JAMA Pediatrics | Original Investigation

Trends in Maternal, Fetal, and Infant Mortality in the US, 2000-2023

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Supplemental content

IMPORTANCE Accurately measuring maternal mortality trends has been challenging due to changes in data collection. This work disambiguates trends from the effects of introducing the pregnancy checkbox on death certificates and also analyzes closely related fetal and infant mortality.

OBJECTIVE To describe trends in maternal, fetal, and infant deaths since 2000, including the impact of the COVID-19 pandemic.

DESIGN, SETTING, AND PARTICIPANTS A national, population-level, epidemiological, cross-sectional analysis during 2000 to 2023 was conducted as well as a staggered difference-in-differences analysis on the pregnancy checkbox, using the US Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiologic Research (WONDER) database on underlying causes of death in the US to identify maternal, infant, and fetal deaths. Study population was restricted to mothers aged 15 to 44 years for all definitions of maternal mortality.

EXPOSURES Staggered introduction of the pregnancy checkbox on death certificates across different states.

MAIN OUTCOMES AND MEASURES Longitudinal study (2000-2023) reporting crude rates per 100 000 population for adjusted maternal mortality and per 1000 population for fetal and infant mortality at the national level and by US Census Bureau–designated main census regions, age groups, and race and ethnicity. Staggered difference-in-differences counterfactuals (1999-2023) on impact of pregnancy checkbox.

RESULTS The introduction of the pregnancy checkbox was associated with 6.78 (95% CI, 1.47-12.09) deaths per 100 000 live births increase in reported maternal mortality, 66% (95% CI, 14%-117%) of the total increase from 2000 to 2019, with a smaller impact on maternal mortality excluding cause unspecified (adjusted maternal death rates). Adjusted maternal death rates remained consistently between 6.75 (95% CI, 5.97-7.61) to 10.24 (95% CI, 9.22-11.34) per 100 000 live births from 2000 until 2021, when it peaked at 18.86 (95% CI, 17.48-20.32); the rate dropped to 10.23 (95% CI, 9.22-11.32) in 2022. The death rates of Native American or Alaska Native women increased the most during the COVID-19 period, almost tripling from 2011 to 2019 (10.70 per 100 000 live births; 95% CI, 7.64-14.57) to the 2020 to 2022 period (27.47 per 100 000 live births; 95% CI, 18.39-39.45). The death rates of non-Hispanic Black women were highest across time—approximately triple the rate of non-Hispanic White women in each time period. Infant death rates per 1000 live births dropped from 6.93 (95% CI, 6.85-7.01) in 2000 to 5.44 (95% CI, 5.36-5.51) in 2020, increasing slightly to 2018 levels in 2021 to 2023. Fetal death rates per 1000 live births decreased from 6.28 (95% CI, 6.16-6.31) in 2005 to 5.53 (95% CI, 5.45-5.60) in 2022.

CONCLUSION AND RELEVANCE Using difference-in-differences analyses, results of this study reveal that the pregnancy checkbox explained much of the observed increase in maternal mortality before the COVID-19 pandemic. Nevertheless, results of this cross-sectional study suggest that, even adjusting for pregnancy checkbox effects, most groups saw increases from 2011 to 2019 to the 2020 to 2022 period, indicating that the COVID-19 pandemic led to worse outcomes. The findings demonstrate the relevance of public health emergencies to maternal health outcomes.

JAMA Pediatr. 2025;179(7):765-772. doi:10.1001/jamapediatrics.2025.0440
Published online April 28, 2025.

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In the US, contributors to maternal mortality include the relatively high cost of health care, systemic racism and bias, and lack of guaranteed maternity leave and universal health coverage.[1-3] Studying trends in maternal mortality in the US has proven challenging due to issues with data reporting. In particular, the staggered introduction of the pregnancy checkbox on death certificates across different states caused inconsistencies in the reporting of maternal deaths, showing large increases in maternal deaths over time concurrent to when the checkboxes were introduced.[4,5] The US Centers for Disease Control and Prevention (CDC) have attempted to adjust for the effect of the checkbox by evaluating codes unlikely to be affected, publishing an extensive report that includes predicted maternal death counts without the introduction of the checkbox revision.[6] However, more recent studies have shown conflicting results, with some making a strong claim that maternal mortality has increased for all groups over time, whereas others contend that this result is an artifact of the staggered implementation of the pregnancy checkbox on death certificates.[7-9]

Although there have been analyses to isolate the mortality codes affected by the introduction of the pregnancy checkbox, none have directly modeled its effect on maternal mortality rates. Additionally, most analyses studying maternal mortality predate the COVID-19 pandemic, summarizing trends up to 2018 or 2019.[4,10] Although the pandemic has impacted health outcomes across all specialties,[11] there is evidence suggesting specific implications for pregnant women; pregnant women infected with the SARS-CoV-2 virus were nearly 8 times as likely to die as their uninfected peers and 4 times as likely to require intensive care.[12] Alongside risk of infection, there were fewer in-person prenatal visits and growth ultrasounds during the COVID-19 pandemic, which has been associated with an increased risk of undetected fetal growth restriction, which in turn, have been associated with adverse pregnancy and perinatal outcomes.[13] Although the rate of fetal deaths has remained stable or decreased in recent years,[14,15] racial and ethnic disparities mirror those in maternal mortality, with the worst outcomes occurring in non-Hispanic Black women and mothers in the South.[15,16] Similarly, infant mortality has also consistently decreased in the last century but remained highest in Southern and non-Hispanic Black mothers.[17] Contrary to impacts on maternal health, there is little evidence to date that the COVID-19 pandemic has led to worse fetal and infant outcomes. Evidence from the first months of the pandemic period (March to July 2020) showed that neonatal deaths during this period were due to prematurity rather than infection.[18] Data from Alabama that compared early pandemic (March-December 2020) and Delta variant (July-September 2021) periods against a baseline period (2016-2019) showed that there was no change in stillbirth or neonatal mortality rates during the COVID-19 periods.[19]

