BMJ Paediatrics Open

Preterm birth and stillbirth rates associated with socioeconomic disparities during COVID-19 pandemic: a population-based cross-sectional study

Laila Aboulatta,[1] Kaarina Kowalec,[1,2] Christine Leong,[1,3] Joseph A Delaney,[1,4] Jamie Falk,[1] Silvia Alessi-Severini,[1,5] Dan Chateau,[6] Qier Tan,[5] Katherine Kearns,[7] Christina Raimondi,[7] Christine Vaccaro,[1] Alekhya Lavu,[1] Lara Haidar,[1] Payam Peymani,[1] Sherif Eltonsy [1,8]

To cite: Aboulatta L, Kowalec K, Leong C, *et al*. Preterm birth and stillbirth rates associated with socioeconomic disparities during COVID-19 pandemic: a population-based cross-sectional study. *BMJ Paediatrics Open* 2023;**7**:e001686. doi:10.1136/bmjpo-2022-001686

► Additional supplemental material is published online only. To view, please visit the journal online (http://dx.doi.org/10.1136/bmjpo-2022-001686).

Received 27 September 2022
Accepted 7 February 2023

For numbered affiliations see end of article.

Correspondence to
Dr Sherif Eltonsy; Sherif.Eltonsy@umanitoba.ca

ABSTRACT

Background Conflicting evidence exists on the impact of the COVID-19 pandemic restrictions on preterm birth (PTB) and stillbirth rates. We aimed to evaluate changes in PTB and stillbirth rates before and during the pandemic period and assess the potential effect modification of socioeconomic status (SES).

Methods Using the linked administrative health databases from Manitoba, Canada, we conducted a cross-sectional study among all pregnant women, comparing 3.5 years pre-pandemic (1 October 2016 to 29 February 2020) to the first year of the pandemic (1 March 2020 to 31 March 2021). We used generalised linear models to assess the quarterly rates of PTB (<37 weeks) and stillbirths. We calculated the predicted trends based on pre-pandemic period data. Finally, we evaluated the PTB and stillbirth rates among lower and higher SES pregnant women (average annual household income) using subgroup analysis and interaction models.

Results We examined 70 931 pregnancies in Manitoba during the study period. The risk of PTB increased by 7.7% (95%CI 1.01 to 1.13) and stillbirths by 33% (95% CI 1.08 to 1.64) during the pandemic period. Following COVID-19 restrictions implemented in March 2020, there were increases in the quarterly rates of both PTB (immediate increase (β_2)=1.37; p=0.0247) and stillbirths (immediate increase (β_2)=0.12; p=0.4434). Among the lower income groups, the pandemic restrictions resulted in an immediate relative increase in PTB and stillbirth rates by 20.12% (immediate increase (β_2)=3.17; p=0.0057) and 27.19% (immediate increase (β_2)=0.48; p=0.0852). However, over the pandemic, the overall PTB rate significantly decreased as a rebound effect by 0.85% per quarter (p=0.0004), whereas the overall stillbirth rate did not decrease significantly (slope decrease (β_3) =−0.01; p=0.8296) compared with the pre-pandemic period. The quarterly rates during the pandemic among the higher income group decreased by 0.39% (p=0.1296) for PTB and increased by 0.07% (p=0.1565) for stillbirth. We observed an effect modification by SES for PTB rates (p=0.047).

Conclusion While the onset of COVID-19 pandemic restrictions was not associated with significant effects on stillbirth rates, we observed an immediate and rebound effect on PTB rates. The impact of COVID-19 on preterm birth was dependent on SES, with higher influence on families with lower SES. Further studies are needed to detect future trend changes during pandemic waves after 2021 and assess potential underlying mechanisms.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ COVID-19 restriction measures have been associated with either a decrease, increase or no change in the rate of preterm birth (PTB) and stillbirth.

⇒ Scarce evidence exists on the association between these changes and maternal socioeconomic status during the pandemic.

WHAT THIS STUDY ADDS

⇒ This study highlights that the impact of the restrictions on PTB differed by maternal socioeconomic status.

⇒ We observed an increase in PTB rates among the lower income group followed by return to pre-pandemic averages within the following three quarters.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our findings provide an additional insight into the complex aetiologies that can be attributed to the increased incidence of preterm and stillbirth deliveries, revealing the differential impacts of pandemic restrictions.

INTRODUCTION

Preterm birth (PTB) is the leading cause of neonatal deaths and can cause long-term complications among the survived infants.[1–3] According to WHO, about 2 million stillbirths occur each year, and 40% of these stillbirths occur during childbirth.[4] Initially, restrictions related to the COVID-19 pandemic, such as virtual visits and social distancing, were considered the only available and effective means of preventing and reducing the spread of the

virus,[5] but influenced access to in-person health services, which can negatively impact maternal and neonatal health.[6 7] The reduced access to prenatal services created a substantial obstacle for pregnant women to receive optimal prenatal care, thereby potentially increasing the risk of adverse pregnancy outcomes.[7–11] In fact, the implemented pandemic measures are believed to have exacerbated the inequalities already present because of various social determinants of health across many countries.[12 13] Pre-pandemic research suggests that pregnant women with lower socioeconomic status (SES) are at higher risk for inadequate prenatal care, leading to an increased risk of adverse pregnancy outcomes, including PTB and stillbirth.[14–16]

Provincial and local governments across Canada have cooperated to impose measures to reduce the COVID-19 burden.[17] Studies in two Canadian provinces, Ontario and Alberta, examined the influence of the COVID-19 first wave (~March 2020) lockdown measures on perinatal health outcomes and found non-significant changes in both PTB and stillbirth rates compared with pre-pandemic period.[18–21] In Manitoba, different pandemic strategies were implemented affecting antenatal care services which could have influenced the health of pregnant women and their infants.[22–27] The policy responses adopted in Manitoba and the low rates of COVID-19 infection provide a unique opportunity to serve as a natural experiment to determine their effects on perinatal outcomes.[28] We, therefore, aimed to assess the impact of the pandemic restrictions implemented during the first and second waves in Manitoba on the incidence of PTB and stillbirth. In addition, we aimed to evaluate if the effect of the COVID-19 restrictions was modified by the maternal SES.

