BMC Nursing

RESEARCH Open Access

# Oxygen delivery and monitoring in neonatal intensive care units in Mexico in 2011 and in 2023: an observational longitudinal study

Luz Consuelo Zepeda Romero[1*], Daniel Perez Rulfo Ibarra[2], Juan Carlos Barrera De Leon[3,4], Valeria Alejandra Salas Cruz[1], David Blanco Bouzo[1], Jose Alfonso Gutierrez Padilla[5] and Clare Gilbert[6]

## Abstract

**Background** Retinopathy of prematurity (ROP) is a leading cause of avoidable blindness in children, particularly in Latin America, where hyperoxia is a significant risk factor. This study evaluated resource availability and use for administering and monitoring supplemental oxygen in Mexico.

**Methods** In 2011, an observational study in which 32 government neonatal intensive care units (NICUs) across Mexico were visited. Data collected included occupancy, staffing levels, and equipment to deliver and monitor supplemental oxygen. Preterm infants receiving oxygen were observed. In 2023, 13 NICUs were revisited, and similar data collected. Staffing levels were benchmarked against Argentinian and US recommendations.

**Results** In 2011, only 38% of NICUs had adequate medical and staffing levels to meet recommended cot-to-staff ratios for all shifts. Staffing ratios were worse during weekends and at night than during weekdays. Only 25.5% of cots had blenders, and 80.1% had saturation monitors. 153 infants were observed 87% of whom were being monitored. Upper and lower oxygen saturations were ≥ 96% in 53%, and ≤ 89% in 8%, respectively. Alarm settings were inadequate, as 38% and 32% of upper and lower alarms were switched off and 16% and 53% were incorrectly set, respectively. In the 13 NICUs with data from 2011 and 2023, cot-to-staff ratios deteriorated over time, and in 2023 no unit had recommended ratios for all shifts. Equipment provision did not change, with similar proportions of babies in oxygen being monitored (79% 2011; 75% 2023). Rates of hyperoxia decreased slightly from 54% in 2011 to 49% in 2023. More upper alarms were set (46% 2011; 75% 2023), but a higher proportion were incorrectly set (52% 2011; 68% 2023).

**Conclusions** Between 2011 and 2023, cot-to-staff ratios worsened, and equipment for safe oxygen delivery and monitoring remained insufficient. Despite available monitoring equipment, oxygen saturations often exceeded recommended levels, and alarms were frequently not set or incorrectly configured. Urgent improvements are needed in healthcare workforce numbers and practices, along with ensuring adequate equipment for safe oxygen delivery.

**Keywords** Retinopathy of prematurity, Mexico, Public health, Risk factors, Oxygen delivery, Oxygen monitoring, Neonatal intensive care units

*Correspondence:
Luz Consuelo Zepeda Romero
drconsuelo@yahoo.com
Full list of author information is available at the end of the article

## Introduction

Survival of neonates has improved considerably over the last few decades in Mexico due to a combination of public health policies and programs to improve maternal and child care, focusing on prevention, maternal nutrition, and improvements in quality of life and education [1]. In 2007, the inclusion of neonatal intensive care in the Seguro Popular Insurance (a public health insurance scheme), was a significant factor. Neonatal survival of babies born at 27–29 week's gestational age (GA) is now 74%, and 90% for babies born at 30–33 weeks. Unfortunately, this progress is associated with high rates of major disability, including blindness from retinopathy of prematurity (ROP), which affects 25% and 19% of survivors in these GA groups, respectively [2].

The quality of neonatal care tends to be higher in high-income countries than in middle-income countries like Mexico. This is primarily due to the greater availability of sophisticated technology, specialized staff, and robust healthcare infrastructure and systems in high-income settings. Many middle-income countries, including Mexico, face challenges that result in variation in the quality of neonatal care between neonatal intensive care units (NICUs) [3]. As a result, many preterm babies are exposed to potentially modifiable risk factors for ROP [4]. In the Latin American region, the proportion of preterm infants who develop Type 1 ROP is 14–20%, which is higher than in high-income settings [5]. Additionally, many of these infants have a GA of >32 weeks and a birth weight (BW) of >1500 g, resembling the characteristics of children who became blind from ROP during the first epidemic which occurred as a result of expose to unregulated 100% supplemental oxygen in the 1940s and 50s [6].

Optimum target oxygen saturations for preterm infants have been a matter of considerable debate, leading to a series of multicentre randomized clinical trials. The trials compared higher (91–95%) and lower (85–89%) target oxygen saturation levels in infants born at a GA of less than 28 weeks, with death or major morbidity as a composite outcome [7]. A meta-analysis by the NeOProM Collaboration of the 4,965 infants enrolled showed no significant difference between the lower and upper SpO2 target ranges on the primary composite outcome of death or major disability at a corrected age of 18–24 months [5, 6]. However, the lower saturation target was associated with lower rates of treatment requiring ROP but higher mortality rates.

Following these studies, most high resource settings now recommend an $SpO_2$ target of 90–94% with the upper alarm set at 95% to avoid hyperoxia which increases the risk of bronchopulmonary dysplasia as well as ROP [8, 9]. However, it is unclear how the findings of the meta-analysis translate to middle- and low-income countries (LIMICs) where many babies with treatment-requiring ROP have a GA of more than 28 weeks, as there have only been a few observational studies from Latin America, for example [9–12]. Nevertheless, the World Health Organization (WHO) recommends that the $SpO_2$ should not be lower than 89% or higher than 94% for preterm babies with a GA of less than 32 weeks. This means that the lower alarm should be set at 88% and the upper at 95% [13].

The safe delivery of oxygen for preterm infants requires considerable resources in terms of equipment to mix, warm, humidify and deliver oxygen, and to measure and monitor oxygen saturations. Neonatal staff need to be aware of the potential harms of saturations that fall outside the target range (i.e. death, cerebral palsy and ROP) and require training and support to respond appropriately when the alarms are activated. The purpose of this study was to assess oxygen delivery and monitoring in NICUs in Mexico, focusing on public sector facilities in large cities in the largest States.

## Methods

In this longitudinal observational study, five States in the Mexican Republic were purposively selected based on population size: Mexico State, Puebla, the Federal District where the capital city is located, Jalisco and Chiapas. (Veracruz State was not included due to flooding.) The five states selected account for 37% of the population (Fig. 1) and almost 40% of births. A list of NICUs in the public sector in each state was obtained from the Ministry of Health, and ranked according to the number of incubators (data available from the Ministry of Health website), as a proxy for the number of high dependency admissions [14].

In each state, NICUs in cities with the largest number of incubators were purposively selected. Thirty-five NICUs were selected, two of whom declined, and one was a short stay unit. The 32 NICUs were visited between June and August 2011.

