

Temporal trends and determinants of COVID-19 vaccine coverage and series initiation during pregnancy in Ontario, Canada, December 2020 to December 2021: A population-based retrospective cohort study



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ABSTRACT

Background: Population-based COVID-19 vaccine coverage estimates among pregnant individuals are limited. We assessed temporal patterns in vaccine coverage (≥ 1 dose before or during pregnancy) and evaluated factors associated with vaccine series initiation (receiving dose 1 during pregnancy) in Ontario, Canada.

Methods: We linked the provincial birth registry with COVID-19 vaccination records from December 14, 2020 to December 31, 2021 and assessed coverage rates among all pregnant individuals by month, age, and neighborhood sociodemographic characteristics. Among individuals who gave birth since April 2021—when pregnant people were prioritized for vaccination—we assessed associations between sociodemographic, behavioral, and pregnancy-related factors with vaccine series initiation using multi-variable regression to estimate adjusted risk ratios (aRR) and risk differences (aRD) with 95% confidence intervals (CI).

Results: Among 221,190 pregnant individuals, vaccine coverage increased to 71.2% by December 2021. Gaps in coverage across categories of age and sociodemographic characteristics decreased over time,

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but did not disappear. Lower vaccine series initiation was associated with lower age (<25 vs. 30–34 years: aRR 0.53, 95%CI 0.51–0.56), smoking (vs. non-smoking: 0.64, 0.61–0.67), no first trimester prenatal care visit (vs. visit: 0.80, 0.77–0.84), and residing in neighborhoods with the lowest income (vs. highest: 0.69, 0.67–0.71). Vaccine series initiation was marginally higher among individuals with pre-existing medical conditions (vs. no conditions: 1.07, 1.04–1.10).

Conclusions: COVID-19 vaccine coverage among pregnant individuals remained lower than in the general population, and there was lower vaccine initiation by multiple characteristics.

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1. Introduction

COVID-19 is associated with a higher risk of severe illness in pregnant individuals than in similarly aged non-pregnant females [1], and with a higher risk of adverse birth outcomes, compared with uninfected pregnant individuals [2]. After COVID-19 vaccines became available in late 2020, many countries adopted recommendations for COVID-19 vaccination during pregnancy [3]. Vaccination during pregnancy has been found to provide similarly effective protection against COVID-19 as in non-pregnant people [4,5], and reduce the risk of COVID-19 infection and hospitalization in young infants [6–8]. Despite these benefits, and increasing evidence that COVID-19 vaccination during pregnancy is not associated with increased risk of adverse outcomes such as spontaneous abortion, preterm birth, stillbirth, postpartum hemorrhage, low neonatal Apgar scores, or neonatal intensive care unit admission [9–15], vaccine coverage has been lower in pregnant individuals in some (e.g., United States [U.S.] [16] and Scotland [17]), but not all (e.g., Sweden and Norway [18]), countries compared to the female population of reproductive age.

Similar to other countries [3], recommendations for COVID-19 vaccination during pregnancy in Canada have changed over time. Initially in late 2020, the National Advisory Committee on Immunization (NACI) advised that pregnant people could be offered COVID-19 vaccination—with informed consent—if they were in an eligible priority group, but otherwise it was not recommended [19] due to the lack of pregnancy-specific safety data resulting from exclusion of pregnant individuals from pre-licensure clinical trials of COVID-19 vaccines [20]. This policy became more permissive over the ensuing months and by May 28, 2021, NACI recommended that a COVID-19 vaccine series should be offered to pregnant people in the authorized age group [21]. In Ontario, Canada, pregnant people were prioritized for vaccination in late April 2021 [22]; due to a limited supply of vaccines through the first 3–4 months of 2021, the vaccination program had not yet expanded to the general adult population by that time. On December 15, 2021, all adults over 18 years of age, including pregnant people, became eligible for a COVID-19 booster dose [23]. In this population-based study in Ontario, we assessed temporal patterns in COVID-19 vaccine coverage among all pregnant people over the first year of the COVID-19 vaccination program, and evaluated factors associated with COVID-19 vaccine series initiation during pregnancy from April 2021, when pregnant people were prioritized for COVID-19 vaccination in the province [22].

2. Methods

2.1. Study design and data sources

We conducted a population-based retrospective cohort study of all pregnant individuals in Ontario, Canada between December 14, 2020 (when the provincial COVID-19 vaccination program began) and December 31, 2021. Data from Ontario's birth registry (<https://www.bornontario.ca>) were used to identify the study pop-

ulation—the registry collects information on the maternal-newborn population from hospitals, midwifery practice groups, and prenatal screening laboratories across the province [24]. Prenatal screening records from hospital- and community-based laboratories and ultrasound clinics are received on a weekly basis; approximately 70% of pregnant individuals in Ontario undergo prenatal screening [25]. After pregnancy completion, integrated maternal-newborn records for births of at least 500 g or ≥ 20 weeks' gestation are transferred to the registry where they are automatically linked with any corresponding prenatal screening records for the index pregnancy [24]. Limited information is available from prenatal screening records alone (maternal age, estimated date of birth, and postal code which is used to obtain area-based socioeconomic variables), while detailed information on maternal demographics, health behaviors, pre-existing health conditions, obstetric complications, and birth outcomes is available from completed birth records.