METHODS

Data source

We used data from the Manitoba Population Research Data Repository at the Manitoba Centre of Health Policy (MCHP) to conduct the study. The Repository is a secure data-rich environment containing person-level health information on virtually the entire population of Manitoba.[29] All records are de-identified and linkable at individual and family levels using a scrambled health number. The validity and reliability of the MCHP Repository for epidemiological studies has been previously reported.[30–32] We used the following databases: (1) the Manitoba Health Insurance Registry (date of birth, sex); (2) hospital abstracts and physician visits (to identify the perinatal outcomes of interest); (3) Drug Program Information Network (prescription drug data to identify comorbidities); (4) Manitoba laboratories (for COVID-19 testing data); (5) postal codes from the Canada Census (to distinguish urban from rural regions); (6) census data for income quintiles based on ranges of mean household income, and grouped into five categories with each quintile assigned to approximately 20% of the population (quintile 1 (mean income=$C17 910) to quintile 5 (mean income=$46 230)).

Study design and population

We conducted a population-based cross-sectional study using the linked data from Manitoba to create a large, pregnancy cohort pre-COVID-19 and during COVID-19. All pregnancies (live birth or stillbirth) in Manitoba were included in the final cohort during the pre-pandemic period (Q4-2016 to Q1-2020) and during the pandemic period (Q2-2020 to Q1-2021). The delivery date was defined as the date that a procedure code of delivery was recorded in the database. Maternal age at delivery, pre-existing comorbid diseases (pre-validated definitions of asthma,[33] diabetes[34] and hypertension[35]), income (quintiles),[36] parity (primipara and multipara) and residence (urban and rural) were extracted from the database. As a proxy for the maternal SES, we used the pre-validated classification based on the median neighbourhood income quintile: lower income (individuals in the lowest and second lowest median neighbourhood income quintile), higher income (individuals residing in the neighbourhoods with the three highest median neighbourhood income quintiles) and income unknown (individuals who cannot be assigned a neighbourhood income from the census data—this category includes individuals residing in facilities such as personal care homes, psychiatric facilities, prisons or wards of the Public Trustee and Child and Family services).[37]

Exposure and outcomes

Pregnant women exposed to the pandemic restrictions during the first and second waves between 1 March 2020 and 31 March 2021 were compared with those who were pregnant before the pandemic period. A strict mitigation strategy was implemented in Manitoba from 13 March 2020 (first wave) followed by a subsequent ease of some restrictions between June and July 2020. More restrictions were applied in August 2020, with Manitoba meeting their peak lockdown measures during the second wave.[25 38] However, we did not investigate the differences in the effect of exposure to pandemic restrictions by trimester. Preterm birth was defined as a live birth where an infant is born at less than 37 weeks' gestation,[39] while stillbirth was identified as a fetal death with a gestation of 20 weeks or greater.[40]

Statistical analysis

We examined pregnant women demographics such as age (≤19 years, 20–34 years and >35 years), area of residence, income and comorbidities that were described before and during the pandemic. We estimated the quarterly rates of both preterm birth which was defined as the number of preterm deliveries within each quarter during the study period with the total number of births during the quarter used as denominator. Stillbirth rate was defined as the number of stillbirths within each quarter during the study period with the total number of births during

the quarter used as denominator. We chose Q2-2020 as the intervention point for the COVID-19 period since the restriction measures started to impact clinical practice in Manitoba by the end of Q1-2020 (March 2020). We calculated the relative risk (RR) and 95% CI for the preterm births and stillbirth rates for the overall pregnancies and by subgroups.

The effect of restriction measures on the preterm birth and stillbirth rates was evaluated using interrupted time series analysis through generalised linear models, to assess both the immediate impact and rebound effect of the COVID-19 pandemic on the quarterly outcome rates within three subgroups: (1) overall incidence, (2) among lower income group and (3) among higher income group.[41] The immediate impact was estimated by the immediate change in level from pre-COVID-19 to post-COVID-19 interruption. Relative percentage change was examined, which is calculated as the relative change in the percentage of rates between Q1-2020 and Q2-2020. The rebound effect was estimated using the change in slope from pre-interruption to post-interruption in the quarterly PTB and stillbirth rates. If an interruption or intervention (COVID-19) has an effect on the outcomes, then a change in level (β2) and/or slope (β3) should be detected between pre-phase and post-phase.[42] In addition, we used generalised linear models to test for the potential effect modification by maternal SES using multiplicative interactions.[43] Sensitivity analysis was conducted, including monthly rates of preterm birth and stillbirth. To assess bias due to seasonal variability that is known to affect pregnancy outcomes, we conducted the analysis using ARIMA models, accounting for autocorrelation between consecutive quarterly observations.[44 45] We also generated forecast models using the autoregressive moving average analysis to compare the observed quarterly PTB and stillbirth rates during the pandemic with the counterfactual expected rates in the absence of the pandemic. We opted to use this method as it provides superior prediction accuracy (using autocorrelations and moving averages over residual errors) and comprehension of the data patterns. Analyses were conducted using SAS V.9.4 (SAS Institute).