After explaining the study and obtaining written informed consent, a senior member of the neonatal staff was interviewed in each NICU using a structured questionnaire developed by the research team (Additional file 1). The questions covered the characteristics of each unit, such as the total number of admissions in 2010 and bed occupancy, survival rates and complications among infants with BWs<1,500 g, resuscitation practices, number and qualification of staff working on the NICU, as well as the availability of equipment to deliver and monitor oxygen. All the nurses on the unit at the time of the visit who were willing to participate were given a self-administered, anonymous questionnaire to complete. The questionnaire had three sections; the first focused on the nurses' qualifications followed by an assessment of their knowledge of complications of prematurity, and

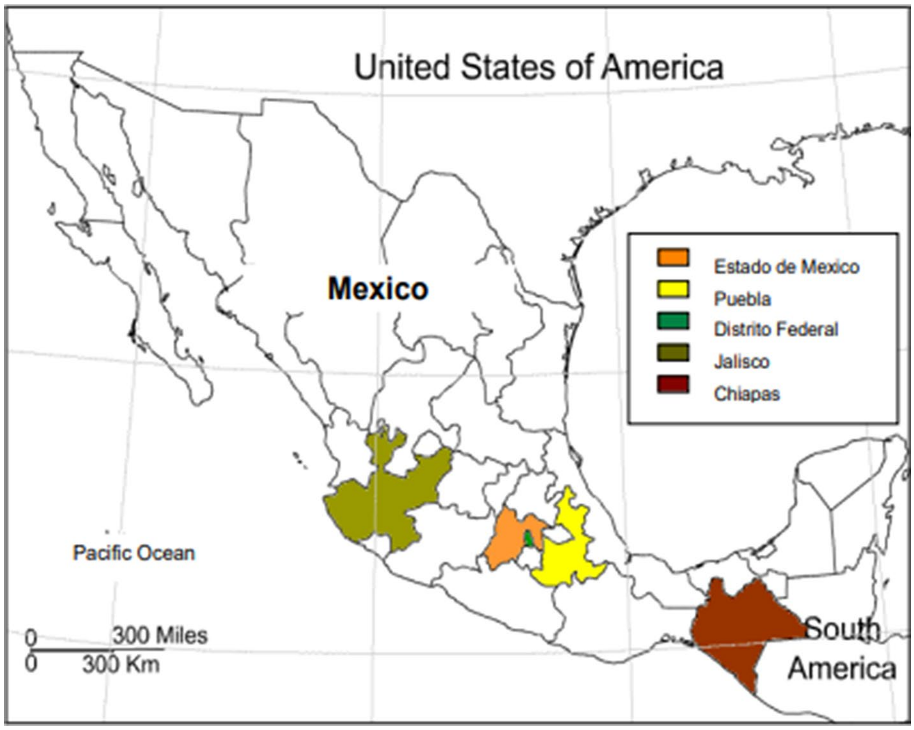


**Fig. 1** Map of Mexico showing States included in the study

oxygen delivery and saturation targets. Lastly, participants were asked about their training hours, courses they had attended, and opportunities for further professional development.

In each unit, preterm babies receiving supplemental oxygen were identified and observed. The equipment being used to deliver oxygen was recorded (blender, compressed air) and method of delivery (CPAP, ventilation etc.). Oxygen monitoring was assessed by observing whether a pulse oximeter was being used, and if so, the saturation levels and upper and lower alarm settings (i.e., not set, correctly or incorrectly set).

In January 2023, 13 of the larger NICUs were revisited to assess the impact of administrative changes within the Mexican healthcare system over the previous decade, after excluding three NICUs with adequate oxygen management in 2011. During the second visit, data collection focused on staffing levels, equipment for oxygen delivery and monitoring, and oxygen saturations and alarm settings in preterm infants receiving supplemental oxygen.

### Bench-marking

Mexican norms for neonatal care do not specify the number or qualifications of staff; norms from Argentina on the regulation of neonatology services and US National Association of Neonatal Nurses were used [15–17]. Cots: staff ratios for nursing and medical staff for shifts at different times of the day and week were calculated. The following shifts were used: weekday mornings, afternoons and nights, and weekend days and nights. Levels of staffing were scored as follows: at or above recommended levels (green) score = 3; below recommendations (yellow) score = 2 and well below recommendations (red) score = 1.

### Data management

Data were entered into a database created in Epi-Info 7 (Center for Disease Control and Prevention, www.cdc.go/epiinfo) and transferred into STATA 11.1 [18] for descriptive analysis. For descriptive analysis, frequency and percentages were used. The Kolmogorov-Smirnov test was used to assess distribution curves. Means and standard deviations were used for normally distributed data, and medians and ranges for skewed data. Student's t-tests were used to compare means, and Mann-Whitney U tests to compare medians. The Chi-square test was used to compare proportions. A significance level of $p < 0.05$ was considered statistically significant.

## Results

### Findings in 2011

#### *Characteristics of the NICUS visited in 2011*

Most of the 32 hospitals and NICUs were financed by the Secretary of Health and Assistance, and three were financed through other mechanisms. The NICUs were located in general hospitals ($n$ = 18), maternity hospitals ($n$ = 8) or pediatric hospitals ($n$ = 6). Twelve NICUs were level II and 20 were level III (Table 1). The total number of high dependency cots was 369 (mean 11.5, range

**Table 1** Characteristics of hospitals and NICUs and bed occupancy in 32 neonatal units in 2011. Shaded NICUs [13] were revisited in 2023

