Neonatal mortality risk for vulnerable newborn types in 15 countries using 125.5 million nationwide birth outcome records, 2000 to 2020

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Vulnerable Newborn multi-country analyses to advance measurement related to preterm birth and small-for-gestational age

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Neonatal mortality risk for vulnerable newborn types in 15 countries using 125.5 million nationwide birth outcome records, 2000 to 2020

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AUTHORS

L Suárez-Idueta[1*], H Blencowe[2*], Y Okwaraji[2], J Yargawa[2], E Bradley[2], A Gordon[3], V Flenady[4], ES Paixao[2,5], ML Barreto[5], S Lisonkova[6], Q Wen[6], P Velebil[7], J Jírová[8], E Horváth-Puhó[9], HT Sørensen[9], L Sakkeus[10], L Abuladze[10,11], KA Yunis[12], A Al Bizri[12], A Barranco[13], L Broeders[14], AE van Dijk[14], F Alyafei[15], T Olukade[15] , N Razaz[16], J Söderling[16], LK Smith[17], ES Draper[17], E Lowry[18], N Rowland[19] , R Wood[20,21], K Monteath[22], I Pereyra[23], G Pravia[23], EO Ohuma[2**], JE Lawn[2**]

On behalf of the National Vulnerable Newborn Mortality Collaborative Group and Vulnerable Newborn Measurement Core Group (listed at the end of the manuscript and as collaborative authors on PubMed)

[1] Mexican Society of Public Health, Mexico City, Mexico

[2] Maternal, Adolescent, Reproductive & Child Health (MARCH) Centre, London School of Hygiene & Tropical Medicine, London, UK

[3] University of Sydney, Faculty of Medicine and Health, New South Wales, Australia

[4] Centre for Research Excellence in Stillbirth, MRI-UQ, Centre of Research Excellence in Stillbirth, Mater Research Institute, The University of Queensland, Brisbane, Australia

[5] Center for Data Integration and Knowledge for Health (CIDACS), Instituto Gonçalo Moniz, Fiocruz Bahia, Fundação Oswaldo Cruz, Salvador, Brazil

[6] Department of Obstetrics & Gynaecology, University of British Columbia, Vancouver, Canada

[7] Department of Obstetrics and Gynaecology, Institute for the Care of Mother and Child, Prague, Czech Republic

[8] Department of Data Analysis, Institute of Health Information and Statistics of the Czech Republic, Prague, Czech Republic

[9] Department of Clinical Epidemiology, Aarhus University and Aarhus University Hospital, Aarhus N, Denmark

[10] School of Governance, Law and Society, Estonian Institute for Population Studies, Tallinn University, Tallinn, Estonia

[11] Finnish Population Research Institute, Väestöliitto.

[12] Department of Pediatrics and Adolescent Medicine, American University of Beirut, Beirut, Lebanon

[13] Directorate of Health Information, Ministry of Health, Mexico City, Mexico

[14] Perined, Utrecht, the Netherlands

[15] Department of Paediatrics, Hamad General Hospital, Doha, Qatar

[16] Clinical Epidemiology Division, Department of Medicine Solna, Karolinska Institutet, Stockholm, Sweden

[17] Department of Health Sciences, College of Life Sciences, University of Leicester, Leicester, United Kingdom

[18] School of Natural and Built Environment, Queen's University Belfast, Belfast, Northern Ireland

[19] Queen's Management School, Queen's University Belfast, Belfast, Northern Ireland

[20] Public Health Scotland, Edinburgh, UK and

[21] Usher Institute, University of Edinburgh, Edinburgh, UK

[22] Pregnancy, Birth and Child Health Team, Public Health Scotland, Edinburgh, UK

[23] Department of Wellness and health, Catholic University of Uruguay, Montevideo, Uruguay

*Joint first authors

** Joint senior authors

Corresponding author Hannah Blencowe (hannah.blencowe@lshtm.ac.uk)

Maternal, Adolescent, Reproductive & Child Health (MARCH) Centre, London School of Hygiene & Tropical Medicine, London, UK

ABSTRACT

Objective: To compare neonatal mortality associated with six novel vulnerable newborn types in 125.5 million livebirths across 15 countries, 2000 to 2020.

Design: Population-based, multi-country study.

Setting: National data systems in 15 middle and high-income countries.

Methods: We used individual-level datasets identified for the Vulnerable Newborn Measurement Collaboration. We examined the contribution to neonatal mortality of six newborn types combining gestational age (preterm, PT vs term, T) and size-for-gestational age (small (SGA, <10th centile), appropriate (AGA, 10-90th centile) or large (LGA, >90th centile)) according to INTERGROWTH-21st newborn standards. Newborn babies with PT or SGA were defined as small and T+LGA was considered as large. We calculated risk ratios (RRs) and population attributable risks (PAR%) for the six newborn types.

Main Outcome Measures Mortality of six newborn types

Results Of 125.5 million livebirths analysed, risk ratios were highest amongst PT+SGA (median: 67.2, Interquartile Range, IQR, 45.6, 73.9), PT+AGA (median: 34.3, IQR, 23.9, 37.5), and PT+LGA (median: 28.3, IQR, 18.4, 32.3). At the population level, PT+AGA was the greatest contributor to newborn mortality (median PAR%: 53.7, IQR, 44.5, 54.9). Mortality risk was highest among newborns <28 weeks (median RR: 279.5, IQR, 234.2, 388.5) compared to babies born between 37 to 42 completed weeks or with a birthweight <1000g (median RR: 282.8, IQR 194.7, 342.8) compared to those between 2500 g and 4000 g as a reference group.

Conclusion Preterm newborn types were the most vulnerable, and associated with highest mortality, particularly with co-existence of preterm and SGA. As PT+AGA is more prevalent, it is responsible for greatest burden of neonatal deaths at population level.

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Keywords Preterm Birth, Size for gestational age, Neonatal Mortality, Vulnerable newborn

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INTRODUCTION

Each year, 2.4 million liveborn babies die within the first 28 days of life (neonatal deaths) [1, 2]. Worldwide, over 80% of these newborn deaths are in low birthweight babies, two-thirds of which are preterm (<37 weeks) [3]. Low birthweight (LBW) defined as <2500 g, has been used for more than a century as a marker of vulnerability for newborns, yet the Global Nutrition Plan target for a 30% reduction in LBW is off track [4]. LBW is due to either being born preterm or small for gestational age (SGA) i.e., <10th centile of birthweight for gestational age and sex or both [4]. Babies who are born preterm or SGA have an increased risk of complications including neonatal morbidity and mortality, stunting and developmental delay in childhood and long-term chronic conditions [5, 6]. Traditionally, preterm birth and SGA have been described as separate conditions even though they may co-exist. Each of these classifications alone is not granular enough to understand varying risks for individual small newborns [7]. For example, newborns born preterm and SGA simultaneously are at particularly high risk of severe clinical complications, requiring neonatal intensive care or leading to death compared to those who are preterm and appropriate for gestational age (AGA, 10th-90th centiles) [8, 9]. Whilst the smallest are at highest risk, it is also important from a public health perspective to understand which groups of babies contribute to the highest levels of mortality at a population level [10].

In 2020, as part of the Lancet Small Vulnerable Newborn Series, a set of newborn types were proposed to advance the classification of newborn vulnerability, by considering gestational age, birthweight and size for gestational age in the same individual [11]. In addition to the well described risk of small babies, being large for gestational age (LGA, >90th

centile) has been associated with birth trauma, hypoglycaemia, hospitalization, overweight and obesity [12-14]. Therefore, categorising each baby based on gestational age (term, T vs preterm, PT) and size for gestational age (SGA, appropriate-for-gestational age (AGA), and LGA) could enable a more detailed investigation of neonatal vulnerability and their potential causal pathways [15]. This comprehensive identification of newborn types could be useful to implement targeted interventions at the individual clinical and public health levels to improve progress for children, ensuring no-one is left behind and all newborns survive and thrive.

This paper aims to fulfil three objectives, namely to quantify the neonatal mortality risk and population attributable risks (PAR%) associated with the following groupings: (1) birthweight categories, (2) gestational age categories, and (3) newborn types with six categories combining gestational age (PT vs T) and size-for-gestational age (SGA, AGA, LGA) in the same individual.

METHODS

Compilation of datasets We aimed to identify population-based data using routine data of births and neonatal deaths of babies born between the 1st of January 2000 to the 31st of December 2020. Potential collaborators and government agencies with national individual-level datasets with high population-level coverage (including more than 80% of births in the country) were invited to participate in a new collaboration focused on the multi-country description of types of vulnerable newborn babies (Vulnerable Newborn Measurement Collaboration). An open call was published in a Lancet comment [11] and widely disseminated through email lists, social media and by contacting authors that previously published analyses using national routine administrative datasets.

Teams with datasets including livebirth records and meeting criteria provided analyses to describe the national prevalence of newborn types, as published in another paper on this series [16]. Amongst these countries, those with information on neonatal deaths formed a subgroup to perform further analyses on neonatal mortality which is the focus of this paper.

This is a retrospective analysis of routinely collected data and therefore we followed the Reporting guidelines of studies Conducted using Observational Routinely-collected Data, the RECORD checklist (Table S1). Ethical approval is summarised in Table S2 for all 15 participating countries and a summary of relevant definitions used is presented in Table S3.

Inclusion and exclusion criteria

We included national datasets compiled for the Vulnerable Newborn Measurement Collaboration with information on livebirths and neonatal deaths that were collected from the 1st of January 2000 with high completeness (at least 80%) for birthweight, gestational age, and sex variables. We excluded individual birth records missing either birthweight, gestational age, sex or with a gestational age $<22^{+0}$ weeks or $>44^{+6}$ weeks for which it was not possible to assess size-for-gestational age. Birth records with implausible birthweights (<250 g or ≥6500 g) or implausible combinations of birthweight and gestational age (defined as birthweight ±5 standard deviations from the mean birthweight at each completed week of gestational age) were also excluded. We evaluated the plausibility of these datasets by comparing the difference between the calculated neonatal mortality rate (NMR) in the dataset and the nationally reported NMR for the same year [17] (Table S4). We excluded specific years of data collection for which we could not undertake this assessment due to the lack of availability of nationally reported neonatal mortality (e.g., Lebanon 2002-2016 and 2018-2019) or when we were not able to calculate NMR due to small or masked cells (e.g., Northern Ireland) (Figure 1).

Data quality

Those who die in the early neonatal period, many of whom are the smallest, are most likely to have missing variables or be missing from datasets entirely. Therefore, to assess the potential impact of this we calculated the percentage of missing variables (birthweight, gestational age and sex) for included country years (Table S5). Table S6 describe the metadata and reporting criteria for the very preterm for each of the 15 countries. We also assessed the impact of registration practices on mortality estimates for each country and region by calculating gestation-specific neonatal mortality rates among babies born between 22 to 32 weeks (Figure S1 and Figure S2) and by comparing the NMR for babies ≥22 weeks vs ≥24 weeks (Table S7).

Exposure definitions

Each baby was categorised based on strata of birthweight (objective 1), gestational age (objective 2), and newborn types (objective 3) combining gestational age, size for gestational age, and sex using a modified version of the INTERGROWTH-21st international newborn size standards extended to include from 22^{+0} to 44^{+6} weeks' gestation [18-20].

For objective 1, all livebirths with birthweight recorded were included in the analysis using strata of 500 g increment (e.g., <1000 g, 1000 g to 1500 g etc), and a reference group between 2500 g and 4000 g. For objective 2, livebirths at ≥22^{+0} weeks were included in analyses using classification for preterm birth based on severity (e.g. extremely preterm: <28^{+0} weeks, very preterm: 28^{+0} to 31^{+6} weeks, moderate preterm: 32^{+0} to 33^{+6} weeks, late preterm: 34^{+0} to 36^{+6} weeks, post-term: ≥42^{+0} weeks) with term births as a reference group (37^{+0} and 41^{+6} completed weeks). For objective 3, we categorised every newborn based on gestational age (preterm birth <37^{+0} completed weeks (PT) or term ≥37^{+0} weeks (T)), and size for gestational age (defined as SGA <10th centile; LGA >90th centile; or AGA between 10th to 90th centile). We created a mutually exclusive set of six newborn types: one reference group T+AGA; four with small babies (PT+SGA, PT+AGA, PT+LGA, T+SGA); and one with large babies (T+LGA) (Figure S3a).

Also, we performed a sensitivity analysis combining gestational age (PT vs T), size (SGA, AGA, LGA) and adding birthweight (low birthweight <2500 g (LBW) or non-low birthweight ≥2500 g (nonLBW)) to assess a secondary set of ten newborn types including one reference group T+AGA+nonLBW; eight including small babies (T+AGA+LBW, T+SGA+nonLBW, T+SGA+LBW, PT+LGA+nonLBW, PT+LGA+LBW, PT+AGA+nonLBW, PT+AGA+LBW, PT+SGA+LBW) and one with large babies (T+LGA+nonLBW) (Figure S3b).

Data analysis

The relative risk of an event (death) is the likelihood of its occurrence among babies within the risk groups (gestational age, birthweight or neonatal types) compared to a reference group, and the population attributable risk is the percentage of cases (deaths) that would be attributable to the risk factor of interest (gestational age or birthweight groups or newborn types) [21]. Among the included newborn records, we calculated:

- Prevalence = the number of livebirths reported in each group of interest / total number of livebirths
- Risk (neonatal mortality rate) = the number of livebirths who experienced the event (neonatal death) / total number of livebirths exposed to the risk of that event per 1000
- Risk ratio = risk (neonatal mortality rate) in each group of interest / risk (neonatal mortality rate) in the reference group
- Population attributable risk = the prevalence multiplied by the relative risk in each group of interest / the sum of the prevalence multiplied by the relative risk of all categories in the population of interest

Each country team analysed their datasets using standardised Stata, R, or SAS programming codes developed centrally by the London School of Hygiene & Tropical Medicine (LSHTM). Standard summary results tables were shared in a hub administered online by LSHTM.

RESULTS

Information on 144 country-years including 125.5 million livebirths and 576,018 deaths collected between 2000 and 2020 in 15 countries was included for analysis (Figure 1 and Table S4). Overall, NMR was highest in Brazil (7.4) and Mexico (6.1) with most countries reporting NMR lower than 5 deaths per 1,000 livebirths (Lebanon: 4.5, the United States (US): 4.1, the Netherlands: 3.7, Qatar: 3.1, Canada: 2.3, Denmark: 2.4, England & Wales: 2.2, Scotland: 2.4, Czech Republic: 1.6, Sweden: 1.3, and Uruguay: 1.3, and Estonia: 1.2).

Objective 1. Neonatal mortality risk associated with birthweight categories

Mortality was highest amongst the smallest babies: the median relative risk of neonatal mortality was 280-fold for babies <1000 g (median: 282.8, IQR, 194.7, 342.8), 60-fold for those between 1000 g to 1500 g (median: 60.7, IQR, 51.0, 66.2), 20-fold for those between 1500 g to 2000 g (median relative risk: 20.3, IQR, 17.4, 23.8) and 6-fold (median relative risk: 6.1, IQR, 5.6, 7.7) for babies between 2000 g to 2500 g, compared to those between 2500 g and 4000 g (Table 1 and Figure 2a).

At the population level, low birthweight babies were responsible for most neonatal deaths, particularly babies born below 1000 g (median PAR% 41.2, IQR, 30.0, 50.4), followed by those between 1000 g to 1500 g (median PAR% 11.8, IQR, 8.1, 12.9), 1500 g to 2000 g (median PAR% 7.2, 6.4, 9.5) and 2000 g to 2500 g (median PAR% 6.1, 5.7, 8.6) (Table 1).

For bigger babies, the median relative risk among those born above 4500 g was 1.2 (IQR 1.0, 2.2) when compared to the reference group between 2500 g to 4000 g. This measure showed greater variability among the group >5000 g (median: 1.5, IQR, 0.0, 4.1) with higher relative mortality risk in Canada (RR 18.8, 95%CI, 14.3, 24.8), Australia (RR 17.1, 95%CI 8.5, 34.4), and Brazil (RR 6.9, 95%CI, 6.2, 7.8), no evidence of an increased risk in Denmark, Scotland, Sweden, England & Wales, and zero observed deaths in Czech Republic, Estonia, Lebanon, Mexico, Qatar, and Uruguay (Figure 2a and Table S8).

Objective 2. Neonatal mortality risk associated with gestational age

Extremely preterm babies below 28 weeks had the highest neonatal mortality rate (median: 273.2 deaths per 1000 livebirths, IQR, 190.0 to 322.7), followed by those very preterm babies from 28 to 31 weeks (median: 32.4, IQR, 22.8, 38.7), moderate preterm from 32 to 33 weeks (median: 13.6, IQR 11.8, 17.3), and late preterm from 34 to 36 weeks (median: 4.3, IQR, 2.6, 5.9) (Table 1 and Table S9).

The risk of dying increased with lower gestational age; babies born extremely preterm had almost 300-fold increased risk (median relative risk: 279.5, IQR, 234.2, 388.5) compared to babies born between 37 to 42 completed weeks as a reference group, followed by those very preterm (median relative risk: 49.8, IQR, 41.7, 54.9), moderate preterm (median relative risk: 21.0, IQR, 17.0, 22.6), and late preterm (median relative risk: 6.0, IQR, 4.7, 7.1) (Table 1, Figure 2b and Table S9).

Across the 15 countries, most neonatal deaths were attributed to babies born below 28 weeks (median PAR% 40.2, IQR, 30.8, 43.7), followed by the group between 28 to 31 weeks (median PAR% 10.9, IQR, 9.5, 13.5), 34 to 36 weeks (media PAR 9.3, IQR 8.3, 10.4), and 32 to 33 weeks (median PAR% 5.7, IQR 5.1, 7.5) (Table 1).

Objective 3. Neonatal mortality risk associated with newborn types

Applying the six newborn types, reported neonatal deaths were more common among PT+SGA livebirths (median mortality rate: 32.0 deaths per 1000 livebirths, IQR, 24.1, 50.7), followed by PT+AGA (median mortality rate: 20.9, IQR, 15.9, 25.0), and PT+LGA (median mortality rate: 16.7 deaths per 1000 livebirths, IQR 13.8, 20.2), T+SGA (median mortality rate: 3.5 deaths per 1000 livebirths, IQR, 2.6, 4.6), T+AGA (median 0.6, IQR, 0.4, 0.7), and T+LGA (median mortality rate: 0.5 per 1000 livebirths, IQR 0.3, 0.5).

The highest relative risk was around 70-fold for PT+SGA (median relative risk: 67.2, IQR, 45.6, 73.9), followed by PT+AGA (median relative risk: 34.3, IQR, 23.9, 37.5), PT+LGA (median relative risk: 28.3, IQR, 18.4, 32.3), and T+SGA (median relative risk: 5.4, IQR, 4.4, 6.3) when compared to the reference category T+AGA (Table 1, Figure 3 and Table S10).