There was no patient or public involvement in this study

RESULTS

During the study period, we included 70 931 pregnant women: 54 306 in the pre-pandemic period and 16 625 during the pandemic period. Of the pregnant women included, the mean age was 29.4 years (SD 5.61) pre-pandemic and 29.7 years (SD 5.56) during the pandemic and over half lived in urban areas in both groups. Twenty five per cent of the pregnancies were among women in

Table 1 Maternal characteristics before and during COVID-19 periods in the Canadian province of Manitoba

Characteristics	Pre-COVID-19 period n=54 306	During COVID-19 period n=16 625	P value
Age, n (%)			
≤19	2442 (4.50)	664 (3.99)	<0.0001
20–34	41 762 (76.91)	12 664 (76.06)	
≥35	10 094 (18.59)	3316 (19.95)	
Parity, n (%)			0.9381
Primipara	36 974 (68.10)	11 326 (68.13)	
Multipara	17 321 (31.90)	5298 (31.87)	
Income, n (%)			0.1441
Quintile 1 (lowest income)	14 486 (24.15)	4352 (26.17)	
Quintile 2	11 759 (24.15)	4013 (24.13)	
Quintile 3	9916 (18.26)	3017 (18.15)	
Quintile 4	9883 (18.2)	3022 (18.18)	
Quintile 5 (highest income)	8140 (14.99)	2500 (15.04)	
Unknown	122 (0.22)	49 (0.29)	
Residence, n (%)			0.0094
Rural	23 814 (43.87)	7480 (45.01)	
Urban	30 474 (56.13)	9139 (54.99)	
Comorbid diseases, n (%)			
Asthma	13 557 (24.96)	4043 (24.32)	0.0919
Hypertension*	4861 (8.95)	1461 (8.79)	0.5183
Diabetes	3372 (6.21)	1084 (6.52)	0.1481

*Hypertension in those aged 19 and older.

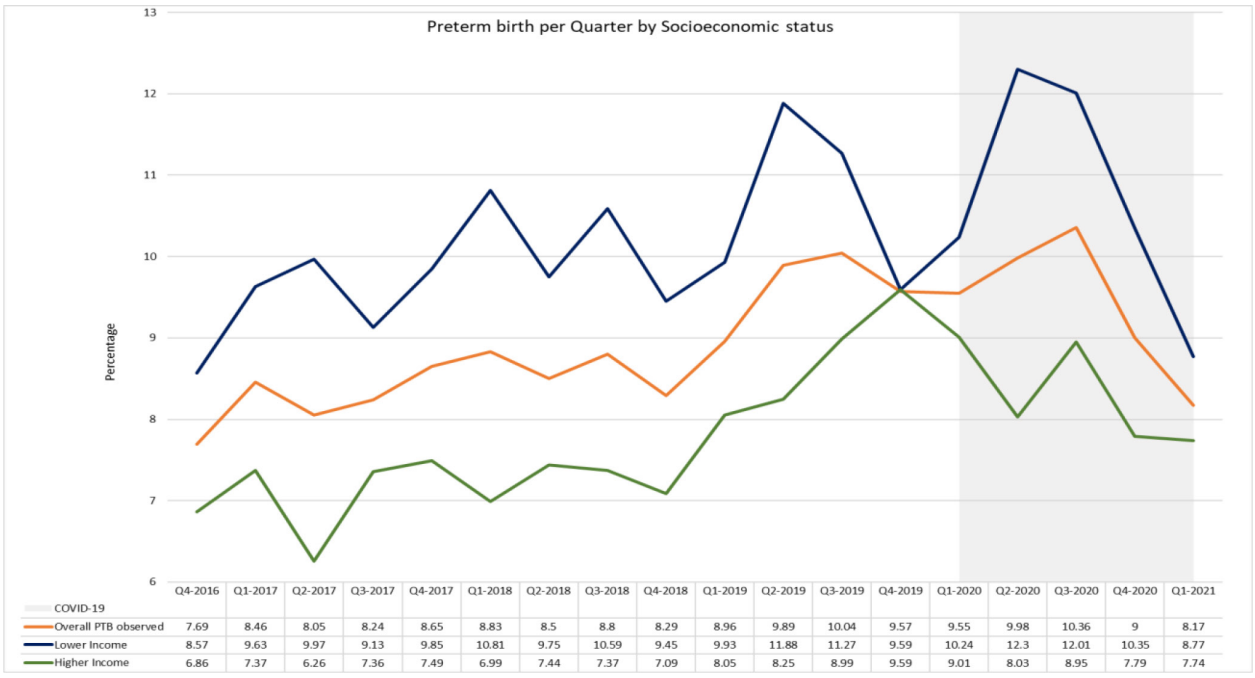


Figure 1 Observed preterm birth (PTB) rates among lower income, higher income and all pregnant women in Manitoba from Q4-2016 until Q1-2021.

the lowest income quintile, while 15% of pregnancies were among women in the highest quintile. Asthma (24%), hypertension (8%) and diabetes (6%) were the most common comorbidities in the pregnant women (table 1).

