification to the Neonatal National Audit Programme in 2010. The number of neonatal units varies over the period of the sample due to data becoming available and permissions being granted or ending for the NNRD and NESCOP, as well as mergers and closures of existing units (see Appendix C). Data on the number of open intensive care cots were not available. IQR = Inter-quartile range.
Table 2 Estimated effect of an increase in the provision of one to one nursing on the mortality rate. Results are presented from two different estimators: (1) OLS, which does not control for the correlation between the one to one nursing and unobserved casemix differences; (2) Instrumental variables estimator, which does control for the correlation between the one to one nursing and unobserved casemix differences using historical nursing levels. Results are interpreted as change in the number of deaths per 100 infants receiving neonatal intensive care per month resulting from a ten percentage point increase in one to one nursing.

<table>
<thead>
<tr>
<th>One to one nursing measured as a proportion of intensive care days(^a)</th>
<th>OLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated effect of a ten percentage point increase in one to one nursing on the monthly mortality rate (deaths per 100 infants receiving intensive care per month)</td>
<td>0.6</td>
</tr>
<tr>
<td>95 % Confidence interval</td>
<td>[0.1, 1.2]</td>
</tr>
<tr>
<td>p-value</td>
<td>0.05</td>
</tr>
<tr>
<td>Number of unique neonatal units</td>
<td>43</td>
</tr>
<tr>
<td>Total observations</td>
<td>2,228</td>
</tr>
</tbody>
</table>

Instrumental variables estimator

| Estimated effect of a ten percentage point increase in one to one nursing on the monthly mortality rate (deaths per 100 infants receiving intensive care per month) | -0.6                                                                |
| 95 % Confidence interval                                       | [-1.2, -0.0]                                                        |
| p-value                                                        | 0.04                                                               |
| Number of unique neonatal units                                | 43                                                                 |
| Total number of observations                                   | 2,140                                                              |

<table>
<thead>
<tr>
<th>One to one nursing measured as a proportion of admissions(^b)</th>
<th>OLS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated effect of a ten percentage point increase in one to one nursing on the monthly mortality rate (deaths per 100 infants receiving intensive care per month)</td>
<td>0.3</td>
</tr>
<tr>
<td>95 % Confidence interval</td>
<td>[0.1, 0.6]</td>
</tr>
<tr>
<td>p-value</td>
<td>0.002</td>
</tr>
<tr>
<td>Number of unique neonatal units</td>
<td>43</td>
</tr>
<tr>
<td>Total observations</td>
<td>2,228</td>
</tr>
</tbody>
</table>

Instrumental variables estimator

| Estimated effect of a ten percentage point increase in one to one nursing on the monthly mortality rate (deaths per 100 infants receiving intensive care per month) | -0.4                                                                |
| 95 % Confidence interval                                       | [-0.7, -0.0]                                                        |
| p-value                                                        | 0.03                                                               |
| Number of unique neonatal units                                | 43                                                                 |
| Total number of observations                                   | 2,140                                                              |

Regressions control for the mean values of gestational age, birth weight z-score, antenatal steroid receipt, and gender as well as year, calendar month, and neonatal unit effects (Appendix B). The number of observations are fewer for the instrumental variables estimation as lagged variables are utilised as instruments. Sensitivity analyses are presented in Appendix C.\(^a\)The proportion of intensive care days on which a one to one nurse to patient ratio was provided.

\(^a\)The proportion of intensive care admissions who received at least one day of care on which one to one nursing was provided.