

Inequalities in neonatal unit mortality in England and Wales between 2012 and 2022: a retrospective cohort study



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Summary

Background Babies born to mothers living in more deprived areas and from ethnic minority groups are at a higher risk of dying during the neonatal period. Preterm and unwell term babies are cared for in neonatal units, and this population contributes substantially to the child mortality rate. The extent of and reasons for socioeconomic and ethnic inequalities in neonatal unit outcomes are unclear. We aimed to evaluate socioeconomic and ethnic inequalities in characteristics and mortality of babies admitted to National Health Service (NHS) neonatal units in England and Wales.

Methods In this retrospective cohort study, any baby that was born at or after 22 weeks' gestation and admitted to an NHS neonatal unit in England and Wales, received neonatal care, and had clinical data registered in the National Neonatal Research Database was eligible for inclusion. Our primary exposures of interest were index of multiple deprivation (IMD) and maternal ethnicity. We assessed inequalities in in-unit mortality before discharge using nested logistic regression models, estimating crude, confounder-adjusted, and case-mix adjusted odds of mortality. Case-mix variables on admission were gestational age, birthweight, sex, maternal age, smoking during pregnancy, the presence of any congenital anomaly, obstetric problem, and previous medical problem in the mother.

Findings Between Jan 1, 2012, and Dec 31, 2022, 709 569 babies were included in the analysis and there were 11 257 (1·6%) neonatal unit deaths. Of the 678 550 babies with complete IMD information, 649 180 (95·7%) babies were born to mothers living in England and 29 308 (4·3%) to mothers living in Wales. 561 621 (79·1%) babies had complete information on exposures and case-mix variables on admission used for logistic regression. More babies in neonatal units were born to women from the most deprived decile (102 419 [15·1%]) compared with the least deprived decile (43 882 [6·5%]). Babies born to women from the most deprived decile were at increased risk of mortality (odds ratio [OR] 1·63 [95% CI 1·48–1·81]) than babies born to women from the least deprived decile. After adjusting for ethnicity, the OR was 1·52 (1·38–1·69), and after adjusting for case-mix, the OR was 1·23 (1·10–1·37). Babies born to mothers who were Black had an OR for mortality of 1·81 (1·67–1·95) compared with mothers who were White, attenuated to 1·68 (1·55–1·81) after adjusting for deprivation, and 1·14 (1·05–1·24) in the case-mix adjusted model. Babies born to mothers who were Asian had an OR for mortality of 1·48 (1·39–1·57) compared with mothers who were White, attenuated to 1·40 (1·32–1·49) after adjusting for deprivation, and 1·36 (1·27–1·45) in the case-mix adjusted model.

Interpretation There are stark socioeconomic and ethnic inequalities in babies admitted to and who die in neonatal units in England and Wales. Mortality inequalities are partly explained by case-mix on entry to the neonatal unit, suggesting in-unit factors such as care practices explaining residual inequalities. Further work to investigate the role of care practices is required, as well as policies and practices to address upstream drivers of these inequalities.

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Introduction

In the past decade, improvements in rates of infant mortality (considered as deaths in the first year of life) in England have stalled and inequalities have increased.¹ The increase in infant mortality in England since 2014 might be due to increasing neonatal mortality (deaths in the first 28 days) in preterm infants.² Babies admitted to neonatal units due to early preterm birth, severe illness, or major congenital anomalies are at the highest risk of mortality, and contribute substantially to the neonatal, infant, and under-5 mortality.^{2,3}

Stark inequalities in neonatal mortality persist in the UK (England, Wales, Scotland, and Northern Ireland), but these are poorly understood.^{4,5} A 2025 perinatal mortality surveillance report highlighted a two-times higher rate of neonatal mortality in the most deprived areas compared with the least deprived areas in the UK (2·50 vs 1·03 per 1000 livebirths).⁶ This finding is also corroborated by the Office for National Statistics (ONS), which highlights wide inequalities in neonatal mortality.⁷ Babies who were Black or Asian had much higher rates of mortality in 2023 compared with babies who were

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Research in context**Evidence before this study**

We systematically searched PubMed for articles published between Jan 1, 2000, and June 30, 2025, without language restrictions, for studies that assessed the associations between maternal socioeconomic status (using individual and area-linked individual measures) or maternal ethnicity and neonatal mortality in the neonatal unit (full search terms can be found in the appendix [p 32]). Our search yielded seven relevant studies. These studies predominantly included preterm populations, were conducted in populations outside of the UK, only looked at inequality through one lens, or did not adjust for key case-mix variables. No studies in our search explored both socioeconomic and ethnic inequalities in mortality across all gestational ages in the neonatal unit.

Added value of this study

We used rich individual-level data on babies admitted to neonatal units in England and Wales from the National Neonatal Research Database to assess socioeconomic and ethnic inequalities in the characteristics of babies who were admitted to and who died in neonatal units between 2012 and 2022. To our knowledge, this is the first study to assess both socioeconomic and ethnic inequalities in mortality in

this high-risk population across all gestational ages, adjusting for multiple case-mix variables on admission. Our research shows that there were persistent inequalities between babies born to mothers living in the most deprived decile compared to the least deprived deciles during the study period. Babies born to women of Black ethnicity had the highest rates of mortality every year, with higher odds of mortality in babies born to women who were Black or Asian compared with women who were White. Even after adjustment for confounders and case-mix variables, residual socioeconomic and ethnic inequalities persist, indicating that there are other factors contributing to the stark inequalities observed.

Implications of all the available evidence

Our findings suggest that case-mix variables on admission only partly explain the inequalities observed and that other factors may be contributing to the residual inequalities, such as care practices. Targeted and culturally sensitive interventions are needed to target such factors for women at higher risk of adverse neonatal outcomes. Policies are also required that focus upstream of these modifiable risk factors, as well as integrated strategies to develop the maternity and neonatal workforce to provide equitable care.