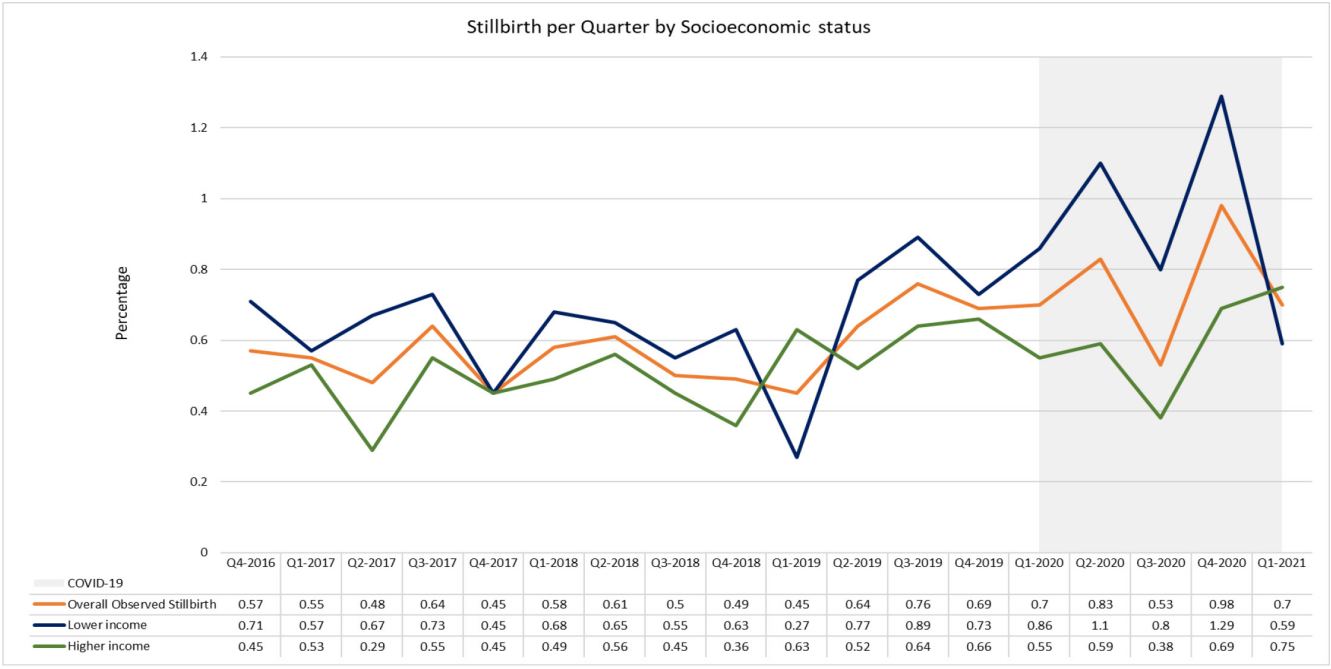
Preterm birth

Figure 1 illustrates the trends of the observed PTB rates during the study period. The average rates of PTB were 8.77% and 9.45% before and during the pandemic period, respectively, with a relative increase of 7.7% (95% CI 1.01 to 1.13). The implementation of mitigation measures was associated with a 4.5% relative increase in PTB rates (immediate increase (β_2)=1.37; p=0.0247). Furthermore, we observed a rebound decrease by 0.85% (p=0.0004) among the quarterly PTB rates (table 2).

Table 2 Preterm birth and stillbirth outcomes before and during the pandemic periods in the Canadian province of Manitoba

Outcomes	Pre-pandemic Q4-2016 to Q1-2020	Pandemic Q2-2020 to Q1-2021	Immediate change* Percentage change‡	Immediate change* Parameter estimate (β_2)	Immediate change* P value	Slope change† Parameter estimate (β_3)	Slope change† P value
Preterm birth, N (%)							
Overall preterm birth	4912 (8.83)	1439 (9.43)	4.50%	**1.37**	**0.0247**	**−0.85**	**0.0004**
Lower income‡	2707 (10.05)	806 (10.86)	20.12%	**3.17**	**0.0057**	**−1.33**	**0.0013**
Higher income§	2211 (7.72)	641 (8.13)	−12.20%	−0.33	0.6535	−0.39	0.1296
Unknown income¶	14 (13.73)	5 (10.72)	NA	NA	NA	NA	NA
Stillbirth, N (%)							
Overall stillbirth	323 (0.58)	118 (0.77)	18.57%	0.12	0.4434	−0.01	0.8296
Lower income§	177 (0.65)	70 (0.95)	27.91%	0.48	0.0852	−0.12	0.2189
Higher income¶	146 (0.51)	47 (0.60)	7.27%	−0.20	0.1714	0.07	0.1565
Unknown income**	0 (0)	1 (1.56)	NA	NA	NA	NA	NA

Significant results are in bold.
*Immediate change examines the change in level immediately after the onset of the pandemic in preterm birth (PTB) and stillbirth rates compared with pre-pandemic period.
†Slope change examines the change in slope during the pandemic in PTB and stillbirth rates compared with pre-pandemic period.
‡Percentage change=(percentage in $Q_2$2020 – percentage in $Q_1$2020)/percentage in $Q_1$2020 × 100.
§Lower income: pregnant women in the lowest and second lowest median neighbourhood income quintile.
¶Higher income: pregnant women residing in the neighbourhoods with the three highest median neighbourhood income quintiles.
**Unknown income: pregnant women who cannot be assigned a neighbourhood income from the census data.
NA, not available.



	Q4-2016	Q1-2017	Q2-2017	Q3-2017	Q4-2017	Q1-2018	Q2-2018	Q3-2018	Q4-2018	Q1-2019	Q2-2019	Q3-2019	Q4-2019	Q1-2020	Q2-2020	Q3-2020	Q4-2020	Q1-2021
COVID-19																		
Overall Observed Stillbirth	0.57	0.55	0.48	0.64	0.45	0.58	0.61	0.5	0.49	0.45	0.64	0.76	0.69	0.7	0.83	0.53	0.98	0.7
Lower income	0.71	0.57	0.67	0.73	0.45	0.68	0.65	0.55	0.63	0.27	0.77	0.89	0.73	0.86	1.1	0.8	1.29	0.59
Higher income	0.45	0.53	0.29	0.55	0.45	0.49	0.56	0.45	0.36	0.63	0.52	0.64	0.66	0.55	0.59	0.38	0.69	0.75

Figure 2 Observed stillbirth rates among lower income, higher income and all pregnant women in Manitoba from Q4-2016 until Q1-2021.