At population level, most neonatal deaths were attributed to PT+AGA (median PAR% 53.7, IQR, 44.5, 54.9), PT+SGA (median PAR% 10.5, IQR, 8.8,12.1), PT+LGA (median PAR% 7.5, IQR, 6.3, 8.3), and T+SGA (median PAR% 4.3, 3.3, 5.7) (Table 1 and Table S10).

A sensitivity analysis considering ten newborn types instead of six, showed that the highest relative risks were among types with the co-existence of preterm and LBW such as those PT+LGA+LBW (median: 114.0, IQR, 102.6, 139.5), PT+SGA+LBW (median: 66.8, IQR, 45.3, 76.7), and PT+AGA+LBW (median: 54.3, IQR, 44.1, 60.6). The median mortality risk ratio for preterm and non-LBW types was 10-fold (median: 10.2, IQR, 7.7, 13.2) for PT+LGA+nonLBW and 4-fold (median:4.2, IQR 3.3, 5.4) for PT+AGA+nonLBW. Among the term types, the median relative risk was 9-fold (median: 9.0, IQR, 7.6, 13.2) among T+SGA+LBW, 3-fold (median: 3.1, IQR 1.8, 4.3) for T+AGA+LBW and 2.6-fold (IQR, 1.9, 3.4) for T+SGA+nonLBW. Large babies (T+LGA+nonLBW) did not show a greater risk of dying compared to the reference group (T+AGA+nonLBW) (Table S11).

DISCUSSION

Main findings

Our dataset of more than 125.5 million livebirth records collected in 15 countries over two decades has provided the first multi-country estimates of mortality related to novel newborn types across regions of Northern America, Australia, Central Asia and Europe (10 countries), Latin America and the Caribbean (3 countries), and Western Asia and Northern

Africa (2 countries) (Figure 1). Data quality was high at least for completeness of three core variables (birthweight, gestational age and sex) (completeness ≥80%).

We found that being both preterm and SGA was the most predictive type in identifying vulnerability to neonatal mortality risk across all countries (PT+SGA median relative risk: 67.2), followed by those PT+AGA (median relative risk: 34.3) and PT+LGA (median relative risk: 28.3). However, as PT+SGA has low prevalence, the population attributable risk is highest for PT+AGA. Since both PT+AGA and PT+LGA had median relative risks around 30, in future, collapsing these two groups into a single 'preterm not SGA' group could further simplify the newborn types to only three, without losing the ability to identify neonatal mortality risk.

The four categories of preterm birth were found to be useful to identify infants at risk of neonatal death. However, neonatal mortality risk was driven particularly by lower gestational age with a clear dose response (median relative risk for <28 weeks: 279.5, 28-31 weeks: 49.8, 32-33 weeks: 21.0, and 34-36 weeks: 6.0). Birthweight strata also show a dose response, with the highest risk at the lower weights (median relative risk for <1000 g: 282.8, 1000g-1500g: 60.7, 1500g-2000g: 20.3, and 2000g-2500g: 6.1), however this is likely to be driven by the association between birthweight and gestational ages. Given the major variation in risk by GA, we underline the value of considering this as a continuum, rather than a dichotomous cut off at 37 weeks.

Mortality rates for babies below 28 weeks varied by countries, with the highest rates reported in Lebanon (542.9 deaths per 1000 babies) and Brazil (428.6 deaths per 1000 babies) and lowest rates in Sweden (136.8 deaths per 1000 babies) and Estonia (137.1 deaths per 1000 babies). These large national variations could be reflective of true differences in population risk (e.g. higher mortality rates expected with more restrictive policies about abortions for congenital anomalies), or variation in access to high quality neonatal intensive care (31). However, it is well recognised that registration systems can selectively miss liveborn newborns at the extremes of gestational age and birthweight and international or inter-hospital comparisons of neonatal mortality may be misleading if these biases are not considered [27, 28].

Bigger babies also had increased risk of neonatal death, as noted overall for babies >42 weeks born in Brazil and the US (compared to 37-42 weeks) and those >4 500g (compared to normal birthweight). Term+LGA category did not show additional risk for early mortality. A more detailed analysis of vulnerability on LGA babies is the focus of another paper on this supplement[32].

Interpretation

Our analysis uses and adapts the recently described Lancet Small Vulnerable Newborn classification [11] to better delineate underlying causal pathways, identify the most vulnerable babies and target interventions. Our paper helps to inform future applications of this classification. The use of six newborn types (combining gestational age and size) versus ten (combining gestational age, size, and birthweight) may be helpful for clinical practice, public health policy and research. Using the six newborn types confirmed the finding that coexistence of preterm and SGA drives a higher mortality risk. Given that LBW is a consequence of being born preterm and/or small-for-gestational age, dropping the LBW outcome may offer a more parsimonious and still useful approach to identifying newborns with common determinants [26]. Given that that gestational age is the main driver of neonatal mortality risk, further research could consider splitting newborn types by gestational age bands. Also, future research is needed to clarify the best category to approach newborn´s vulnerability on bigger babies, such as those above the 97th centile or post-term [12-14].

Strengths and limitations

This multi-country collaboration has substantial strengths regarding the analysis of large national routine administrative datasets with more than 125.5 million livebirths and almost 600,000 neonatal deaths. These results are likely to be representative of the overall populations in these countries as these datasets included more than 80% of all livebirths in the country with high levels of completeness for three key variables to assess newborn types. Another strength is the use of a common international standards (INTERGROWTH-21st) for direct comparisons among 15 countries data.

Although data quality was high in terms of completeness, there were some remaining limitations due to missing variables and record linkage quality (Table S5 and Table S6). More importantly, we cannot fully account for inter-country variability in perceived viability and reporting of very preterm babies (Table S6), which still poses challenges to international comparisons of neonatal mortality [27, 28]. Variability in the registration of very premature babies was particularly noted among babies from 22^{+0} to 23^{+6} weeks (Figure S1 and Figure S2), impacting the ranking of national mortality rates for babies ≥22 vs ≥24 completed weeks (Table S7). Another limitation is lack of confirmation of the method for gestational age estimation, this may drive potential misclassifications on size for gestational age as some datasets only provided gestational age data in completed weeks and not exact days.

In addition, no eligible datasets were identified from Sub-Saharan Africa or Southern Asia where more than 80% of all neonatal deaths occur and where neonatal survival progress is needed the most [3]. To seek to close this gap, the Vulnerable Newborn Measurement Collaborative group have analysed sub-national data from research studies in these regions[29]. This paper focuses only on neonatal deaths following livebirth, but stillbirths are presented in another paper in this series [30].

Many important research gaps are highlighted by this work. Whilst accurate gestational age assessment is widely available in countries participating in this study, such information is more limited in many high-burden settings which could limit the applicability of these newborn types in these settings. Innovative bedside tools to assess both gestational age and size-for-gestational age could help target interventions and improve care and survival. Cohort analyses using these types would be valuable to provide more granular information on medium to long-term risk of non-fatal life-course outcomes including non-communicable conditions than traditional analyses based on LBW alone.

CONCLUSION

This novel multi-country analysis is based on large and nationwide datasets with 125.5 million livebirths and more than half a million neonatal deaths collected in 15 high and upper-middle-income countries. These six newborn types were found to be predictive of those most vulnerable to neonatal mortality and could be useful clinically to identify newborn vulnerability. Our analysis underlines again the large burden driven by preterm, with the greatest risk being PT+SGA and the largest population-attributable impact being PT+AGA. The use of these newborn types could potentially help research studies to better delineate underlying causal pathways, rather than a focus on LBW dichotomous cut offs, and accelerate progress for the prevention of 15 million preterm births per year.

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Competing interests

All authors have filled in the ICMJE form.

Authors' contributions

The Vulnerable Newborn collaborative was planned by JEL and REB. This analysis was designed by HB and EOO with JEL. All authors contributed to the study protocol, with inputs from the wider Vulnerable Newborn Measurement Collaboration. Analysis was undertaken by LSI with EOO. The manuscript was drafted by LSI with HB, EOO and JEL. All authors helped revise the manuscript. All authors reviewed and agreed on the final version

Ethics approval

The Vulnerable Newborn Measurement Collaboration was granted ethical approval from the Institutional Review Boards of the London School of Hygiene & Tropical Medicine (ref: 22858) and Johns Hopkins University. All the 15 country teams had ethical approval for use of data or exemptions based on the current remit.

Availability of data and material

Data sharing and transfer agreements were jointly developed and signed by all collaborating partners. All data used in these analyses are available in the Supplementary Information. The pooled aggregate data will be available at https://doi.org/10.17037/DATA.00003095 at the time of publication with the exception of those from countries where data sharing is not permitted.

Australian data disclosures

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National Collaborative Group for Vulnerable Newborn Mortality

Australia: Vicki Flenady; Adrienne Gordon; Kara Warrilow; Harriet Lawford

Brazil: Enny S. Paixao; Mauricio Lima Barreto; Ila Rocha Falcao

Canada: Sarka Lisonkova; Qi Wen

Czech Republic: Petr Velebil; Jitka Jírová

Denmark: Erzsébet Horváth-Puhó, Henrik T Sørensen

Estonia: Luule Sakkeus; Liili Abuladze

Lebanon: Khalid A. Yunis; Ayah Al Bizri; Pascale Nakad

Mexico: Lorena Suárez-Idueta; Arturo Barranco Flores; Jesus Felipe Gonzalez Roldan; Sonia Lopez Alvarez

Netherlands: Lisa Broeders; Aimée E. van Dijk

Qatar: Fawzia Alyafei; Mai AlQubaisi; Tawa O. Olukade; Hamdy A. Ali; Mohamad Rami Alturk

Sweden: Neda Razaz; Jonas Söderling

UK_England and Wales: Lucy K Smith; Bradley N. Manktelow; Ruth J. Matthews; Elizabeth Draper; Alan Fenton; Jennifer J. Kurinczuk

UK_Northern Ireland: Estelle Lowry; Neil Rowland

UK_Scotland: Rachael Wood; Celina Davis; Kirsten Monteath; Samantha Clarke

Uruguay: Isabel Pereyra, Gabriella Pravia

USA: Sarka Lisonkova; Qi Wen

Vulnerable Newborn Measurement Core Group

LSHTM: Joy E. Lawn; Hannah Blencowe; Eric Ohuma; Yemi Okwaraji; Judith Yargawa; Ellen Bradley

JHU: Bob Black; Joanne Katz; Dan Erchick; Elizabeth Hazel; Mike Diaz; Anne CC Lee

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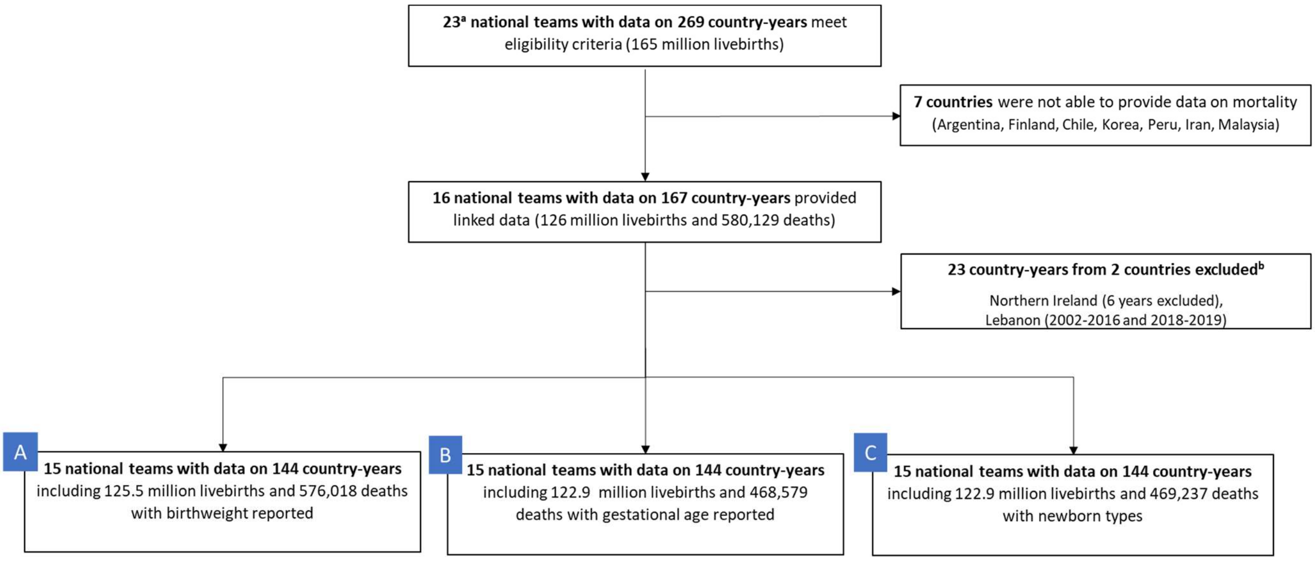
KEY FINDINGS

1. WHAT WAS KNOWN?
Babies born preterm (<37 weeks), Small for gestational age (SGA, <10th centile), and Large for Gestational Age (LGA, >90th centile) are at higher risk of dying during the neonatal period. Previous studies have usually estimated the association of preterm birth, SGA, and LGA with neonatal mortality separately even though these conditions can overlap.
2. WHAT WAS DONE THAT IS NEW?
In this study, we used 15 national livebirth and linked neonatal death datasets collected between 2000 to 2020 to compare neonatal mortality and population attributable fractions associated with strata of birthweight, gestational age, and newborn types combining information on gestational age (preterm (PT), or term (T)) and size for gestational age (SGA, appropriate-for-gestational age (AGA), LGA). Six newborn types were defined: four small (PT+SGA, PT+AGA, PT+LGA, T+SGA), one large (T+LGA), and one reference (T+AGA).
3. WHAT WAS FOUND?
Our pooled dataset of 125.5 million livebirths from 15 countries provides the first multi-country mortality estimates of these newborn types. Of the six newborn types, babies born preterm and SGA (PT+SGA) had the highest risk of neonatal death (median relative risk: 67.2, interquartile range, IQR, 45.6, 73.9), but this group are low prevalence. Hence at the population level, most neonatal deaths were attributable to PT+AGA newborn type (median population attributable risk (PAR%): 53.7, IQR 44.5, 54.9). Mortality was highest among babies born <28 weeks and those <1000g (median risk ratio (RR) ≥ 280-fold).
4. WHAT NEXT?
Action in preventive programmes: These six newborn types are relevant for identifying the most vulnerable newborn babies at the clinical level (PT+SGA), and the greatest contributors to neonatal mortality at the population level (PT+AGA). **Research gaps:** Additional analyses of newborn types in lower-income settings, such as South Asia where SGA rates are very high is needed. Innovative use at the bedside could help target interventions and improve care. Cohort analyses using these types would be valuable to provide more granular information than LBW alone for non-fatal lifecourse outcomes including non-communicable conditions.

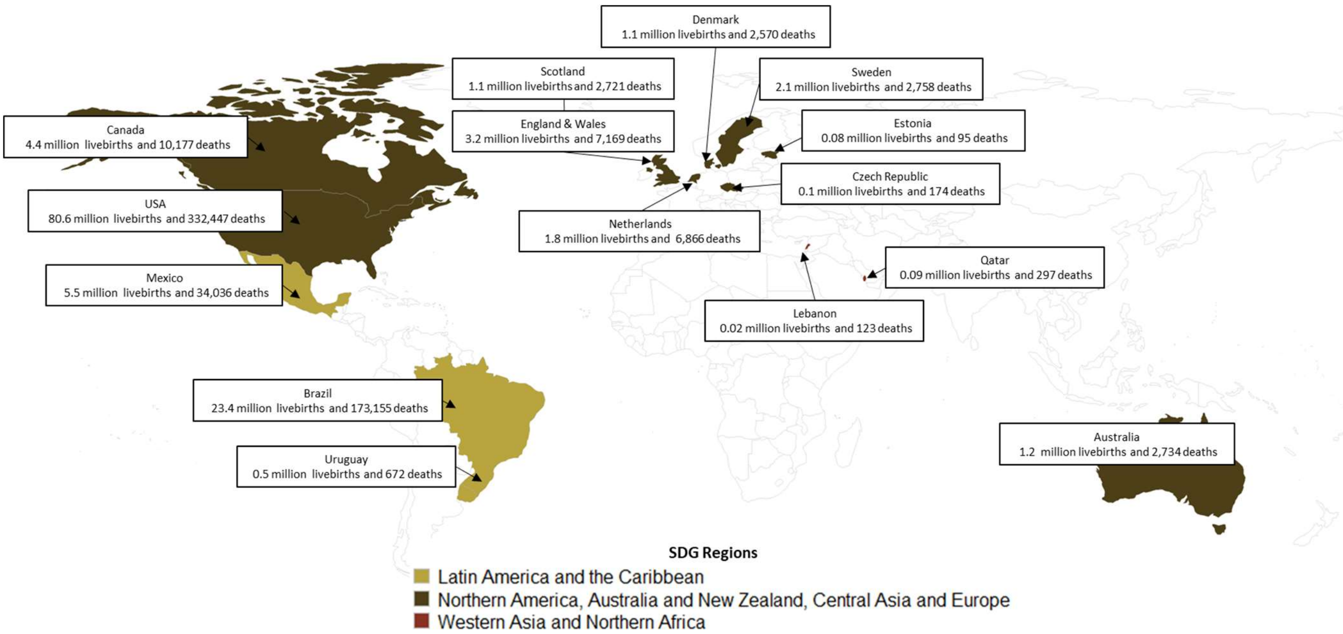
FIGURES AND TABLES

Figure 1. Input dataset of Vulnerable Newborn Mortality study

a. Flowchart



b. Number of livebirths in millions and neonatal deaths, by country[c]



[a] 23 countries from the Vulnerable Newborn Collaboration were invited to participate on the Mortality study [(16)]

[b] Lebanon 2002-2016 and 2018-2019 were excluded due to the lack of availability of neonatal mortality reported to UNIGME, Northern Ireland was excluded because we were not able to calculate NMR due to small, masked cells