We deterministically linked birth records for completed pregnancies during the study period with the provincial COVID-19 immunization database, COVaxON, which contains information for all COVID-19 vaccines administered, regardless of delivery site or provider. We additionally linked prenatal screening records for individuals still pregnant as of December 31, 2021 to the COVaxON database, so that ongoing pregnancies could be used for coverage estimates among all pregnant people. Residential postal codes were used to link the study population to area-based socioeconomic information from Statistics Canada's 2016 Census (the most recent Census data available when this study was conducted) and the Ontario Marginalization Index [26]. Additional information on data sources is provided in Table S1.

2.2. Study population

Ontario is Canada's largest province with publicly-funded health care and approximately 140,000 births each year. To assess temporal patterns in COVID-19 vaccine coverage (i.e., having received at least one dose of a COVID-19 vaccine before or during pregnancy) among all individuals who were pregnant at any point during the study period, we included all completed pregnancies from December 14, 2020 to December 31, 2021, and those pregnancies still ongoing as of December 31, 2021.

To evaluate factors associated with COVID-19 vaccine series initiation during pregnancy, we excluded ongoing pregnancies due to limited information available on the prenatal screening records from which the ongoing pregnancies are identified. We also excluded births prior to April 1, 2021 because vaccination during pregnancy was limited before that time due to eligibility criteria in Ontario's vaccination program [22]. Records with documented gestational age <20 weeks and birth weight <500 g, or pregnancy termination were also excluded, as these events are not systematically captured in the registry. Finally, we excluded individuals who had received ≥ 1 dose of COVID-19 vaccine before pregnancy, since they were few in number during the study period (most individuals vaccinated prior to conception gave birth in 2022) and we

were specifically interested in vaccine series initiation during pregnancy.

2.3. Measures

2.3.1. Vaccination status and timing

Information on COVID-19 vaccine doses and dates of administration were obtained from the COVaxON database. We used date of birth combined with gestational age to estimate the date of conception for completed pregnancies, and used the estimated date of birth (predominantly from early ultrasound assessment) from prenatal screening records to derive the date of conception for ongoing pregnancies. We considered a vaccine dose to have been received during pregnancy if administered between the date of conception up to 1 day before birth, inclusive.

- **COVID-19 vaccine coverage** was defined as the proportion of all pregnant individuals in any given time interval who had received at least one dose of any COVID-19 vaccine by that point in time (dose 1, dose 2, or dose 3 [i.e., first booster dose]), either before or during pregnancy (i.e., to evaluate the proportion of individuals who were protected while pregnant).
- **COVID-19 vaccine series initiation** during pregnancy was defined as having received dose 1 of COVID-19 vaccine during pregnancy (i.e., to explore factors associated with initiating their vaccine series when pregnant).

2.3.2. Sociodemographic and pregnancy characteristics

The following information from the prenatal screening records was available for the entire study population (completed pregnancies and those still ongoing at the end of the study period): maternal age (<25, 25–29, 30–34, 35–39, ≥40 years), calendar timing of conception (before July 2020, August–September 2020, October–November 2020, December 2020 or later), and area-based measures from Statistics Canada's 2016 Census (rural/urban residence; neighborhood income quintile) and the Ontario Marginalization Index, which provides measures of social and economic marginalization in four dimensions represented by quintiles (residential instability, material deprivation, dependency, ethnic concentration) [26]. See Table S1 for additional information on study variables.

Additional variables from birth records were available for completed pregnancies: pre-pregnancy body mass index (<30/≥30 kg/m²); first prenatal visit in the first trimester (yes/no); self-reported smoking (yes/no) or substance use (yes/no) during pregnancy; public health unit region of residence (seven regions); pre-existing maternal health conditions (asthma, chronic hypertension, diabetes, heart disease, thyroid disease); parity (number of previous live and stillbirths: 0, 1 ≥ 2); and multiple birth (yes/no).

2.4. Statistical analysis

2.4.1. Temporal patterns in COVID-19 vaccine coverage among all pregnant individuals

We used heat maps to visually display calendar and gestational timing of COVID-19 vaccine doses received during pregnancy. Rates of COVID-19 vaccine coverage (≥1 dose of COVID-19 vaccine before or during pregnancy) among pregnant individuals—completed and ongoing pregnancies—were calculated by month. The denominator for each month was the number of individuals who were pregnant at any point during the month (i.e., any birth during the month or ongoing pregnancy as of the last day of the month). From April 1, 2021 to the end of the study—the time period reflecting widespread availability of COVID-19 vaccines to pregnant people—we further stratified monthly coverage rates by maternal age

and neighborhood quintiles for household income and material deprivation. We quantified gradients in coverage over time across these characteristics using unadjusted rate differences, with corresponding 95% confidence intervals (CI), contrasting <25 years of age vs. ≥40, lowest neighborhood income vs. highest, and highest material deprivation vs. lowest.