The risk of PTB deliveries during the pandemic have increased with a RR of 1.08 (95% CI 1.00 to 1.16) among the lower income group and RR of 1.05 (95% CI 0.97 to 1.15) among the higher income group. Before the pandemic period, we found a 30.2% relative difference between lower and higher income groups (10.05% vs 7.72%). In the lower income group, 10.86% of women had preterm delivery compared with 8.13% in the higher income group during the pandemic, with a relative difference of 33.6% (table 2).

Among pregnant women with lower income, the onset of pandemic measures was associated with a 20.2% relative increase in PTB rates (immediate increase (β_2)=3.17; p=0.0057), while a 12.2% relative reduction was observed among higher income women (immediate decrease (β_2)=−0.33; p=0.6535). Moreover, we observed a rebound decrease in the preterm deliveries among the lower income group (1.33% decrease quarterly; p=0.0013) (table 2). Online supplemental figure S1 shows the relative percentage change of preterm birth during the study period.

Stillbirth

Figure 2 demonstrates the trends of the observed stillbirth rates pre-pandemic and during the pandemic periods. The average rates of stillbirth were 0.58% and 0.77% before and during the pandemic period, respectively, with a relative increase of 33% (95% CI 1.08 to 1.64). Immediately after the onset of the pandemic, there was a relative 18.6% increase in the overall stillbirth rates (immediate increase (β_2)=0.12; p=0.4434). A minor non-significant rebound decrease among the quarterly stillbirth rates was observed (slope decrease (β_3)=−0.01, p=0.8296) (table 2).

The risk of stillbirths during the pandemic have increased with a RR of 1.46 (95% CI 1.11 to 1.93) among the lower income group and RR of 1.18 (95% CI 0.85 to 1.63) among the higher income group. Before the pandemic period, we found a 27.5% relative difference between lower and higher income groups, 0.65% versus 0.51%, respectively. Among pregnant women with lower income, the rate of stillbirth was 0.95% compared with 0.60% in the higher income group during the pandemic, with a relative difference of 58.3%. Within the income subgroups, the rates of stillbirth deliveries did not differ significantly between the pandemic and pre-pandemic periods (table 2). Online supplemental figure S2 shows the relative percentage change of stillbirth during the study period.

SES effect modification

We assessed the interaction between COVID-19 restrictions and income (as a proxy for SES) on the overall incidence of PTB and stillbirth. Our models suggested an effect modification by income for the overall incidence of PTB (p=0.047). Although there was an increase in stillbirth rates among the lower income group, the income effect modification was not significant (p=0.643, online supplemental table S1).

Sensitivity analysis

Examining the effect of restrictions using the monthly rates of PTB and stillbirth was conducted, which provided larger number of observation points to analyse. However, given the small numbers of monthly stillbirth rates in Manitoba, the analysis was not conducted. Monthly PTB rates analysis provided similar results to the quarterly rates (online supplemental table S2). Online

supplemental figures S3 and S4 illustrate the trends of the observed versus expected PTB and stillbirth rates during the study period. During the first quarter of 2021, the absolute differences in the observed and expected overall PTB rate was 2.05% compared with 1.89% and 1.64% among the lower and higher income groups, respectively. However, the absolute difference in the observed and expected stillbirth rates were 0.04%, 0.69% and 0.17% among the overall, lower income and higher income groups, respectively.

DISCUSSION

In this Canadian province-wide study, we observed a significant increase in the overall rates of PTB immediately after the onset of COVID-19 restrictions. The observed increase in the PTB rate could be considered clinically significant, followed by a return to pre-pandemic averages within the following three quarters. Such a trend was observed among stillbirths but was hardly detected due to the low sample size. We also observed a 20% relative increase in PTB rates among the lower income group immediately after the measures were applied. Such an impact was not observed within the higher SES group. Our data suggest that the pandemic restrictions had a rebound effect on the overall PTB rates, mostly attributed to the impact within the lower income group.

While the exact reasons for the observed increase followed by reversal to pre-pandemic level have yet to be determined, various social or behavioural changes during the pandemic lockdown may have contributed to the change in the overall PTB rates.[46] Our study shows that changes in PTB rates are inconsistent among pregnant women with different SES. Our results support the hypothesis that the higher income group has some social privilege as increased social support, reduced work-related or social stress, decreased anxiety, reduced exposure to environmental pollutants and better hygiene measures which can minimise the impact of the pandemic measures.[11 47–50] On the other hand, pandemic restrictions among the lower SES group resulted in financial insecurities, increased stress and mental health concerns, and changes in maternity care practice that affected maternal health leading to higher PTB rates.[7 19 51 52]

Evidence indicates that the COVID-19 pandemic and associated lockdown measures exacerbated existing social inequalities.[7 53] However, in a study published in the Netherlands,[47] no association between COVID-19 restrictions and adverse perinatal outcomes were observed while accounting for SES as an effect modifier. Caniglia *et al* showed a significant reduction in PTB rates post-lockdown period compared with during lockdown, highlighting that lockdown restrictions may have a delayed effect on adverse pregnancy outcomes.[54] In the largest city in the Canadian province of Alberta (Calgary), Alshaikh *et al* reported that during the first-wave lockdown, stillbirth and PTB rates remained unchanged; however, very preterm birth rate (<32 weeks of gestation) dropped significantly.[19] Three retrospective cohort studies, in the Canadian province of Ontario, examined the association between the pandemic first-wave and perinatal outcomes, and reported non-significant changes in PTB and stillbirth rates.[18 20 21] Differences between these studies and the current study may be attributable to differences in the analytical methods performed, the pandemic time frame examined and the pandemic measures implemented among the provinces. Our study assessed 12 months during the pandemic period (up to March 2021), whereas these studies examined the period until October and December 2020. In addition, previous studies used databases which covered only maternal and neonatal data until discharge, whereas the current study provides more generalisable results due to the use of a province-wide database that includes the entire Manitoban pregnant population without restrictions of insurance coverage. In addition, the effect modification by SES was not assessed in the aforementioned studies.[18–21]