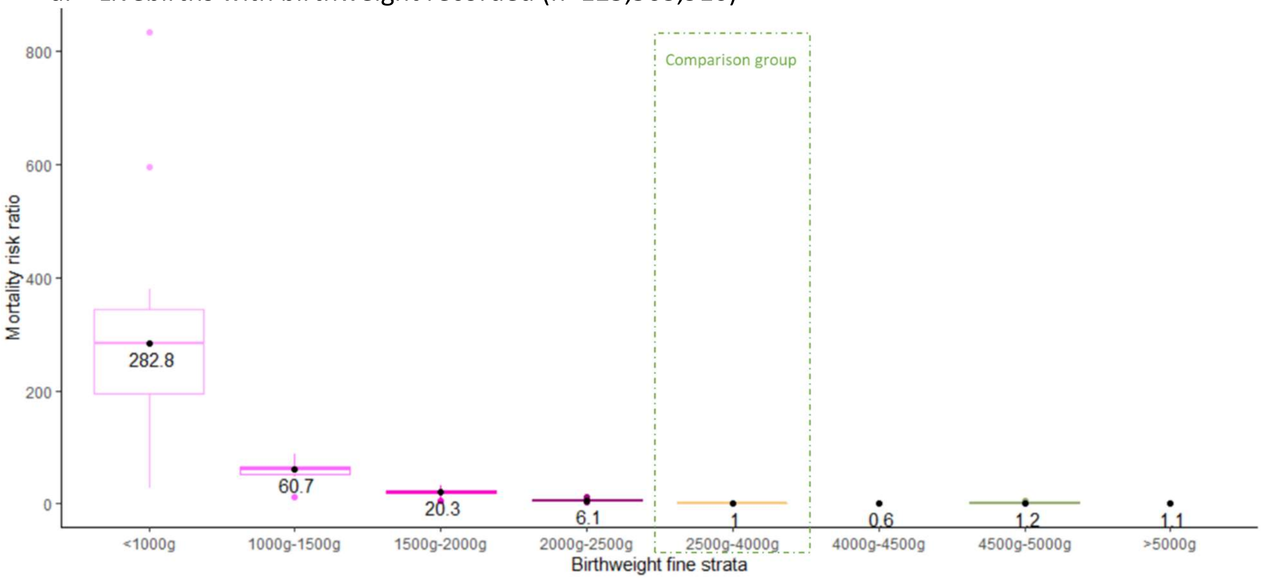
[c] Map legends show the distribution of the 125.5 million babies with birthweight recorded included in these analyses

Table 1. Number of livebirths, deaths, median prevalence, neonatal mortality rate, relative risk and PAR% in 15 countries, results by fine strata of birthweight, gestational age and six newborn types

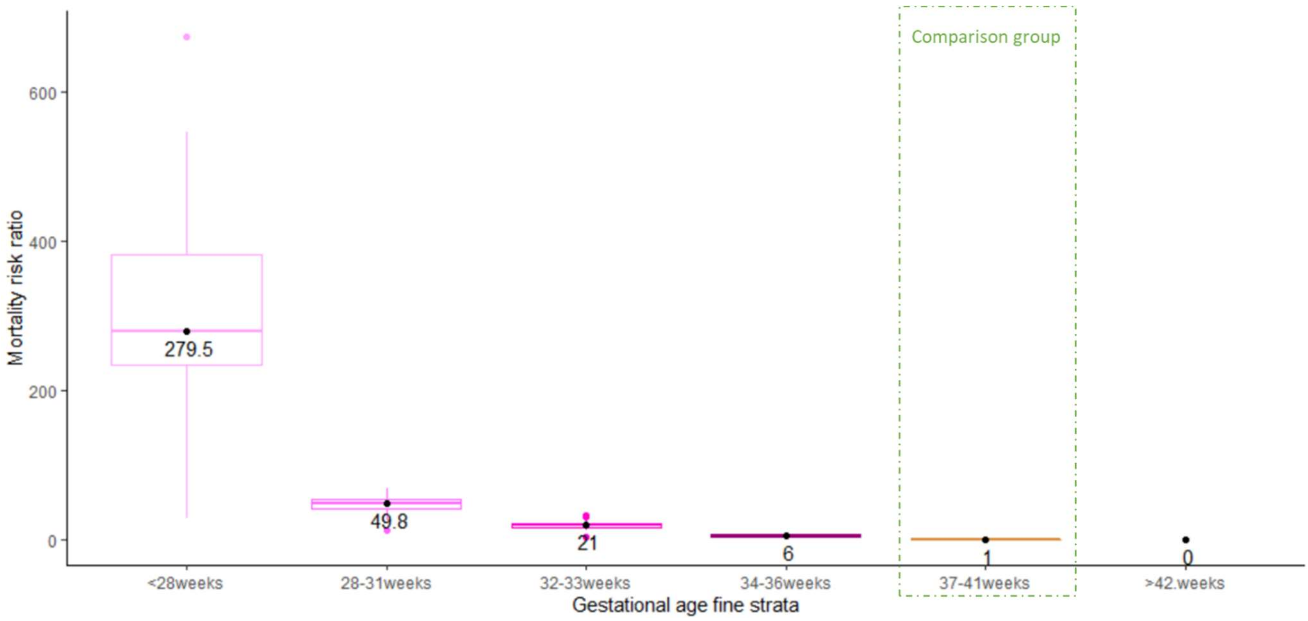
Categories	Livebirths Number (%)	Deaths Number (%)	Prevalence Median (IQR)	NMR Median (IQR)	Relative risk Median (IQR)	PAR (%) Median (IQR)
Birthweight, fine strata in grams						
<1000g	806,220 0.6	298,351 51.8	0.4 (0.3, 0.5)	286.3 (149.4, 359.1)	282.8 (194.7, 342.8)	41.2 (30.0, 50.4)
1000g to 1500g	889,149 0.7	53,206 9.2	0.6 (0.5, 0.7)	38.7 (32.8, 44.5)	60.7 (51.0, 66.2)	11.8 (8.1, 12.9)
1500g to 2000g	1,907,640 1.5	42,583 7.4	1.4 (1.2, 1.6)	13.2 (11.2, 16.5)	20.3 (17.4, 23.8)	7.2 (6.4, 9.5)
2000g to 2500g	6,282,035 5.0	43,319 7.5	4.4 (4.0, 5.0)	4.7 (3.4, 5.6)	6.1 (5.6, 7.7)	6.1 (5.7, 8.6)
2500g to 4000g	105,710,403 84.2	130,077 22.6	83.8 (80.2, 85.2)	0.7 (0.4, 0.8)	Reference	Reference
4000 to 4500g	8,532,051 6.8	6,308 1.1	8.4 (5.6, 11.3)	0.5 (0.3, 0.6)	0.6 (0.6, 0.8)	-1.1 (-1.7, -0.4)
4500g to 5000g	1,233,821 1.0	1,506 0.3	1.1 (0.7, 1.8)	0.7 (0.7, 1.0)	1.2 (1.0, 2.2)	0.1 (0.0, 0.3)
>5000g	142,370 0.1	673 0.1	0.1 (0.1, 0.2)	0.9 (0.0, 3.2)	1.5 (0.0, 4.1)	0.1 (0.0, 0.1)
Gestational age, fine strata in completed weeks						
<28	661,172 0.5	197,292 42.1	0.4 (0.3, 0.5)	273.2 (190.0, 322.7)	279.5 (234.2, 388.5)	40.2 (30.8, 43.7)
28 to 31	1,129,628 0.9	56,329 12.0	0.7 (0.7, 0.9)	32.4 (22.8, 38.7)	49.8 (41.7, 54.9)	10.9 (9.5, 13.5)
32 to 33	1,494,543 1.2	27,192 5.8	0.9 (0.9, 1.1)	13.6 (11.8, 17.3)	21.0 (17.0, 22.6)	5.7 (5.1, 7.5)
34 to 36	8,786,215 7.1	51,030 10.9	5.5 (5.0, 7.0)	4.3 (2.6, 5.9)	6.0 (4.7, 7.1)	9.3 (8.3, 10.4)
37 to 42	110,525,200 89.9	135,690 29.0	92.3 (90.4, 93.0)	0.7 (0.4, 0.8)	Reference	Reference
>42	354,266 0.3	1,043 0.2	0 (0,0)	0 (0, 1.6)	0 (0, 1.5)	0.0 (0.0, 0.0)
Newborn types						
PT+SGA	909,260 0.7	61,109 13.0	0.7 (0.6, 0.8)	32.0 (24.1, 50.7)	67.2 (45.6, 73.9)	10.5 (8.8, 12.1)
PT+AGA	8,906,867 7.2	233,632 49.8	6.0 (5.6, 7.1)	20.9 (15.9, 25.0)	34.3 (23.9, 37.5)	53.7 (44.5, 54.9)
PT+LGA	2,251,550 1.8	38,166 8.1	1.0 (0.8, 1.3)	16.7 (13.8, 20.2)	28.3 (18.4, 32.3)	7.5 (6.3, 8.3)
T+SGA	5,706,866 4.6	33,978 7.2	4.1 (3.2, 5.4)	3.5 (2.6, 4.6)	5.4 (4.4, 6.3)	4.3 (3.3, 5.7)
T+AGA	84,137,711 68.4	87,500 18.6	68.8 (67.3, 70.9)	0.6 (0.4, 0.7)	Reference	Reference
T+LGA	20,016,260 17.1	14,852 3.2	18.2 (13.5, 22.0)	0.5 (0.3, 0.5)	0.8 (0.7, 0.8)	-1.1 (-0.7, -1.4)

Figure 2. Mortality risk ratios by birthweight and gestational age, for 15 countries from 2000 to 2020

a. Livebirths with birthweight recorded (n=125,503,910)



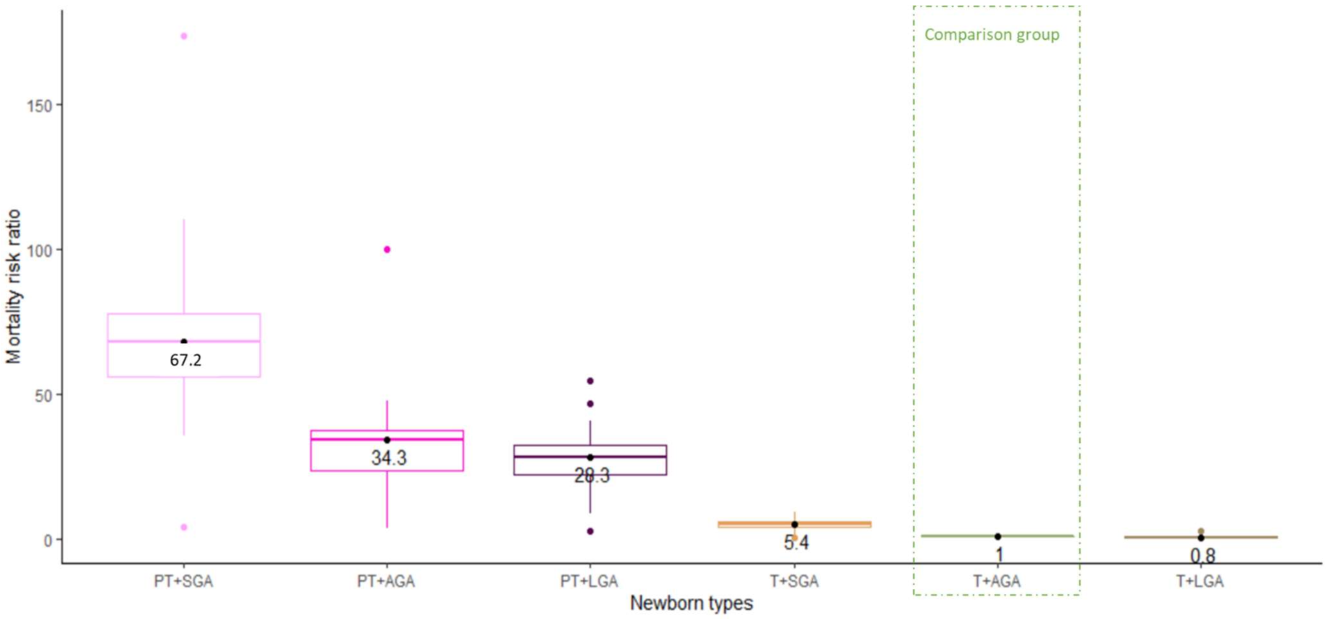
b. Livebirths with gestational age recorded (n=122,951,125)



Each point represents the mortality risk ratio. Box plots summarise median values and IQR (25th and 75th percentiles).

Figure 3. Mortality risk ratios by 6 newborn types, for 15 countries from 2000 to 2020

a. Livebirths with newborn types assessed (n=122,928,744)



Each point represents the relative risk ratio by country. Box plots summarise the median values and IQR (25th and 75th percentiles).

SUPPLEMENT TITLE: Vulnerable Newborn multi-country analyses related to preterm births and small-for-gestational age

PAPER TITLE

Neonatal mortality risk for vulnerable newborn types in 15 countries using 125.5 million nationwide birth outcome records from 2000 to 2020

PAPER RUNNING TITLE

Mortality risk for newborn types in 15 countries

SUPPORTING INFORMATION

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Table S1: RECORD guidelines checklist

The reporting of studies conducted using observational routinely collected data

	#	STROBE items	Location	RECORD items	Location in manuscript where items are reported
Title and abstract					
	1	(a) Indicate the study's design with a commonly used term in the title or the abstract (b) Provide in the abstract an informative and balanced summary of what was done and what was found		RECORD 1.1: The type of data used should be specified in the title or abstract. When possible, the name of the databases used should be included. RECORD 1.2: If applicable, the geographic region and timeframe within which the study took place should be reported in the title or abstract. RECORD 1.3: If linkage between databases was conducted for the study, this should be clearly stated in the title or abstract.	*Title: "Neonatal mortality risk for vulnerable newborn types in 15 countries using 125.5 million nationwide birth outcome records, 2000 to 2020"*
Background rationale	2	Explain the scientific background and rationale for the investigation being reported			Introduction (Paragraphs 1-2)
Objectives	3	State specific objectives, including any prespecified hypotheses			Introduction (Paragraph 3)
Study Design	4	Present key elements of study design early in the paper			Methods (Paragraph 1)
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection			Methods (Paragraphs 1-2)

Participants	6	*(a) Cohort study* - Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study* - Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study* - Give the eligibility criteria, and the sources and methods of selection of participants *(b) Cohort study* - For matched studies, give matching criteria and number of exposed and unexposed *Case-control study* - For matched studies, give matching criteria and the number of controls per case		RECORD 6.1: The methods of study population selection (such as codes or algorithms used to identify subjects) should be listed in detail. If this is not possible, an explanation should be provided. RECORD 6.2: Any validation studies of the codes or algorithms used to select the population should be referenced. If validation was conducted for this study and not published elsewhere, detailed methods and results should be provided. RECORD 6.3: If the study involved linkage of databases, consider use of a flow diagram or other graphical display to demonstNMR the data linkage process, including the number of individuals with linked data at each stage.	Methods (Paragraphs 4) under the subheading Inclusion and Exclusion criteria Figure 1. Flowchart
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable.		RECORD 7.1: A complete list of codes and algorithms used to classify exposures, outcomes, confounders, and effect modifiers should be provided. If these cannot be reported, an explanation should be provided.	Methods under the subheading exposure definitions
Data sources/ measurement	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group			Methods under the subheading exposure definitions
Bias	9	Describe any efforts to address potential sources of bias			Quality assessment described Methods under the subheading Data quality (Supplementary material S4b, S4c, S4d, S4f)

Study size	10	Explain how the study size was arrived at			Methods under the subheading Inclusion and exclusion criteria. Flowchart Figure 1
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why			Methods under the subheading exposure definitions
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding (b) Describe any methods used to examine subgroups and interactions (c) Explain how missing data were addressed (d) *Cohort study* - If applicable, explain how loss to follow-up was addressed *Case-control study* - If applicable, explain how matching of cases and controls was addressed *Cross-sectional study* - If applicable, describe analytical methods taking account of sampling stNMRgy (e) Describe any sensitivity analyses			Methods under the subheading data analysis
Data access and cleaning methods		..		RECORD 12.1: Authors should describe the extent to which the investigators had access to the database population used to create the study population. RECORD 12.2: Authors should provide information on the data cleaning methods used in the study.	Methods under the subheading data analysis
Linkage		..		RECORD 12.3: State whether the study included person-level, institutional-level, or other data linkage across two or more databases. The methods of linkage and methods of linkage quality evaluation should be provided.	Supplementary table S4c
Results					

Participants	13	(a) Report the numbers of individuals at each stage of the study (*e.g.*, numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed) (b) Give reasons for non-participation at each stage. (c) Consider use of a flow diagram		RECORD 13.1: Describe in detail the selection of the persons included in the study (*i.e.,* study population selection) including filtering based on data quality, data availability and linkage. The selection of included persons can be described in the text and/or by means of the study flow diagram.	Results (Paragraph 1 and Figure 1)
Descriptive data	14	(a) Give characteristics of study participants (*e.g.*, demographic, clinical, social) and information on exposures and potential confounders (b) Indicate the number of participants with missing data for each variable of interest (c) *Cohort study* - summarise follow-up time (*e.g.*, average and total amount)			Supplementary material S4b
Outcome data	15	*Cohort study* - Report numbers of outcome events or summary measures over time *Case-control study* - Report numbers in each exposure category, or summary measures of exposure *Cross-sectional study* - Report numbers of outcome events or summary measures			Results (Paragraph 2-12, Figures 2 and 3, and Supplementary material S5a, S5b, S5c)

Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (e.g., 95% confidence interval). Make clear which confounders were adjusted for and why they were included (b) Report category boundaries when continuous variables were categorized (c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period			Results (Paragraph 2-12, Figures 2 and 3, and Supplementary material S5a, S5b, S5c)
Other analyses	17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses			Results (Paragraph 12)
Key results	18	Summarise key results with reference to study objectives			Discussion under the subheading main findings
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias		RECORD 19.1: Discuss the implications of using data that were not created or collected to answer the specific research question(s). Include discussion of misclassification bias, unmeasured confounding, missing data, and changing eligibility over time, as they pertain to the study being reported.	Discussion under the subheading strengths and limitations
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence			Discussion under the subheading interpretation
Generalisability	21	Discuss the generalisability (external validity) of the study results			Discussion under the subheading strengths and limitations

Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based			The source of founding is included in the Abstract and the funding role is described at the end of the manuscript under the subheading Funding role
Accessibility of protocol, raw data, and programming code		..		RECORD 22.1: Authors should provide information on how to access any supplemental information such as the study protocol, raw data, or programming code.	Under the subheading Availability of data and material

Source [1]

Table S2: Ethics approval or exemptions of Institutional Review Boards

Country of origin for data	Institutional Review Board(s) or data access provider	Ref/Number	Date of approval
London School of Hygiene & Tropical Medicine (LSHTM)	LSHTM - Observational / Interventions Research Ethics Committee	22858	17th May 2021
Australia	Australian Institute of Health and Welfare Ethics Committee	EO2018/2/451	4th May 2021
Brazil	Federal University of Bahia's Institute of Public Health Ethics Committee	18022319.4.0000.5030	3rd September 2019
Canada	UBC C&W Research Ethics Board	H21-00653	31st March 2021
Estonia	Ethics Committee of National Institute for Health Development	770	9th August 2021
Lebanon	Institutional Review Board, American University of Beirut	PED.KY.01	13th July 2021
Mexico	Centre of Investigation in Health Sciences, Anahuac University, Mexico	202214	31st March 2022
Qatar	Medical Research Center, Hamad Medical Corporation, Doha-Qatar	MRC-01-21-277	25th April 2021
UK_England and Wales	1. National Information Governance Board 2. Confidentiality Advisory Group of the Health Research Authority 3. Health & Social Care Information Centre (HSCIC), Data Access Advisory Group	1. ECC 5-05 (f)/2012 2. 15/CAG/0119 3. DARS-NIC-359651-H3R1P-v5.2.	1. 10th October 2012 2. 1st May2015
UK_Scotland	Public Health Scotland	20210218-VulnerableNewbornMeasurement	30th March 2021
Exemptions (*e.g., IRB approval not required for public or aggregate data, existing ethics approval in place, etc)*			
Czech Republic			
Denmark			
Netherlands			
Sweden			
Uruguay			
USA publicly available data from https://www.cdc.gov/nchs/data_access/Vitalstatsonline.htm			