2.4.2. Factors associated with COVID-19 vaccine series initiation during pregnancy

Among individuals who gave birth between April 1 and December 31, 2021 and had not received any vaccine doses prior to pregnancy, we computed unadjusted rates of COVID-19 vaccine series initiation during pregnancy by maternal sociodemographic factors, health behaviors, pre-existing health conditions, and pregnancy characteristics. Associations between these factors and vaccine series initiation were assessed using log Poisson generalized linear models with robust error estimation to produce rate ratios (RR) with 95% confidence intervals (CI). To compute rate differences (RD), we used a modified least squares approach with a robust variance estimator, implemented using the 'GLIMMIX' procedure in SAS Version 9.4 (SAS Institute Inc, Cary, NC). Adjusted models included maternal age (continuous), week of conception (categorical), neighborhood income quintile (quintiles 1–5), rural vs. urban residence, and public health unit region of residence. Multiple imputation was used to address missing covariate values (variables with missing information are shown in Table S2). We used a fully conditional specification to generate five multiple imputation datasets using the 'MI' procedure; these datasets were used in all regression models to produce coefficients and standard errors, which were combined using the 'MIANALYZE' procedure.

2.5. Ethical approval.

This study received ethical approval from the Children's Hospital of Eastern Ontario Research Ethics Board.

3. Results

There were 143,133 completed pregnancies and 78,057 ongoing pregnancies (still pregnant as of December 31, 2021 or birth record not yet transferred to the birth registry), for a total of 221,190 individuals who were pregnant during the study period (Fig. 1). Across the entire time period, 81,104 (36.7%) individuals received at least one dose of COVID-19 vaccine during pregnancy (Table S3). Fig. 2 displays the temporal and gestational timing of the first COVID-19 vaccination received during pregnancy (i.e., dose 1, dose 2, or dose 3). Following an initial cluster of vaccinations among pregnant individuals in January 2021, the most intense periods of vaccinations during pregnancy occurred from late April to early June 2021, after pregnancy was prioritized, and in December 2021, when all adults ≥18 years became eligible for a booster dose. Among completed pregnancies, the majority of first doses received during pregnancy (whether dose 1, dose 2, or dose 3) occurred in the second and third trimester, whereas among ongoing pregnancies, the largest number of first doses was administered at earlier gestational ages, especially during the first trimester (Figure S1).

3.1. Temporal patterns in COVID-19 vaccine coverage

Among all 221,190 individuals who were pregnant at any point between December 14, 2020 and December 31, 2021, vaccine coverage (≥1 dose before or during pregnancy) increased from 0.03% to 71.2% by December 2021 (Fig. 3 and Table S4). Among pregnant individuals in the month of December 2021, 2.8% had only received