In a meta-analysis of 36 studies, Yang *et al* found a non-significant reduction in the odds of PTB during the pandemic period in national studies (unadjusted OR 0.99, 95% CI 0.94 to 1.03); however, a significant reduction was observed in single-centre studies (unadjusted OR 0.99, 95% CI 0.86 to 0.94).[55] Moreover, there was no difference in stillbirth rates between pre-pandemic and pandemic periods in both single-centre and national studies.[55] In another meta-analysis of 17 studies, Vaccaro *et al* observed a significant association between lockdown restrictions and an increased risk of stillbirth (RR=1.33, 95% CI 1.04 to 1.69), but not preterm birth (RR=0.93, 95% CI 0.84 to 1.03).[56]

Our study has major strengths to mention. We used province-wide administrative health data which included the entire pregnant population in the province of Manitoba. Furthermore, we included 1 year of the pandemic period, thus facilitating the investigation of the association between COVID-19 restrictions and the examined outcomes. In addition, we used different model specifications to account for autocorrelation that could influence the study outcomes and we used interrupted time series analysis which minimised the impact of the measured and unmeasured confounding factors. The limitations of this study should also be acknowledged. We did not examine the influence of COVID-19 infection on the study outcomes; however, the number of reported COVID-19 positive pregnant women was small in relation to the total pregnancies in our cohort, and it is unlikely that viral infection would change our results.[46] Although we did not investigate variations across the different regions of Manitoba, the changes to maternal healthcare were implemented across the provincial healthcare system minimising any differential variability within the data. However, some rural regions and those of lower SES may have been differentially impacted during the pandemic compared with urban areas and larger cities. Given that pandemic restrictions disrupted the health systems and lifestyle of pregnant women, we

used interrupted time series analysis to assess the immediate and long-term (rebound) effect of the pandemic restrictions. We interpreted the immediate change (β_2) as representing a homogeneous group of newborns of deliveries in a span of 3 months (one quarter). As restrictions continue to impact perinatal healthcare, this might lead to additional cases of preterm/stillbirth, represented in a group of newborns experiencing those restrictions at varied pregnancy stages and periods, creating a rather heterogeneous group. However, we observed a rebound to pre-pandemic baseline levels through the change in slope results. Importantly, causal interpretation of restrictions cannot be inferred from this study, as women were not only exposed to restrictions but also to the virus and other factors—so results should be interpreted with caution. Moreover, we could not consider the following: births occurring outside of hospitals, maternal smoking and alcohol/substance use, and vaccination rates among pregnant women in Manitoba. We used quarterly rates for our main analysis, and monthly stillbirth rates analysis was not feasible. In a sensitivity analysis, monthly PTB rates showed similar results, although additional noise was introduced. The study power was limited at instances due to the short follow-up period; however, our sensitivity analysis supported the primary model's results.[57]

CONCLUSION

The initial implementation of COVID-19 restrictions was associated with an increase in the rates of preterm births, followed by reversion to the pre-COVID-19 level. The pandemic has revealed important maternal socioeconomic disparities, with significantly higher rates of PTB among lower income pregnant women. The restrictions did not coincide with significant changes in the stillbirth rates in Manitoba. Further studies are needed to monitor trend changes during subsequent pandemic waves and assess potential underlying mechanisms.

Author affiliations
[1]College of Pharmacy, Rady Faculty of Health Sciences, University of Manitoba, Winnipeg, Manitoba, Canada
[2]Department of Medical Epidemiology and Biostatistics, Karolinska Institutet, Stockholm, Sweden
[3]Department of Psychiatry, Rady Faculty of Health Sciences, University of Manitoba, Winnipeg, Manitoba, Canada
[4]Department of Epidemiology, University of Washington, Seattle, Washington, USA
[5]Manitoba Centre for Health Policy, University of Manitoba, Winnipeg, Manitoba, Canada
[6]College of Health and Medicine, Australian National University, Canberra, Australian Capital Territory, Australia
[7]Department of Family Medicine, College of Medicine, University of Manitoba, Winnipeg, Manitoba, Canada
[8]Children's Hospital Research Institute of Manitoba, Winnipeg, Manitoba, Canada

Acknowledgements The authors acknowledge the Manitoba Centre for Health Policy for use of data contained in the Manitoba Population Research Data Repository under project (HIPC#2020/2021-33). Data used in this study are from the Manitoba Population Research Data Repository housed at the Manitoba Centre for Health Policy, University of Manitoba and were derived from data provided by Manitoba Health.

Contributors SE, KK and LA conceptualised and designed the study, drafted the manuscript, carried out the initial analyses and interpretation, and reviewed and revised the manuscript. JAD, SA-S, JF, CL, DC, KK and CR contributed to study conception and design, and reviewed and critically revised the manuscript. QT assisted in data acquisition and data analyses, and critically revised the manuscript. PP, AL, LH and CV contributed to the study design, and reviewed and critically revised the manuscript. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work. SE is responsible for the overall content as the guarantor.

Funding This work was supported by a research grant from Research Manitoba.