Table S3: Definitions

Consistent with the International Classification of Disease 10th and 11th revisions [2, 3]

INTERGROWTH-21st international standards [4, 5]

Definitions	
Livebirth	Is the complete expulsion or extraction from a woman of a fetus, irrespective of the duration of the pregnancy, which, after such separation, shows signs of life
Birthweight	Is defined as the weight of the fetus or newborn obtained immediately after birth. For livebirths, measurement of birthweight within the first hour of life before significant postnatal weight loss has occurred is preferable. If the birth weight was measured repeatedly, the median value will be used. Birthweight can be measured using digital or analogue scales. For the purposes of this work, weights of newborn taken at ≥72 hours after birth will be excluded.
Gestational age	The duration of gestation measured from the first day of the last menstrual period (LMP). Gestational age will be analysed in days where possible. Gestational age measured by LMP, early pregnancy ultrasound or best obstetric estimate (BEO) will be included
Neonatal death	A neonatal death is defined as a death during the first 28 days after live birth (days 0-27). An early neonatal death is a death during the first 7 days after live birth (days 0 – 6), a late neonatal death is a death day 7 – 27 after a livebirth.
Calculated variables	
Preterm birth	A birth before 37 completed weeks of gestation (or before 259 days of gestation) as measured from the first day of the last menstrual period (LMP) or by early ultrasound.
Term birth	A birth from 37 completed weeks of gestation as measured from the first day of the last menstrual period (LMP) or by early ultrasound.
Low birthweight	A birth with birthweight of less than 2500grams
Non-Low birthweight	A birth with birthweight of ≥2500grams
Small for gestational age	A birth with a birthweight for gestational age and sex of <10th centile according to INTERGROWTH-21st international standards
Appropriate for gestational age	A birth with a birthweight for gestational age and sex from 10th to 90th centiles according to INTERGROWTH-21st international standards
Large for gestational age	A birth with a birthweight for gestational age and sex of >90th centile according to INTERGROWTH-21st international standards

Input data

Table S4. Assessment of plausibility of joined dataset 167 country-years from 2000 to 2020, by Objective

(a: records with birthweight (BW) reported, b: records with Gestational Age (GA) reported, c: Records with newborn types assessed)

Calculated Neonatal Mortality NMR (NMR): the number of persons who experienced the event (neonatal death: deaths that occurred from day 0 to 27) divided by the number of livebirths per 1000 calculated from the national dataset

Reported NMR: NMR reported by the country to the United Nations Inter-Agency Group for Child Mortality Estimation (UNIGME) [6]

Difference= calculated NMR – Reported NMR

Country	Year	NMR Reported to UNIGME	a. Records with birthweight reported				b. Records with gestational age reported				c. Records with newborn types assessed			
			Livebirths	Deaths	NMR	Difference	Livebirths	Deaths	NMR	Difference	Livebirths	Deaths	NMR	Difference
Australia	2016	2.3	312,554	736	2.4	0.1	312,268	570	1.8	-0.4	312,126	572	1.8	-0.4
Australia	2017	2.4	303,382	739	2.4	0	303,148	551	1.8	-0.6	303,092	532	1.8	-0.7
Australia	2018	2.3	300,738	635	2.1	-0.2	300,688	532	1.8	-0.6	300,550	509	1.7	-0.6
Australia	2019	2.4	300,654	624	2.1	-0.3	300,586	513	1.7	-0.7	300,404	483	1.6	-0.8
Brazil	2011	9.8	2,909,757	21,552	7.4	-2.4	1,567,290	10,973	7	-2.8	1,566,290	10,905	7	-2.8
Brazil	2012	9.6	2,903,294	21,437	7.4	-2.2	2,658,567	18,321	6.9	-2.7	2,657,277	18,224	6.9	-2.7
Brazil	2013	9.4	2,901,989	20,978	7.2	-2.2	2,764,608	18,763	6.8	-2.6	2,763,191	18,737	6.8	-2.6
Brazil	2014	9.2	2,977,620	21,038	7.1	-2.1	2,885,796	19,283	6.7	-2.5	2,884,400	19,272	6.7	-2.5
Brazil	2015	9	3,012,086	21,363	7.1	-1.9	2,926,642	19,564	6.7	-2.3	2,925,494	19,554	6.7	-2.3
Brazil	2016	9	2,857,886	22,341	7.8	-1.2	2,797,095	20,788	7.4	-1.6	2,796,010	20,600	7.4	-1.6
Brazil	2017	8.9	2,920,048	22,805	7.8	-1.1	2,859,648	21,217	7.4	-1.5	2,858,521	21,016	7.4	-1.5
Brazil	2018	8.5	2,943,410	21,641	7.4	-1.1	2,895,362	20,325	7	-1.5	2,894,256	20,110	6.9	-1.6
Canada	2005	4.1	255,090	680	2.7	-1.4	224,784	491	2.2	-1.9	224,886	589	2.6	-1.5
Canada	2006	3.7	259,971	600	2.3	-1.4	252,689	449	1.8	-1.9	252,780	567	2.2	-1.5
Canada	2007	3.8	272,457	710	2.6	-1.2	272,146	561	2.1	-1.7	272,277	706	2.6	-1.2
Canada	2008	3.7	282,459	715	2.5	-1.2	282,145	548	1.9	-1.8	282,307	708	2.5	-1.2
Canada	2009	3.7	284,534	709	2.5	-1.2	284,260	563	2	-1.7	284,405	709	2.5	-1.2
Canada	2010	3.9	281,190	670	2.4	-1.5	280,904	509	1.8	-2.1	281,076	674	2.4	-1.5
Canada	2011	3.7	280,890	696	2.5	-1.2	280,614	530	1.9	-1.8	280,774	689	2.5	-1.2
Canada	2012	3.6	281,802	656	2.3	-1.3	281,432	523	1.9	-1.7	281,561	652	2.3	-1.3
Canada	2013	3.8	281,080	670	2.4	-1.4	280,654	508	1.8	-2	280,811	664	2.4	-1.4

Canada	2014	3.6	284,452	636	2.2	-1.4	283,884	498	1.8	-1.8	284,015	632	2.2	-1.4
Canada	2015	3.5	283,249	552	1.9	-1.6	282,690	424	1.5	-2	282,815	550	1.9	-1.6
Canada	2016	3.4	283,931	537	1.9	-1.5	283,579	413	1.5	-1.9	283,703	539	1.9	-1.5
Canada	2017	3.5	280,277	592	2.1	-1.4	279,916	438	1.6	-1.9	280,068	588	2.1	-1.4
Canada	2018	3.4	276,934	636	2.3	-1.1	276,649	486	1.8	-1.6	276,745	619	2.2	-1.2
Canada	2019	3.2	274,872	557	2	-1.2	274,266	431	1.6	-1.6	274,396	556	2	-1.2
Canada	2020	3.2	266,267	561	2.1	-1.1	265,634	422	1.6	-1.6	265,768	558	2.1	-1.1
Czech Republic	2019	1.6	112,231	174	1.6	0	109,492	168	1.5	-0.1	109,492	168	1.5	-0.1
Denmark	2000-2017	3.1	1,100,854	2,598	2.4	-0.7	1,100,854	2,598	2.4	-0.7	1,100,854	2,598	2.4	-0.7
Estonia	2015	1.5	13,905	21	1.5	0.0	13,911	21	1.5	0.0	13,905	21	1.5	0.0
Estonia	2016	1.2	13,859	17	1.2	0.0	13,872	17	1.2	0.0	13,858	17	1.2	0.0
Estonia	2017	1.4	13,508	18	1.3	0.1	13,519	18	1.3	0.1	13,508	18	1.3	0.1
Estonia	2018	1	14,157	14	1.0	0.0	14,186	14	1.0	0.0	14,155	14	1.0	0.0
Estonia	2019	0.9	13,872	13	0.9	0.0	13,909	13	0.9	0.0	13,871	13	0.9	0.0
Estonia	2020	0.9	13,009	12	0.9	0.0	13,030	12	0.9	0.0	13,001	12	0.9	0.0
Lebanon	2001	11.5	10,009	75	7.5	-4	9,726	80	8.2	3.3	9,700	72	7.4	4.1
Lebanon	2002		10,164	66	6.5		9,975	67	6.7		9,878	63	6.4	
Lebanon	2003		6,999	41	5.9		6,963	44	6.3		6,795	41	6	
Lebanon	2004		9,400	66	7		9,180	62	6.8		9,019	56	6.2	
Lebanon	2005		13,246	89	6.7		13,126	80	6.1		12,608	70	5.6	
Lebanon	2006		14,584	113	7.7		14,484	107	7.4		14,073	98	7	
Lebanon	2007		15,538	109	7		15,592	110	7.1		14,874	88	5.9	
Lebanon	2008		17,558	88	5		17,447	95	5.4		16,839	83	4.9	
Lebanon	2009		19,776	82	4.1		19,067	80	4.2		18,602	74	4	
Lebanon	2010		21,126	83	3.9		20,813	78	3.7		20,141	71	3.5	
Lebanon	2011		21,902	70	3.2		21,595	70	3.2		20,775	64	3.1	
Lebanon	2012		25,028	68	2.7		24,766	70	2.8		23,853	61	2.6	
Lebanon	2013		26,191	52	2		25,930	51	2		25,030	50	2	
Lebanon	2014		21,211	60	2.8		21,039	56	2.7		20,533	53	2.6	
Lebanon	2015		17,823	47	2.6		17,782	46	2.6		17,227	45	2.6	
Lebanon	2016		17,576	37	2.1		17,541	34	1.9		16,918	33	2	
Lebanon	2017	5.5	16,248	43	2.6	-2.9	16,240	43	2.6	-2.9	15,815	42	2.7	-2.8
Lebanon	2018		16,506	30	1.8		16,586	29	1.7		16,173	28	1.7	
Lebanon	2019		13,793	54	3.9		13,809	55	4		13,461	52	3.9	
Mexico	2017	7.2	1,948,078	11,992	6.2	-1	1,948,078	11,992	6.2	-1	1,948,078	11,992	6.2	-1
Mexico	2018	6.7	1,848,862	11,279	6.1	-0.6	1,848,862	11,279	6.1	-0.6	1,848,862	11,279	6.1	-0.6
Mexico	2019	6.5	1,763,976	10,765	6.1	-0.4	1,763,976	10,765	6.1	-0.4	1,763,976	10,765	6.1	-0.4
Netherlands	2010	2.8	177,512	712	4	1.2	176,457	586	3.3	0.5	176,296	582	3.3	0.5
Netherlands	2011	2.7	175,582	709	4	1.3	174,521	568	3.3	0.6	174,300	564	3.2	0.5
Netherlands	2012	2.6	173,551	637	3.7	1.1	171,725	510	3	0.4	171,497	507	3	0.4

Netherlands	2013	2.8	168,186	663	3.9	1.1	167,046	527	3.2	0.4	166,833	525	3.1	0.3
Netherlands	2014	2.7	172,170	653	3.8	1.1	170,717	502	2.9	0.2	170,486	496	2.9	0.2
Netherlands	2015	2.5	166,913	587	3.5	1	165,793	477	2.9	0.4	165,525	470	2.8	0.3
Netherlands	2016	2.6	169,682	623	3.7	1.1	168,769	496	2.9	0.3	168,507	490	2.9	0.3
Netherlands	2017	2.7	166,513	661	4	1.3	165,468	536	3.2	0.5	165,147	528	3.2	0.5
Netherlands	2018	2.6	162,423	645	4	1.4	161,636	534	3.3	0.7	161,157	520	3.2	0.6
Netherlands	2019	2.7	164,565	665	4	1.3	163,533	510	3.1	0.4	163,263	496	3	0.3
Northern Ireland	2016 - 2021	2.7	155,992	290	1.9	-0.8	155,906	290	1.9	-0.8	155,992	290	1.9	-0.8
Qatar	2016	3.3	22,035	70	3.2	-0.1	22,035	70	3.2	-0.1	22,035	70	3.2	-0.1
Qatar	2017	3.8	23,936	88	3.7	-0.1	23,936	88	3.7	-0.1	23,936	88	3.7	-0.1
Qatar	2018	3.8	23,549	67	2.8	-1	23,549	67	2.8	-1	23,549	67	2.8	-1
Qatar	2019	3.7	24,817	72	2.9	-0.8	24,817	72	2.9	-0.8	24,817	72	2.9	-0.8
Scotland	2000	3.9	52,492	189	3.6	-0.3	52,495	191	3.6	-0.3	52,474	188	3.6	-0.3
Scotland	2001	3.7	51,279	175	3.4	-0.3	51,269	171	3.3	-0.4	51,255	169	3.3	-0.4
Scotland	2002	3.6	50,442	134	2.7	-0.9	50,436	136	2.7	-0.9	50,418	133	2.6	-1
Scotland	2003	3.6	51,557	156	3	-0.6	51,560	156	3	-0.6	51,531	154	3	-0.6
Scotland	2004	3.5	53,098	144	2.7	-0.8	53,090	144	2.7	-0.8	53,070	140	2.6	-0.9
Scotland	2005	3.5	52,794	150	2.8	-0.7	52,818	150	2.8	-0.7	52,769	148	2.8	-0.7
Scotland	2006	3.5	53,473	136	2.5	-1	53,476	129	2.4	-1.1	53,433	127	2.4	-1.1
Scotland	2007	3.3	56465	153	2.7	-0.6	56,493	145	2.6	-0.7	56,418	141	2.5	-0.8
Scotland	2008	3.2	58,616	144	2.5	-0.7	58,621	136	2.3	-0.9	58,553	133	2.3	-0.9
Scotland	2009	3.2	57812	143	2.5	-0.7	57,823	136	2.4	-0.8	57,759	133	2.3	-0.9
Scotland	2010	3	57,840	123	2.1	-0.9	57,826	121	2.1	-0.9	57,807	120	2.1	-0.9
Scotland	2011	3	57,492	138	2.4	-0.6	57,463	135	2.3	-0.7	57,455	135	2.3	-0.7
Scotland	2012	2.9	56,831	132	2.3	-0.6	56,804	124	2.2	-0.7	56,774	123	2.2	-0.7
Scotland	2013	2.7	54,961	113	2.1	-0.6	54,983	112	2	-0.7	54,886	109	2	-0.7
Scotland	2014	2.7	55,817	128	2.3	-0.4	55,653	121	2.2	-0.5	55,578	121	2.2	-0.5
Scotland	2015	2.7	54,352	90	1.7	-1	54,169	83	1.5	-1.2	54,111	83	1.5	-1.2
Scotland	2016	2.8	53684	112	2.1	-0.7	53,371	104	1.9	-0.9	53,256	101	1.9	-0.9
Scotland	2017	2.8	51,930	104	2	-0.8	51,945	100	1.9	-0.9	51,659	98	1.9	-0.9
Scotland	2018	2.8	50,374	88	1.7	-1.1	50,530	85	1.7	-1.1	50,333	82	1.6	-1.2
Scotland	2019	2.8	48,637	87	1.8	-1	48,677	84	1.7	-1.1	48,622	81	1.7	-1.1
Scotland	2020	2.8	46,678	83	1.8	-1	46,697	80	1.7	-1.1	46,656	80	1.7	-1.1
Sweden	2000 - 2019	1.4	2,102,671	2,758	1.3	-0.1	2,102,671	2,755	1.3	-0.1	2,102,671	2,755	1.3	-0.1
England & Wales	2015	2.7	666,881	1,527	2.3	-0.4	666,881	1,527	2.3	-0.4	666,881	1,527	2.3	-0.4
England & Wales	2016	2.8	666,539	1,490	2.2	-0.6	666,539	1,490	2.2	-0.6	666,539	1,490	2.2	-0.6
England & Wales	2017	2.8	649,066	1,454	2.2	-0.6	649,066	1,454	2.2	-0.6	649,066	1,454	2.2	-0.6
England & Wales	2018	2.8	621,468	1,385	2.2	-0.6	621,468	1,385	2.2	-0.6	621,468	1,385	2.2	-0.6