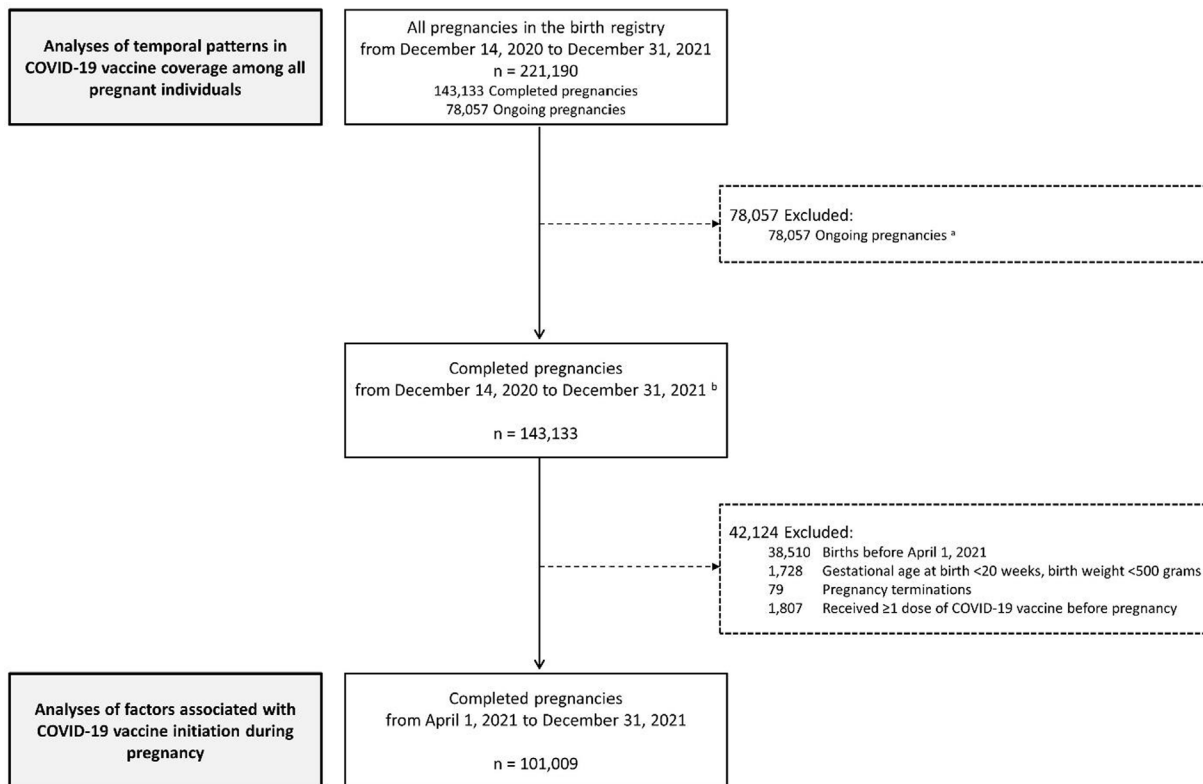


Fig. 1. Study flow diagram. ^aOngoing pregnancies comprised those that were ongoing as of December 31, 2021 (n = 56,163) and those with an estimated date of birth before December 31, 2021, but the birth record had not yet been transferred to the birth registry (n = 21,894). ^bBirths that already occurred and the birth record had been transferred to the birth registry.

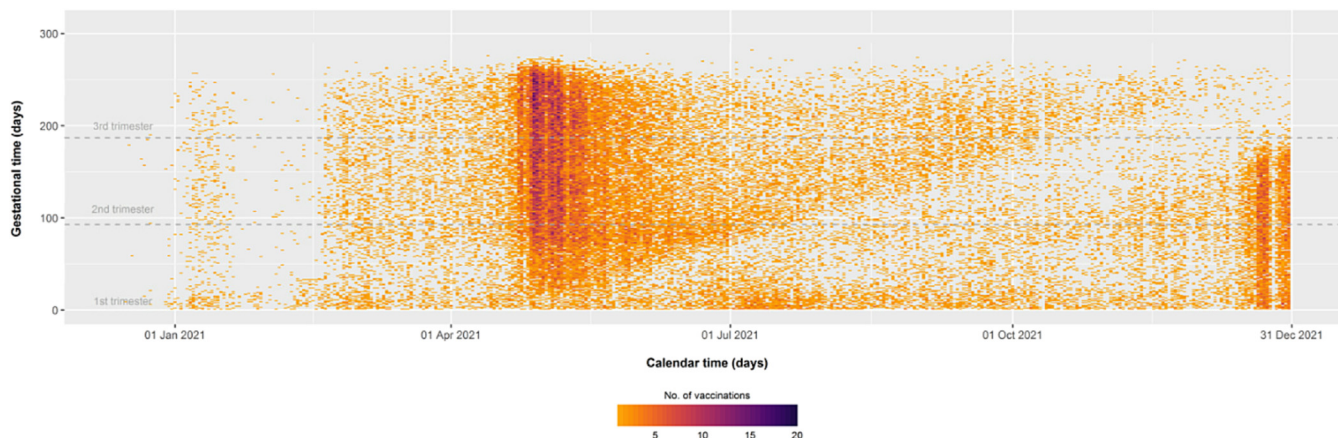


Fig. 2. Heat map of daily number of first COVID-19 vaccine doses administered during pregnancy by calendar time (x-axis) and gestational time (y-axis), December 14, 2020 to December 31, 2021 ^{a, b, c}

^aIncludes vaccinations administered during pregnancy among all pregnant individuals (i.e., completed pregnancies, as well as those that were still ongoing as of December 31, 2021; records with an estimated date of birth before December 31, 2021 for which the birth record had not yet been transferred to the birth registry were grouped with the completed pregnancies in the heat map). Individual heat maps for completed pregnancies and ongoing pregnancies can be found in Figure S1. ^bHeat map displays the first dose of COVID-19 vaccine that was received during pregnancy (i.e., dose 1, dose 2, or dose 3); 81,104 individuals received ≥ 1 dose of COVID-19 vaccine during pregnancy. Individual heat maps for each dose received during pregnancy can be found in Figure S1. ^cOn December 14, 2020 (beginning of Ontario’s COVID-19 vaccination program), pregnant people could be offered COVID-19 vaccination—with informed consent—if they were in an eligible early priority group, but otherwise it was initially not recommended during pregnancy. Pregnant people were prioritized within Ontario’s vaccination program in late April 2021. On December 15, 2021, all adults over 18 years of age, including pregnant people, became eligible to receive a COVID-19 booster dose.

dose 1 by that point, 55.9% had received doses 1 and 2, and 12.5% had received three doses.

Between April and December 2021, large differences in vaccine coverage were noted by maternal age, neighborhood income quintile, and neighborhood quintile of material deprivation (Fig. 4).