White, and differences between ethnic groups increase with social deprivation, indicating an intersection between ethnicity and socioeconomic status.⁸

Despite research indicating that there are both socioeconomic and ethnic inequalities in neonatal mortality, key research gaps exist. Previous studies have not quantified socioeconomic and ethnic inequalities in mortality among babies cared for on neonatal units across gestational ages for several reasons. First, most databases and reports only capture deaths within the first 28 days of life, but for babies receiving neonatal intensive care, the length of stay can last more than 100 days.⁷ Second, the underlying reasons for any inequalities in neonatal mortality remain unclear; case-mix variables, defined as a set of patient characteristics that could affect an outcome and explain reasons for differences among populations,⁸ are important to consider in neonatal mortality. However, previous reports have shown crude rates of mortality and effect measures, often without describing the effect of case-mix variables on admission. It is important to understand how inequalities in mortality within a neonatal unit could change after key risk factors at admission are considered to understand times and targets for intervention.

National, individual-level data can provide a rich source from which to assess time trends as well as the role of case-mix and care-based variables on inequalities in adverse neonatal outcomes. The National Neonatal Research Database (NNRD) is a national database that

holds data on the care of all admissions to NHS neonatal units in England, Wales, Scotland, and the Isle of Man, with a high level of completeness and data quality.⁹ Therefore, using data from the NNRD, the primary objectives of this study were to describe the sociodemographic characteristics of babies admitted to NHS neonatal units in England and Wales and to evaluate trends in socioeconomic and ethnic inequalities in mortality before discharge, assessing how case-mix factors on admission can influence mortality inequalities. The secondary objective of this study was to describe socioeconomic and ethnic inequalities in death using a multi-state competing risks model.

Methods**Study design and participants**

This study was a retrospective cohort study using the NNRD. NNRD data are held by the Neonatal Data Analysis Unit (NDAU) team at Imperial College London (London, UK). Data managers at the NDAU are responsible for data cleaning and providing data cuts once approvals are provided.¹⁰

Inclusion criteria were any baby born at 22 weeks' gestation or more and admitted to an NHS neonatal unit to receive care in England and Wales. Exclusion criteria were babies born at less than 22 weeks, those whose first admission was at more than 7 days old (who were specifically coded as being admitted from home or unknown location), or those that did not

For more on the NNRD see
<https://www.imperial.ac.uk/neonatal-data-analysis-unit/neonatal-data-analysis-unit/contributing-to-the-nnrd/>

receive any neonatal care (eg, only received transitional care).

We extracted data on all babies admitted to participating NHS neonatal units in England and Wales. All NHS neonatal units in England and Wales contributed to this data cut. Data comprised individual-level pseudonymised data from electronic health record systems of each admission to a contributing neonatal unit. Ethical approval was provided by London–Camden & Kings Cross Research Ethics Committee (23/LO/0069).

Almost all babies who are born alive at 24–34 weeks' gestation will be admitted to a neonatal unit and therefore in the NNRD. Only unwell term babies are admitted to a neonatal unit, therefore babies within the NNRD are not representative of the whole neonatal population. Babies born at less than 24 weeks' gestation might not be admitted, depending on clinical judgment and changing national guidelines.

Procedures

The primary outcome of interest, in-unit mortality, was defined as death before final discharge from a neonatal unit. Discharge outcome at last admission per baby was used to define death before discharge (appendix p 8). The outcome was defined as a binary variable. For any scenarios in which a code of death occurred outside of the last episode for a baby, a senior neonatologist was consulted, and care pathways were reviewed on an individual basis. Where the care pathway was plausible, the status at the last episode was used as the final outcome (appendix p 9).

Area-level measure of socioeconomic status of the mother was derived from country-specific (England, Wales, Scotland) Index of Multiple Deprivation (IMD) deciles and scores linked to lower layer super output areas provided at source in the dataset. Layer super output areas were derived from the mother's postcode and are small geographical areas, developed from Census data, each approximately covering 400–1200 households.¹¹ IMD is a relative measure of deprivation across layer super output areas based on income, employment, health, education, crime, housing, and living environment (quality of the indoor and outdoor local environment).¹²

Baby's ethnicity was assumed from the mother's ethnicity and grouped into ethnic group categories defined by the NDAU and used in previous research using the NNRD, which are also used as default by the ONS. Categories were White, Asian or Asian British, Black or Black British, Mixed, other ethnic groups, and unknown or not stated.

In this study, case-mix variables on admission were key risk factors for neonatal mortality that can be clustered due to deprivation and ethnicity and are therefore unequally distributed. These were gestational age, birthweight, sex, maternal age, smoking during pregnancy, presence of any congenital anomaly, obstetric

problem, and previous medical problem in the mother (appendix pp 3–9).

Complete cases were used based on data being available on all of the following details: IMD deciles, mother's ethnicity, gestational age at birth, birthweight, sex, maternal age, smoking during pregnancy, presence of any congenital anomaly, obstetric problem, previous medical problem in mother, and outcome at final discharge. A direct acyclic graph was developed to visually represent how deprivation, ethnicity, and case-mix variables on admission influence one another and ultimately the outcome of neonatal mortality (appendix p 3).

Statistical analysis

The analysis progressed in two stages for the primary objective. First, we explored the characteristics of all eligible babies and their mothers who were admitted to neonatal units in England and Wales. To understand if any observed social gradient in the NNRD population followed similar patterns to the general population, we