England & Wales	2019	2.8	608,538	1,313	2.2	-0.6	608,538	1,313	2.2	-0.6	608,538	1,313	2.2	-0.6
Uruguay	2009	4.3	41,104	35	0.9	-3.4	40,090	35	0.9	-3.4	39,970	35	0.9	-3.4
Uruguay	2010	3.9	33,771	23	0.7	-3.2	33,247	23	0.7	-3.2	33,162	23	0.7	-3.2
Uruguay	2011	3.9	41,866	91	2.2	-1.7	41,277	89	2.2	-1.7	41,210	87	2.1	-1.8
Uruguay	2012	5.6	45,326	69	1.5	-4.1	44,846	69	1.5	-4.1	44,758	68	1.5	-4.1
Uruguay	2013	5.3	46,369	49	1.1	-4.2	45,998	49	1.1	-4.2	45,925	48	1	-4.3
Uruguay	2014	5	46,825	46	1	-4	46,506	46	1	-4	46,456	46	1	-4
Uruguay	2015	5	46,842	50	1.1	-3.9	46,534	51	1.1	-3.9	46,477	50	1.1	-3.9
Uruguay	2016	5.2	45,459	78	1.7	-3.5	45,156	78	1.7	-3.5	45,103	77	1.7	-3.5
Uruguay	2017	4.3	41,884	50	1.2	-3.1	41,664	50	1.2	-3.1	41,619	50	1.2	-3.1
Uruguay	2018	3.9	38,771	48	1.2	-2.7	38,503	48	1.2	-2.7	38,466	48	1.2	-2.7
Uruguay	2019	3.5	35,662	68	1.9	-1.6	35,387	68	1.9	-1.6	35,343	68	1.9	-1.6
Uruguay	2020	4.3	34,886	65	1.9	-2.4	34,581	64	1.9	-2.4	34,551	64	1.9	-2.4
USA	2000	4.6	4,061,092	18,120	4.5	-0.1	4,011,706	14,336	3.6	-1	4,011,112	14,253	3.6	-1
USA	2001	4.5	4,030,307	17,810	4.4	-0.1	3,982,855	13,947	3.5	-1	3,982,387	13,861	3.5	-1
USA	2002	4.7	4,026,197	18,136	4.5	-0.2	3,977,311	14,174	3.6	-1.1	3,976,859	14,107	3.5	-1.2
USA	2003	4.6	4,095,477	18,572	4.5	-0.1	4,043,012	14,215	3.5	-1.1	4,042,904	14,197	3.5	-1.1
USA	2004	4.5	4,118,277	18,323	4.4	-0.1	4,066,556	14,037	3.5	-1	4,066,505	14,022	3.4	-1.1
USA	2005	4.5	4,145,258	18,435	4.4	-0.1	4,107,177	14,075	3.4	-1.1	4,107,089	14,044	3.4	-1.1
USA	2006	4.5	4,272,106	18,640	4.4	-0.1	4,238,782	14,410	3.4	-1.1	4,238,731	14,392	3.4	-1.1
USA	2007	4.4	4,323,391	18,626	4.3	-0.1	4,311,757	14,359	3.3	-1.1	4,311,708	14,341	3.3	-1.1
USA	2008	4.3	4,254,111	17,859	4.2	-0.1	4,244,010	13,573	3.2	-1.1	4,243,964	13,553	3.2	-1.1
USA	2009	4.2	4,136,809	16,899	4.1	-0.1	4,127,677	12,907	3.1	-1.1	4,127,631	12,897	3.1	-1.1
USA	2010	4.1	4,006,465	15,892	4	-0.1	3,997,225	12,205	3.1	-1	3,997,192	12,191	3	-1.1
USA	2011	4.1	3,959,481	15,709	4	-0.1	3,951,654	11,942	3	-1.1	3,951,607	11,934	3	-1.1
USA	2012	4	3,960,052	15,615	3.9	-0.1	3,952,011	11,721	3	-1	3,951,961	11,700	3	-1
USA	2013	4	3,940,035	15,576	4	0	3,929,746	11,482	2.9	-1.1	3,929,692	11,461	2.9	-1.1
USA	2014	3.9	3,997,358	15,498	3.9	0	3,990,370	11,552	2.9	-1	3,990,322	11,539	2.9	-1
USA	2015	3.9	3,987,951	15,440	3.9	0	3,981,482	11,604	2.9	-1	3,981,428	11,581	2.9	-1
USA	2016	3.9	3,942,236	15,046	3.8	-0.1	3,938,207	11,271	2.9	-1	3,935,732	11,259	2.9	-1
USA	2017	3.8	3,855,948	14,622	3.8	0	3,851,269	10,891	2.8	-1	3,850,067	10,874	2.8	-1
USA	2018	3.7	3,792,248	14,069	3.7	0	3,787,911	10,513	2.8	-0.9	3,786,657	10,496	2.8	-0.9
USA	2019	3.5	3,747,254	13,560	3.6	0.1	3,743,787	10,061	2.7	-0.8	3,741,978	10,043	2.7	-0.8

Canada: excluding data from Quebec and mortality after discharge

Table S5. Number of missing values on three core variables (birthweight, gestational age, and sex) among included country-years

Country	Period of observation	Livebirths	Missing values					
			Birthweight		Gestational age		Sex	
	(years)	(n)	(n)	(%)	(n)	(%)	(n)	(%)
Australia	2016-2019	1,217,919	539	<0.1	548	<0.1	108	<0.1
Brazil	2011-2018	23,439,789	13,442	0.1	2,036,695	8.7	4,217	<0.1
Canada	2005-2020	4,163,541	347	<0.1	34,794	0.8	160	<0.1
Czech Republic	2019	112,231	1,512	1.3	2,719	2.4	0	0.0
Denmark	2000-2017	1,125,560	20,903	1.9	18,748	1.7	294	<0.1
England & Wales	2015-2019	3,212,492	0	0.0	0	0.0	0	0.0
Estonia	2015-2020	82,427	0	0.0	0	0.0	0	0.0
Lebanon	2001 & 2017	26,792	535	2.0	709	2.6	677	2.5
Netherlands	2010-2019	1,861,400	2,277	0.1	12,520	0.7	59	<0.1
Qatar	2016-2019	95,906	350	0.4	1,202	1.3	5	<0.1
Scotland	2000-2020	1,127,984	1,357	0.1	1,659	0.1	181	<0.1
Sweden	2000-2019	2,102,671	0	0.0	0	0.0	0	0.0
Uruguay	2009-2020	499,345	580	0.1	5,350	1.1	0	0.0
US	2000-2019	80,710,348	78,490	0.1	317,158	0.4	1,672	<0.1

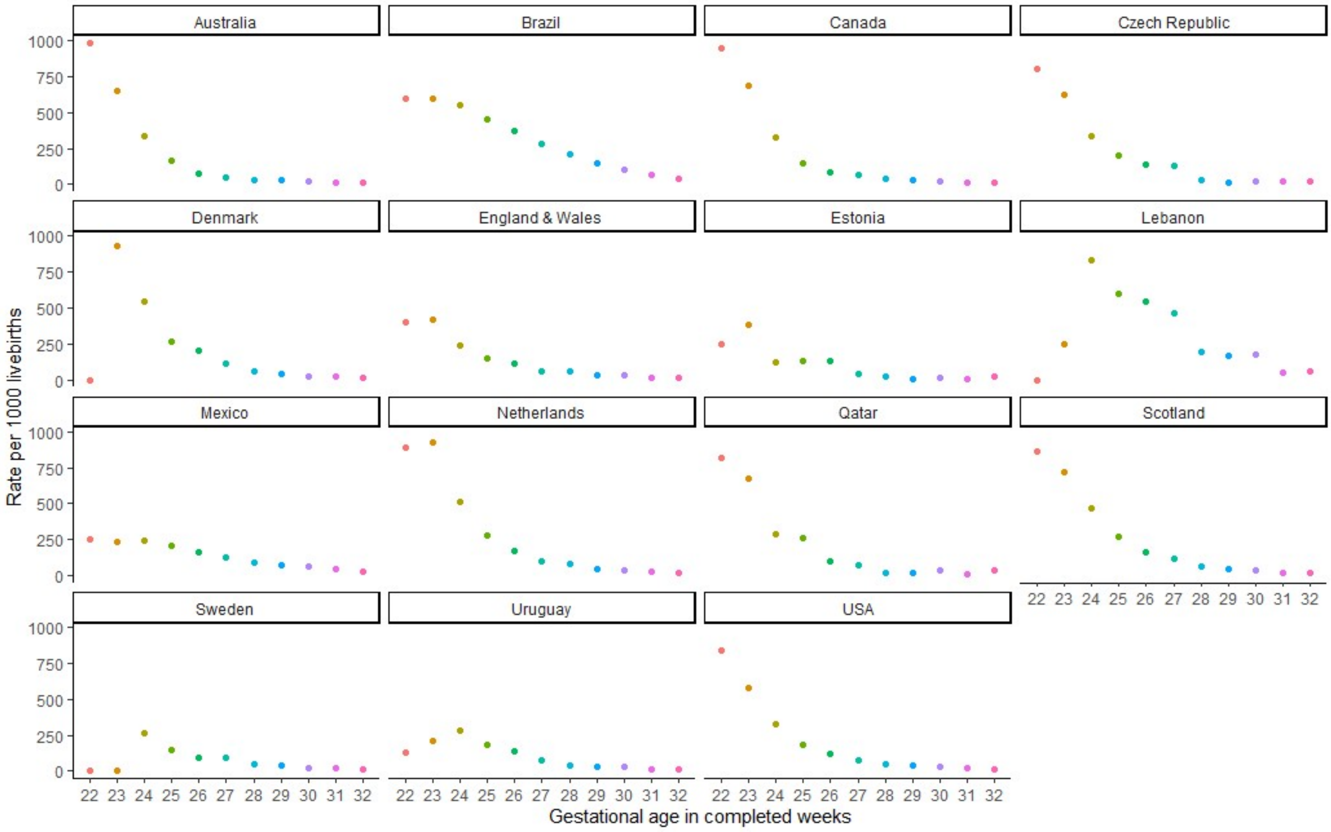
Table S6. Summary of metadata

Country	Units for reporting Birthweight/ Gestational age	Data linkage	Reporting criteria for very preterm		
			Exclusions criteria based on BW	**Exclusion criteria based on GA**	**Are births following induced Termination of Pregnancy included in the data source?**
Australia	Grams Completed weeks	Not applicable as livebirths, stillbirths and neonatal deaths are all included as part of the National Perinatal Data Collection	A small number of births <400 grams are included	A small number of births < 20 weeks are included	Both livebirths and stillbirths may include termination of pregnancy after 20 weeks.
Brazil	Grams Completed weeks	Livebirths and death records were linked using the name of the mother, maternal date of birth or age (when the date of birth was missing), and the municipality of residence of the mother as matching variables using CIDACS-RL software	<350g	<20 weeks	No
Canada	Grams Completed weeks	Data were obtained from the Discharge Abstract Database (DAD) which collates all hospitalization records of maternal hospitalizations for childbirth and also links maternal and live birth infant records. The province of Quebec does not contribute data to DAD. Home births were not included	None	None	No
Czech Republic	Grams Weeks +days	Information system of newborn is linked at the individual level to the Registry of Reproductive Health and Information system of the dead	None	<22 weeks	No
Denmark	Grams Days	Information on livebirths and stillbirths were extracted from the Danish Medical Birth Registry. These data were linked to the Danish Civil Registration System to define infant death	None	None	No
England & Wales	Grams Completed weeks	Data linkage with birth notifications, and birth and stillbirth registrations and neonatal death registrations	None	22 weeks	No

Estonia	Grams Weeks +days	Estonian Medical Birth Register is Linked at the individual level to the Registry of Causes of Death	None	<22 weeks	No
Lebanon	Grams Weeks+ days		None	<22 weeks	No
Mexico	Weeks +days Completed weeks	Livebirths and deaths records were linked using the variables sex, date of birth, place of residence and place of occurrence using CIDACS-RL software	None	None	No
Netherlands	Grams Weeks + days	Records from midwifes, clinical obstetricians/gynaecologists and neonatologist are linked nationally	Gestational age ≥22 weeks; if g.a. missing, birthweight ≥500 g	Gestational age ≥22 weeks; if g.a. missing, birthweight ≥500 g	Both livebirths and stillbirths up to 24 weeks gestation may include termination of pregnancy
Qatar	Kilograms and grams Weeks and days	Not applicable	None	None	Yes, all births included
Scotland	Grams Completed weeks	SMR02 is a file based on babies (live and stillbirths) was matched with NHS Lothian file and NRS infant deaths	None	None	No induced ToPs are included
Sweden	Grams Days	National databases that are linked together using the person-unique national registration numbers of children	None	<23 weeks	Included after 22 weeks
Uruguay	Grams Completed weeks		None	None	No
United States of America	Grams Completed weeks	Data on live births are available from the NCHS – Vital Statistics online. It includes data from live birth certificates. Linkages are performed to obtain information on infant death from Vital Statistics; the proportion of linked infant deaths is generally high, it differs by year (overall 98.7%-99.4%), and by state (e.g., 92.8%-100% in 2000)	None	None	The NCHS recommendation for fetal death definition is to exclude TOPs. Some states do exclude TOPs regardless of gestational age, while some states include TOPs

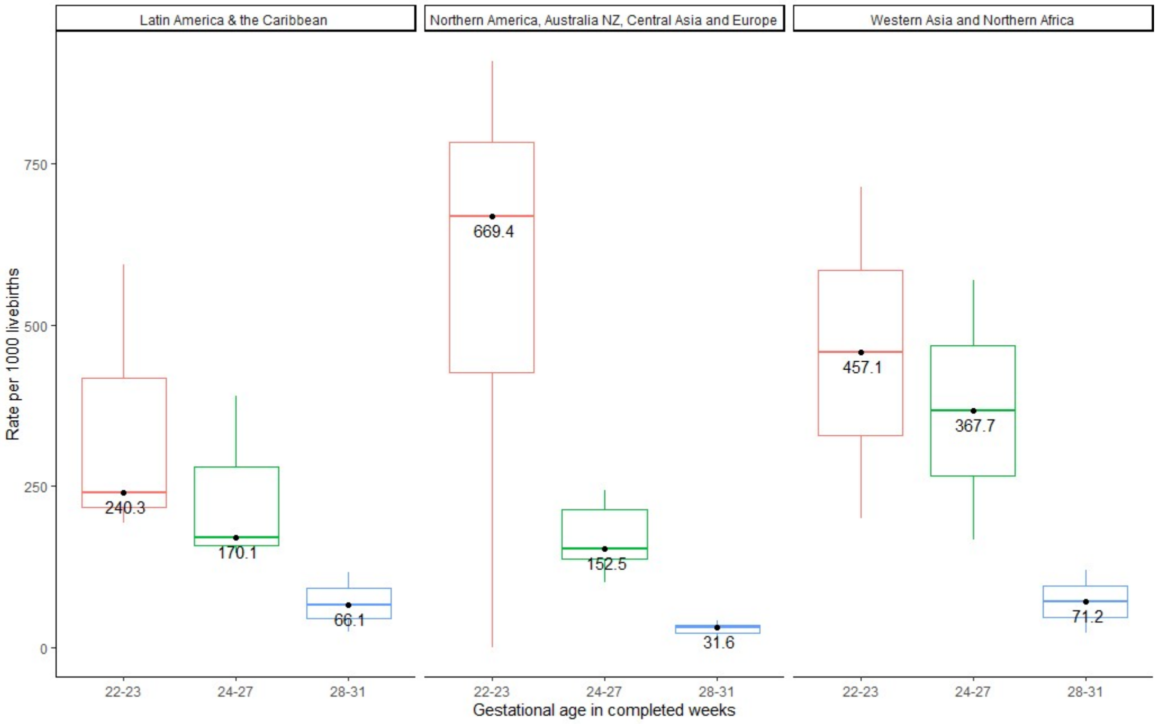
Figure S1. Neonatal mortality NMRs by gestational age among very preterm births (22 to 32 completed weeks) in 15 countries

NMR: number of neonatal deaths / number of livebirths per 1000



Each point indicates the NMR for each gestational age in completed weeks

Figure S2. Neonatal mortality NMRs by gestational age among very preterm births (22 to 32 completed weeks) by region



Numbers show median NMRs and box plots summarize the median, 25th and 75th percentiles

Table S7. Ranking of neonatal mortality NMRs comparing two groups of babies (≥22 weeks and ≥24 weeks) in 15 countries

Ranking	≥22 weeks			Ranking	≥24 weeks		
	Livebirths (n)	Deaths (n)	NMR per 1000		Livebirths (n)	Deaths (n)	NMR per 1000
Brazil	21,355,008	149,234	7.0	Brazil	21,334,724	137,181	6.4
Mexico	5,560,916	34,036	6.1	Mexico	5,559,909	33,794	6.1
Lebanon	25,966	123	4.7	Lebanon	25,961	122	4.7
USA	80,234,505	253,275	3.2	Qatar	94,239	227	2.4
Qatar	94,337	297	3.1	USA	80,132,448	182,680	2.3
Netherlands	1,849,432	5,556	3.0	Denmark	1,100,286	2,324	2.1
Denmark	1,100,854	2,598	2.4	Netherlands	1,847,584	3,875	2.1
Scotland	1,126,199	2,643	2.3	Scotland	1,125,732	2,288	2.0
England and Wales	3,212,492	7,169	2.2	England and Wales	3,208,542	5,560	1.7
Australia	1,216,690	2,166	1.8	Czech Republic	109,458	146	1.3
Canada	4,386,246	7,794	1.8	Sweden	2,102,671	2,755	1.3
Czech Republic	109,492	168	1.5	Uruguay	493,613	636	1.3
Uruguay	493,789	670	1.4	Australia	1,215,746	1,419	1.2
Sweden	2,102,671	2,755	1.3	Canada	4,382,662	4,935	1.1
Estonia	82,427	95	1.2	Estonia	82,384	80	1.0

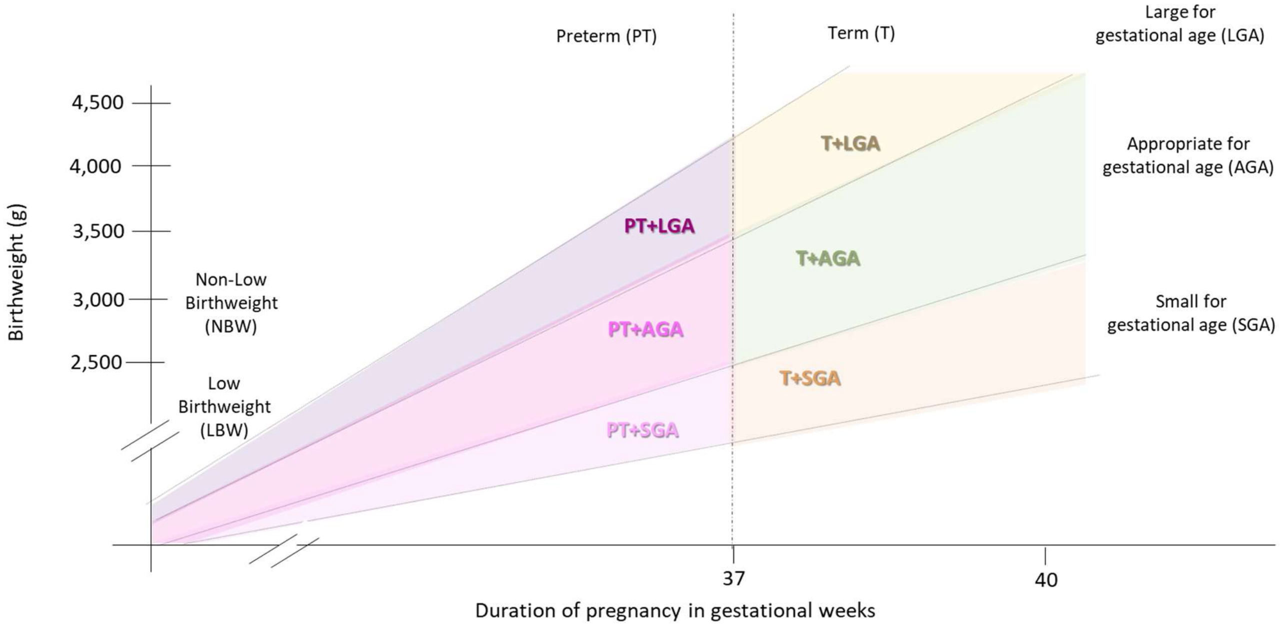
Region key

Latin America and the Caribbean

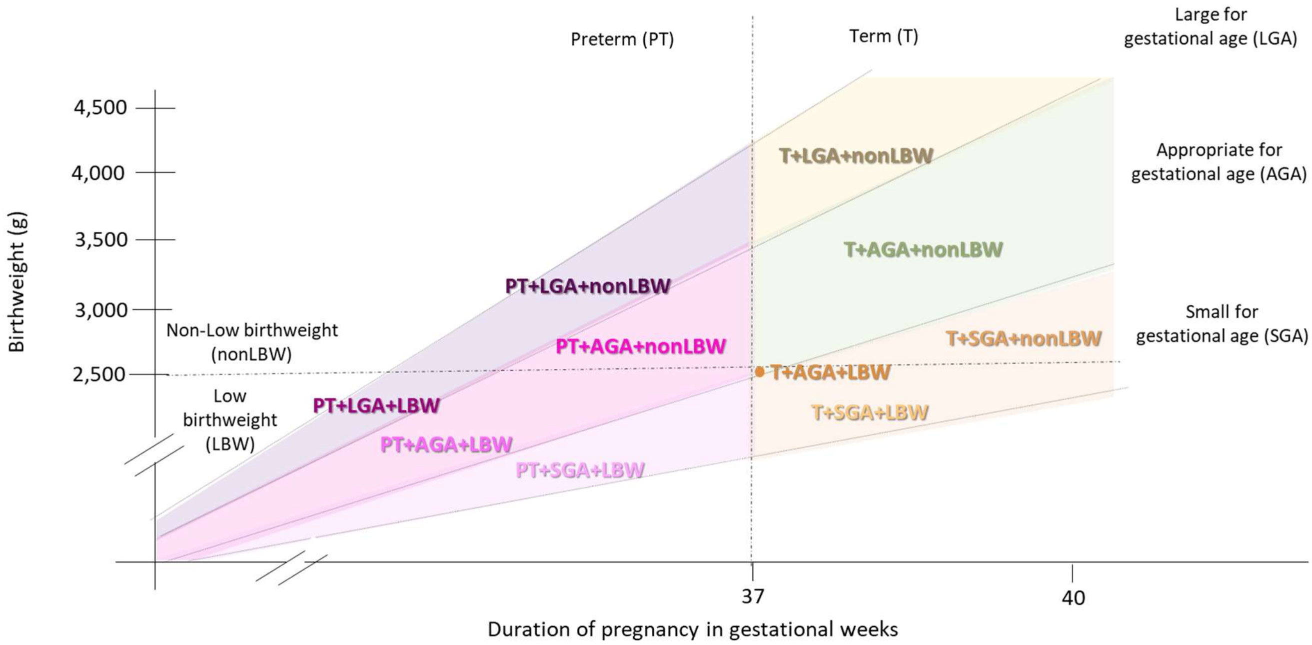
Northern America, Australia and New Zealand, Central Asia and Europe

Figure S3. Overview of Vulnerable newborn types based on gestational age, size for gestational age and birthweight.