Among individuals who were pregnant in April 2021, coverage was initially 13 percentage points lower among those <25 years of age compared with those ≥ 40 years of age (5.1% vs. 18.3%, respectively; Fig. 4A and B, Table S5), but the gap increased to 26 percentage points in May. The difference in coverage between

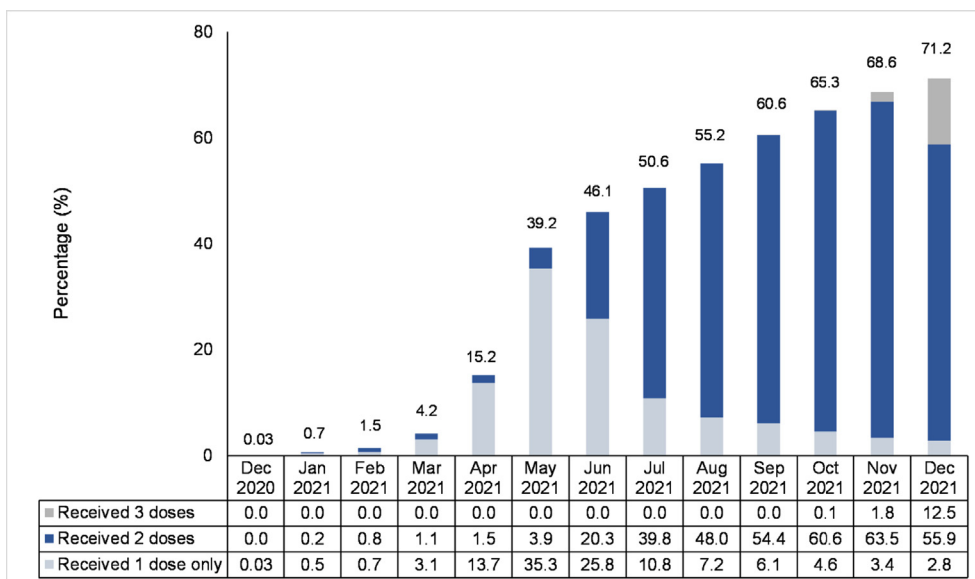


Fig. 3. Temporal trends in rates of COVID-19 vaccine coverage (≥ 1 dose of COVID-19 vaccine before or during pregnancy) among all pregnant individuals by month, December 14, 2020 to December 31, 2021 ^{a, b, c, d}

^aCoverage was calculated among all completed and ongoing pregnancies in each calendar month (i.e., any birth during the month or ongoing pregnancy as of the last day of the month). ^bDoses received either before or during pregnancy. ^cData for estimates displayed in plot can be found in Table S4. ^dOn December 14, 2020 (beginning of Ontario’s COVID-19 vaccination program), pregnant people could be offered COVID-19 vaccination—with informed consent—if they were in an eligible early priority group, but otherwise it was not recommended during pregnancy. Pregnant people were prioritized within Ontario’s vaccination program in late April 2021. On December 15, 2021, all adults over 18 years of age, including pregnant people, became eligible to receive a COVID-19 booster dose.

these two age groups decreased over time after August, but remained 20 percentage points lower by December 2021 (53.1% vs. 73.5%, respectively). The differences between the lowest and highest quintiles of neighborhood income (Fig. 4C and D) and material deprivation (Fig. 4E and F) were less pronounced, and also decreased over time.

3.2. Factors associated with COVID-19 vaccine series initiation during pregnancy

Among 101,009 individuals who gave birth between April 1 and December 31, 2021, 45.7% of individuals initiated their COVID-19 vaccine series, but there was substantial variation by sociodemographic and pregnancy-related characteristics (Table 1). Across maternal age groups, vaccine initiation during pregnancy was lowest among individuals <25 years of age (24.8%), compared with those 30–34 years of age (50.2%); the corresponding adjusted RR (aRR) was 0.53 (95% CI 0.51–0.56) and was 21 percentage points lower (aRD –21.9, 95% CI –23.0 to –20.9). Vaccine initiation during pregnancy was also lower among smokers compared with non-smokers (26.4% vs. 47.1%; aRR 0.64, 95% CI 0.61–0.67; aRD –14.8, 95% CI –15.9 to –13.7), among those who reported substance use during pregnancy compared with non-use (29.2% vs. 46.6%; aRR 0.72, 95% CI 0.69–0.76; aRD –11.0, 95% CI –12.2 to –9.7), among those with no prenatal care visit in the first trimester compared with having a first trimester visit (35.4% vs. 46.4; aRR 0.80, 95% CI 0.77–0.84; aRD –8.8, 95% CI –10.0 to –7.6), and among individuals living in rural compared with urban areas (38.6% vs. 46.9%; aRR 0.86, 95% CI 0.83–0.88; aRD –6.6, 95% CI –7.4 to –5.7). Vaccine series initiation was lowest among those in the lowest neighborhood income quintile compared with the highest (37.3% vs. 54.1%; aRR 0.69, 95% CI 0.67–0.71; aRD –16.9, 95% CI: –17.9 to –15.9), and among individuals in the highest material deprivation quintile compared with the lowest (34.9% vs. 55.5%; aRR 0.70, 95% CI 0.67–0.73; aRD –15.6, 95% CI –17.0 to –14.3). Vaccine series initiation was marginally higher among those with a pre-existing medical condition compared with no pre-existing

condition (50.3% vs. 45.2%, aRR 1.07, 95% CI 1.04–1.10; aRD 3.5, 95% CI 2.5 to 4.4) but there was no difference by maternal pre-pregnancy body mass index ≥ 30.0 kg/m², compared with <30.