Given the availability of new data, this study analyzes and compares long-term trends in maternal, fetal, and infant deaths, including the years affected by the pregnancy checkbox rollout and the years after the COVID-19 outbreak for as long as the data are available. There are 2 main aims to this work: (1) to disentangle the true trends in maternal mortality from the impacts of changes in data collection and (2) to describe the impact of the COVID-19 pandemic on maternal, fetal, and infant deaths. We use methods from existing literature to parse out the effect of the pregnancy checkbox to extract true trends in maternal mortality over time.

Key Points

Question How have trends in maternal, fetal, and infant mortality in the US changed since 2000 taking into account implementation of a pregnancy checkbox on death certificates?

Findings In this cross-sectional study including data from the National Vital Statistics Service, maternal mortality remained relatively constant from 2000 to 2020 until it spiked to an all-time high in 2021, then returned to 2020 levels in 2022. Mortality in most demographic groups increased in 2020 to 2022 relative to the 2011 to 2019 period, indicating that the COVID-19 pandemic led to worse outcomes for most mothers; fetal and infant death rates largely decreased during the same period.

Meaning Results suggest that maternal health was difficult to track due to changes in reporting practices, but public health emergencies such as the COVID-19 pandemic can have large negative impacts.

Methods

For ethics, we used the Health Research Authority decision tools. Our study was considered research, and according to the NHS Research Ethics Committee review tool,[20] we did not need NHS Research Ethics Committee review or informed consent, as we only used data that were (1) publicly available, (2) anonymized, and (3) aggregated outside of clinical settings. Per the Brown University Human Subjects Self-Determination Tool, our study did not involve human participants and, therefore, did not require review by the Brown University institutional review board. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines for cross-sectional studies.[21]

Data

We used data from the National Vital Statistics System (NVSS), which is a repository of publicly available data collected and maintained by the CDC, a US national agency that monitors and provides guidance on matters of public health interest. Data from the multiple causes of mortality, fetal deaths, and live births tables were extracted and linked using CDC Wide-Ranging Online Data for Epidemiologic Research (WONDER), the extraction interface. The extraction tool provides data at aggregate level, suppressing low numbers (less than 10) within any specified grouping and imposes limitations on spatiotemporal granularities to prevent reidentification of individuals. Participant race and ethnicity were identified through the database and included Asian or Pacific Islander, non-Hispanic Black, Hispanic, Native American or Alaska Native, and non-Hispanic White. Including racial and ethnic groups in a mortality study is crucial for identifying disparities in health outcomes and helps in developing targeted interventions to address inequities and improve public health for all groups.[22]

For infant deaths, we extracted all-cause deaths for the population younger than 1 year. For fetal deaths, we extracted data directly from the recorded fetal deaths table, which reports fetal deaths at 20 weeks' gestation or more and does not include induced terminations of pregnancy.[23] For maternal deaths, we studied 4 different definitions for the purpose of separating out the true trends from the effects of the checkbox, informed by results from Joseph et al.[4] The first definition was a traditional definition of *maternal mortality*—deaths within 42 days post partum—including codes A34, O00-O94, and O98-O99 as the underlying cause of death. The second definition was the remainder of deaths in the pregnancy-related deaths period (between 43 days and 365 days post partum), which we call *late maternal mortality*, identified using codes O96-O97. The third definition separates out maternal deaths from unspecified causes from the first definition using codes O26.8, O95, and O99, which we call *unspecified maternal mortality*. Joseph et al[4] demonstrated that the late maternal death codes and the unspecified maternal death codes (definitions 2 and 3) increased as a result of the death certificate revision, whereas other codes remained constant during the 2003 to 2017 period and argued that this was a more reliable proxy for maternal mortality. We examined maternal mortality without the unspecified maternal death codes, which we call *maternal mortality excluding cause unspecified*. In addition to specifying these codes, we limited the extraction to deaths in females aged 15 to 44 years (a conservative and plausible age range for when most pregnancies would occur). We evaluated the impact of the pregnancy checkbox on these different measures and use this to guide reporting.

Statistical Analysis

We reported crude mortality rates indexed by live births (per 100 000 live births for maternal and per 1000 live births for fetal and infant mortalities). Where reported, data from 2022 are provisional, and data from 2023 are births and deaths from the first half of the year (January to June) doubled to approximate the yearly counts. We were unable to report age-weighted rates for all definitions due to low counts but included the age-weighted rates for maternal mortality excluding cause unspecified to demonstrate that age-weighted trends are similar to crude rates.