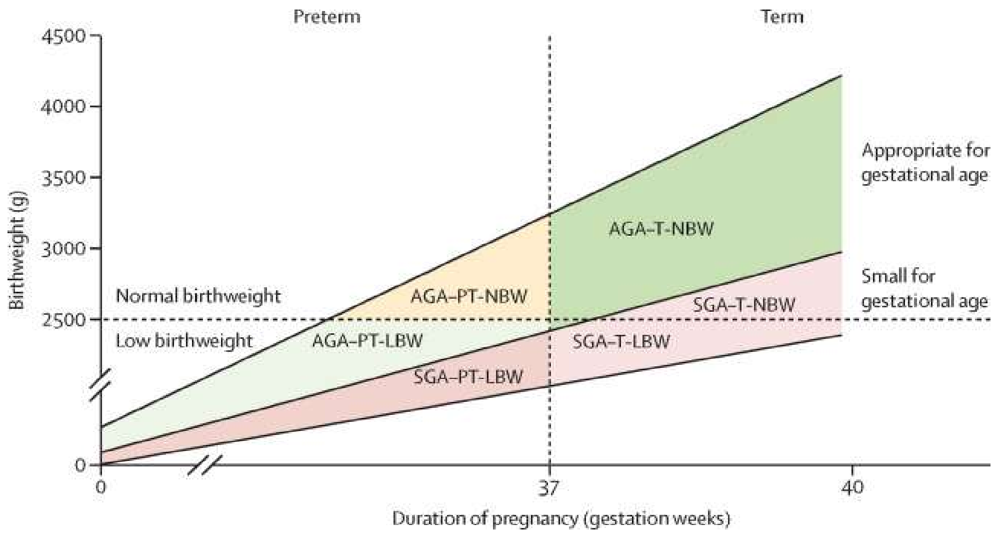
a. Six newborn types used in the main analysis.



b. Ten newborn types used in the secondary analysis - including birthweight dimension



c. Original newborn types proposed by Ashorn *et al* [7]



This figure illustrates the six newborn types (a) used in the main analysis and more granular expansion of these types adding the birthweight dimension (b) used in the secondary analysis in this paper.

Additional results:

Table S8. Neonatal mortality NMR, population attributable risk, and crude relative risk of neonatal mortality for birthweight fine strata (reference 2,500g to 4,000g), by country

Prevalence = the number of livebirths reported in each group of interest / total number of livebirths

Neonatal Mortality NMR (NMR): the number of persons who experienced the event (neonatal death) divided by the total number of persons exposed to the risk of that event per 1000

Population attributable risk (PAR): was calculated for each level of exposure with the following formula where *pr* is the prevalence and *RR* is the relative risk [8]

$$\text{PAR for type } of\ interest = \frac{pr(type\ of\ interest)\big(RR(type\ of\ interest - 1)\big)}{\sum_{all\ types} pr(type)\, x\, RR(type)}$$

Relative risk: the absolute risk within a specific category divided by the absolute risk in the reference group, expressed as a ratio

Country	Total			2,500g to 4,000g			
	Livebirths (n)	Deaths (n)	Rate per 1000	Livebirths (n)	Deaths (n)	Prevalence (%)	Rate per 1000
Australia	1,217,328	2,734	2	1,020,141	436	83.8	0.4
Brazil	23,426,090	173,155	7.4	20,247,168	45,452	86.4	2.2
Canada	4,429,455	10,177	2.3	3,655,142	1,144	82.5	0.3

Czech Republic	112,231	174	1.6	94,014	42	83.8	0.4
Denmark	1,100,854	2,598	2.4	848,717	654	77.1	0.8
England and Wales	3,212,492	7,169	2.2	2,636,657	1,844	82.1	0.7
Estonia	82,310	95	1.2	64,153	27	77.9	0.4
Lebanon	26,257	118	4.5	22,859	40	87.1	1.7
Mexico	5,560,916	34,036	6.1	5,039,848	25,819	90.6	5.1
Netherlands	1,861,306	6,866	3.7	1,498,550	1,220	80.5	0.8
Qatar	94,337	297	3.1	81,009	55	85.9	0.7
Scotland	1,126,627	2,722	2.4	900,470	698	79.9	0.8
Sweden	2,102,671	2,758	1.3	1,626,048	964	77.3	0.6
Uruguay	498,765	672	1.3	421,206	153	84.4	0.4
USA	80,652,053	332,447	4.1	67,554,421	51,529	83.8	0.8

Country	**<1,000g**						
	Livebirths (n)	**Deaths (n)**	**Prevalence (%)**	**Rate per 1000**	**PAR (%)**	**Relative risk (n)**	**95%CI (n)**
Australia	5,178	1,768	0.4	341.4	57.8	595.8	(537.9, 659.9)
Brazil	142,717	64,898	0.6	454.7	29.8	139.6	(138.0, 141.1)
Canada	19,957	7,063	0.5	353.9	62.7	835.4	(785.8, 888.3)
Czech Republic	1,895	84	1.7	44.3	46.9	95.1	(65.8, 137.3)
Denmark	3,605	1,255	0.3	348.1	41.1	335.4	(306.4, 367.0)
England and Wales	17,568	3,273	0.5	186.3	41.5	224.7	(212.6, 237.5)
Estonia	261	31	0.3	118.8	30.3	252.4	(152.6, 417.3)
Lebanon	77	39	0.3	506.5	25.4	192.5	(128.8, 287.6)
Mexico	13,409	2,172	0.2	162.0	5.4	27.4	(26.3, 28.5)
Netherlands	9,635	4,309	0.5	447.2	53.9	379.9	(357.3, 403.9)
Qatar	489	140	0.5	286.3	41.2	328.1	(242.6, 443.7)
Scotland	4,296	1,205	0.4	280.5	38.4	282.8	(258.6, 309.3)
Sweden	5,261	695	0.3	132.1	23.0	196.9	(179.2, 216.4)
Uruguay	2,237	306	0.4	136.8	42.4	331.4	(274.0, 400.8)
USA	579,635	211,113	0.7	364.2	56.2	350.3	(347.0, 353.6)

Country	**1,000g to 1,500g**						
	Livebirths (n)	**Deaths (n)**	**Prevalence (%)**	**Rate per 1000**	**PAR (%)**	**Relative risk (n)**	**95%CI (n)**
Australia	6,620	187	0.5	28.2	7.9	64.3	(54.3, 76.2)
Brazil	174,547	25,529	0.7	146.3	14.7	57.0	(56.1, 57.8)
Canada	25,040	709	0.6	28.3	8.2	88.0	(80.2, 96.6)
Czech Republic	669	21	0.6	31.4	11.8	68.2	(40.6, 114.5)
Denmark	5,835	258	0.5	44.2	10.7	55.0	(47.7, 63.4)
England and Wales	19,500	666	0.6	34.2	9.5	47.3	(43.3, 51.6)
Estonia	362	14	0.4	38.7	14.6	88.5	(46.7, 167.4)
Lebanon	155	24	0.6	154.8	20.2	76.8	(47.3, 124.6)
Mexico	25,170	1,599	0.5	63.5	4.1	11.7	(11.2, 12.3)

Netherlands	10,538	466	0.6	44.2	7.9	52.1	(46.9, 57.8)
Qatar	738	33	0.8	44.7	11.8	63.1	(41.2, 96.6)
Scotland	7,594	305	0.7	40.2	11.8	49.9	(43.7, 56.9)
Sweden	9,066	338	0.4	37.3	12.1	60.7	(53.7, 68.5)
Uruguay	3,809	90	0.8	23.6	13.7	63.6	(49.1, 82.3)
USA	599,506	22,967	0.7	38.3	7.9	48.4	(47.7, 49.2)

Country	**1,500g to 2,000g**						
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**Relative risk**	**95%CI**
	(n)	**(n)**	**(%)**	**per 1000**	**(%)**	**(n)**	**(n)**
Australia	15,880	150	1.3	9.4	6.2	21.9	(18.2, 26.4)
Brazil	369,804	17,641	1.6	47.7	10.8	20.3	(20.0, 20.7)
Canada	55,647	558	1.3	10.0	6.4	31.7	(28.7, 35.1)
Czech Republic	1,587	13	1.4	8.2	7.2	18.2	(9.8, 33.8)
Denmark	12,580	162	1.1	12.9	6.6	16.5	(13.9, 19.6)
England and Wales	43,704	576	1.4	13.2	8.1	18.6	(17.0, 20.4)
Estonia	724	9	0.9	12.4	9.4	29.2	(13.8, 61.8)
Lebanon	478	7	1.8	14.6	6.0	8.3	(3.7, 18.4)
Mexico	64,898	1,395	1.2	21.5	3.1	4.1	(3.9, 4.4)
Netherlands	22,611	370	1.2	16.4	6.3	19.8	(17.7, 22.2)
Qatar	1,765	33	1.9	18.7	11.8	27.1	(17.6, 41.5)
Scotland	16,500	214	1.5	13.0	8.1	16.5	(14.2, 19.3)
Sweden	18,145	271	0.9	14.9	9.6	24.8	(21.7, 28.4)
Uruguay	7,905	66	1.6	8.3	9.9	22.8	(17.1, 30.4)
USA	1,275,412	21,118	1.6	16.6	7.2	21.4	(21.0, 21.7)

Country	**2,000g to 2,500g**						
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**Relative risk**	**95%CI**
	(n)	**(n)**	**(%)**	**per 1000**	**(%)**	**(n)**	**(n)**
Australia	53,099	154	4.4	2.9	5.7	6.8	(5.6, 8.1)
Brazil	1,299,612	16,610	5.5	12.8	9.1	5.6	(5.5, 5.7)
Canada	183,318	490	4.1	2.7	5.2	8.5	(7.7, 9.5)
Czech Republic	4,893	12	4.4	2.5	5.8	5.5	(2.9, 10.4)
Denmark	35,438	166	3.2	4.7	6.1	6.1	(5.1, 7.2)
England and Wales	154,349	639	4.8	4.1	8.0	5.9	(5.4, 6.5)
Estonia	2,089	11	2.5	5.3	11.0	12.5	(6.2, 25.1)
Lebanon	1,532	6	5.8	3.9	3.3	2.2	(0.9, 5.3)
Mexico	266,439	2,290	4.8	8.6	2.7	1.7	(1.6, 1.7)
Netherlands	70,134	370	3.8	5.3	5.6	6.5	(5.7, 7.2)
Qatar	5,712	33	6.1	5.8	11.0	8.5	(5.5, 13.0)
Scotland	49,971	228	4.4	4.6	7.7	5.9	(5.1, 6.8)
Sweden	54,417	312	2.6	5.7	10.5	9.6	(8.5, 10.9)
Uruguay	25,043	45	5.0	1.8	5.7	4.9	(3.5, 6.9)
USA	4,075,989	21,953	5.1	5.4	6.8	7.0	(6.9, 7.1)

Country	4,000 to 4,500g						
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI
	(n)	(n)	(%)	per 1000	(%)	(n)	(n)
Australia	102,107	19	8.4	0.2	-1.1	0.4	(0.3, 0.7)
Brazil	1,044,426	2,205	4.5	2.1	-0.1	0.9	(0.9, 1.0)
Canada	414,097	107	9.3	0.3	-0.3	0.8	(0.7, 1.0)
Czech Republic	8,253	1	7.4	0.1	-1.6	0.3	(0.0, 2.0)
Denmark	159,341	75	14.5	0.5	-2.1	0.6	(0.5, 0.8)
England and Wales	295,023	136	9.2	0.5	-1.1	0.7	(0.6, 0.8)
Estonia	12,516	2	15.2	0.2	-3.5	0.4	(0.1, 1.6))
Lebanon	1,026	1	3.9	1.0	-0.8	0.6	(0.1, 4.1)
Mexico	148,582	748	2.7	5.0	0.0	1.0	(0.9, 1.1)
Netherlands	213,935	108	11.5	0.5	-1.2	0.6	(0.5, 0.8)
Qatar	4,197	3	4.4	0.7	0.1	1.1	(0.3, 3.4)
Scotland	124,876	54	11.1	0.4	-1.8	0.6	(0.4, 0.7)
Sweden	314,857	129	15.0	0.4	-2.2	0.7	(0.6, 0.8)
Uruguay	34,036	9	6.8	0.3	-0.5	0.7	(0.4, 1.4)
USA	5,654,779	2,705	7.0	0.5	-0.6	0.6	(0.6, 0.7)

Country	4,500g to 5,000g						
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI
	(n)	(n)	(%)	per 1000	(%)	(n)	(n)
Australia	13,218	12	1.1	0.9	0.3	2.1	(1.2, 3.8)
Brazil	130,339	544	0.6	4.2	0.2	1.9	(1.7, 2.0)
Canada	67,473	54	1.5	0.8	0.4	2.6	(1.9, 3.4)
Czech Republic	864	1	0.8	1.2	0.4	2.6	(0.4, 18.8)
Denmark	31,315	23	2.8	0.7	0.0	1.0	(1.4, 0.6)
England and Wales	41,966	29	1.3	0.7	0.0	1.0	(0.7, 1.4)
Estonia	2,019	1	2.5	0.5	0.2	1.2	(0.2, 8.7)
Lebanon	117	1	0.4	8.5	0.8	4.9	(0.7, 35.0)
Mexico	2,347	13	0.0	5.5	0.0	1.1	(0.6, 1.9)
Netherlands	32,974	14	1.8	0.4	-0.2	0.5	(0.3, 0.9)
Qatar	397	0	0.4	0.0	-0.1	0.0	(0, 0)
Scotland	20,666	15	1.8	0.7	0.0	0.9	(0.6, 1.6)
Sweden	66,053	41	3.1	0.6	0.1	1.0	(0.8, 1.4)
Uruguay	4,132	3	0.8	0.7	0.2	2.0	(0.6, 6.3)
USA	819,941	755	1.0	0.9	0.0	1.2	(1.1, 1.3)

Country	>5,000g						
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI
	(n)	(n)	(%)	per 1000	(%)	(n)	(n)
Australia	1,085	8	0.1	7.4	0.3	17.1	(8.5, 34.4)
Brazil	17,477	276	0.1	15.8	0.2	6.9	(6.2, 7.8)
Canada	8,781	52	0.2	5.9	0.6	18.8	(14.3, 24.8)
Czech Republic	56	0	0.0	0.0	0.0	0.0	(0,0)

Denmark	4,023	5	0.4	1.2	0.1	1.6	(0.7, 3.9))
England and Wales	3,725	6	0.1	1.6	0.1	2.3	(1.0, 5.1)
Estonia	186	0	0.2	0.0	-0.1	0.0	(0,0)
Lebanon	13	0	0.0	0.0	0.0	0.0	(0,0)
Mexico	223	0	0.0	0.0	0.0	0.0	(0,0)
Netherlands	2,929	9	0.2	3.1	0.1	3.8	(2.0, 7.2)
Qatar	30	0	0.0	0.0	0.0	0.0	(0,0)
Scotland	2,251	2	0.2	0.9	0.0	1.1	(0.3, 4.6)
Sweden	8,824	8	0.4	0.9	0.1	1.5	(0.8, 3.1)
Uruguay	397	0	0.1	0.0	0.0	0.0	(0,0)
USA	92,370	307	0.1	3.3	0.1	4.3	(3.9, 4.9)

Table S9. Neonatal mortality NMR, population attributable risk, and crude relative risk of neonatal mortality for gestational age fine strata (reference 37 to 42 completed weeks), by country

Prevalence = the number of livebirths reported in each group of interest / total number of livebirths

Neonatal Mortality NMR (NMR): the number of persons who experienced the event (neonatal death) divided by the total number of persons exposed to the risk of that event per 1000

Population attributable risk (PAR): was calculated for each level of exposure with the following formula where *pr* is the prevalence and *RR* is the relative risk [8]

$$\text{PAR for type } of\ interest = \frac{pr(type\ of\ interest)(RR(type\ of\ interest-1))}{\sum_{all\ types} pr(type) x\ RR(type)}$$

Relative risk: the absolute risk within a specific category divided by the absolute risk in the reference group, expressed as a ratio

Country	Total (all groups)			37 to 42 weeks (reference group)			
	Livebirths (n)	Deaths (n)	Rate per 1000	Livebirths (n)	Deaths (n)	Prevalence (%)	Rate per 1000
Australia	1,216,690	2,166	1.8	1,118,699	435	91.95	0.4
Brazil	21,355,008	149,234	7.0	18,665,492	45,531	87.41	2.4
Canada	4,386,246	7,794	1.8	4,030,983	1,281	91.90	0.3