| State code | NICU code | Health provider | Type of hospital | Type of deliveries | Unit Level | Infants admitted | Cots (*n*) | Occupancy (%) |
|---|---|---|---|---|---|---|---|---|
| State A | 1 | SSA | General | N/high risk | 3 | N/high risk | 9 | 100 |
| State A | 2 | ISSSTE | General | N/high risk | 2 | N/high risk | 15 | 53 |
| State A | 3 | SSA | Paediatric | None | 3 | High risk | 8 | 100 |
| **State A** | **4** | **SSA** | **Maternity** | **N/high risk** | **3** | **N/high risk** | **14** | **100** |
| **State A** | **5** | **SSA** | **Maternity** | **N/high risk** | **3** | **N/high risk** | **14** | **100** |
| State A | 6 | SSA | General | High risk | 2 | Normal | 6 | 117 |
| State A | 7 | SSA | General | N/high risk | 2 | N/high risk | 10 | 60 |
| **State A** | **8** | **SSA** | **Maternity** | **High risk** | **3** | **Normal** | **19** | **53** |
| State B | 9 | SSA | General | None | 2 | High risk | 11 | 45 |
| **State B** | **10** | **SSA** | **Maternity** | **N/high risk** | **3** | **Normal** | **17** | **82** |
| State B | 11 | SSA | General | N/high risk | 2 | N/high risk | 20 | 45 |
| State B | 12 | SSA | Paediatric | None | 3 | High risk | 7 | 100 |
| State C | 13 | SSA | Maternity | High risk | 3 | Normal | 16 | 100 |
| State C | 14 | SSA | Paediatric | None | 3 | High risk | 11 | 92 |
| State C | 15 | SSA | General | N/high risk | 3 | N/high risk | 8 | 75 |
| **State C** | **16** | **SSA** | **Maternity** | **Normal** | **2** | **Normal** | **15** | **107** |
| **State C** | **17** | **SSA** | **Maternity** | **High risk** | **3** | **Normal** | **16** | **88** |
| State C | 18 | SSA | General | Normal | 2 | Normal | 8 | 100 |
| **State C** | **19** | **SSA** | **General** | **Normal** | **3** | **Normal** | **14** | **100** |
| State C | 20 | SSA | Paediatric | None | 3 | High risk | 4 | 50 |
| State C | 21 | SSA | Paediatric | None | 2 | High risk | 11 | 79 |
| **State D** | **22** | **SSA** | **General** | **None** | **3** | **High risk** | **22** | **82** |
| **State D** | **23** | **SSA** | **General** | **N/high risk** | **2** | **Normal** | **18** | **100** |
| **State D** | **24** | **SSA** | **General** | **N/high risk** | **3** | **Normal** | **10** | **100** |
| **State D** | **25** | **SSA** | **General** | **N/high risk** | **3** | **Normal** | **8** | **88** |
| **State D** | **26** | **SSA** | **Maternity** | **Normal** | **3** | **N/high risk** | **18** | **78** |
| State E | 27 | IMSS | General | N/high risk | 3 | N/high risk | 8 | 100 |
| State E | 28 | ISSSTE | General | N/high risk | 2 | N/high risk | 4 | 50 |
| State E | 29 | SSA | General | Normal | 2 | Normal | 6 | 100 |
| State E | 30 | SSA | General | Normal | 2 | Normal | 6 | 83 |
| **State E** | **31** | **SSA** | **General** | **N/high risk** | **3** | **N/high risk** | **8** | **163** |
| State E | 32 | SSA | Paediatric | None | 3 | High risk | 8 | 100 |

SSA = Secretaria de Salud y Asistencia (Secretary of Health and Assistance); IMSS = Instituto Mexicano del Seguro Social (Mexican Social Security Institute); ISSSTE = Instituto de Seguridad Social y Servicios para los trabajadores del Estado (Institute of Social Security and Services for State Workers); N/High risk = normal and high risk deliveries / infants. Bold font = neonatal units revisited in 2023

4–22). Four NICUs had 50% or lower occupancy at the time of the visit, in 12 occupancy was 50–99%; in 13 it was 100% and exceeded 100% in three units. There was no difference in survival rates for preterm babies with a birthweight of <1500 g between level II and level III units (level II: mean 69.4% (range 50–85), median 71% (SD ± 11.4%); level III mean 71.9% (range 48–93), median 72% (SD ± 12.4%), U Mann Whitney for medians $p = 0.72$).

## Staffing levels

### *Physicians*

There were 160 shifts across the week in the 32 units. Staffing levels of physicians (pediatricians or neonatologists) were better than for nursing (Fig. 2).

Recommended staffing levels for physicians is 8 cots / physician. For all the shifts, 66% were at or above recommended levels, 19% were below and 16% were well below. Eleven NICUs (34%) had the required number of physicians for all shifts, and eight (25%) NICUs had ratios that were inadequate for three or more of the five shifts. Staffing levels did not differ between level II and III units (median 7.2 (6-10.5) and 8 (6.2–12.7) $p = 0.526$, respectively).

Average cots: physician ratios varied by shift. During weekday mornings the average was 6:1 (range 2–11:1) and 9:1 (range 3–20:1) during weekday nights. During weekends the ratio was 8:1 (range 2.6–22) during the day and 9:1 (range 3-22) during the night.

### *Nurses*

Units were staffed by nurses trained in neonatology (specialist nurses), general and auxiliary nurses. Half (54%) of

| | Nursing Staff | | | | | | Medical Staff | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Level | Morning M-F | Afternoon M-F | Night M-F | Day weekend | Night weekend | % Graduate Nurse | Morning M-F | Afternoon M-F | Night M-F | Day weekend | Night weekend |
| 2 | 2 | 2 | 2.7 | 2 | 2.7 | 44.4 | 7.5 | 7.5 | 7.5 | 7.5 | 7.5 |
| 2 | 1.2 | 1.8 | 1.8 | 2.3 | 2.3 | 40 | 6 | 6 | 6 | 6 | 6 |
| 2 | 2 | 3 | 3 | 3 | 3 | 36.4 | 2 | 5 | 5 | 5 | 3 |
| 2 | 1.7 | 1.7 | 1.7 | 1.7 | 2.5 | 0 | 11 | 11 | 11 | 11 | 11 |
| 2 | 1.8 | 2.3 | 2.3 | 2.3 | 2.3 | 47.6 | 10 | 10 | 20 | 20 | 20 |
| 2 | 2.5 | 2.5 | 3 | 2.5 | 3 | 3.6 | 7 | 14 | 14 | 14 | 14 |
| 2 | 2 | 2 | 2.7 | 2.7 | 4 | 25 | 8 | 8 | 8 | 8 | 8 |
| 2 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 29.4 | 4.6 | 7 | 7 | 7 | 4.7 |
| 2 | 2 | 2 | 2.3 | 2 | 2.3 | 30.5 | 6 | 9 | 9 | 6 | 9 |
| 2 | 1 | 2 | 2 | 2 | 2 | 33.3 | 4 | 4 | 4 | 4 | 4 |
| 2 | 1.5 | 2 | 2 | 2 | 2 | 0 | 6 | 6 | 6 | 6 | 6 |
| 2 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 0 | 3 | 6 | 3 | 3 | 3 |
| 3 | 1.8 | 2.3 | 3 | 2.3 | 3 | 31.6 | 4.5 | 4.5 | 9 | 4.5 | 9 |
| 3 | 2 | 2 | 2.7 | 2 | 2.7 | 30 | 8 | 8 | 8 | 8 | 8 |
| 3 | 1.8 | 2.3 | 2.8 | 2.8 | 2.8 | 48.3 | 7 | 14 | 14 | 14 | 14 |
| 3 | 2 | 2 | 2.8 | 2.3 | 2.8 | 26.7 | 7 | 14 | 14 | 14 | 14 |
| 3 | 1.4 | 1.7 | 1.7 | 1.7 | 1.7 | 48.4 | 4.7 | 4.75 | 4.75 | 4.75 | 4.7 |
| 3 | 2.3 | 2.8 | 2.8 | 2.8 | 2.8 | 23.1 | 8.5 | 8.5 | 17 | 7 | 17 |
| 3 | 1.2 | 1.4 | 1.4 | 1.4 | 1.4 | 50 | 7 | 7 | 7 R | 7 | 7 |
| 3 | 1 | 1 | 1.3 | 1.3 | 1.3 | 50 | 2.6 | 8 | 8 | 8 | 8 |
| 3 | 2 | 2 | 2 | 2 | 2 | 33.3 | 6 | 6 | 6 | 6 | 6 |
| 3 | 0.8 | 1 | 1 | 1 | 1 | 16.1 | 4 | 8 | 8 | 8 | 8 |
| 3 | 1.8 | 2.3 | 2.8 | 2.8 | 2.8 | 68.9 | 4 | 4 | 4 | 3.2 | 4 |
| 3 | 2.5 | 2.5 | 3.3 | 3.3 | 3.3 | 100 | 7 | 14 | 14 | 7 | 14 |
| 3 | 0.4 | 0.5 | 0.7 | 1 | 0.7 | 0 | 2 | 4 | 4 | 4 | 4 |
| 3 | 2.3 | 2.6 | 2.6 | 2.6 | 2.6 | 29.4 | 11 | 22 | 22 | 22 | 22 |
| 3 | 2 | 2.5 | 2.5 | 2.5 | 2.5 | 46.5 | 5 | 5 | 5 | 5 | 5 |
| 3 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 26.3 | 4 | 8 | 8 | 8 | 8 |
| 3 | 2.3 | 2.3 | 2.3 | 2.3 | 2.3 | 29.4 | 9 | 9 | 9 | 9 | 6 |
| 3 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 20 | 8 | 8 | 8 | 8 | 8 |
| 3 | 2.2 | 3.3 | 3.3 | 3.3 | 3.3 | 4.5 | 2.6 | 4 | 8 | 2.6 | 8 |
| 3 | 1.6 | 2 | 2 | 2 | 2 | 30 | 4 | 8 | 8 | 8 | 8 |