We used staggered difference-in-differences (DID) to estimate the effect of the implementation of pregnancy checkbox in 50 states, using the Callaway & Sant'Anna estimator (eMethods in Supplement 1) with 2 outcomes separately: (1) maternal mortality and (2) maternal mortality excluding cause unspecified.[24] Based on previous literature, we expected to find a large effect on (1) maternal mortality and a smaller and possibly insignificant effect on (2) maternal mortality excluding cause unspecified. We used the year of checkbox implementation on death certificates in a given state as the treatment provided by NVSS, using not-yet-treated states in each year as the comparison group (eMethods in Supplement 1).[24,25] We reported average effects across different lengths after the implementation and counterfactual trends estimated using the average treatment effect per calendar year or overall average effect where year estimates were unreliable (ie, outside of the checkbox rollout or where year estimates were negative at the tails of the treatment period). Inference was conducted using bootstrapping.[24]

Geographically, we examined trends at the national level, as well as by census region when the data were available at that granularity. We also computed rates separately across demographic groups including 5-year age groups and race and ethnic groups. We calculated the 95% CI for each rate using the Byar method.[26,27] Data were analyzed using R, version 2024.04.1+748 (R Project for Statistical Computing).

Results

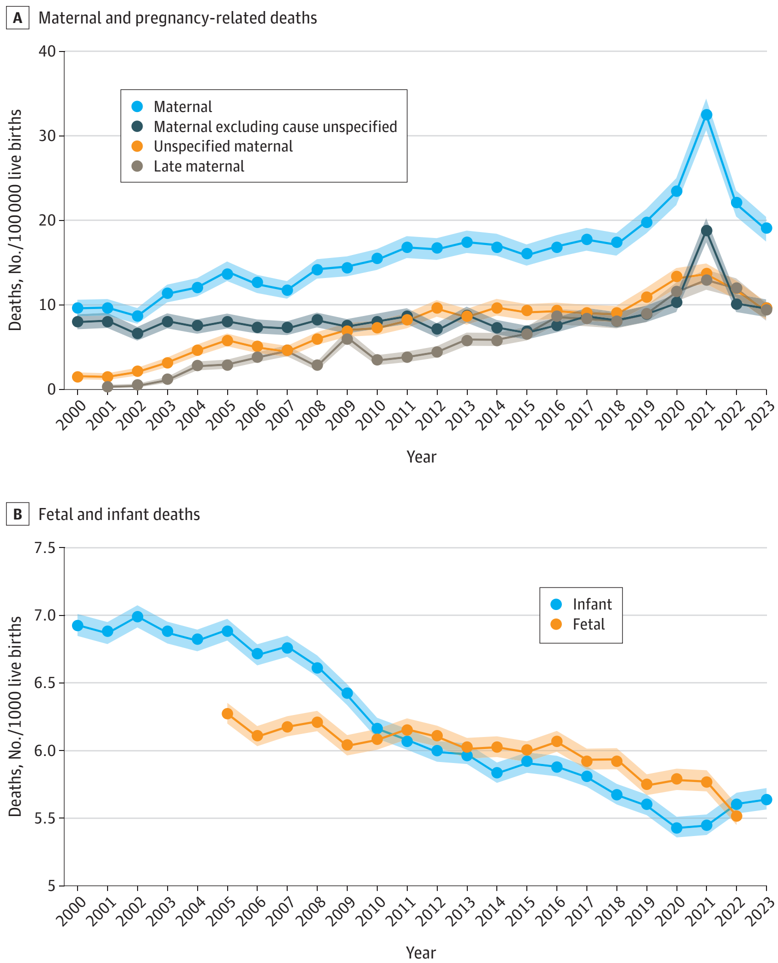
Temporal Trends

Maternal Deaths

Crude Rates The rate of maternal mortality excluding cause unspecified per 100 000 live births—our proxy definition for true trends—remained consistently between 6.75 (95% CI, 5.97-7.61) to 10.24 (95% CI, 9.22-11.34) per 100 000 live births until 2021, when it peaked at 18.86 (95% CI, 17.48-20.32) (**Figure 1**A). In 2022, the rate dropped back down to 10.23 (95% CI, 9.22-11.32). In comparison, all other definitions of maternal deaths per 100 000 live births—which include codes affected by the checkbox implementation on death certificates—increased steadily from the start of the time period until 2020: maternal mortality from 9.66 (95% CI, 8.73-10.67) in 2000 to 23.42 (95% CI, 21.87-25.06) in 2020, late maternal mortality from 0.37 (95% CI, 0.21-0.62) in 2001 to 11.57 (95% CI, 10.49-12.74) in 2020, and unspecified maternal mortality from 1.63 (95% CI, 1.26-2.08) in 2000 to 13.18 (95% CI, 12.03-14.43) in 2020. We were unable to report age-weighted rates for all definitions due to low counts. The eFigure in Supplement 1 shows rates of age-weighted maternal mortality excluding cause unspecified by year, which shows a similar trend to that of crude rates.