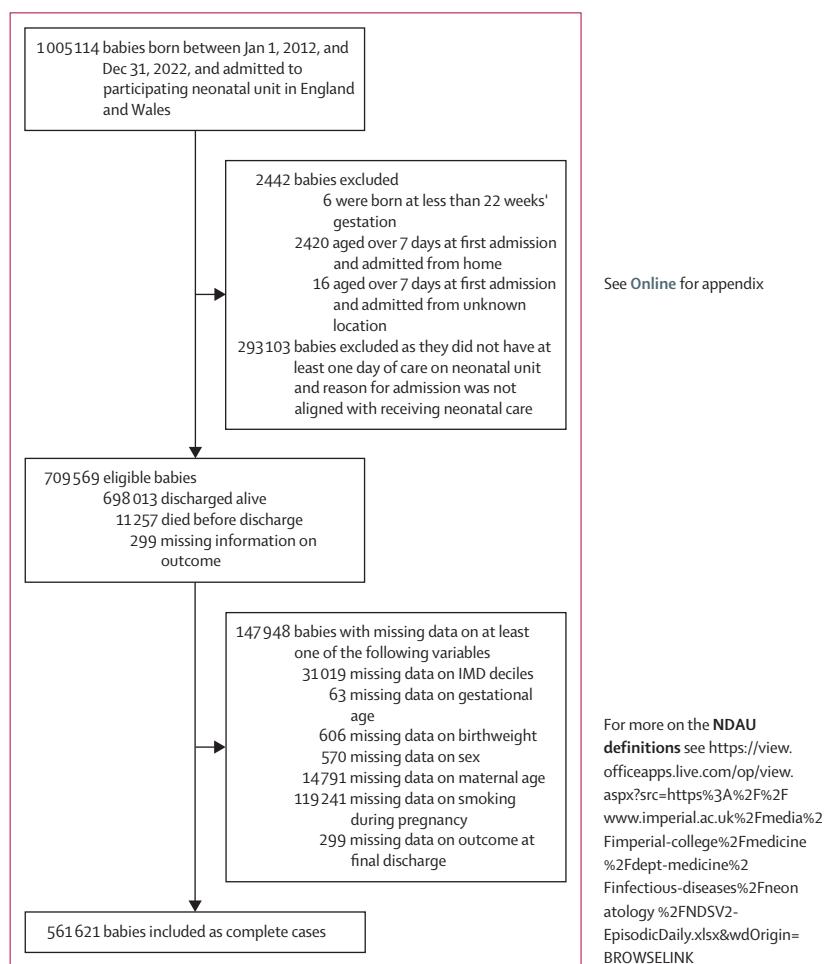


Figure 1: Study cohort profile
IMD=index of multiple deprivation.

plotted the distribution of IMD deciles in the number of livebirths in England and Wales, using published ONS data. We plotted mortality per 1000 babies by birth year overall and by IMD decile and maternal ethnic group. We tested for a change in trend using segmented logistic regression. We also plotted the difference in mortality per 1000 babies between IMD 1 and IMD 10 between 2012 and 2022 with 95% CIs. Finally, we assessed the proportion of babies that died within each ethnic group and IMD decile, to observe socioeconomic inequalities across different ethnic groups.

Second, logistic regression was used to quantify the inequalities in mortality using nested regression models

in completed cases only. Three models were developed for each exposure of interest, socioeconomic status, and ethnicity and each model was built over the previous model. The first was a crude model, the second adjusted for confounders (where socioeconomic status was exposure, ethnicity was a confounder, and where ethnicity was exposure, socioeconomic status was a confounder), and the third adjusted for case-mix variables on admission (including confounder from model two), providing odds ratios using complete cases. As both IMD and ethnicity were derived from the mother, we tested for interactions between the two variables to assess if this interaction should be included in the regression.

For the secondary objective, we assessed time to death or discharge using a competing risks model in completed cases only. Time in unit was assessed from the time of first admission to the time of discharge or

	Eligible population (n=709 569)	Complete cases (n=561 621)
Primary outcome		
Number of deaths before final discharge	11 257/709 270 (1.6%)	9135 (1.6%)
Number of alive discharges	698 013/709 270 (98.4%)	552 486 (98.4%)
Maternal and birth characteristics		
Index of Multiple Deprivation		
1 (most deprived)	102 419/678 550 (15.1%)	83 400 (14.8%)
2	88 555/678 550 (13.1%)	72 937 (13.0%)
3	81 543/678 550 (12.0%)	67 608 (12.0%)
4	73 969/678 550 (10.9%)	61 243 (10.9%)
5	66 646/678 550 (9.8%)	55 417 (9.9%)
6	62 471/678 550 (9.2%)	52 016 (9.3%)
7	55 888/678 550 (8.2%)	46 587 (8.3%)
8	52 847/678 550 (7.8%)	43 833 (7.8%)
9	50 330/678 550 (7.4%)	41 704 (7.4%)
10 (least deprived)	43 882/678 550 (6.5%)	36 876 (6.6%)
Country of mother's residence		
England	649 180/678 550 (95.7%)	537 221 (95.7%)
Wales	29 308/678 550 (4.3%)	24 352 (4.3%)
Scotland	62/678 550 (<0.1%)	48 (<0.1%)
Mother's ethnicity		
White	431 398 (60.8%)	361 852 (64.4%)
Asian or Asian British	71 819 (10.1%)	61 773 (11.0%)
Black or Black British	34 477 (4.9%)	29 235 (5.2%)
Mixed	9 600 (1.4%)	8 105 (1.4%)
Other ethnic group	13 657 (1.9%)	11 398 (2.0%)
Unknown or not stated	148 618 (20.9%)	89 258 (15.9%)
Gestational age		
Extremely preterm (22 to <28 weeks)	26 366/709 506 (3.7%)	22 117 (3.9%)
Very preterm (28 to <32 weeks)	56 534/709 506 (8.0%)	47 467 (8.5%)
Moderate to late preterm (32 to <37 weeks)	242 441/709 506 (34.2%)	195 952 (34.9%)
Term (≥37 weeks)	384 165/709 506 (54.1%)	296 085 (52.7%)
<34 weeks	151 239/709 506 (21.3%)	126 668 (22.6%)
≥34 weeks	558 267/709 506 (78.7%)	434 953 (77.4%)

(Table continues in next column)

	Eligible population (n=709 569)	Complete cases (n=561 621)
(Continued from previous column)		
Birthweight, g*	2733.1 (933.2)	2704.5 (941.4)
Extremely low birthweight, <1000 g	27 878/708 963 (3.9%)	23 543 (4.2%)
Very low birthweight, <1500 g	75 447/708 963 (10.6%)	63 598 (11.3%)
Low birthweight, <2500 g	282 261/708 963 (39.8%)	232 167 (41.3%)
Sex of the baby†		
Male	403 432/708 999 (56.9%)	319 740 (56.9%)
Female	305 567/708 999 (43.1%)	241 881 (43.1%)
Maternal age, years‡		
<20	18 815/694 778 (2.7%)	14 850 (2.6%)
20–24	95 028/694 778 (13.7%)	76 106 (13.6%)
25–29	176 216/694 778 (25.4%)	142 098 (25.3%)
30–34	215 917/694 778 (31.1%)	175 071 (31.2%)
35–40	141 442/694 778 (20.4%)	115 001 (20.5%)
>40	47 360/694 778 (6.8%)	38 495 (6.9%)
Congenital anomaly present (including minor)§		
	92 859 (13.1%)	77 185 (13.7%)
Maternal health		
Medical problems prior to pregnancy§	164 220 (23.1%)	141 683 (25.2%)
Obstetric problems during pregnancy§	300 484 (42.3%)	265 005 (47.2%)
Smoking during pregnancy	96 834/590 328 (16.4%)	92 130 (16.4%)
Eligible population includes all babies born at 22 weeks' gestation or more, excluding babies whose first admission was at over 7 days old and those admitted from home or an unknown location. *Where Z scores of birthweight for gestational age were over 5 standard deviations from 0, they were assumed as missing. †Missing may include indeterminate sex. ‡Where maternal age was <10 years or >65 years, assumed as missing. §Detailed list of conditions provided in the appendix (pp 5–8); where no information was documented on the presence of a condition, it was assumed as no problem present.		
Table: Population characteristics for babies born between 2012 and 2022 and admitted to a neonatal unit in England and Wales contributing to the National Neonatal Research Database		