4. Discussion

In this population-wide study of over 200,000 individuals who were pregnant during the first year of Ontario’s COVID-19 vaccination program, coverage with at least one dose (before or during pregnancy) increased to 71.2% among those pregnant in December 2021—this included 12.5% that had received a third dose. Despite prioritization of pregnant individuals for vaccination in late April 2021 [22], coverage with at least one dose remained lower than in the general population of females aged 18–49 years, among whom it was approximately 88% by the end of 2021 (Figure S2). Gradients in 1-dose vaccine coverage among pregnant individuals across categories of maternal age, neighborhood income, and material deprivation decreased by the end of 2021, but did not disappear.

Lower vaccine coverage among pregnant individuals, compared with the general population of reproductive-age females, is a concern given the higher risk of adverse outcomes following COVID-19 during pregnancy [1,2]. Other countries have noted similar gaps early in their COVID-19 vaccination programs—by May 8, 2021, 16.3% of 135,968 pregnant individuals in seven U.S. states (Vaccine Safety Datalink sites) had received at least one dose of COVID-19 vaccine during pregnancy, and 11.1% had completed their primary series, while 24.9% of non-pregnant females of similar age had completed their primary series [16]. A population-based study in Scotland estimated that 32.3% of those who gave birth in October 2021 had received two doses of COVID-19 vaccine, whereas 77.4% of females 18–44 years in the general population had received two doses by that time [17]. In contrast, a population-based cohort study of 164,560 women who gave birth from May 2021 through May 2022 in Sweden and Norway found that vaccine uptake by pregnant women was comparable to vaccination rates in