**Fig. 2** Nursing and medical staffing levels (number of cots per member of staff) by type of unit (level II or III) in 2011

the shifts had overall nursing levels at or above recommended levels (i.e., 2 cots/nurse), 13% were below and 33% were well below recommendations. Only 11 (34%) NICUs had the recommended ratio for all shifts and in 15 (47%) ratios were inadequate for three or more of the five shifts (Fig. 2).

Although the cots: nurse ratios were often 2:1, as recommended, there was considerable variation by shift. The range during weekday mornings was 1-2.7 and during weekday nights the range was 0.7–3.3. The worst ratio, range 0.7-4, was during the night at weekends when 16 NICUs had ratios of one nurse to 2.5 or more cots. There was no significant difference in nursing levels between level II and III units; median 12 (interquartile range 8.25-15) and 9.50 (interquartile range 6.25-15), respectively (U Mann Whitney for medians, $p=0.60$).

In most units less than 30% of nurses were specialized nurses, and 5 units did not have any trained nurses, all nursing staff being auxiliaries and general nurses. In four (13%) NICUs the proportion of neonatal nurses was below recommendations, and in 27 (84%) NICUs it was well below recommendations.

### *Nurses' knowledge of ROP*

Anonymous questionnaires were administered to 152 nurses. Half of the nurses had less than three years of experience in neonatal care; 53% were general nurses, 29% were certified or specialist nurses, 5% were auxiliary nurses, 7% did not specify and 6% were students.

However, their salary scale did not always reflect their qualifications as 43% were paid as general nurses, 34% as auxiliary nurses and 10% as specialist nurses. Half (50%) of the nurses had attended less than two hours of formal teaching in the previous year and 28% had attended 20 or more hours of teaching. A third (35%) said they had not been given any opportunity for training; 49% said they would welcome additional professional development and 20% would value training in neonatal intensive care.

Over a third (37%) of the nurses knew that ROP was a major complication of prematurity and a third (32%) said that they were aware of the Mexican ROP technical guidelines. Most (87%) knew that high and low oxygen saturation levels were harmful, and 68% knew that monitors have an upper limit alarm. Additionally, 42% described the correct upper limit alarm for oxygen saturation, and 66% identified the lower limit.

#### Equipment to deliver and monitor supplemental oxygen

Over half of the units (18/32, 56%) did not have equipment to blend air and oxygen, and only six (19%) had enough blenders for all babies receiving supplemental oxygen. Over half the units (56%) had enough equipment to monitor oxygen saturation in all babies receiving oxygen; in eight units, up to 50% of babies could be monitored, and in the remaining six < 50% could be monitored. There was no significant difference between level II and level III units in terms of their ability to blend air and oxygen (median equipment score 3; range 0.8-4 for level II and III units), nor in equipment for monitoring oxygen saturation levels: level II (median equipment score 2.51 ± SD 0.95; range 0.8-4) vs. level III (median 3.0 ± SD 0.93; range 0.87-4) ($p = 0.894$). Protocols on safe oxygen saturation levels were present in four of the 12 level II NICUs and in five of the 20 level III units (27% overall) ($p = 0.207$).

#### Oxygen saturation levels

153 preterm babies aged less than 30 days receiving oxygen were observed, 20 (13%) of whom were not being monitored. Overall, only 39% of babies had oxygen saturations within the range recommended at the time (i.e., 89–94%), and in 53% saturations were ≥ 95% (Fig. 3A).

Level III units had a higher proportion of infants with saturations within the range recommended than level II units, but this was not statistically significant (Chi-sq test, $p = 0.07$).

In 7 of the 18 units with adequate equipment to monitor oxygen saturation, none of the infants had oxygen saturations of ≥ 95%. In 3 NICUs, all infants had oxygen saturations of ≥ 95%.

#### Alarm settings

Alarm settings and oxygen saturation levels were available for 133 babies being monitored (Fig. 4A). In half the units, both alarms were switched on, but in 11 (34%) both