Staggered DID Estimates Implementation of the pregnancy checkbox on death certificates was associated with significant increases in maternal mortality (**Figure 2**A). In comparison, the effect with maternal mortality excluding cause unspecified was smaller and insignificant (Figure 2B). The overall average treatment effect was 6.78 deaths (95% CI, 1.47-12.09) per 100 000 live births for maternal mortality and 1.82 deaths (95% CI, −0.74 to 4.38) per 100 000 live births for maternal mortality excluding cause unspecified. We estimate that the checkbox accounted for 66% (95% CI, 14%-117%) of the observed change in maternal mortality from 2000 to 2019, ie, the true change was only 3.5 deaths (95% CI, −1.8 to 8.8) per 100 000 live births. The counterfactual trends for both definitions are reasonably constant before the COVID-19 period (Figure 2B). The observed trend for maternal mortality excluding cause unspecified follows the counterfactual trend line more closely than the observed trend for all maternal mortality (Figure 2B).

Figure 1. Rates of Maternal, Fetal, and Infant Deaths by Year, 2000-2023



A, Maternal and pregnancy-related deaths. B, Fetal and infant deaths. The 2022 count is provisional. The 2023 count is provisional and partial; deaths in the first half of 2023 were doubled to approximate the yearly mortality. The 95% CIs are shaded around each line. Maternal deaths are identified using underlying cause of death codes A34, O00-O94, and O98-O99. Late maternal deaths are identified using codes O96-O97. Unspecified maternal deaths are identified using codes O26.8, O95, and O99. Late maternal mortality is censored for 2000 due to low counts (<10). Infant deaths include all-cause deaths for the population younger than 1 year. Fetal deaths include deaths at 20 weeks' gestation or more and do not include induced terminations of pregnancy. Fetal mortality was only available for 2005 to 2022.

Infant and Fetal Deaths

The rate of infant deaths per 1000 live births dropped from 6.93 (95% CI, 6.85-7.01) in 2000 to 5.44 (95% CI, 5.36-5.51) in 2020 (Figure 1B). There was an increase over the last 3 years to 5.64 (95% CI, 5.57-5.72) in 2023. Fetal deaths decreased marginally from 6.28 (95% CI, 6.16-6.31) to 5.53 (95% CI, 5.45-5.60) per 1000 live births from 2005 to 2022.

Demographic Trends

Maternal Deaths

Across all time periods, non-Hispanic Black women had the highest observed rate of maternal mortality across time—approximately triple the rate of non-Hispanic White women in each time period—excluding cause unspecified across all race and ethnic groups. Before the COVID-19 pandemic, the rate per 100 000 live births was quadruple that of non-Hispanic White women: 20.65 (95% CI, 19.52-21.84) vs 5.00 (95% CI, 4.71-5.30) in 2001 to 2010 and 20.51 (95% CI, 19.29-21.79) vs 5.94 (95% CI, 5.59-6.30) in 2011 to 2019. In 2020 to 2022, non-Hispanic Black women saw a 38.42% increase from the previous period to 28.40 (95% CI, 25.81-31.18), whereas non-Hispanic White women saw a 68.54% increase to 10.00 (95% CI, 9.19-10.87).

From 2011 to 2019 to the COVID-19 period (2020-2022), rates increased significantly for all age groups (except women aged 15-19 years), women in the Northeast, and across all race and ethnic groups (**Figure 3**). Geographically, women in the South saw the greatest increase from 10.27 (95% CI, 9.74-10.82) to 17.75 (95% CI, 16.52-19.04) (Figure 3B). Native American or Alaska Native women had the largest increase of all demographic subgroups from 10.70 (95% CI, 7.64-14.57) to 27.47 (95% CI, 18.39-39.45) (Figure 2C).