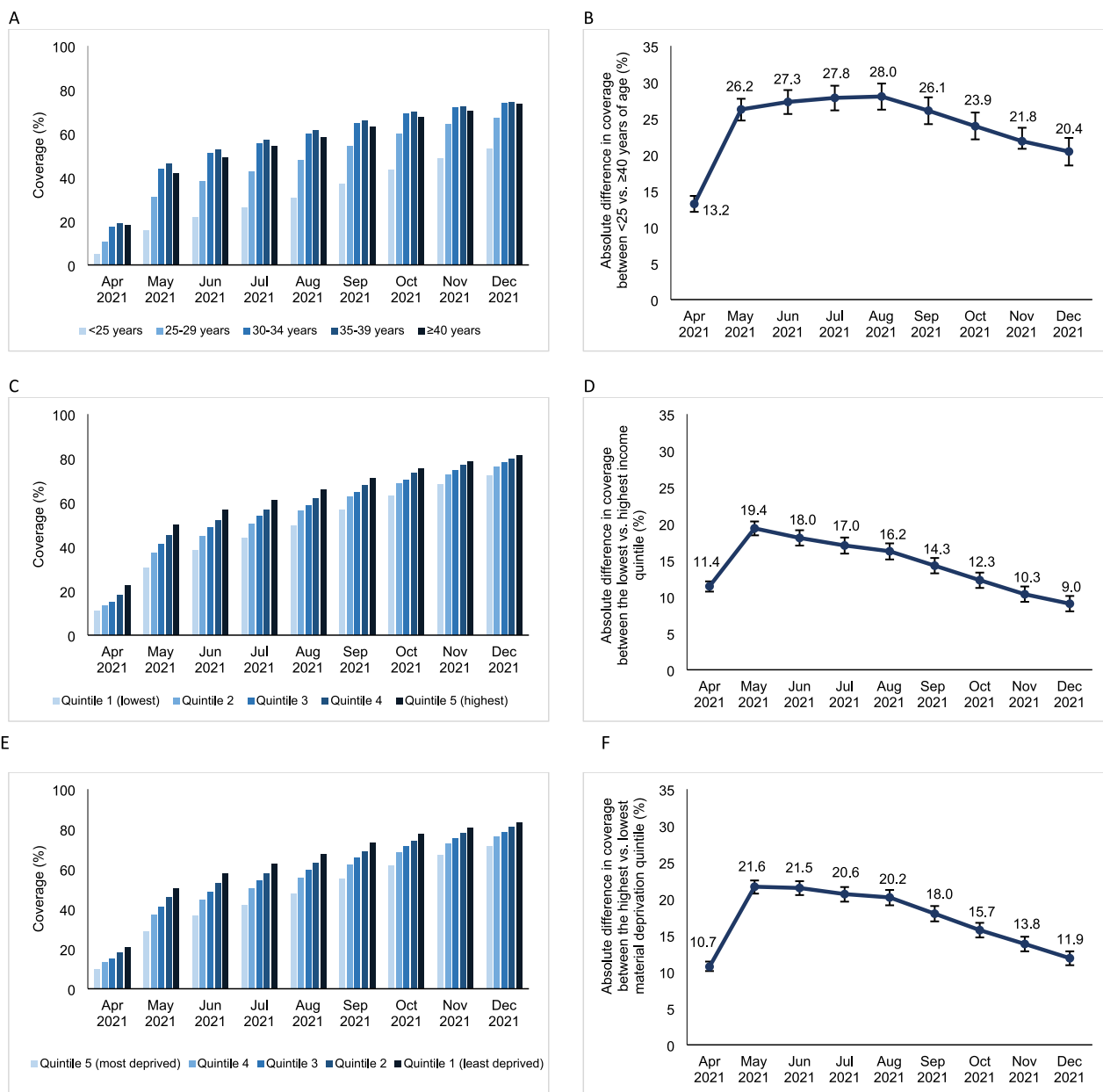


Fig. 4. Temporal trends in rates of COVID-19 vaccine coverage (≥ 1 dose of COVID-19 vaccine before or during pregnancy) among all pregnant individuals by month from April 1, 2021 to December 31, 2021, stratified by maternal age (A, B), neighborhood income quintile (C, D), and neighborhood quintile of material deprivation (E, F). Panels A, C, and E display coverage estimates (≥ 1 dose of COVID-19 vaccine during pregnancy). Panels B, D, and F display the absolute differences in coverage between the lowest and highest category. Coverage was calculated among all completed and ongoing pregnancies in each calendar month (i.e., any birth during the month or ongoing pregnancy as of the last day of the month). Data for estimates displayed in plot can be found in Table S5.

the general female population of reproductive age [18]. It was reported that 78% and 87% of women giving birth in Sweden and Norway, respectively, were vaccinated with at least one dose of COVID-19 prior to delivery, which was similar to the overall vaccination coverage in these countries (i.e., 77% in Sweden, 85% in Norway) [18].

Several studies have sought to identify factors associated with COVID-19 vaccination during pregnancy—being younger, not having sufficient prenatal care, living in areas with higher socioeconomic deprivation, and being a smoker during pregnancy were among the factors found to be associated with lower likelihood of getting vaccinated against COVID-19 during pregnancy [16–18,27,28]. Our results are very comparable to these earlier findings. In addition, although obesity and chronic medical conditions are

known risk factors for severe COVID-19 [29], we found that COVID-19 vaccine series initiation was not higher among those with a high pre-pregnancy body mass index and only marginally higher among pregnant individuals with pre-existing chronic medical conditions. Higher pre-pregnancy body mass index was found to be associated with lower uptake of COVID-19 vaccination during pregnancy in Sweden, but not Norway, and uptake was higher among those with pre-existing chronic medical conditions in both countries [18].

Unsurprisingly, the factors associated with COVID-19 vaccine series initiation in Ontario were also similar to those observed in Ontario during the 2009–2010 A/H1N1 influenza pandemic, when 42.6% of people who gave birth between November 2009 and April 2010 received the pandemic monovalent A/H1N1 influenza vaccine

Table 1
Factors associated with COVID-19 vaccine series initiation during pregnancy, among completed pregnancies from April 1, 2021 to December 31, 2021.