Czech Republic	109,492	168	1.5	101,779	47	92.96	0.5
Denmark	1,100,854	2,598	2.4	1,026,140	697	93.21	0.7
England and Wales	3,212,492	7,169	2.2	2,966,254	2,032	92.33	0.7
Estonia	82,427	95	1.2	76,091	33	92.31	0.4
Lebanon	25,966	123	4.7	23,345	39	89.91	1.7
Mexico	5,560,916	34,036	6.1	5,177,919	26,278	93.11	5.1
Netherlands	1,849,432	5,556	3.0	1,719,661	1,269	92.98	0.7
Qatar	94,337	297	3.1	84,793	71	89.88	0.8
Scotland	1,126,199	2,643	2.3	1,039,449	764	92.30	0.7
Sweden	2,102,671	2,755	1.3	1,981,034	1,079	94.22	0.5
Uruguay	493,789	670	1.4	448,592	156	90.85	0.3
USA	80,234,505	253,275	3.2	72,064,969	55,978	89.82	0.8

Country	**<28 weeks (extremely preterm)**						
	Livebirths (n)	**Deaths (n)**	**Prevalence (%)**	**Rate per 1000**	**PAR (%)**	**Relative risk (n)**	**95%CI**
Australia	4,612	1,243	0.4	269.5	51.6	546.2	(491.2, 607.3)
Brazil	107,879	46,232	0.5	428.6	24.5	123.3	(121.8, 124.8)
Canada	17,699	4,835	0.4	273.2	56.3	675.4	(635.9, 717.3)
Czech Republic	319	75	0.3	235.1	39.6	412.4	(290.3, 585.8)
Denmark	3,522	1,266	0.3	359.5	41.3	389.5	(425.3, 356.7))
England and Wales	15,930	3,248	0.5	203.9	40.8	247.4	(234.5, 261.0)
Estonia	299	41	0.4	137.1	40.4	278.2	(178.1, 434.4)
Lebanon	70	38	0.3	542.9	22.9	211.0	(140.7, 316.2)
Mexico	11,674	2,056	0.2	176.1	5.1	29.7	(28.4, 30.9)
Netherlands	7,532	3,012	0.4	399.9	46.0	387.4	(363.8, 412.4)
Qatar	501	137	0.5	273.5	40.2	256.7	(194.8, 338.2)
Scotland	3,977	1,137	0.4	285.9	37.1	302.7	(277.4, 330.4)
Sweden	5,249	718	0.2	136.8	23.7	221.0	(201.8, 242.1)
Uruguay	1,926	291	0.4	151.1	40.1	377.6	(312.2, 456.6)
USA	479,983	132,963	0.6	277.0	46.5	279.5	(276.8, 282.1)

Country	**28 to 31 weeks (very preterm)**						
	Livebirths (n)	**Deaths (n)**	**Prevalence (%)**	**Rate per 1000**	**PAR (%)**	**Relative risk (n)**	**95%CI (n)**
Australia	8,190	179	0.7	21.9	9.1	55.0	(46.3, 65.4)
Brazil	227,340	26,450	1.1	116.3	17.6	42.8	(42.2, 43.5)
Canada	31,288	691	0.7	22.1	9.9	68.0	(62.0, 74.6)
Czech Republic	722	17	0.7	23.5	10.6	49.8	(28.8, 86.4)
Denmark	7,933	279	0.7	35.2	11.8	50.1	(43.6, 57.4)
England and Wales	23,518	783	0.7	33.3	11.3	47.1	(43.4, 51.1)
Estonia	465	6	0.6	12.9	6.4	29.4	(12.4, 69.8)
Lebanon	183	22	0.7	120.2	18.1	64.3	(38.9, 106.5)
Mexico	26,385	1,743	0.5	66.1	4.5	12.3	(11.7, 12.9)

Netherlands	13,017	541	0.7	41.6	10.9	54.1	(49.0, 59.8)
Qatar	950	21	1.0	22.1	7.4	25.9	(15.9, 41.9)
Scotland	9,356	336	0.8	35.9	13.4	47.2	(41.6, 53.6)
Sweden	12,263	377	0.6	30.7	13.5	54.8	(48.8, 61.5)
Uruguay	4,397	105	0.9	23.9	16.1	67.1	(52.5, 85.8)
USA	763,621	24,779	1.0	32.4	10.5	40.5	(39.9, 41.1)

Country	**32 to 33 weeks (moderate preterm)**						
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**Relative risk**	**95%CI**
	(n)	**(n)**	**(%)**	**per 1000**	**(%)**	**(n)**	**(n)**
Australia	11,434	94	0.9	8.2	4.7	21.0	(16.8, 26.2)
Brazil	341,967	11,587	1.6	33.9	7.9	13.5	(13.2, 13.7)
Canada	42,074	350	1.0	8.3	5.0	26.0	(23.1, 29.2)
Czech Republic	1,018	16	0.9	15.7	10.0	33.5	(19.1, 58.9)
Denmark	10,369	114	0.9	11.0	4.7	16.0	(13.2, 19.5)
England and Wales	27,287	372	0.8	13.6	5.3	19.6	(17.6, 21.9)
Estonia	567	8	0.7	14.1	8.6	32.1	(14.9, 69.2)
Lebanon	304	9	1.2	29.6	7.7	17.2	(8.4, 35.3)
Mexico	41,644	1,035	0.7	24.9	2.4	4.8	(4.5, 5.1)
Netherlands	16,496	270	0.9	16.4	5.4	21.8	(19.1, 24.9)
Qatar	1,153	21	1.2	18.2	7.4	21.4	(13.2, 34.7)
Scotland	11,477	145	1.0	12.6	5.7	17.0	(14.2, 20.3)
Sweden	15,862	200	0.8	12.6	7.1	22.9	(19.7, 26.6)
Uruguay	5,510	43	1.1	7.8	6.5	22.3	(15.9, 31.2)
USA	967,381	12,928	1.2	13.4	5.4	17.0	(16.7, 17.3)

Country	**34 to 36 weeks (late preterm)**						
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**Relative risk**	**95%CI**
	(n)	**(n)**	**(%)**	**per 1000**	**(%)**	**(n)**	**(n)**
Australia	73,573	211	6.0	2.9	9.6	7.4	(6.2, 8.7)
Brazil	1,792,906	18,620	8.4	10.4	10.7	4.2	(4.2, 4.3)
Canada	263,820	637	6.0	2.4	8.2	7.6	(6.9, 8.3)
Czech Republic	5,468	13	5.0	2.4	6.8	5.1	(2.8, 9.5)
Denmark	51,751	239	4.7	4.6	9.0	6.8	(5.8, 7.8)
England and Wales	176,704	733	5.5	4.1	9.3	6.0	(5.5, 6.6)
Estonia	3,436	6	4.2	1.7	5.1	4.0	(1.7, 9.6)
Lebanon	2,053	15	7.9	7.3	10.7	4.3	(2.4, 7.9)
Mexico	302,785	2,922	5.4	9.7	4.1	1.9	(1.8, 2.0)
Netherlands	92,464	464	5.0	5.0	8.4	6.8	(6.1, 7.5)
Qatar	6,854	47	7.3	6.9	15.4	8.1	(5.6, 11.8)
Scotland	61,288	260	5.4	4.2	9.0	5.8	(5.0, 6.6)
Sweden	88,263	381	4.2	4.3	12.5	7.9	(7.0, 8.9)
Uruguay	33,341	75	6.8	2.2	10.1	6.5	(4.9, 8.5)
USA	5,831,509	26,407	7.3	4.5	9.8	5.8	(5.7, 5.9)

Country	>42 weeks						
	Livebirths (n)	Deaths (n)	Prevalence (%)	Rate per 1000	PAR (%)	Relative risk (n)	95%CI (n)
Australia	182	Not provided					
Brazil	219,424	814	0.0	3.7	0.0	1.5	(1.4, 1.6)
Canada	382	0	0.0	0.0	0.0	0.0	(0, 0)
Czech Republic	186	0	0.0	0.0	0.0	0.0	(0, 0)
Denmark	1,139	0	0.0	0.0	0.0	0.0	(0, 0)
England and Wales	2,799	1	0.0	0.4	0.0	0.5	(0.1, 3.7)
Estonia	1,569	1	0.0	0.6	0.0	1.5	(0.2, 10.7)
Lebanon	11	0	0.0	0.0	0.0	0.0	(0, 0)
Mexico	509	2	0.0	3.9	0.0	0.8	(0.2, 3.1)
Netherlands	262	0	0.0	0.0	0.0	0.0	(0, 0)
Qatar	86	0	0.0	0.0	0.0	0.0	(0, 0)
Scotland	652	1	0.0	1.5	0.0	2.1	(0.3, 14.8)
Sweden	0	0	0.0	0.0	0.0	0.0	(0, 0)
Uruguay	23	0	0.0	0.0	0.0	0.0	(0, 0)
USA	127,042	220	0.0	1.7	0.0	2.2	2.0, 2.5)

Table S10. Neonatal mortality NMR, population attributable risk, and crude relative risk of neonatal mortality for 6 newborn types (reference T+AGA), by country

Prevalence = the number of livebirths reported in each group of interest / total number of livebirths

Neonatal Mortality NMR (NMR): the number of persons who experienced the event (neonatal death) divided by the total number of persons exposed to the risk of that event per 1000

Population attributable risk (PAR): was calculated for each level of exposure with the following formula where *pr* is the prevalence and *RR* is the relative risk [8]

$$\text{PAR for type } of\ interest = \frac{pr(type\ of\ interest)(RR(type\ of\ interest - 1))}{\sum_{all\ types} pr(type)x\ RR(type)}$$

Relative risk: the absolute risk within a specific category divided by the absolute risk in the reference group, expressed as a ratio

Country	Total		T+AGA			
	Livebirths (n)	Deaths (n)	Livebirths (n)	Deaths (n)	Prevalence (%)	Rate per 1000
Australia	1,216,172	2,096	836,833	288	68.8	0.3
Brazil	21,345,439	148,418	14,678,798	27,030	68.8	1.8

Canada	4,388,387	10,000	2,970,502	748	67.7	0.3
Czech Republic	109,492	168	80,651	32	73.7	0.4
Denmark	1,100,854	2,598	709,716	446	64.5	0.6
England and Wales	3,212,492	7,169	2,251,910	1,342	70.1	0.6
Estonia	82,298	95	52,294	20	63.5	0.4
Lebanon	25,515	114	18,280	25	71.6	1.4
Mexico	5,560,916	34,036	4,342,347	21,801	78.1	5.0
Netherlands	1,846,558	5,483	1,235,592	812	66.9	0.7
Qatar	94,337	297	67,589	42	71.6	0.6
Scotland	1,124,817	2,599	757,774	497	67.4	0.7
Sweden	2,102,671	2,755	1,412,703	668	67.2	0.5
Uruguay	493,040	664	341,543	109	69.3	0.3
USA	80,225,526	252,745	54,381,179	33,640	67.8	0.6

Country	**PT+SGA**							
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**RR**	**95%CI**	
	(n)	**(n)**	**(%)**	**per 1000**	**(%)**	**(n)**	**(n)**	
Australia	7,747	186	0.6	24.0	8.6	68.2	56.8	81.8
Brazil	184,780	23,092	0.9	125.0	14.2	60.4	59.4	61.5
Canada	26,860	766	0.6	28.5	7.5	110.1	99.7	121.7
Czech Republic	730	20	0.7	27.4	11.6	67.2	38.6	117.0
Denmark	5,422	285	0.5	52.6	10.5	79.5	68.7	92.0
England and Wales	27,402	662	0.9	24.2	8.9	39.6	36.1	43.4
Estonia	286	2	0.3	7.0	1.2	6.0	1.5	24.3
Lebanon	271	14	1.1	51.7	11.6	36.0	18.9	68.5
Mexico	37,018	790	0.7	21.3	1.7	4.2	3.9	4.5
Netherlands	10,899	528	0.6	48.4	9.3	70.4	63.2	78.4
Qatar	863	43	0.9	49.8	13.9	76.4	50.2	116.3
Scotland	7,786	273	0.7	35.1	10.1	51.7	44.7	59.8
Sweden	10,807	346	0.5	32.0	12.1	65.6	57.7	74.6
Uruguay	3,566	83	0.7	23.3	12.2	71.3	53.7	94.7
USA	584,823	34,019	0.7	58.2	12.9	88.9	87.6	90.3

Country	**PT+AGA**							
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**RR**	**95%CI**	
	(n)	**(n)**	**(%)**	**per 1000**	**(%)**	**(n)**	**(n)**	
Australia	77,760	1,304	6.4	16.8	60.2	47.9	42.1	54.4
Brazil	1,491,029	66,036	7.0	44.3	42.4	23.1	22.8	23.4
Canada	280,730	7,258	6.4	25.9	71.6	100.1	92.9	107.9
Czech Republic	6,177	93	5.6	15.1	53.7	37.4	25.0	55.8
Denmark	57,053	1,382	5.2	24.2	51.6	37.7	33.9	41.9
England and Wales	191,142	3,987	5.9	20.9	53.7	34.3	32.3	36.5
Estonia	3,774	46	4.6	12.2	30.6	10.4	7.4	14.8
Lebanon	1,825	56	7.2	30.7	46.5	21.8	13.6	34.8
Mexico	319,589	6,586	5.7	20.6	14.4	4.0	3.9	4.2

Netherlands	102,958	3,272	5.6	31.8	58.1	46.9	43.4	50.6
Qatar	7,290	166	7.7	22.8	54.2	35.9	25.6	50.3
Scotland	67,902	1,363	6.0	20.1	50.5	30.0	27.1	33.3
Sweden	97,940	1,155	4.7	11.8	40.2	24.7	22.4	27.1
Uruguay	36,379	381	7.4	10.5	55.6	32.5	26.3	40.2
USA	6,165,319	140,547	7.7	22.8	54.0	36.1	35.6	36.5

Country	PT+LGA							
	Livebirths	Deaths	Prevalence	Rate	PAR (%)	RR	95%CI	
	(n)	(n)	(%)	per 1000	(%)	(n)	(n)	
Australia	12,215	201	1.0	16.5	9.3	47.1	39.3	56.3
Brazil	791,532	13,194	3.7	16.7	8.1	8.9	8.7	9.1
Canada	49,522	695	1.1	14.0	6.9	55.0	49.6	60.9
Czech Republic	620	8	0.6	12.9	4.6	32.1	14.9	69.4
Denmark	11,100	231	1.0	20.8	8.6	32.5	27.7	38.0
England and Wales	24,895	487	0.8	19.6	6.6	32.2	29.1	35.7
Estonia	691	13	0.8	18.8	8.9	16.0	9.0	28.5
Lebanon	449	10	1.8	22.3	8.2	16.0	7.7	33.0
Mexico	25,881	380	0.5	14.7	0.7	2.9	2.6	3.2
Netherlands	15,425	425	0.8	27.6	7.5	40.8	36.3	45.9
Qatar	1,305	17	1.4	13.0	5.5	20.7	11.8	36.3
Scotland	10,086	210	0.9	20.8	7.8	31.1	26.5	36.5
Sweden	12,890	175	0.6	13.6	6.1	28.3	24.0	33.4
Uruguay	5,109	46	1.0	9.0	6.7	28.0	19.8	39.4
USA	1,289,830	22,074	1.6	17.1	8.5	27.2	26.8	27.7

Country	T+SGA							
	Livebirths	Deaths	Prevalence	Rate	PAR	RR	95%CI	
	(n)	(n)	(%)	per 1000	(%)	(n)	(n)	
Australia	34,081	53	2.8	1.6	2.8	6.0	4.6	7.7
Brazil	1,524,445	14,494	7.1	9.5	8.1	5.1	5.0	5.2
Canada	142,368	341	3.2	2.4	3.1	9.5	8.4	10.8
Czech Republic	5,583	12	5.1	2.1	5.9	5.4	2.8	10.5
Denmark	32,092	113	2.9	3.5	3.6	5.6	4.5	6.9
England and Wales	133,988	426	4.2	3.2	4.9	5.3	4.8	5.9
Estonia	1,524	8	1.9	5.2	4.6	4.5	2.2	9.3
Lebanon	1,585	6	6.2	3.8	3.4	2.8	1.1	6.7
Mexico	371,565	2,194	6.7	5.9	1.0	1.2	1.1	1.2
Netherlands	56,877	237	3.1	4.2	3.7	6.3	5.5	7.3
Qatar	5,349	23	5.7	4.3	6.7	6.9	4.1	11.5
Scotland	50,411	144	4.5	2.9	4.3	4.3	3.6	5.2
Sweden	69,761	208	3.3	3.0	6.4	6.3	5.4	7.3
Uruguay	18,853	24	3.8	1.3	2.7	4.0	2.6	6.2
USA	3,258,384	15,695	4.1	4.8	5.5	7.8	7.6	7.9

Country	T+LGA							
	Livebirths	Deaths	Prevalence	Rate	PAR	RR	95%CI	
	(n)	(n)	(%)	per 1000	(%)	(n)	(n)	
Australia	247,536	64	20.4	0.3	-1.0	0.8	0.6	1.0
Brazil	2,674,855	4,572	12.5	1.7	-0.2	0.9	0.9	1.0
Canada	918,405	192	20.9	0.2	-0.4	0.8	0.7	1.0
Czech Republic	15,731	3	14.4	0.2	-2.0	0.5	0.1	1.6
Denmark	285,471	141	25.9	0.5	-1.5	0.8	0.7	0.9
England and Wales	583,155	265	18.2	0.5	-1.2	0.8	0.7	0.9
Estonia	23,729	6	28.8	0.3	-15.9	0.2	0.1	0.5
Lebanon	3,105	3	12.2	1.0	-1.1	0.7	0.2	2.3
Mexico	464,516	2,285	8.4	4.9	-0.1	1.0	0.9	1.0
Netherlands	424,807	209	23.0	0.5	-1.3	0.7	0.6	0.9
Qatar	11,941	6	12.7	0.5	-0.5	0.8	0.3	1.9
Scotland	230,858	112	20.5	0.5	-1.5	0.7	0.6	0.9
Sweden	498,570	203	23.7	0.4	-1.2	0.9	0.7	1.0
Uruguay	87,590	21	17.8	0.2	-1.1	0.8	0.5	1.2
USA	14,545,991	6,770	18.1	0.5	-0.9	0.8	0.7	0.8

Table S11. Neonatal mortality NMR, population attributable risk, and crude relative risk of neonatal mortality for 10 newborn types (reference T+AGA+nonLBW), by country

Prevalence = the number of livebirths reported in each group of interest / total number of livebirths

Neonatal Mortality NMR (NMR): the number of persons who experienced the event (neonatal death) divided by the total number of persons exposed to the risk of that event per 1000