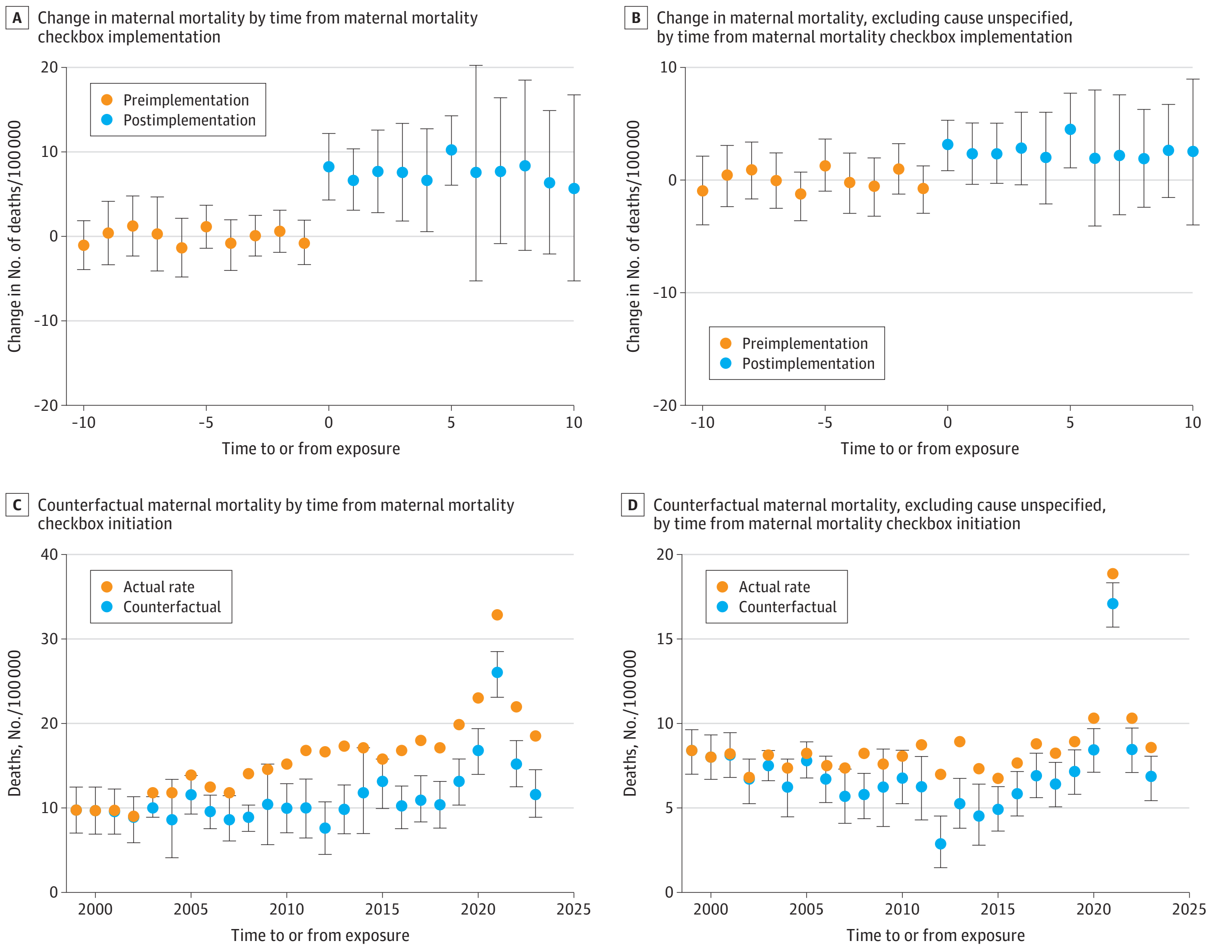
Infant Deaths

Infant deaths decreased significantly across all time periods for all census regions (**Figure 4**A). All race and ethnic groups saw a constant or decreasing rate of infant deaths (Figure 4B).

Discussion

Maternal mortality excluding cause unspecified—which are composed of underlying causes of death codes not affected by the implementation of the pregnancy checkbox on death certificates[4]—has remained relatively consistent over the pre-COVID-19 pandemic period, whereas all other maternal mor-

Figure 2. Effect of Pregnancy Checkbox on Cause of Death Coding



A and B, Average treatment effect of maternal mortality checkbox by length of exposure. C and D, Counterfactual mortality by years pre/post state checkbox introduction. Difference-in-differences results using the year of checkbox implementation on death certificates in a given state as the treatment and not-yet-treated states in each year as the comparison group (see the eMethods in Supplement 1 for technical specifications). Maternal deaths are identified using underlying cause of death codes A34, O00-O94, and O98-O99. Maternal mortality excluding cause unspecified are maternal deaths (identified using underlying cause of death codes A34, O00-O94, and O98-O99), excluding unspecified maternal deaths (O26.8, O95, and O99). Years were limited to 10 years pre/post checkbox implementation due to sparse numbers in the treated (pre) or untreated (post) group in the tails. The actual 2022 count is provisional. The actual 2023 count is provisional and partial; deaths in the first half of 2023 were doubled to approximate the yearly mortality.

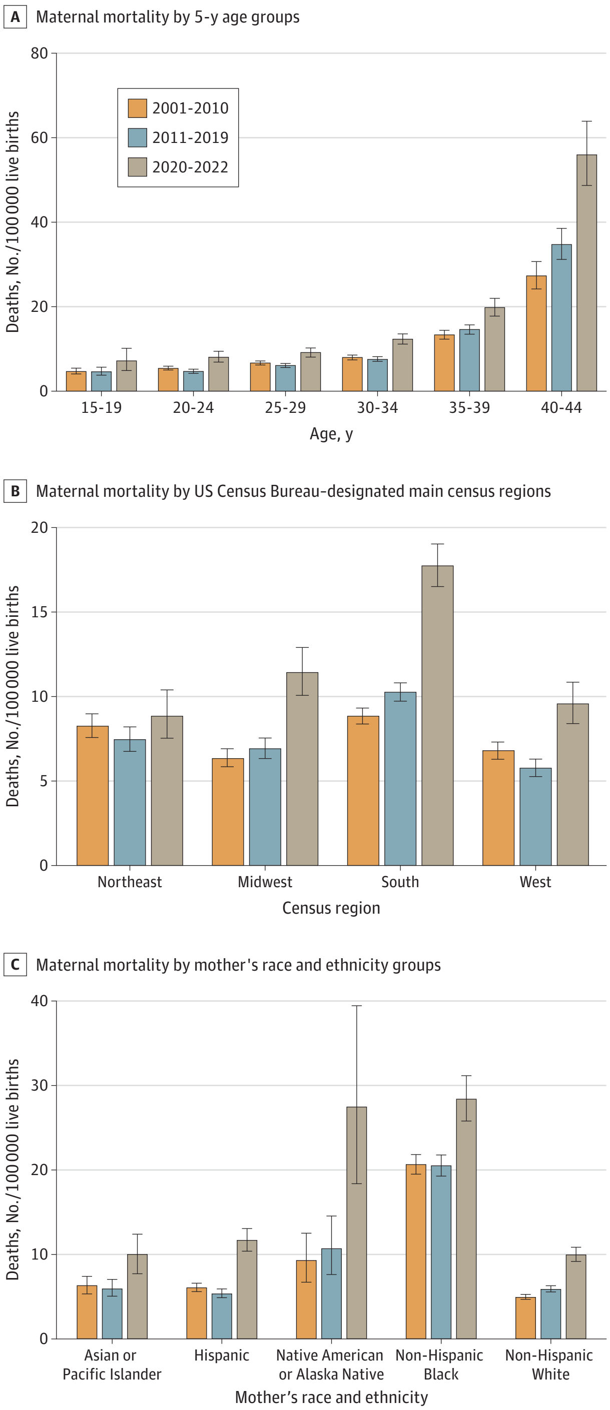
tality definitions saw an increase. In this cross-sectional study, we were the first, to our knowledge, to explicitly model the association of the staggered implementation of pregnancy checkbox with maternal mortality by state. We also contributed to the literature on fetal and infant deaths by examining a continuous, multidecade trend that includes data beyond the Delta wave.