death at the last admission. Any individuals with missing time were excluded from this analysis. Any negative time due to data entry errors were assumed as 0. In the competing risks model, the aim was to assess the time it took for patients to move from one state (entering the unit) to either being discharged (state two) or dying (state three). Again, three models for each exposure, socioeconomic status, and ethnicity, were used to quantify the inequalities in time to death from the multi-state model, this time using Cox proportional hazards with complete cases (appendix pp 9–10).

We undertook a subgroup analysis for the primary outcome for babies born above and below 34 weeks' gestation as the NNRD is highly representative of the preterm population below this gestational age (appendix p 18).

We conducted several sensitivity analyses. We re-ran all regression models by country, excluding babies born at

less than 24 weeks' gestation and excluding babies with missing ethnicity data. To account for missing data for our primary analysis, we ran multiple imputation by chained equations for key missing variables used in the nested regression analysis as well as an additional imputation for unknown or not stated ethnicity (appendix p 10).

Statistical analyses were conducted in R (version 4.4.1) and R Studio (version 2024.09.1.).

Role of the funding source

The funders of the study had no role in study design, data analysis, data interpretation, or writing of the report.

Results

Between Jan 1, 2012, and Dec 31, 2022, 1005 114 babies were born and registered to the NNRD in England and Wales. After exclusions, there were 709 569 babies included in the descriptive analysis (figure 1). 147 948 (20.9%) babies in the eligible cohort had

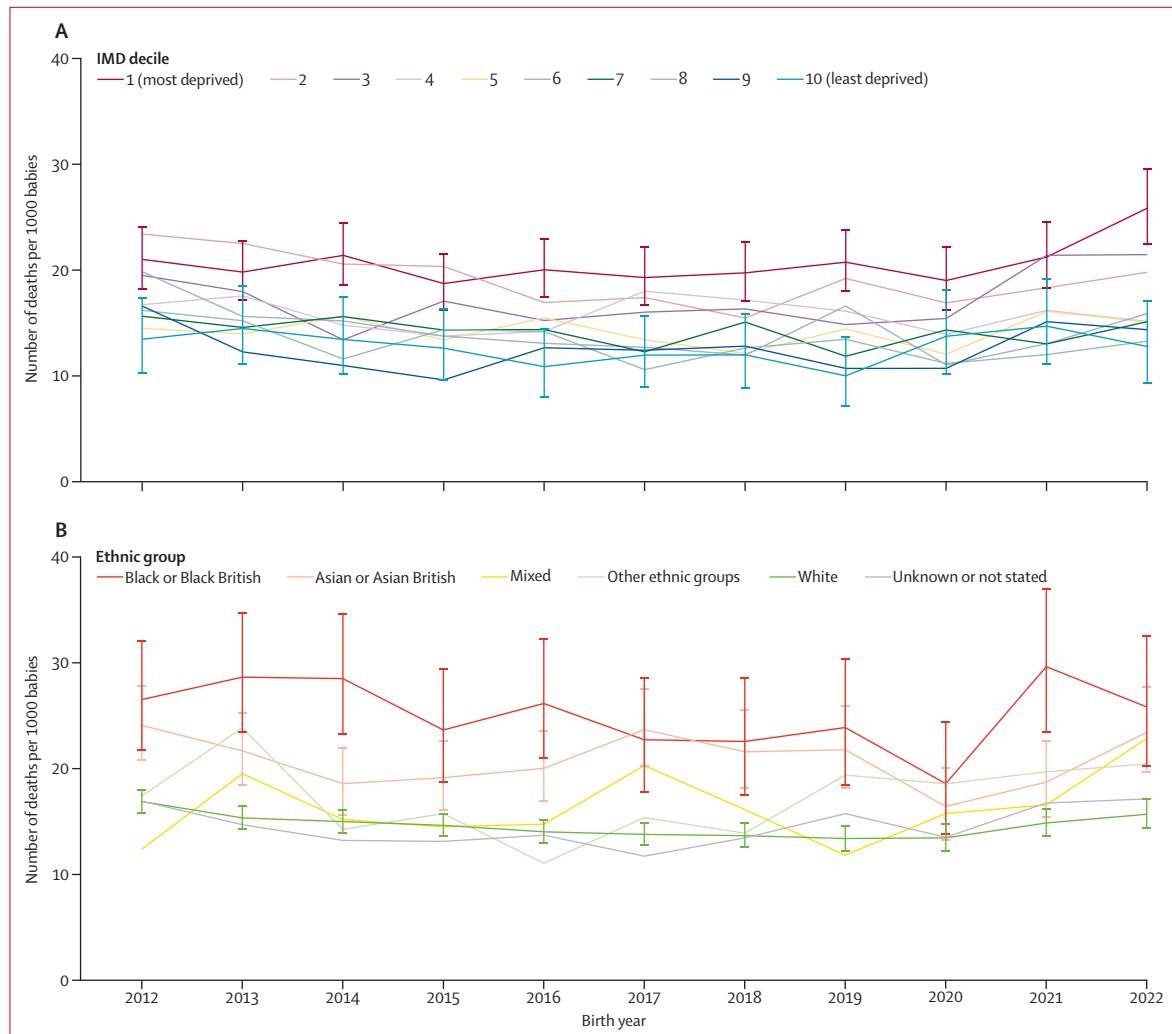


Figure 2: In-unit mortality rate by IMD (A) and maternal ethnicity (B)
IMD=Index of multiple deprivation.

missing data, meaning data from 561621 babies were included in the complete case analysis. Maternal and birth characteristics of both the eligible cohort and complete cases are listed in the table. Characteristics of babies with missing data can be found in the appendix (pp 26–28).