Disclaimer The results and conclusions are those of the authors and no official endorsement by the Manitoba Centre for Health Policy, Manitoba Health or other data providers is intended or should be inferred.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data cannot be shared publicly because of privacy restrictions. Data are available from the University of Manitoba and MCHP Institutional Data Access/Ethics Committee (contact via https://umanitoba.ca/manitoba-centre-for-health-policy/) for researchers who meet the criteria for access to confidential data.

ORCID iD
Sherif Eltonsy http://orcid.org/0000-0002-0520-5406

REFERENCES

1 Lawn JE, Gravett MG, Nunes TM, *et al*. Global report on preterm birth and stillbirth (1 of 7): definitions, description of the burden and opportunities to improve data. *BMC Pregnancy Childbirth* 2010;10 Suppl 1:S1.
2 Lawn JE, Cousens S, Zupan J, *et al*. 4 million neonatal deaths: when? Where? Why? *Lancet* 2005;365:891–900.
3 Chawanpaiboon S, Vogel JP, Moller A-B, *et al*. Global, regional, and national estimates of levels of preterm birth in 2014: a systematic review and modelling analysis. *Lancet Glob Health* 2019;7:e37–46.
4 World Health Organization. Stillbirth. 2022. Available: https://www.who.int/health-topics/stillbirth#tab=tab_1
5 Honein MA, Christie A, Rose DA, *et al*. Summary of guidance for public health strategies to address high levels of community transmission of SARS-CoV-2 and related deaths, December 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:1860–7.
6 Kotlar B, Gerson E, Petrillo S, *et al*. The impact of the COVID-19 pandemic on maternal and perinatal health: a scoping review. *Reprod Health* 2021;18:10.
7 Kc A, Gurung R, Kinney MV, *et al*. Effect of the COVID-19 pandemic response on intrapartum care, stillbirth, and neonatal mortality outcomes in Nepal: a prospective observational study. *Lancet Glob Health* 2020;8:e1273–81.
8 Ravaldi C, Mosconi L, Crescioli G, *et al*. n.d. Are pregnant women satisfied with perinatal standards of care during COVID-19 pandemic? [Preprint]. *Public and Global Health*
9 Allotey J, Stallings E, Bonet M, *et al*. Clinical manifestations, risk factors, and maternal and perinatal outcomes of coronavirus disease