Accounting for the checkbox implementation, counterfactual trends show that both maternal mortality and maternal mortality excluding cause unspecified were reasonably constant before the COVID-19 pandemic. In 2021, the rate nearly doubled from the previous year, reaching the highest point since the start of the millennium. This may be explained by the Delta wave, which was declared a variant of concern by the CDC in May 2021 and associated with a higher risk of adverse maternal outcomes in France and Switzerland compared with pre-Delta or Omicron periods.[28] The US Government Accountability Office found that 25% of maternal deaths in 2020 and 2021 were related to the COVID-19 pandemic.[29] Another contributing factor could have been relaxation of social distancing requirements in this period, which may have led to increased social mixing and COVID-19 infection rates, leading to a higher incidence of pregnancy complications.

Maternal mortality rates returned to 2020 levels in 2022. Further investigation on the differences in antenatal and postpartum care across the pandemic years may provide more information on interventions that could reduce adverse maternal outcomes in future pandemics.

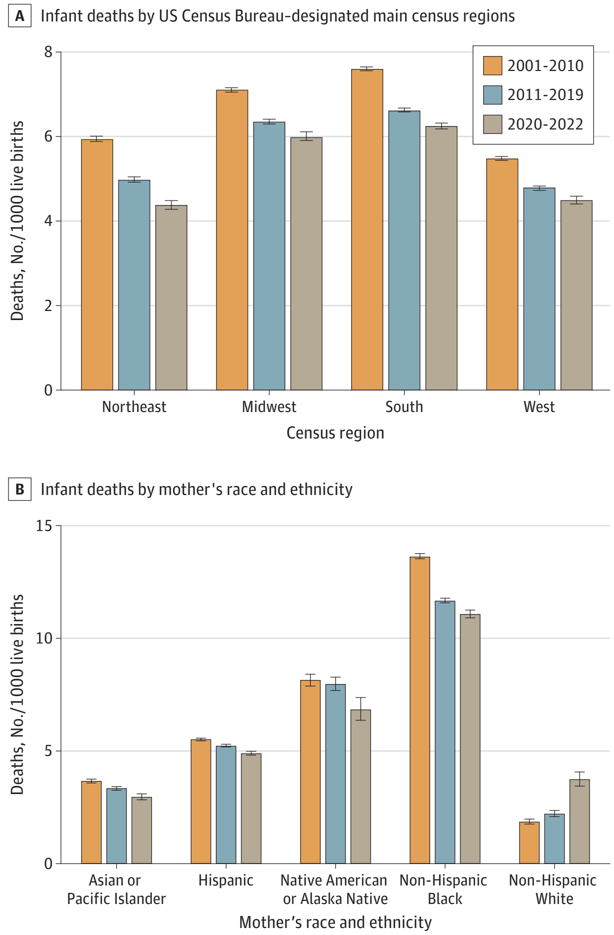
Although a few demographic groups saw modest increases over time in maternal mortality excluding cause unspecified from 2001 to 2010 to the 2011 to 2019 period, we note that in the DID analysis, we found that the yearly adjusted maternal mortality rates were slightly inflated compared with the predicted counterfactuals in 2011 to 2019 (Figure 2B). Thus,

Figure 3. Rates of Maternal Mortality Excluding Cause Unspecified by Demographic Subgroups, 2001-2022



A, By 5-year age groups. B, By US Census Bureau–designated main census regions. C, By mother's race and ethnic groups. Maternal mortality excluding cause unspecified are maternal deaths (identified using underlying cause of death codes A34, O00-O94, and O98-O99) excluding unspecified maternal deaths (O26.8, O95, and O99). The 95% CIs are shown in black. The 2022 count is provisional. Rates are not age adjusted due to suppression in small groups. The eFigure in Supplement 1 contains age-weighted rates of maternal mortality excluding cause unspecified.

Figure 4. Rates of Infant Deaths by Demographic Subgroups, 2001-2022



A, By US Census Bureau–designated main census regions. B, By mother's race and ethnic groups. Infant deaths include all-cause deaths for the population younger than 1 year. The 95% CIs are shown in black. The 2022 count is provisional.

it is conceivable that the modest increases over time by demographic group may be due to the checkbox implementation. We were unable to derive counterfactuals for demographic groups due to low counts at those granularities.