There was a social gradient in babies admitted to NHS neonatal units in England and Wales, with 102419 (15·1%) of 678550 babies born to mothers living in the most deprived decile (IMD 1) and 43882 (6·5%) born to mothers living in the least deprived decile (IMD 10). For comparison, among livebirths in England and Wales, 13·7% were from the most deprived decile and 7·1% from the least deprived decile (appendix p 11).

Temporal trends in mortality by both IMD decile and maternal ethnic group using the eligible cohort are shown in figure 2. In-unit mortality for the most deprived decile was 21·0 per 1000 babies (95% CI 18·2–24·1) in 2012 and 25·9 per 1000 babies in 2022 (22·4–29·6). In the least deprived decile, it was 13·5 deaths per 1000 babies (10·2–17·5) in 2012 and 12·8 per 1000 babies in 2022 (9·3–17·2). In-unit mortality rates declined steadily from 2012 to 2020 (14·2 deaths [13·2–15·1] per 1000 babies in 2020) before increasing back to 17·6 deaths per 1000 babies in 2022 (16·5–18·7; appendix p 11). The segmented regression indicated a significant breakpoint

in the mortality rate at the end of 2019 ($p<0\cdot0001$) with a negative slope before the breakpoint, indicating decreasing rates, and an increase afterwards.

The rate of deaths before discharge using the eligible cohort can be found in figure 2. For babies born to mothers who were White, the lowest rate of deaths before discharge was 13·4 per 1000 babies in 2019 (95% CI 12·2–14·9) and highest at 16·9 per 1000 babies in 2012 (15·8–18·1). For babies born to mothers who were Black, the lowest rate was in 2020 at 18·6 per 1000 babies (13·8–24·5) and was highest at 29·7 per 1000 babies in 2021 (23·4–27·1). For babies born to mothers who were Asian, the in-unit mortality rate was lowest at 16·4 per 1000 babies in 2020 (13·3–20·2) and the highest in 2012 with a rate of 24·1 deaths per 1000 babies (20·7–27·9).

In the eligible cohort, there was a social gradient in most ethnic groups for the proportion of babies admitted to a neonatal unit that died when babies born to mothers in the most deprived decile were compared with those born in the least deprived decile (White mothers 1·9% [95% CI 1·8–2·0; IMD 1] vs 1·3% [1·1–1·4; IMD 10]; Black mothers 2·9% [2·5–3·3; IMD 1] vs 1·4% [0·4–2·3; IMD 10]; figure 3). The 95% CIs presented for the proportions are much wider for babies who died and were born to mothers of Black and Mixed ethnicity, most notably due to smaller populations in these groups. No

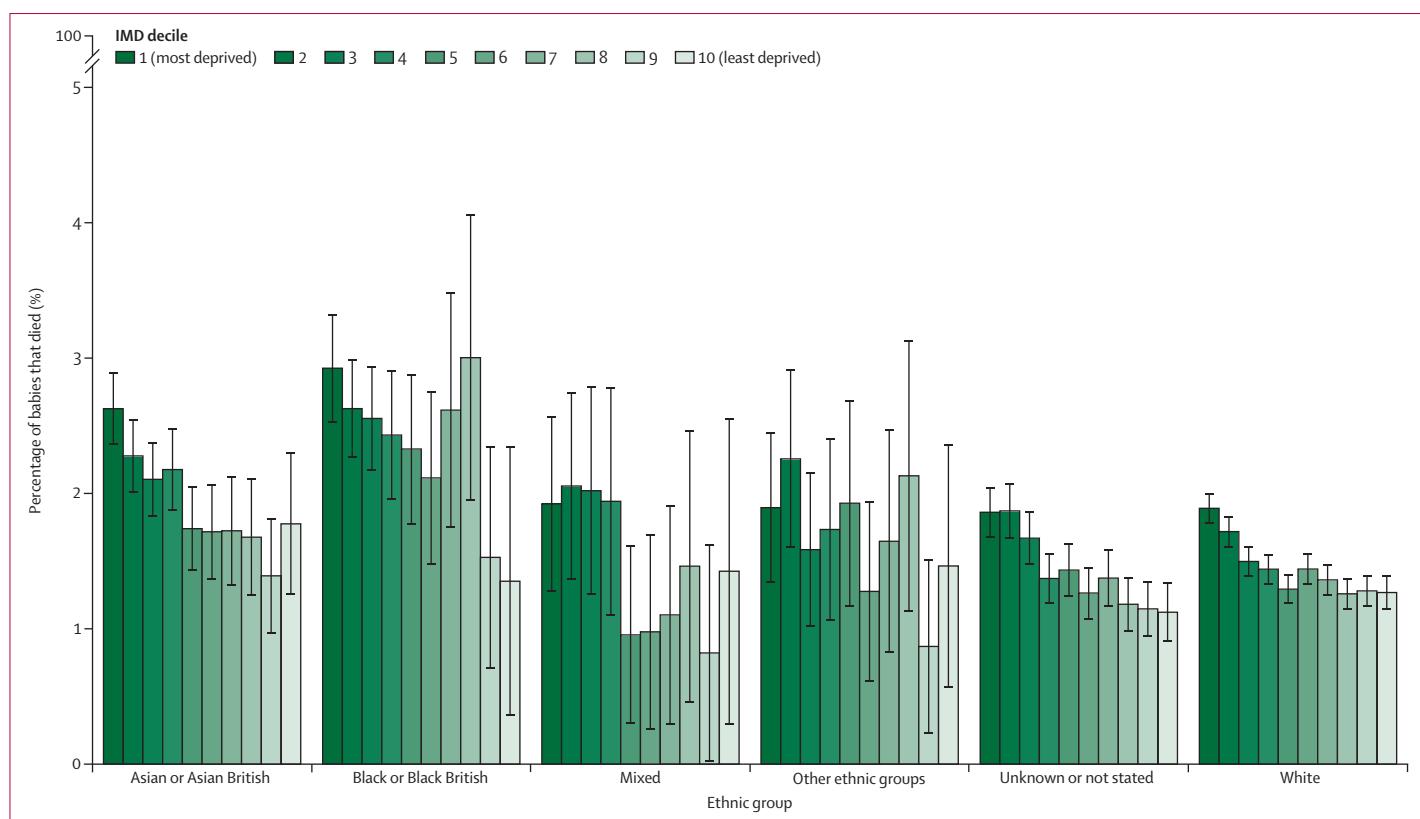


Figure 3: Percentage of babies that died by IMD and ethnicity

Data are presented as %. Error bars show 95% CI. IMD=index of multiple deprivation.

interaction was observed between IMD and ethnicity (likelihood ratio test $p=0.71$), therefore, this interaction was not used in the logistic regression models.