2019 in pregnancy: living systematic review and meta-analysis. *BMJ* 2020;370:m3320.
10 Knight M, Bunch K, Vousden N, *et al*. Characteristics and outcomes of pregnant women admitted to hospital with confirmed SARS-CoV-2 infection in UK: national population based cohort study. *BMJ* 2020;369:m2107.
11 Hedermann G, Hedley PL, Bækvad-Hansen M, *et al*. Danish premature birth rates during the COVID-19 lockdown. *Arch Dis Child Fetal Neonatal Ed* 2021;106:93–5.
12 Health inequity and the effects of COVID-19. 2020. Available: https://www.euro.who.int/en/health-topics/health-determinants/social-determinants/publications/2020/health-inequity-and-the-effects-of-covid19-2020
13 CDC. Health equity considerations and racial and ethnic minority groups. 2022. Available: https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/race-ethnicity.html
14 Kim MK, Lee SM, Bae S-H, *et al*. Socioeconomic status can affect pregnancy outcomes and complications, even with a universal healthcare system. *Int J Equity Health* 2018;17:2.
15 Luque-Fernandez MA, Thomas A, Gelaye B, *et al*. Secular trends in stillbirth by maternal socioeconomic status in spain 2007–15: a population-based study of 4 million births. *Eur J Public Health* 2019;29:1043–8.
16 Frey HA, Klebanoff MA. The epidemiology, etiology, and costs of preterm birth. *Semin Fetal Neonatal Med* 2016;21:68–73.
17 COVID-19 daily epidemiology update - Canada.ca. 2022. Available: https://health-infobase.canada.ca/covid-19/epidemiological-summary-covid-19-cases.html
18 Shah PS, Ye XY, Yang J, *et al*. Preterm birth and stillbirth rates during the COVID-19 pandemic: a population-based cohort study. *CMAJ* 2021;193:E1164–72.
19 Alshaikh B, Cheung PY, Soliman N, *et al*. Impact of lockdown measures during COVID-19 pandemic on pregnancy and preterm birth. *Am J Perinatol* 2022;39:329–36.
20 Roberts NF, Sprague AE, Taljaard M, *et al*. Maternal-newborn health system changes and outcomes in Ontario, Canada, during wave 1 of the COVID-19 pandemic—a retrospective study. *J Obstet Gynaecol Can* 2022;44:664–74.
21 Simpson AN, Snelgrove JW, Sutradhar R, *et al*. Perinatal outcomes during the COVID-19 pandemic in Ontario, Canada. *JAMA Netw Open* 2021;4:e2110104.
22 Province of Manitoba. Pandemic response system. 2022. Available: https://www.gov.mb.ca/covid19/prs/index.html
23 Factsheet Public Health Manitoba. Pregnancy, birthing and bringing baby home what can I do to protect myself against COVID-19? What can I expect at the hospital for labour and delivery? 2021: 1–4. Available: https://manitoba.ca/asset_library/en/covid/factsheet_pregnancy.pdf
24 Money D, Yudin M, Watson H, *et al*. The Society of Obstetricians and Gynaecologists of Canada. Committee Opinion No. 400: COVID-19 and pregnancy; 2020.
25 Aboulatta L, Kowalec K, Delaney J, *et al*. Trends of COVID-19 incidence in Manitoba and public health measures: March 2020 to February 2022. *BMC Res Notes* 2022;15.
26 Epidemiological summary of COVID-19 cases in Canada - Canada.ca. 2021. Available: https://health-infobase.canada.ca/covid-19/epidemiological-summary-covid-19-cases.html
27 Ontario agency for health protection and promotion (Public Health Ontario). Epidemiologic summary: COVID-19 in Ontario - January 15, 2020 to May 8, 2020; 2020. 18.
28 Been JV, Sheikh A. COVID-19 must catalyse key global natural experiments. *J Glob Health* 2020;10:010104.
29 University of Manitoba. The Manitoba Population Research Data Repository | Manitoba Centre for Health Policy. 2022. Available: https://umanitoba.ca/manitoba-centre-for-health-policy/data-repository
30 Kozyrskyj AL, Mustard CA. Validation of an electronic, population-based prescription database. *Ann Pharmacother* 1998;32:1152–7.
31 Roos LL Jr, Roos NP, Cageorge SM, *et al*. How good are the data? Reliability of one health care data bank. *Med Care* 1982;20:266–76.
32 Roos LL, Mustard CA, Nicol JP, *et al*. Registries and administrative data: organization and accuracy. *Med Care* 1993;31:201–12.
33 University of Manitoba, Max Rady College of Medicine. Term: asthma | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=102278
34 University of Manitoba, Max Rady College of Medicine. Concept: diabetes - measuring prevalence | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewConcept.php?conceptID=1085
35 University of Manitoba, Max Rady College of Medicine. Term: hypertension prevalence | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=104903
36 University of Manitoba, Max Rady College of Medicine. Term: income quintiles / income quintile | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=102882
37 University of Manitoba, Max Rady College of Medicine. Term: socio-economic status (SES) | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=103590#a_references
38 Bank of Canada. COVID-19 stringency index. 2022. Available: https://www.bankofcanada.ca/markets/market-operations-liquidity-provision/covid-19-actions-support-economy-financial-system/covid-19-stringency-index/
39 University of Manitoba, Max Rady College of Medicine. Term: preterm birth | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=103933
40 University of Manitoba, Max Rady College of Medicine. Term: stillbirth | MCHP concept dictionary and glossary for population-based research. 2022. Available: http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=103939
41 Schaffer AL, Dobbins TA, Pearson SA. Interrupted time series analysis using autoregressive integrated moving average (ARIMA) models: a guide for evaluating large-scale health interventions. *BMC Med Res Methodol* 2021;21:58.
42 Penfold RB, Zhang F. Use of interrupted time series analysis in evaluating health care quality improvements. *Acad Pediatr* 2013;13:S38–44.
43 Braumoeller BF. Hypothesis testing and multiplicative interaction terms. *Int Org* 2004;58:807–20.
44 Bernal JL, Cummins S, Gasparrini A. Interrupted time series regression for the evaluation of public health interventions: a tutorial. *Int J Epidemiol* 2017;46:348–55.
45 Darrow LA, Strickland MJ, Klein M, *et al*. Seasonality of birth and implications for temporal studies of preterm birth. *Epidemiology* 2009;20:699–706.
46 Money DD, Gynecology PO. Canadian surveillance of Covid-19 in pregnancy: epidemiology, maternal and infant outcomes Report #4: released June 3. In: *Matern Infant Outcomes Five Can Prov* . 2021: Box 42. 1–15. Available: www.ridprogram.med.ubc.ca
47 Been JV, Burgos Ochoa L, Bertens LCM, *et al*. Impact of COVID-19 mitigation measures on the incidence of preterm birth: a national quasi-experimental study. *Lancet Public Health* 2020;5:e604–11.
48 Gallo LA, Gallo TF, Borg DJ, *et al*. n.d. Preterm birth rates in a large tertiary australian maternity centre during COVID-19 mitigation measures [Preprint]. *Obstet Gynecol*
49 Wheeler S, Maxson P, Truong T, *et al*. Psychosocial stress and preterm birth: the impact of parity and race. *Matern Child Health J* 2018;22:1430–5.
50 Kramer MS, Lydon J, Séguin L, *et al*. Stress pathways to spontaneous preterm birth: the role of stressors, psychological distress, and stress hormones. *Am J Epidemiol* 2009;169:1319–26.
51 Lebel C, Mackinnon A, Bagshawe M, *et al*. Elevated depression and anxiety symptoms among pregnant individuals during the COVID-19 pandemic [published correction appears in J Affect Disord. 2021 Jan 15;279:377-379]. *J Affect Disord J* 2020;277:5–13.
52 Vindegaard N, Benros ME. COVID-19 pandemic and mental health consequences: systematic review of the current evidence. *Brain Behav Immun* 2020;89:531–42.
53 Shakespeare C, Dube H, Moyo S, *et al*. Resilience and vulnerability of maternity services in Zimbabwe: a comparative analysis of the effect of COVID-19 and lockdown control measures on maternal and perinatal outcomes, a single-centre cross-sectional study at Mpilo Central Hospital. *BMC Pregnancy Childbirth* 2021;21:416.
54 Caniglia EC, Magosi LE, Zash R, *et al*. Modest reduction in adverse birth outcomes following the COVID-19 lockdown. *Am J Obstet Gynecol* 2021;224:615.
55 Yang J, D'Souza R, Kharrat A, *et al*. COVID-19 pandemic and population-level pregnancy and neonatal outcomes: a living systematic review and meta-analysis. *Acta Obstet Gynecol Scand* 2021;100:1756–70.
56 Vaccaro C, Mahmoud F, Aboulatta L, *et al*. The impact of COVID-19 first wave national lockdowns on perinatal outcomes: a rapid review and meta-analysis. *BMC Pregnancy Childbirth* 2021;21:676.
57 Abeysinghe T, Balasooriya U, Tsui A. Small-sample forecasting regression or ARIMA models? *J Quant Econ* 2003;1:103–13.