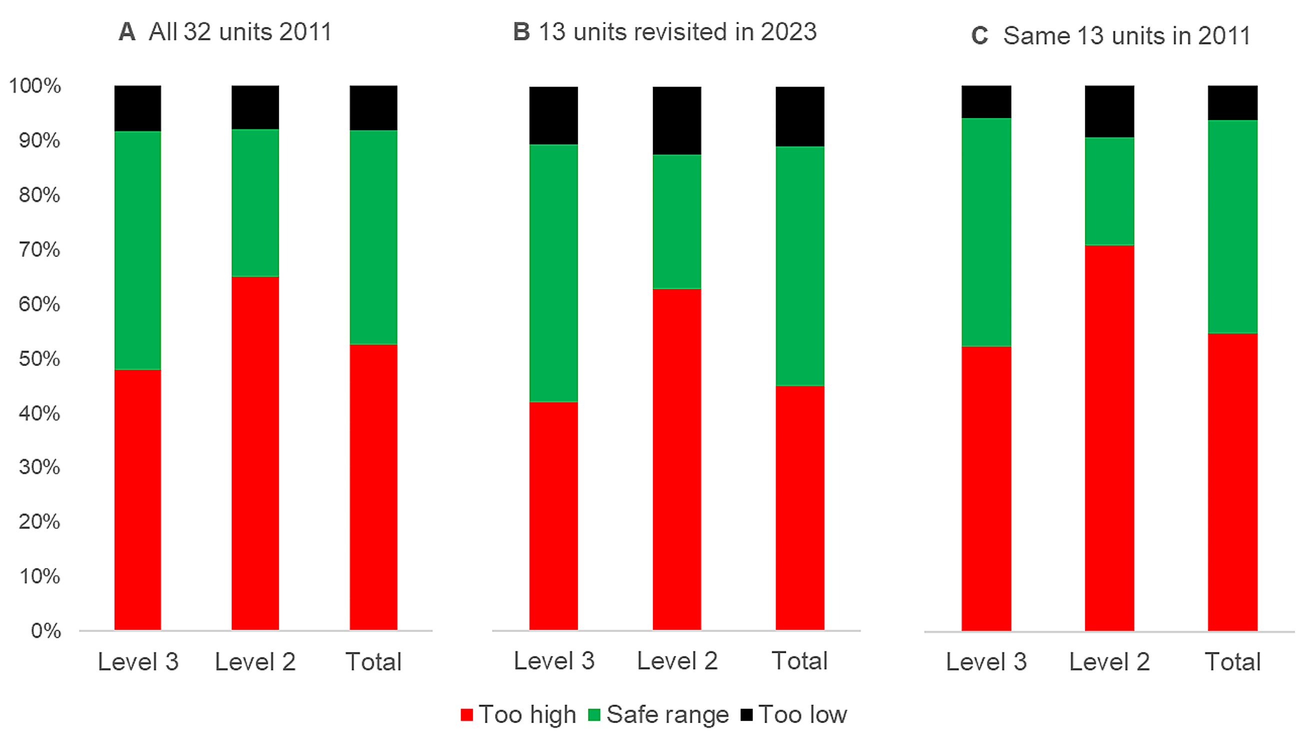


**Fig. 3** Oxygen saturations in babies observed, by level of neonatal care **A**. All 32 units in 2011, **B**. 13 units revisited in 2023 and **C**. data for the same 13 units first visited in 2011

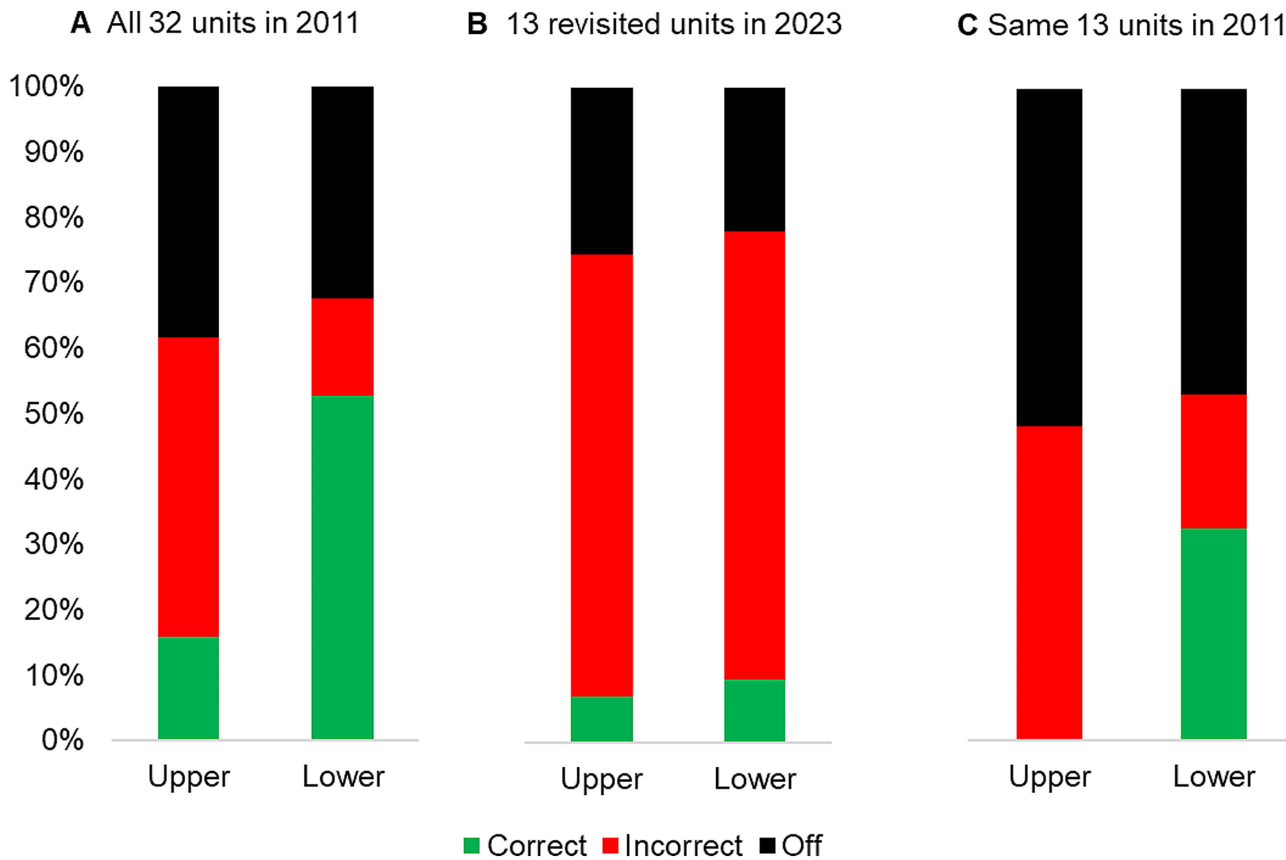


**Fig. 4** Monitor alarms settings in babies observed **A** All 32 units in 2011, **B** 13 units revisited in 2023 and **C** data for the same 13 units first visited in 2011

were switched off. If only one alarm was on, the lower alarm was more likely to be switched on than the upper alarm. In the majority of NICUs, the upper and lower alarms were not correctly set; both alarms were switched on and set correctly in only one level III unit. In 24 units, the upper alarm was set at 100%; in eight units, the lower alarm was set at 80%, and the majority of other lower alarms were set at 84% or 85%.

### Findings in 2023

#### *Characteristics of the NICUS visited*

The 13 NICUs revisited were financed by the Secretary of Health and Assistance (see bold font in Table 1). The NICUs were located in general hospitals ($n$ = 6) and maternity wards ($n$ = 7). Three NICUs were level II and ten were level III. The total number of high-dependency cots was 241 (mean 18.8, range 4–35). Two NICUs had 100% occupancy and four exceeded (range 123–150%) capacity.

#### *Staffing levels*

Cots: staff ratios were worse in 2023 than in 2011 for physicians and nurses for all five shifts across the week (Fig. 5).

#### *Oxygen delivering, saturations and alarm settings*

In 2023, 145 babies were observed; 97 had been observed in the same 13 NICUs in 2011. The proportion of infants being monitored was similar (79% in 2011; 75% in 2023). Oxygen saturations were similar in terms of the proportion with saturations within the recommended range (39% in 2011; 44% in 2023)(Fig. 3B and C). The proportion of monitors with activated alarms had improved and the proportion with correctly set lower alarms increased from 0% in 2011 to 7% in 2023 (Fig. 4B and C).