For babies born to mothers living in the most deprived decile compared with the least, the odds ratio of mortality before final discharge was 1.63 (95% CI 1.48–1.81). After adjusting for ethnicity, this reduced to an odds ratio of 1.52 (1.38–1.69), and 1.23 (1.10–1.37) after adjusting for ethnicity and all case-mix variables on admission (figure 4A). For babies born to mothers who were Black, the odds of mortality before final discharge compared with babies born to mothers who were White were 1.81 (1.67–1.95), 1.68 (1.55–1.81) when adjusted for IMD only, and 1.14 (1.05–1.24) after adjusting for IMD and all case-mix variables on admission (figure 4B). For babies born to mothers of Asian ethnicity, compared with babies born to mothers

of White ethnicity, odds ratios for the three models were 1.48 (1.39–1.57), 1.40 (1.32–1.49), and 1.36 (1.27–1.45), respectively.

For the competing risks analysis, limited attenuation of the effect measure was observed. For babies born to mothers living in the most deprived decile, compared with the least deprived decile, the hazard ratio was 1.40 (95% CI 1.27–1.55), 1.43 (1.29–1.58) when adjusted for ethnicity only, and 1.54 (1.39–1.71) after adjusting for ethnicity and all case-mix variables on admission (appendix pp 14–15). For babies born to mothers who were Black compared with mothers who were White, hazard ratios for the three models were 1.40 (1.30–1.52), 1.44 (1.33–1.55) after adjusting for IMD, and 1.56 (1.45–1.68) after adjusting for IMD and all case-mix variables on admission. For babies born to mothers of Asian ethnicity, hazard ratios

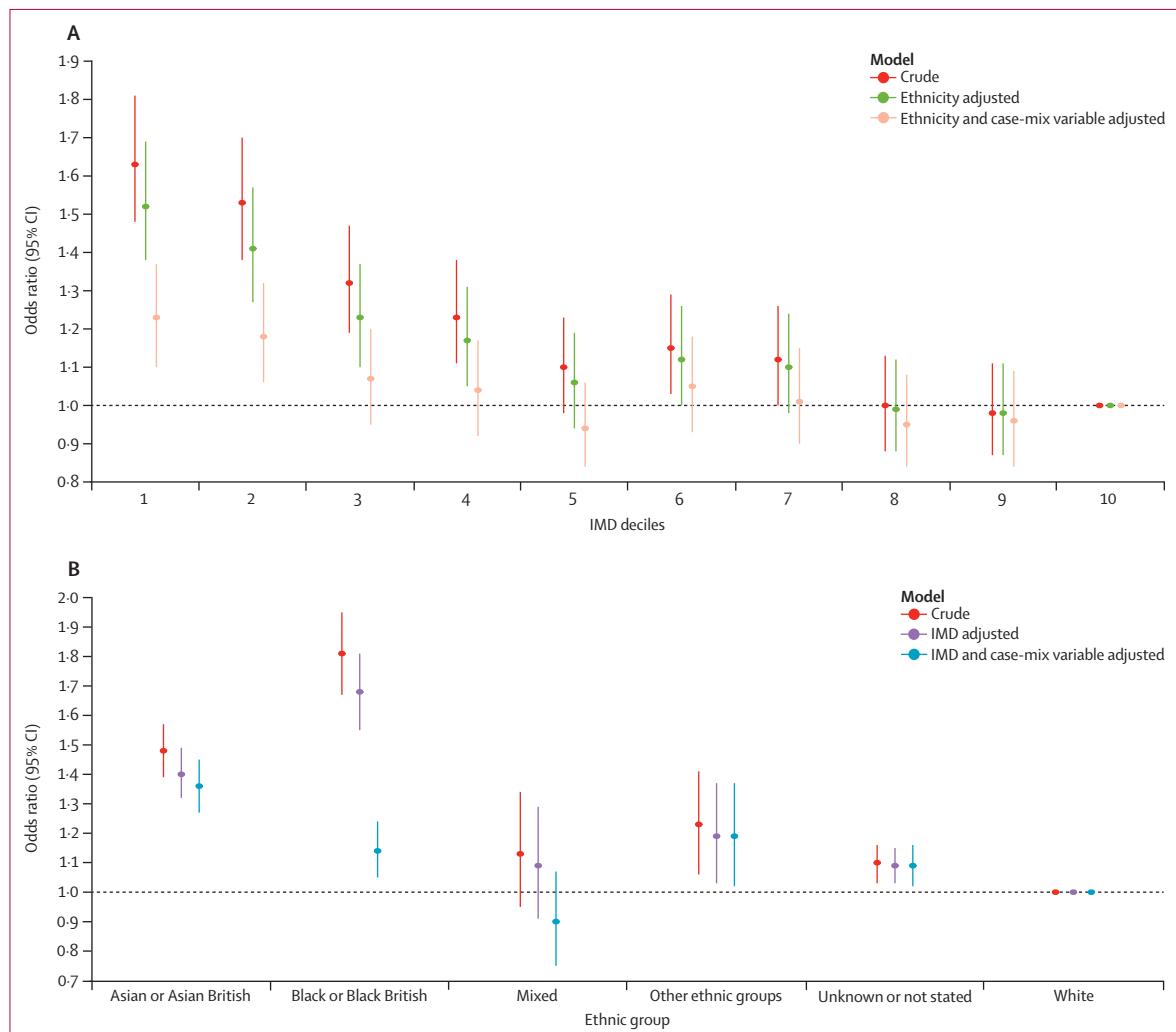


Figure 4: Association between IMD deciles (A) and ethnic group with in-unit mortality (B)

Odds ratio from nested logistic regression models, estimating crude, confounder-adjusted, and case-mix adjusted odds of mortality. (A) Crude, ethnicity adjusted, and ethnicity and case-mix variable adjusted. (B) Crude, IMD adjusted, IMD and case-mix variable adjusted. Case-mix variables were: sex, mother's age, smoking during pregnancy, previous medical problem, obstetric problems, birthweight, gestational age, and congenital anomalies. IMD=index of multiple deprivation.

for the three models were 1·34 (1·27–1·43), 1·37 (1·29–1·45), and 1·33 (1·25–1·41) respectively (appendix pp 14–15).