Most groups saw an increase from 2011 to 2019 to the 2020 to 2022 period, which demonstrates that the COVID-19 pandemic led to worse outcomes for most mothers. The South saw increases between all time periods. Non-Hispanic Black women had the highest mortality in all 3 periods, which may be due to systemic bias and racism that affect socioeconomic determinants of health and, more specifically, systemic discrimination within the US health care system.[3,30-32] Native American or Alaska Native women saw the largest increase during the COVID-19 period, with the rate more than doubling from 2011 to 2019 to the 2020 to 2022 period. These results may indicate the need for targeted interventions by racial and ethnic groups and regions.

The only region that did not see a statistically significant increase during the COVID-19 pandemic period was the Northeast. Further research is necessary to determine whether this was due to random variation or could be explained by better implementation of and compliance with public health guidelines, availability of health care staff in the region, or other social and environmental factors.

In contrast to Fleszar et al,[7] we show that prepandemic levels of maternal mortality remained flat across regions and race and ethnic groups. The difference in results are likely due to the fact that we use direct counts after accounting for the effects of pregnancy checkbox rollout, whereas their Bayesian modeling approach was driven by priors that borrow strength across states, groups, and time, without an explicit control for the checkbox effect.[8]

All 4 definitions of maternal mortality follow a similar pattern from 2016. This indicates that the checkbox implementation is no longer falsely inflating trends over time, and the standard definition for maternal mortality may be used to track trends starting in 2016 and beyond.

Infant deaths decreased consistently over the last 2 decades, with a slight rise from 2020 to 2023. In contrast, fetal deaths declined from 2021 to 2022. Infant deaths were the highest among non-Hispanic Black infants across all-time periods, which could be attributed to systemic racism; Ramos et al[33] demonstrated that increase in the Systemic Racism Index was associated with an increase the Non-Hispanic Black to Non-Hispanic White infant mortality rate ratio at the county level. Fetal and infant deaths should be monitored further as more up-to-date data are released, to check for any persisting effects of the COVID-19 pandemic.

Limitations

There are several limitations to this study. First, because fetal deaths were only available from 2005 to 2022, we could not perform the equivalent time period comparisons. However, preliminary evidence from the last 3 available years demonstrates that the trend in fetal deaths may be more similar to infant deaths than maternal deaths. Second, because the study focuses on rare events, it was difficult to get adequate numbers at the granularity necessary to observe trends over time at multiple levels of aggregation (eg, state by year, age-race combination by year). Third, although we aimed to separate the effects of the checkbox, it is still an incomplete audit of the data quality; it is unclear by what mechanism the checkbox questions are driving up unspecified maternal deaths. Fourthly, there are alternative data sources that use different approaches to estimate mortality, which may show differing trends.[34] Finally, this study does not evaluate the underlying causes of maternal deaths. Joseph et al[4] examined several underlying causes such as diabetes, liver disease, and chronic hypertension, which all showed different trends over time. A future study could further examine and compare these underlying causes separately.

Conclusions

It is difficult to track trends in maternal mortality in the US due to changes over time in data coding and collection. In this cross-sectional study, all measures of maternal mortality indicated a marked rise in 2021, demonstrating the relevance of public health emergencies to maternal health outcomes. Any future initiatives on pandemic preparedness planning should consider provisions for childbirth and antenatal and postpartum care to limit preventable maternal deaths. With the exception of 2021, and accounting for changes in reporting, maternal mortality remained flat over the last 2 decades. By contrast, fetal and infant mortality has been decreasing across this period, although there is a worrying rise in the last 3 years in infant mortality. Redoubled efforts, including careful measurement of the problem, are needed to improve maternal and child health.

ARTICLE INFORMATION

Accepted for Publication: January 15, 2025.

Published Online: April 28, 2025. doi:10.1001/jamapediatrics.2025.0440

Author Contributions: Ms Park and Dr Flaxman had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: All authors.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Park, Parks, Flaxman.
Critical review of the manuscript for important intellectual content: All authors.
Statistical analysis: Park, Parks, Flaxman.
Obtained funding: Parks, Flaxman.
Administrative, technical, or material support: Bilinski, Parks.
Supervision: Flaxman.

Conflict of Interest Disclosures: Dr Parks reported receiving grants from the National Institute of Environmental Health Sciences (NIEHS) during the conduct of the study. Dr Bilinski reported receiving grants from the National Institutes of Health, the US Centers for Disease Control and Prevention (Council of State and Territorial Epidemiologists [CSTE]), and the National Center for HIV, Viral Hepatitis, STD, and Tuberculosis Prevention (NCHHSTP), and personal fees from Adam Goff (nursing home modeling) outside the submitted work. No other disclosures were reported.

Funding/Support: This work was supported in part by grant NIGMS 1R35GM155224 from the National Institutes of Health (Dr Bilinski), grant EP/V002910/2 from the Engineering and Physical Sciences Research Council (EPSRC) (Dr Flaxman), and grant EP/S02428X/1 from EPSRC Centre for Doctoral Training in Health Data Science (Ms Park).

Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Data Sharing Statement: See Supplement 2.

Additional Contributions: We thank Selena Linden, MSc (University of Oxford), for help with data collection. Beyond usual salary, no one received financial compensation for their contribution.