## Discussion

The prevention of Type 1 ROP requires high quality neonatal care from immediately after birth, which includes avoiding hyperoxia and fluctuating hyperoxia / hypoxia [19]. The safe delivering of oxygen requires supplies of compressed air and oxygen, adequate equipment which is well maintained, and an adequate number of staff who know about the risk of hyperoxia as well as hypoxia. Staff need to be skilled in using the equipment and setting the alarms, monitoring oxygen saturations and responding appropriately when the alarms are triggered.

In this study, the majority of neonatal nurses in some of the largest NICUs in Mexico were aware that hyperoxia as well as hypoxia are harmful, and although two

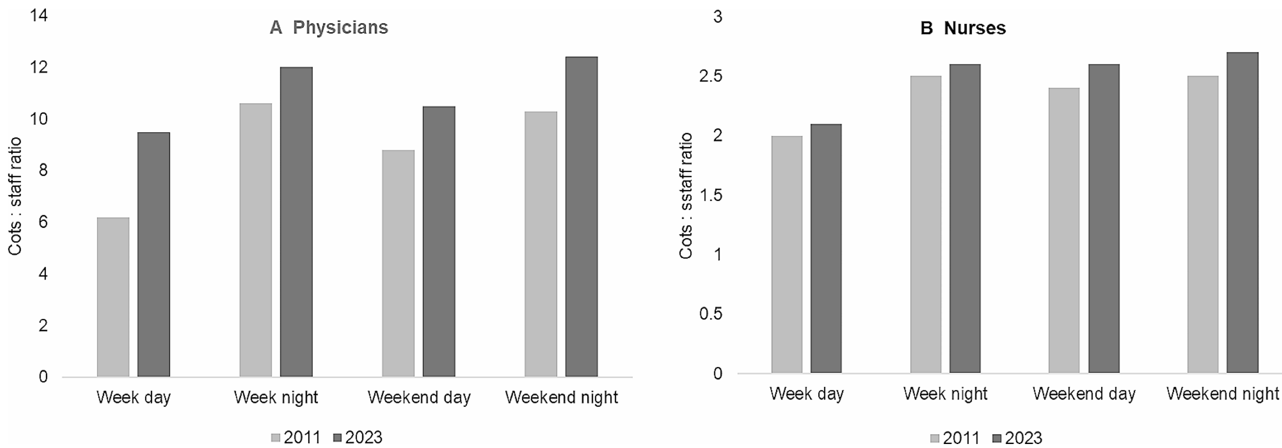


**Fig. 5** Cots: staff ratios in 13 NICUs in 2011 and 2023 for **A** physicians and **B** nurses

thirds knew the lower saturation alarm limit, less than half knew the upper safe limit. There was a marked lack of equipment to safely deliver oxygen, which included a lack of air-oxygen blenders, as well as equipment to monitor oxygen saturations. When monitoring equipment was available, both alarms were switched off in one third of the infants observed. Both alarms were switched on and correctly set in only one level III unit. These findings may, in part, explain why 15% of the infants observed who were receiving supplemental oxygen were not being monitored at all, and in over half of those being monitored, oxygen saturations were ≥95%. We are not aware of any other studies which have observed oxygen saturation levels in preterm infants receiving supplemental oxygen, but a study in India also showed that upper alarms were switched off or were incorrectly set in 94% of infants; a higher proportion had lower alarms correctly set and switched on, as in our study [20]. These findings suggest that nursing staff are motivated to reduce the risk of hypoxia.

In 2023 oxygen saturations were not very different from those in 2011, but more alarms were switched off or were not correctly set. This finding is surprising, given that there was less equipment and graduate nurses in 2023 compared with 2011. One interpretation is that there was a better understanding of the need to control oxygen levels in 2023 compared with 2011.

### Low nurse: baby ratios and training

Factors which are likely to have contributed to these findings included overcrowded units which would worsen cots: staff ratios. In 2011, the number of qualified and specialist nurses was also below recommended levels, and half of the nurses interviewed had received less than two hours of formal training in neonatal care in the previous year.

Low nurse: baby ratios in NICUs are not limited to low resource settings and have been reported in the United Kingdom [21] and the United States of America [22], for example. Low numbers of nurses and inadequate training are recognised bottlenecks in the delivery of neonatal care in low resource settings [23]. Under staffing has been associated with delayed or missed care practices [21], higher rates of nosocomial infection [22], inpatient mortality [24] and poorer patient care and counselling of parents [22]. Given the variation in case mix between level II and level III NICUs, as well as within level III units, there is considerable debate concerning optimal staffing levels and the skills mix required [21]. Overcrowding, as is often the case in low- and middle-income settings, increases demands on nursing staff and can also increase infection rates [25]. In low resource settings recruiting and retaining nursing staff is challenging, particularly in rural areas, which is compounded by a lack of competency-based training and refresher training, and low motivation [23]. In our study the number of graduate nurses was lower in 2023 than in 2011 in a significant proportion of NICUs. Although reasons for this were not explored, poor remuneration and hospital policies to rotate staff to different services, such as pediatric emergency care, may have been contributory factors.

In our study, less than one in three nurses knew that ROP was a potential complication of preterm birth. Similar findings have been reported from other low resource settings [20, 26]. For example, in a study in a government hospital in Kerala, India, only 48% of nurses had a diploma in nursing; >50% had up to 5 years of experience in paediatric care and 73% also worked in other areas in the hospital. Half of the nurses had some knowledge of ROP but only a quarter had a good level of knowledge and were able to identify optimal oxygen target saturations to prevent it [27].

### Lack of equipment and protocols

In our study, lack of equipment limited the ability of staff to adequately deliver and monitor supplemental oxygen, a frequent finding in NICUs in low- and middle-income countries [20, 28, 29]. In addition, most units did not have written protocols on oxygen delivery. In 2023 the availability of equipment to deliver and monitor oxygen was worse than in 2011 in almost 40% of the units revisited.

Improving the quality of neonatal care is challenging in low- and middle-income countries, where there is less emphasis on teamwork and where perinatal services are less well organized than in high income countries. [30] However, several quality improvement initiatives have demonstrated that packages of evidence-based practices delivered primarily by nurses can reduce neonatal mortality, [31] improve the outcomes of neonatal care, [32] lead to a more rational use of supplemental oxygen, [28, 33] and less exposure to hyper- or hypoxia [34]. An initiative in Lima, Peru, which entailed workshops for neonatal nurses on oxygen management, led to a lower incidence of treatment requiring ROP in three of the six NICUs included [11]. Training nurses in the optimal use of oxygen in Mexico City also led to a reduction in aggressive ROP (personal communication).