For the robustness tests, the estimates stayed consistent despite the differences in the characteristics of babies born above and below 34 weeks' gestation (appendix pp 19–21). We reran all regression models by country, excluding babies born at less than 24 weeks' gestation, and excluding babies with missing ethnicity. Estimates from the regression models stayed consistent, except for ethnicity associations for Wales alone, which were highly variable due to small numbers per ethnic group (appendix pp 22–25). For the sensitivity analysis using multiple imputation, with and without imputing ethnicity, none of the re-estimated results changed our main conclusion (appendix pp 26–30).

Discussion

In this study of socioeconomic and ethnic inequalities in mortality of babies cared for in neonatal units in England and Wales, we show increasing mortality since 2020 and stark inequalities in rates of death before neonatal unit discharge. Babies born to mothers who were Black have the highest rates of mortality most years. Ethnic inequalities, although variable, have persisted and remained high in 2022. Our analysis shows that inequalities in case-mix variables on admission, and risk factors for mortality evident on admission, only partly explain the inequalities observed, with residual socioeconomic and ethnic inequalities evident.

To our knowledge, this is the first study to investigate both socioeconomic and ethnic inequalities in mortality in the neonatal care population throughout all gestational ages. Our findings corroborate other studies examining neonatal and infant mortality in England. A doubling of the neonatal mortality rate between the most and least deprived areas was observed in a UK perinatal surveillance report in 2022.⁵ Our study also shows that babies born to mothers who were Black had the highest rates of mortality every year, and that even in the least deprived decile, the number of babies that died who were born to mothers who were Black remained high. Similar patterns have been reported in infant mortality by Esan and colleagues, where deprivation gradients were seen in all ethnic groups except for the Black ethnic group, where infant mortality rates remained high.¹³

Our study found that certain risk factors for adverse neonatal outcomes at admission partly explained the inequalities observed in in-unit mortality, but that residual inequalities remain. For in-unit mortality, case-mix variables explained just over half of the socioeconomic inequalities (attenuation in confounder OR by 56% from 1·52 to 1·23) and over 75% of ethnic inequalities in Black mothers (attenuation in confounder OR by 79% from 1·68 to 1·14).¹⁴ A 2024 study found that preterm birth, smoking during pregnancy, low maternal age, and maternal depression each attenuated the association of

deprivation and infant mortality between 10% and 15%, but in total only 38% of inequality in infant mortality could be explained by multiple factors.¹⁵ Residual inequalities might exist due to other factors not adjusted for in the analysis, including care-related variables previously identified as socioeconomically patterned.¹⁶

There are various possible explanations as to why an attenuation of both socioeconomic and ethnic inequalities in mortality was observed. Previous literature suggests women living in deprivation might engage more in behaviours such as smoking, alcohol use, and substance use during pregnancy.¹⁷ These increase the risk of pregnancy-related complications; for example, smoking during pregnancy was found to be a large mediator in inequalities in preterm birth,¹⁸ a known risk factor for admissions to the neonatal unit and subsequent mortality.¹⁷ In our study, a much larger attenuation of ethnic inequality was observed in babies born to women who were Black compared with babies born to women who were Asian. Additionally, we observed that residual ethnic inequalities in the time to death remained high in our secondary analysis, with limited attenuation in the competing risks model. These findings might be an indicator of residual inequalities in care practices or other upstream drivers of inequalities, as babies who were discharged earlier were more likely to be born to mothers not living in deprived areas. Moreover, data from 2023 indicated higher rates of neonatal mortality in babies who were Asian compared with babies who were Black.⁶ Therefore, there might be other risk factors unequally clustered in women who were Asian that we did not adjust for,¹⁹ and wider social circumstances or congenital anomalies in this population affecting the observed inequalities.

In the subgroup analysis, we observed similar patterns in babies over 34 weeks' gestation, but in babies under 34 weeks, we saw a different pattern in ethnic inequalities. This result could be partly explained by collider bias²⁰ due to stratifying by gestational age, a mediator in the relationship between ethnicity and in-unit mortality. There might be other characteristics of this population specific to preterm babies compared with those born closer to term, which we were not able to explore in this study.

This study has several limitations. The NNRD is not representative of the general population and entry into the NNRD might be selective due to multiple reasons. For extremely preterm babies, entry into this dataset and the decision to provide care to babies under 24 weeks' gestation is often dependent on clinical judgement, and national guidance has changed during the period of this study.²¹ Decisions to admit might also be dependent on known socioeconomic and ethnic inequalities in the risk of stillbirth, delivery room deaths, and preterm birth,⁶ of which some of these populations might not be included in the NNRD. To mitigate the potential effects of clinical and temporal variability in the admission of babies born

at less than 24 weeks, we conducted a sensitivity analysis on the primary outcome excluding this population. Additionally, we conducted a subgroup analysis to look at inequalities in the preterm population. Future work on linking the NNRD with other datasets such as hospital episodes statistics will improve coverage.

For missing data, imputations were made where plausible with multiple imputation by chained equations. Although we found minimal difference in the outputs, limitations with using multiple imputation by chained equations include the assumption that variables are missing at random. Whilst we hypothesise that very sick babies and babies that ultimately died in the NNRD had the most complete data, we did observe that a small proportion of these babies had missing data. Therefore, the missing data could introduce biases, and a potential underestimation of the inequality observed.