Population attributable risk (PAR): was calculated for each level of exposure with the following formula where *pr* is the prevalence and *RR* is the relative risk [8]

$$\text{PAR for type } of\ interest = \frac{pr(type\ of\ interest)\big(RR(type\ of\ interest - 1)\big)}{\sum_{all\ types} pr(type) x\ RR(type)}$$

Relative risk: the absolute risk within a specific category divided by the absolute risk in the reference group, expressed as a ratio

Country	Total		T+AGA+nonLBW			
	Livebirths	Deaths	Livebirths	Deaths	Prevalence	Rate
	(n)	(n)	(n)	(n)	(n)	per 1000
Australia	1,216,172	2,096	829,536	280	68.2	0.3
Brazil	21,345,439	148,418	14,582,011	26,458	68.3	1.8
Canada	4,388,387	10,000	2,951,138	696	67.2	0.2
Czech Republic	109,492	168	80,129	32	73.2	0.4

Denmark	1,100,854	2,598	706,526	434	64.2	0.6
England and Wales	3,212,492	7,169	2,230,635	1,301	69.4	0.6
Estonia	82,298	95	52,059	20	63.3	0.4
Lebanon	25,515	114	18,158	25	71.2	1.4
Mexico	5,560,916	34,036	4,306,929	21,561	77.4	5.0
Netherlands	1,846,558	5,483	1,227,273	799	66.5	0.7
Qatar	94,337	297	66,955	37	71.0	0.6
Scotland	1,124,817	2,599	753,001	490	66.9	0.7
Sweden	2,102,671	2,755	1,410,281	663	67.1	0.5
Uruguay	493,040	664	338,993	107	68.8	0.3
USA	80,225,526	252,745	53,971,259	32,604	67.3	0.6

Country	PT+SGA+LBW							
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI	
	(n)	(n)	(n)	per 1000	(%)	(n)	(n)	
Australia	7,747	186	0.6	24.0	8.7	69.5	57.8	83.5
Brazil	184,780	23,092	0.9	125.0	14.4	61.3	60.3	62.4
Canada	26,860	766	0.6	28.5	7.7	117.6	106.2	130.2
Czech Republic	730	20	0.7	27.4	11.6	66.8	38.4	116.3
Denmark	5,422	285	0.5	52.6	10.6	81.3	70.2	94.2
England and Wales	27,402	662	0.9	24.2	8.9	38.4	34.1	43.3
Estonia	286	2	0.3	7.0	2.1	18.1	4.2	77.0
Lebanon	271	14	1.1	51.7	11.8	35.7	18.8	68.0
Mexico	37,018	790	0.7	21.3	1.7	4.2	3.9	4.5
Netherlands	10,899	528	0.6	48.4	9.4	71.0	63.7	79.1
Qatar	863	43	0.9	49.8	14.0	85.9	55.6	132.7
Scotland	7,786	273	0.7	35.1	10.2	52.1	45.0	60.3
Sweden	10,807	346	0.5	32.0	12.2	66.0	58.1	75.1
Uruguay	3,566	83	0.7	23.3	12.2	72.1	54.2	95.8
USA	584,823	34,019	0.7	58.2	13.0	91.1	89.7	92.4

Country	PT+LGA+LBW						
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI
	(n)	(n)	(n)	per 1000	(%)	(n)	(n)
Australia	2,094	147	0.2	70.2	6.6	194.4	(160, 236.3)
Brazil	71,302	8,992	0.3	126.1	5.6	61.8	(60.4, 63.2)
Canada	8,958	526	0.2	58.7	5.1	235.2	(210.4, 262.9)
Czech Republic	143	6	0.1	42.0	3.5	100.9	(42.8, 237.7)
Denmark	2,063	157	0.2	76.1	5.7	115.2	(96.4, 137.6)
England and Wales	4,570	344	0.1	75.3	4.5	114.0	(99.2, 130.1)
Estonia	160	11	0.2	68.8	11.2	167.5	(81.5, 344.2)
Lebanon	35	6	0.1	171.4	4.6	106.4	(46.1, 245.7)
Mexico	2,911	197	0.1	67.7	0.5	12.7	(11.1, 14.5)
Netherlands	3,297	316	0.2	95.8	5.4	134.4	(118.5, 152.5)
Qatar	268	13	0.3	48.5	4.2	83.8	(45.0, 155.8)
Scotland	2,159	157	0.2	72.7	5.7	104.2	(87.5, 124.1)
Sweden	1,426	104	0.1	72.9	3.5	144.7	(118.4, 176.7)

Uruguay	991	35	0.2	35.3	5.1	108.1	(74.2, 157.5)
USA	217,635	16,133	0.3	74.1	6.1	114.3	(112.2, 116.4)

Country	PT+AGA+LBW							
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI	
	(n)	(n)	(n)	per 1000	(%)	(n)	(n)	
Australia	45,695	1,273	3.8	27.9	59.3	80.3	70.6	91.4
Brazil	812,417	61,983	3.8	76.3	40.0	39.1	38.6	39.7
Canada	162,693	7,108	3.7	43.7	70.2	177.5	164.3	191.9
Czech Republic	3,883	88	3.5	22.7	51.2	55.5	37.1	83.1
Denmark	33,773	1,315	3.1	38.9	49.4	61.0	54.8	68.0
England and Wales	120,084	3,796	3.7	31.6	50.9	49.9	45.2	55.1
Estonia	2,113	45	2.6	21.3	47.5	54.3	32.1	91.8
Lebanon	972	51	3.8	52.5	42.9	36.3	22.6	58.3
Mexico	199,076	5,559	3.6	27.9	13.1	5.5	5.3	5.6
Netherlands	60,803	3,125	3.3	51.4	55.6	75.1	69.5	81.2
Qatar	4,537	156	4.8	34.4	51.3	60.2	42.1	86.0
Scotland	42,253	1,301	3.8	30.8	48.6	45.9	41.4	50.9
Sweden	50,779	1,030	2.4	20.3	36.3	42.3	38.4	46.6
Uruguay	21,498	365	4.4	17.0	53.8	52.9	42.7	65.6
USA	3,662,791	134,560	4.6	36.7	52.1	58.7	58.0	59.4

Country	PT+AGA+nonLBW							
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI	
	(n)	(n)	(n)	per 1000	(%)	(n)	(n)	
Australia	32,065	31	2.6	1.0	0.9	2.7	1.8	3.9
Brazil	678,612	4,053	3.2	6.0	2.0	3.3	3.2	3.4
Canada	118,037	150	2.7	1.3	1.3	5.4	4.5	6.4
Czech Republic	2,294	5	2.1	2.2	2.5	5.4	2.1	14.0
Denmark	23,280	67	2.1	2.9	2.1	4.7	3.6	6.0
England and Wales	71,058	191	2.2	2.7	2.1	4.4	3.7	5.2
Estonia	1,661	1	2.0	0.6	0.4	1.6	0.2	11.7
Lebanon	853	5	3.3	5.9	3.5	4.2	1.6	11.0
Mexico	120,513	1,027	2.2	8.5	1.2	1.7	1.6	1.8
Netherlands	42,155	147	2.3	3.5	2.3	5.3	4.5	6.4
Qatar	2,753	10	2.9	3.6	2.9	6.6	3.3	13.2
Scotland	25,649	62	2.3	2.4	1.8	3.7	2.8	4.8
Sweden	47,161	125	2.2	2.7	3.8	5.6	4.6	6.8
Uruguay	14,881	16	3.0	1.1	1.7	3.4	2.0	5.8
USA	2,502,528	5,987	3.1	2.4	1.8	4.0	3.8	4.1

Country	PT+LGA+nonLBW							
	Livebirths	Deaths	Prevalence	Rate	PAR	Relative risk	95%CI	
	(n)	(n)	(n)	per 1000	(%)	(n)	(n)	
Australia	10,121	54	0.8	5.3	2.4	15.7	11.8	21.0
Brazil	720,230	4,202	3.4	5.8	2.0	3.2	3.1	3.3
Canada	40,564	169	0.9	4.2	1.6	17.6	14.9	20.8

Czech Republic	477	2	0.4	4.2	1.1	10.5	2.5	43.5
Denmark	9,037	74	0.8	8.2	2.7	13.2	10.3	16.9
England and Wales	20,325	143	0.6	7.0	1.8	11.4	9.4	13.7
Estonia	531	2	0.6	3.8	2.0	9.8	2.3	41.7
Lebanon	414	4	1.6	9.7	3.1	7.0	2.4	19.9
Mexico	22,970	183	0.4	8.0	0.2	1.6	1.4	1.8
Netherlands	12,128	109	0.7	9.0	1.9	13.7	11.2	16.7
Qatar	1,037	4	1.1	3.9	1.2	7.0	2.5	19.5
Scotland	7,927	53	0.7	6.7	1.9	10.2	7.7	13.5
Sweden	11,464	71	0.5	6.2	2.4	13.1	10.3	16.7
Uruguay	4,118	11	0.8	2.7	1.5	8.4	4.5	15.7
USA	1,072,195	5,941	1.3	5.5	2.1	9.1	8.9	9.4

Country	**T+SGA+LBW**							
	Livebirths (n)	**Deaths (n)**	**Prevalence (n)**	**Rate per 1000**	**PAR (%)**	**Relative risk (n)**	**95%CI (n)**	
Australia	17,277	34	1.4	2.0	2.2	8.7	6.5	11.8
Brazil	631,594	10,417	3.0	16.5	6.5	9.0	8.8	9.2
Canada	63,689	268	1.5	4.2	2.6	17.8	15.4	20.5
Czech Republic	2,428	12	2.2	4.9	6.6	12.3	6.4	23.9
Denmark	13,010	72	1.2	5.5	2.5	9.0	7.0	11.5
England and Wales	61,790	311	1.9	5.0	3.8	8.2	7.1	9.4
Estonia	641	7	0.8	10.9	7.3	28.1	11.9	66.3
Lebanon	762	4	3.0	5.2	2.7	3.8	1.3	10.9
Mexico	95,493	670	1.7	7.0	0.6	1.4	1.3	1.5
Netherlands	26,685	166	1.4	6.2	2.8	9.5	8.0	11.2
Qatar	2,402	22	2.5	9.2	7.1	16.4	9.7	27.8
Scotland	21,136	98	1.9	4.6	3.3	7.1	5.7	8.8
Sweden	21,455	131	1.0	6.1	4.4	12.9	10.7	15.6
Uruguay	9,596	18	1.9	1.9	2.3	5.9	3.6	9.8
USA	1,536,139	12,588	1.9	8.2	4.7	13.5	13.2	13.7

Country	**T+SGA+nonLBW**							
	Livebirths (n)	**Deaths (n)**	**Prevalence (n)**	**Rate per 1000**	**PAR (%)**	**Relative risk (n)**	**95%CI (n)**	
Australia	16,804	19	1.4	1.1	0.6	3.3	2.1	5.3
Brazil	892,851	4,077	4.2	4.6	1.7	2.5	2.4	2.6
Canada	78,679	73	1.8	0.9	0.6	3.9	3.1	5.0
Czech Republic	3,155	0	2.9	0.0	-0.8	0.0	0.0	0.0
Denmark	19,082	41	1.7	2.1	1.2	3.5	2.5	4.8
England and Wales	72,198	115	2.2	1.6	1.0	2.6	2.1	3.2
Estonia	883	1	1.1	1.1	0.7	2.9	0.4	21.9
Lebanon	823	2	3.2	2.4	0.8	1.8	0.4	7.4
Mexico	276,072	1,524	5.0	5.5	0.4	1.1	1.0	1.2
Netherlands	30,192	71	1.6	2.4	1.0	3.6	2.8	4.6
Qatar	2,947	1	3.1	0.3	-0.2	0.6	0.1	4.5
Scotland	29,275	46	2.6	1.6	1.1	2.4	1.8	3.3

Sweden	48,306	77	2.3	1.6	2.0	3.4	2.7	4.3
Uruguay	9,257	6	1.9	0.6	0.5	2.1	0.9	4.7
USA	1,722,245	3,107	2.1	1.8	0.8	3.0	2.9	3.1

Country	**T+AGA+LBW**							
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR**	**Relative risk**	**95%CI**	
	(n)	**(n)**	**(n)**	**per 1000**	**(%)**	**(n)**	**(n)**	
Australia	7,297	8	0.6	1.1	0.3	3.2	1.6	6.6
Brazil	96,787	572	0.5	5.9	0.3	3.2	3.0	3.5
Canada	19,364	52	0.4	2.7	0.5	11.4	8.6	15.1
Czech Republic	522	0	0.5	0.0	-0.1	0.0	0.0	0.0
Denmark	3,190	12	0.3	3.8	0.4	6.1	3.4	10.8
England and Wales	21,275	41	0.7	1.9	0.4	3.1	2.3	4.3
Estonia	235	0	0.3	0.0	-0.1	0.0	0.0	0.0
Lebanon	122	0	0.5	0.0	-0.2	0.0	0.0	0.0
Mexico	35,418	240	0.6	6.8	0.2	1.4	1.2	1.5
Netherlands	8,319	13	0.5	1.6	0.1	2.4	1.4	4.1
Qatar	634	5	0.7	7.9	1.6	14.2	5.6	35.9
Scotland	4,773	7	0.4	1.5	0.2	2.3	1.1	4.7
Sweden	2,422	5	0.1	2.1	0.1	4.4	1.8	10.6
Uruguay	2,550	2	0.5	0.8	0.2	2.5	0.6	10.1
USA	409,920	1,036	0.5	2.5	0.3	4.2	3.9	4.4

Country	**T+LGA+nonLBW**							
	Livebirths	**Deaths**	**Prevalence**	**Rate**	**PAR (%)**	**Relative risk**	**95%CI**	
	(n)	**(n)**	**(n)**	**per 1000**	**(%)**	**(n)**	**(n)**	
Australia	247,536	64	20.4	0.3	-0.9	0.8	0.6	1.0
Brazil	2,674,855	4,572	12.5	1.7	-0.2	0.9	0.9	1.0
Canada	918,405	192	20.9	0.2	-0.3	0.9	0.8	1.0
Czech Republic	15,731	3	14.4	0.2	-2.0	0.5	0.1	1.6
Denmark	285,471	141	25.9	0.5	-1.4	0.8	0.7	1.0
England and Wales	583,155	265	18.2	0.5	-1.3	0.7	0.6	0.9
Estonia	23,729	6	18.2	0.3	-2.2	0.7	0.3	1.6
Lebanon	3,105	3	12.2	1.0	-1.2	0.7	0.2	2.3
Mexico	464,516	2,285	8.4	4.9	-0.1	1.0	0.9	1.0
Netherlands	424,807	209	23.0	0.5	-1.3	0.8	0.6	0.9
Qatar	11,941	6	12.7	0.5	-0.2	0.9	0.4	2.2
Scotland	230,858	112	20.5	0.5	-1.5	0.7	0.6	0.9
Sweden	498,570	203	23.7	0.4	-1.2	0.9	0.7	1.0
Uruguay	87,590	21	17.8	0.2	-1.0	0.8	0.5	1.2
USA	14,545,991	6,770	18.1	0.5	-0.8	0.8	0.8	0.8

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Title: Neonatal mortality risk for vulnerable newborn types in 15 countries using 125.5 million nationwide birth outcome records, 2000 to 2020

Editor´s comments

1. Overall comments: Excellent paper, very large dataset with appropriate analysis. Congratulations to the authors

Response: Thank you so much for your very kind comments, they are highly appreciated

2. Mortality was highest among newborns <28 weeks (median RR: 279.5, IQR, 234.2, 388.5) or with a birthweight <1000g (median RR: 282.8, IQR 194.7, 342.8).

Response: Thank you for the suggestion. We have edited to “Mortality risk” as suggested.

“Mortality risk was highest among newborns <28 weeks (median RR: 279.5, IQR, 234.2, 388.5) **compared to babies born between 37 to 42 completed weeks as a reference group** ***or with a birthweight <1000g (median RR: 282.8, IQR 194.7, 342.8)*** **compared to those between 2500 g and 4000 g** ***as a reference group”.***

3. LBW is due to either being born preterm or small for gestational age (SGA) i.e., <10^{th} centile of birthweight for gestational age and sex [1].

Response: Thank you for the suggestion. We agree and have edited as suggested.

“LBW is due to either being born preterm or small for gestational age (SGA) i.e., <10^{th} centile of birthweight for gestational age and sex or both”.

4. This paper aims to quantify the neonatal mortality risk and population attributable risks (PAR%) associated with three groupings of analysis: (1) birthweight categories, (2) gestational age categories, and (3) newborn types with six categories combining gestational age (PT vs T) and size-for-gestational age (SGA, AGA, LGA) in the same individual.

Response: Thank you for the suggestion. We have modified the paragraph accordingly as below.

"This paper aims to fulfil three objectives, namely to quantify the neonatal mortality risk and population attributable risks (PAR%) associated with the following groupings: (1) birthweight categories, (2) gestational age categories, and (3) newborn types with six categories combining gestational age (PT vs T) and size-for-gestational age (SGA, AGA, LGA) in the same individual".

5. We created a mutually exclusive set of six newborn types: one reference group T+AGA; four small groups (PT+SGA, PT+AGA, PT+LGA, T+SGA); and one large (T+LGA) group.

Response: Thank you for the suggestion. We have replaced "groups" with "babies" for clarity as below

" We created a mutually exclusive set of six newborn types: one reference group T+AGA; four with small babies (PT+SGA, PT+AGA, PT+LGA, T+SGA); and one with large babies (T+LGA)".

"Also, *we performed a sensitivity analysis combining gestational age (PT vs T), size (SGA, AGA, LGA) and adding birthweight (low birthweight <2500 g (LBW) or non-low birthweight*

≥2500 g (nonLBW)) to assess a secondary set of ten newborn types including one reference group T+AGA+nonLBW; eight including small babies (T+AGA+LBW, T+SGA+nonLBW, T+SGA+LBW, PT+LGA+nonLBW, PT+LGA+LBW, PT+AGA+nonLBW, PT+AGA+LBW, PT+SGA+LBW) and one with large babies (T+LGA+nonLBW)".

6. One comment was on the figures (OPTIONAL): Could it be useful to describe the different types PTSGA, PTAGA, PTLGA, TSGA, TAGA, TLGA in a simple figure (hannah you have one in your slides)?

Response: Given that we have this figure in the main text of the prevalence paper, we have added the figure with overview of vulnerable newborns to supplementary material in this paper (Figure S3)

7. We wondered whether it could be nice to have a 3D figure with a three axis histogram with GA and BW categories on the X and Z axes; and PAR on the Y axis, to show the relationship between prematurity and BW in relation to risk in a more graphical format. I am happy to allow 1-2 more figures to appear in the paper in relation to this, and of course you would need to renumber the figures.

Response: Thank you for this important suggestion. We agree that a 3D figure of BW by GA and PAR would be a great visual, however, we do not have data of BW disaggregated by GA and therefore we are unable to create such a figure.

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