ROP has a multifactorial etiology and although there has rightly been a focus on oxygen management, other aspects of perinatal care are also important. These include provision of antenatal steroids when preterm delivery is threatened; [35] prevention of hypothermia in labour wards, control of sepsis and improved nutrition including the provision of mothers' breast milk, [36] reducing pain, and providing supportive care, including kangaroo care. Oral caffeine, which is usually given to prevent or treat apnea of prematurity, is one of the few therapies shown in high quality randomized controlled trails (RCTs) to reduce the incidence of severe ROP [37].

Some of the changes between 2011 and 2023 regarding staffing levels and equipment, and therefore oxygen management, are likely to reflect political and regulatory changes in Mexico during the intervening period. In 2003, Mexico instituted a national health insurance plan, Seguro Popular, which provided access to a package of comprehensive health services with financial protection for more than 50 million people [38]. Neonatal care was included, and by 2011, the infant mortality rate had declined to 15/1000 live births. By 2012, Mexico was on track to achieve universal health coverage [39]. However, in 2019, the new government cancelled Seguro Popular as part of an anti-corruption campaign, which led to sudden and drastic cuts of 30–40% in spending on government health services. The cuts included terminating all contracts with third parties, such as contracting agencies which provided staff to government facilities, and the suspension of payments to non-governmental organizations to provide services, such as HIV testing and management. Time will tell if the cuts lead to reforms that strengthen the health system, including the care of newborns.

Limitations of this study include the selection of large NICUs located in the most densely populated capitals of the country, potentially limiting generalizability of the findings to smaller NICUs and less populated states. In addition, nurses' knowledge of oxygen management and ROP was not assessed in 2023.

## Conclusions

Despite government guidelines, this study highlights considerable challenges related to the safe delivery of oxygen, including overcrowded units, low nursing levels and a lack of equipment. Nurses also demonstrated inadequate knowledge of safe oxygen management, which may contribute to poor practices.

Neonatologist and paediatricians need to assume team leadership roles, by ensuring they are up to date on best practices, that protocols for oxygen management are established and implemented, and that nursing staff receive ongoing professional development and support. Advocacy is required with health care providers and hospital administrators for better nurse training, with refresher training and clear career pathways, and to reduce the rotation of skilled neonatal staff to other services. Advocacy will also be needed to ensure that neonatal units are adequately equipped to deliver oxygen and to monitor oxygen saturations.

Preventing ROP by improving the quality of neonatal care would be cost-efficient, avoiding the costs of treatment and the lifelong expenses associated with blindness. Without sustained policies and practices which improve neonatal care, ROP will remain the main avoidable cause of blindness in children in Mexico.

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12912-024-02227-x.

Supplementary Material 1

Supplementary Material 2

### Acknowledgements

We thank the hospitals that assisted us in data collection.

### Author contributions

LCZR and VASC collected the data and created the database. JCBL and DPRI analyzed and drew conclusions based on the databases. DBB and JAGP graphed the results and created the figures. CG assisted in visualizing the database results. All authors contributed to the main text of the manuscript and participated in its revision.

### Funding

The 2011 component of the study was supported by the Hammond Fund, the London School of Hygiene & Tropical Medicine), the Trust Fund, the Sear Foundation and the Lieutenant-Colonel Henry Kirkpatrick Scholarship. The 2023 component was funded by the authors.

**Data availability**

The data that support the findings of this study are not openly available due to reasons of sensitivity and are available from the corresponding author upon reasonable request.

## Declarations

**Ethics approval and consent to participate**

The study was approved by the ethics committee of the London School of Hygiene & Tropical Medicine and by the Ministry of Maternal and Child Health in Mexico. No names were collected, and a unique study number was allocated to each NICU, the heads of each NICU authorized the collection of data. In each of the NICUs a written informed consent form was obtained.

**Consent for publication**

Not applicable.

**Author details**

[1]Neonatal Ophtalmology, Pediatric Surgery, Hospital Civil de Guadalajara, University Center of Health Sciences, University of Guadalajara, Zapopan, Jalisco, Mexico
[2]Departamento de Reproduccion Humana, Crecimiento y Desarrollo, Universidad de Guadalajara, Centro Universitario de Ciencias de la Salud, Guadalajara, Jalisco, Mexico
[3]Departamento de Pediatría, Hospital Materno Infantil Esperanza Lopez Mateos, Secretaria de Salud Jaisco, Zapopan, Jalisco, Mexico
[4]Departamento de Salud, Centro Universitario Los Valles, Universidad de Guadalajara, Ameca, Jalisco, Mexico
[5]División de Discipinas Clínicas, Centro Universitario de Ciencias de la Salud, Universidad De Guadalajara, Zapopan, Jalisco, Mexico
[6]Department of Clinical Research, London School of Hygiene & Tropical Medicine, London, UK

Received: 20 February 2024 / Accepted: 5 August 2024
Published online: 26 August 2024