Another limitation includes missingness and classification in the ethnicity variable. There is no clear consensus in the UK for electronic health records like the NNRD on how to handle missing ethnicity data, particularly when ethnicity is the exposure of interest.²⁰ Exclusion, imputation, and treating not known or not stated as distinct categories are all used in practice, each with advantages and limitations. Given concerns about non-random missingness and the ethics of imputing a social construct, we applied all three approaches in our analysis. However, none altered our main conclusions. The categories of ethnicity used were broad but in line with those commonly used by the NDAU and ONS. However, we know from Mothers and Babies: Reducing Risk through Audits and Confidential Enquiries across the UK reports that even within certain ethnic groups there was a difference in neonatal mortality rates and the effect of socioeconomic deprivation.⁶ We also recognise that ethnicity was assumed from the mother's ethnicity, introducing possible misclassification of ethnicity for babies who have parents from mixed ethnicities. Future work could include looking at granular ethnic groups to explore this relationship further.

We also acknowledge that we used within-country deciles of IMD in our analysis. Although IMD differs between UK nations in terms of domain, composition, weighting, and underlying indicators, this approach is a commonly used method.²² However, as this method does carry a risk of misclassification, we conducted a sensitivity analysis, running models by country. We found results comparable, except for ethnic inequalities in babies born to women living in Wales, highly attributable to small patient numbers. Although looking at inequalities across all UK nations would have been interesting, the additional regulatory and governance requirements were unfeasible for this study.

Finally, we could not investigate the factors mediating the association between deprivation and in-unit mortality and between ethnicity and in-unit mortality, or the role of care practices, as only case-mix variables on admission

were investigated. Subsequent planned analyses will look at the effect of care practices within the neonatal unit and how they explain the residual inequalities observed in this study. It would also be important to conduct further research exploring the role of these case-mix variables on admission using causal models, as many are likely to be on the causal pathway.

Despite limitations, there are numerous strengths of this study. To our knowledge, this is the first study to explore inequalities in mortality using neonatal data across all gestational ages; research on socioeconomic inequalities in neonatal survival from over 10 years ago only included very preterm infants.²³ There has been no research examining this in both preterm and term infants, the latter group forming over half of neonatal admissions.²⁴ Ethnic inequalities in this specific population had yet to be explored in a UK context; we were able to explore time trends over a 10-year period and the role of factors that could affect the relationship between both socioeconomic deprivation and ethnicity in neonatal mortality. There was high completeness for key variables; a previous validation study of the NNRD indicated completeness of patient characteristics being over 90%.⁹

Our analysis has important policy implications. Our findings show rising inequalities in neonatal mortality in babies admitted to neonatal care—findings that are aligned with widening inequalities observed in the rates of neonatal and infant mortality. Within the UK, neonatal mortality has remained high in comparison with other countries in the Organisation for Economic Co-operation and Development.²⁵ Reasons for this can include the high income inequalities that exist²⁶ as well as the effect of austerity measures disproportionately affecting families living in the most deprived areas of England.²⁷ Compared with countries in the European Union, the UK's progress in improving neonatal mortality has stalled.²⁸ Despite previous government targets aimed at halving the neonatal mortality rates by 2025, a 2023 policy progress report highlighted that neonatal death rates are off track to meet this target.²⁹ The new UK Government recently launched a child action plan, pledging to prioritise child health and includes a focus on health inequalities.³⁰

Integrated strategies at both policy and practice level are needed to address stark inequalities in the UK neonatal mortality rates.³¹ These strategies include developing the maternity multi-professional workforce and providing equitable care in neonatal units.³² For practitioners, strengthening pro-equity practices will help. Examples include targeted co-production of interventions for women from ethnic minority backgrounds and those living in areas of deprivation and ensuring personalised care and support plans are provided in a range of languages and formats to mitigate against digital exclusion.³³ Modifiable risk factors should also be targeted to reduce inequalities in mortality in the neonatal care population. Examples include interventions to reduce smoking in pregnancy,

with a focus on targeted and culturally sensitive interventions to women at higher risk of adverse neonatal outcomes. Policies also need to focus upstream, considering the wider social determinants of perinatal health, with a focus on improving socioeconomic conditions in the perinatal period.³¹

Contributors

SS carried out the statistical analyses and led the drafting of the manuscript (supported by DT-R and DKS). SS, DT-R, DKS, CG, NS, IS, NG, and KH contributed to the study design and analysis plan. All authors contributed to the interpretation of the results. SS, DKS, OBE and DT-R accessed and verified the data reported in the manuscript. All authors had access to the data and reviewed and approved the final manuscript.

Declaration of interests

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Data sharing statement

Data can be obtained from a third party and are not publicly available. The National Neonatal Research Database (NNRD) has been created through the collaborative efforts of neonatal services across the country to be a national resource. The NNRD was developed and is maintained and managed at the Neonatal Data Analysis Unit (NDAU) at the Chelsea and Westminster National Health Service Foundation Trust campus of Imperial College London (London, UK). Researchers, clinicians, managers, commissioners, and others are welcome to use the NNRD and NNRD-AI. The NDAU receives no core funding to support the NNRD or NNRD-AI. For this reason, a charge is necessary to cover the costs of maintaining and developing the NNRD and NNRD-AI, data transfer, extraction, cleaning and storage, and any analyses requested. A steering board provides oversight of the NNRD and NNRD-AI. The steering board does not provide peer review but ensures the request is legitimate, feasible, and in the interests of patients or the public. If the request is approved, the applicant is notified and asked to obtain necessary regulatory approvals. Applicants are asked to confirm that research findings will be published. On confirmation of regulatory approval, all eligible neonatal units are sent a copy of the research protocol, inviting them to participate. In the case of nationally commissioned service evaluations, all neonatal units are notified of the request by the lead organisation. These processes ensure that neonatal units are able to decline participation in research if they wish and are fully informed about national initiatives. If you are thinking of using the NNRD or NNRD-AI for research or health services audit or evaluations, please first read the information available from <https://www.imperial.ac.uk/neonatal-data-analysis-unit/neonatal-data-analysis-unit/utilising-the-nnrd> carefully, follow the process shown and complete the Health Data Research UK data access request (<https://web.www.healthdatagateway.org/dataset/67020745-9def-4c6e-b5ac-bb273bd0a20e>).

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