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Supplementary Online Content

Park RY, Bilinski A, Parks RM, Flaxman S. Trends in maternal, fetal, and infant mortality in the US, 2000-2023. *JAMA Pediatr*. Published online April 28, 2025. doi:10.1001/jamapediatrics.2025.0440

eMethods. Details on Difference-in-Difference Analysis

eFigure. Rates of Age-Weighted Maternal Mortality Excluding Cause Unspecified by Year, 2000-2023

eReferences

This supplementary material has been provided by the authors to give readers additional information about their work.

eMethods. Details on Staggered Difference-in-Differences (DID) analysis

Model specification:

To estimate DID with staggered treatment timings, we estimate population-weighted (the population is the number of live births) group-time average treatment effects on the treated (ATTs) using the Callaway-Sant'Anna estimator. This first defines treatment cohorts according to the time at which they initiated treatment (i.e., G_i=g indicates that unit i initiated treatment at time g). For the group-time ATT corresponding to group g at time T, we conduct DD comparing units in cohort G_i=g to units not-yet-treated at time T (i.e. G_i>T), with the pre-intervention time period set as time g-1. In OLS notation, we estimate:

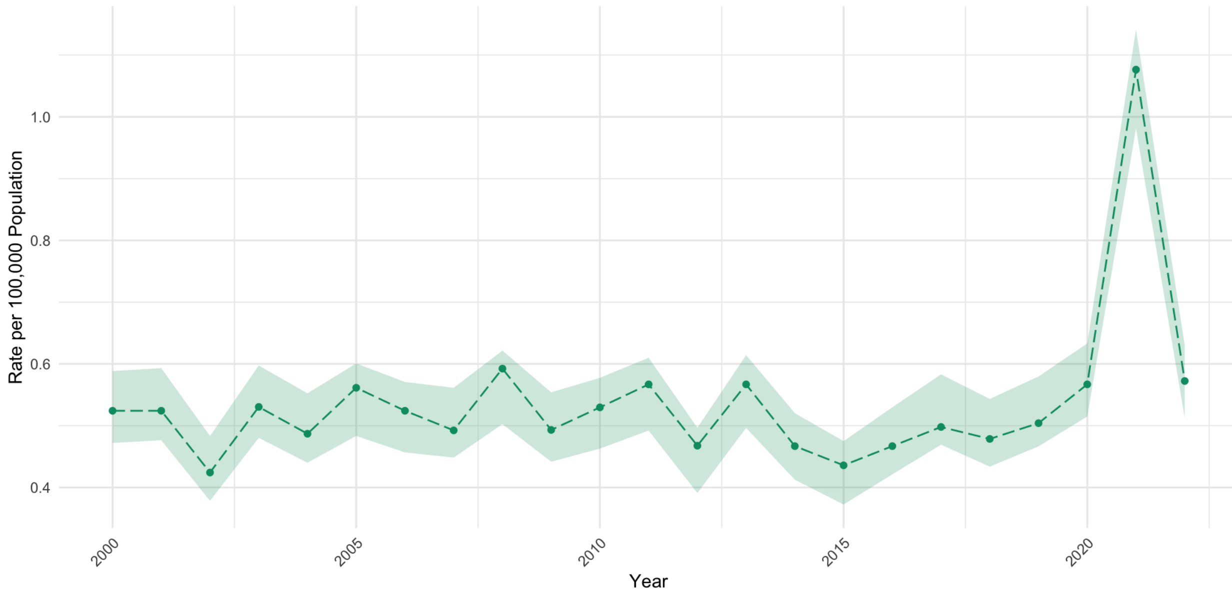
$$Y_{i,t}=\eta_i+\tau_t+ \delta_{g,T}\, I(G_i=g \;\&\; t=T) + \epsilon_{i,t} \qquad \text{(S1)}$$

weighting by births, where $Y_{g,t}$ is the outcome under study, η_i is a time fixed effect, τ_t is a time fixed effect, and $I(G_i=g \;\&\; t=T)$ indicates both that unit i is treated and time is equal to T. The regression includes only data for units with G_i=g and G_i>g (cohort g and not-yet-treated units) at times T and T-1. The parameter $\delta_{g,T}$ indicates the group-time ATT of interest.

Group-time ATTs were estimated from 1999 to 2023. We aggregate the group-time ATT at three levels, i.e. average the $\delta_{g,T}$ with weights proportional to group size, following the default implementation in did[1]: (1) the overall average treatment effect, calculated as the overall group-time average, (2) average treatment effect at different lengths of exposure to treatment (**Figure 2**A) and (3) average treatment effect at each calendar year (**Figure 2**B).[2]

Counterfactuals are presented in Figures 2C and 2D. Due to small numbers of treated or comparison units at the beginning and ends of the period, we used the overall group-time average to calculate the counterfactuals in 1999-2001 and 2017-2023 for maternal mortality and 1999-2002 and 2015-2023 for maternal mortality excluding cause unspecified.

eFigure. Rates of Age-Weighted Maternal Mortality Excluding Cause Unspecified by Year, 2000-2023



The yearly death rates are weighted by the distribution of mothers less than 35 and greater than or equal to 35 in 2000. The 2022 count is provisional. The 2023 count is provisional and partial; deaths in the first half of 2023 are doubled to approximate the yearly mortality. The 95% confidence intervals are shaded around the line.

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