**References**

1. Hernández-Bringas HH, Narro-Robles J. Mortalidad Infantil en México: logros y desafíos. Papeles De población. 2019;25(101):17–49.
2. Profit J, Lee D, Zupancic JA, Papile L, Gutierrez C, Goldie SJ, et al. Clinical benefits, costs, and cost-effectiveness of neonatal intensive care in Mexico. PLoS Med. 2010;7(12):e1000379.
3. Gilbert C, Malik ANJ, Nahar N, Das SK, Visser L, Sitati S, et al. Epidemiology of ROP update - Africa is the new frontier. Semin Perinatol. 2019;43(6):317–22.
4. Kim SJ, Port AD, Swan R, Campbell JP, Chan RVP, Chiang MF. Retinopathy of prematurity: a review of risk factors and their clinical significance. Surv Ophthalmol. 2018;63(5):618–37.
5. Arnesen L, Duran P, Silva J, Brumana L. A multi-country, cross-sectional observational study of retinopathy of prematurity in Latin America and the Caribbean. Rev Panam Salud Publica. 2016;39(6):322–9.
6. Zepeda-Romero LC, Meza-Anguiano A, Barrera-de Leon JC, Angulo-Castellanos E, Ramirez-Ortiz MA, Gutierrez-Padilla JA, et al. Case series of infants presenting with end stage retinopathy of prematurity to two tertiary eye care facilities in Mexico: underlying reasons for late presentation. Matern Child Health J. 2015;19(6):1417–25.
7. Darlow BA, Husain S. Primary prevention of ROP and the oxygen saturation targeting trials. Semin Perinatol. 2019;43(6):333–40.
8. Askie LM, Darlow BA, Finer N, Schmidt B, Stenson B, Tarnow-Mordi W, et al. Association between Oxygen Saturation Targeting and Death or disability in extremely Preterm infants in the neonatal oxygenation prospective Meta-analysis collaboration. JAMA. 2018;319(21):2190–201.
9. Cummings JJ, Polin RA, Committee On F. Newborn. Oxygen targeting in extremely low Birth Weight infants. Pediatrics. 2016;138(2).
10. Sweet DG, Carnielli V, Greisen G, Hallman M, Ozek E, Plavka R, et al. European Consensus guidelines on the management of respiratory distress syndrome – 2016 update. Neonatology. 2017;111(2):107–25.
11. Gordillo L, Villanueva AM, Quinn GE. A practical method for reducing blindness due to retinopathy of prematurity in a developing country. J Perinat Med. 2012;40(5):577–82.
12. Zepeda-Romero LC, Lundgren P, Gutierrez-Padilla JA, Gomez-Ruiz LM, Quiles Corona M, Orozco-Monroy JV, et al. Oxygen monitoring reduces the risk for retinopathy of Prematurity in a Mexican Population. Neonatology. 2016;110(2):135–40.
13. Organization WH, WHO Recommendations on Interventions to Improve Preterm Birth Outcomes. (2025). Accesed November 2023 [ http://www.who.int/reproductivehealth/publications/maternal_perinatal_health/preterm-birth-highlights/en/
14. Secretaria de Salud ¨Directorio de Infraestructura¨. (2011) Accesed June 2024 [ http://www.sinais.salud.gob.mx/infraestructura/directorio.html
15. Diario Oficial de la Federación. ¨Organización y funcionamiento de las unidades y cuidados.(2013). Accesed June 2024 [ http://dof.gob.mx/nota_detalle.php?codigo=5314307&fecha=17/09/2013
16. Argentina Ministerio de Salud. Norma de Organización y Funcionamiento de los Servicios de Neonatología y Cuidados Intensivos Neonatales, incorporada al Programa Nacional de Garantía de Calidad de la Atención Médica June 2024 2002 [Available from: Retrieved from: servicios.infoleg.gob.ar/infolegInternet/anexos/70000–74999/74680/norma.htm
17. American National Association of Neonatal Nurse. (2014). Position Statement #3009 minimun Registered Nurse Staffing in NICUs 2014. Accesed June 2024. [ http://nann.org/uploads/About/PositionPDFS/1.4.6_RN%20Staffing%20in%20the%20NICU.pdf
18. Stata Statistical Software. Release 11.1. [Internet]. 2010.
19. Hellstrom A, Smith LE, Dammann O. Retinopathy of prematurity. Lancet. 2013;382(9902):1445–57.
20. Sabherwal S, Gilbert C, Foster A, Kumar P. Status of Oxygen Monitoring in four selected Special Care Newborn Units in India. Indian Pediatr. 2020;57(4):317–20.
21. Pillay T, Nightingale P, Owen S, Kirby D, Spencer A. Neonatal nurse staffing and delivery of clinical care in the SSBC Newborn Network. Arch Dis Child Fetal Neonatal Ed. 2012;97(3):F174–8.
22. Rogowski JA, Staiger D, Patrick T, Horbar J, Kenny M, Lake ET. Nurse staffing and NICU infection rates. JAMA Pediatr. 2013;167(5):444–50.
23. Moxon SG, Lawn JE, Dickson KE, Simen-Kapeu A, Gupta G, Deorari A, et al. Inpatient care of small and sick newborns: a multi-country analysis of health system bottlenecks and potential solutions. BMC Pregnancy Childbirth. 2015;15(Suppl 2):S7.
24. Sherenian M, Profit J, Schmidt B, Suh S, Xiao R, Zupancic JA, et al. Nurse-to-patient ratios and neonatal outcomes: a brief systematic review. Neonatology. 2013;104(3):179–83.
25. Dahl TM, Solevag AL. A cross-sectional study of neonatal intensive care unit overcrowding and understaffing associated with bacterial outbreaks. Acta Paediatr. 2022;111(11):2090–7.
26. Thuileiphy T, Joshi P, Dolma Y, Paul J, Joshi M, Gudiya, et al. A descriptive survey on knowledge gap related to retinopathy of prematurity and its prevention and management among nurses in a tertiary care hospital. Indian J Ophthalmol. 2021;69(8):2122–5.
27. Bindu Sankar KPP. A study to assess the knowledge regarding retinopathy of Prematurity among Staff nurses in a Tertiary Care Centre. Kerala Int J Nur Edu Res. 2018;6(3):253–5.
28. Deorari AK, Kumar P, Chawla D, Thukral A, Goel S, Bajaj R et al. Improving the quality of Health Care in Special neonatal care units of India: a before and after intervention study. Glob Health Sci Pract. 2022;10(5).
29. Herrod SK, Stevenson A, Vaucher YE, Lambert SR, Isenberg SJ, Yap VL, et al. Oxygen management among infants in neonatal units in sub-saharan Africa: a cross-sectional survey. J Perinatol. 2021;41(11):2631–8.
30. Darlow BA, Gilbert CE, Quiroga AM. Setting up and improving retinopathy of prematurity programs: interaction of neonatology, nursing, and ophthalmology. Clin Perinatol. 2013;40(2):215–27.
31. Walker D, Otieno P, Butrick E, Namazzi G, Achola K, Merai R, et al. Effect of a quality improvement package for intrapartum and immediate newborn care on fresh stillbirth and neonatal mortality among preterm and low-birthweight babies in Kenya and Uganda: a cluster-randomised facility-based trial. Lancet Glob Health. 2020;8(8):e1061–70.
32. Gilbert C, Darlow B, Zin A, Sivasubramaniam S, Shah S, Gianini N, et al. Educating neonatal nurses in Brazil: a before-and-after study with interrupted time series analysis. Neonatology. 2014;106(3):201–8.
33. Chawla D, Deorari A. Retinopathy of prematurity prevention, screening and treatment programmes: progress in India. Semin Perinatol. 2019;43(6):344–7.
34. Sivanandan S, Sethi T, Lodha R, Thukral A, Sankar MJ, Agarwal R, et al. Target Oxygen Saturation among Preterm neonates on Supplemental Oxygen Therapy: a Quality Improvement Study. Indian Pediatr. 2018;55(9):793–6.

35. Travers CP, Clark RH, Spitzer AR, Das A, Garite TJ, Carlo WA. Exposure to any antenatal corticosteroids and outcomes in preterm infants by gestational age: prospective cohort study. Bmj-Brit Med J. 2017;356.
36. Bharwani SK, Green BF, Pezzullo JC, Bharwani SS, Bharwani SS, Dhanireddy R. Systematic review and meta-analysis of human milk intake and retinopathy of prematurity: a significant update. J Perinatol. 2016;36(11):913–20.
37. Schmidt B, Roberts RS, Davis P, Doyle LW, Barrington KJ, Ohlsson A, et al. Long-term effects of caffeine therapy for apnea of prematurity. N Engl J Med. 2007;357(19):1893–902.
38. Agren D. AMLO's Mexico leads to drastic cuts to health system. Lancet. 2019;393(10188):2289–90.
39. Knaul FM, González-Pier E, Gómez-Dantés O, García-Junco D, Arreola-Ornelas H, Barraza-Lloréns M, et al. The quest for universal health coverage: achieving social protection for all in Mexico. Lancet. 2012;380(9849):1259–79.

## Publisher's Note