Characteristic	All completed pregnancies, April 1, 2021 to December 31, 2021		Received dose 1 of COVID-19 vaccine during pregnancy					
	N(101,009) ^a	%	Yes (n = 46,196)	Vaccine initiation rate per 100	Unadjusted rate ratio (95% CI)	Adjusted rate ratio(95% CI) ^b	Unadjusted rate difference per 100 (95% CI)	Adjusted rate difference per 100 (95% CI) ^b
Overall	101,009	100	46,196	45.7				
Maternal age (years)								
<25	8,214	8.1	2,040	24.8	0.49 (0.47 to 0.52)	0.53 (0.51 to 0.56)	-25.3 (-26.4 to -24.3)	-21.9 (-23.0 to -20.9)
25–29	24,291	24.0	9,290	38.2	0.76 (0.74 to 0.78)	0.80 (0.78 to 0.82)	-12.0 (-12.7 to -11.2)	-10.0 (-10.8 to -9.3)
30–34	40,480	40.1	20,324	50.2	1 (ref)	1 (ref)	0.0	0.0
35–39	23,035	22.8	12,177	52.9	1.05 (1.03 to 1.08)	1.02 (1.00 to 1.04)	2.7 (1.8 to 3.5)	1.3 (0.5 to 2.0)
≥40	4,989	4.9	2,365	47.4	0.94 (0.90 to 0.99)	0.92 (0.88 to 0.96)	-2.8 (-4.3 to -1.3)	-4.1 (-5.5 to -2.7)
Mean age (SD)	32 (4.9)	-	33 (4.4)	-	-	-	-	-
Parity								
0 (nulliparous)	43,933	43.5	21,181	48.2	0.99 (0.97 to 1.01)	1.05 (1.03 to 1.08)	-0.4 (-1.1 to 0.3)	2.4 (1.8 to 3.1)
1 (primiparous)	35,697	35.3	17,359	48.6	1 (ref)	1 (ref)	0.0	0.0
≥2 (multiparous)	21,379	21.2	7,656	35.8	0.74 (0.72 to 0.76)	0.72 (0.71 to 0.74)	-12.9 (-13.7 to -12.0)	-13.6 (-14.4 to -12.8)
Multiple birth								
No	99,503	98.5	45,485	45.7	1 (ref)	1 (ref)	0.0	0.0
Yes	1,506	1.5	711	47.2	1.03 (0.96 to 1.11)	0.95 (0.89 to 1.03)	1.5 (-1.0 to 4.0)	-2.1 (-4.5 to 0.3)
Any pre-existing maternal medical condition^c								
No	89,657	88.8	40,491	45.2	1 (ref)	1 (ref)	0.0	0.0
Yes	11,352	11.2	5,705	50.3	1.11 (1.08 to 1.14)	1.07 (1.04 to 1.10)	5.1 (4.1 to 6.1)	3.5 (2.5 to 4.4)
Thyroid disease	5,998	5.9	3,213	53.6	1.18 (1.14 to 1.23)	1.11 (1.07 to 1.15)	8.3 (7.0 to 9.6)	5.4 (4.2 to 6.7)
Asthma	3,897	3.9	1,799	46.2	1.01 (0.96 to 1.06)	1.03 (0.98 to 1.08)	0.45 (-1.1 to 2.0)	1.5 (-0.03 to 3.0)
Diabetes	1,120	1.1	552	49.3	1.08 (0.99 to 1.17)	1.03 (0.94 to 1.12)	3.6 (0.6 to 6.5)	1.3 (-1.5 to 4.2)
Chronic hypertension	936	0.9	456	48.7	1.07 (0.97 to 1.17)	0.98 (0.89 to 1.07)	3.0 (-0.2 to 6.2)	-0.9 (-4.0 to 2.2)
Heart disease	124	0.1	65	52.4	1.15 (0.90 to 1.46)	1.09 (0.86 to 1.39)	6.7 (-2.1 to 15.5)	4.8 (-3.7 to 13.3)
Smoked during pregnancy								
Yes	6,518	6.5	1,721	26.4	0.56 (0.54 to 0.59)	0.64 (0.61 to 0.67)	-20.6 (-21.8 to -19.5)	-14.8 (-15.9 to -13.7)
No	94,491	93.5	44,475	47.1	1 (ref)	1 (ref)	0.0	0.0
Substance use during pregnancy^d								
Yes	5,175	5.1	1,509	29.2	0.63 (0.60 to 0.66)	0.72 (0.69 to 0.76)	-17.3 (-18.6 to -16.1)	-11.0 (-12.2 to -9.7)
No	95,834	94.9	44,687	46.6	1 (ref)	1 (ref)	0.0	0.0
First prenatal care visit in the first trimester								
No	5,887	5.8	2,084	35.4	0.76 (0.73 to 0.80)	0.80 (0.77 to 0.84)	-11.1 (-12.3 to -9.8)	-8.8 (-10.0 to -7.6)
Yes	95,122	94.2	44,112	46.4	1 (ref)	1 (ref)	0.0	0.0
Maternal BMI (kg/m²)								
≥30.0 (obese)	21,409	21.2	9,524	44.5	0.96 (0.94 to 0.99)	0.98 (0.96 to 1.01)	-1.7 (-2.5 to -0.8)	-0.7 (-1.5 to 0.04)
<30.0	79,600	78.8	36,672	46.1	1 (ref)	1 (ref)	0.0	0.0
Neighborhood median family income quintiles								
1 (Lowest)	20,700	20.5	7,716	37.3	0.69 (0.67 to 0.71)	0.69 (0.67 to 0.71)	-16.8 (-17.8 to -15.8)	-16.9 (-17.9 to -15.9)
2	20,471	20.3	8,748	42.7	0.79 (0.77 to 0.81)	0.81 (0.78 to 0.83)	-11.4 (-12.5 to -10.4)	-10.5 (-11.5 to -9.5)
3	21,581	21.4	9,899	45.9	0.85 (0.82 to 0.87)	0.87 (0.84 to 0.89)	-8.3 (-9.3 to -7.2)	-7.2 (-8.2 to -6.3)
4	21,372	21.2	10,691	50.0	0.92 (0.90 to 0.95)	0.94 (0.92 to 0.97)	-4.1 (-5.1 to -3.1)	-3.1 (-4.1 to -2.2)
5 (Highest)	16,885	16.7	9,142	54.1	1 (ref)	1 (ref)	0.0	0.0

Table 1 (continued)

Characteristic	All completed pregnancies, April 1, 2021 to December 31, 2021		Received dose 1 of COVID-19 vaccine during pregnancy					
	N(101,009) ^a	%	Yes (n = 46,196)	Vaccine initiation rate per 100	Unadjusted rate ratio (95% CI)	Adjusted rate ratio(95% CI) ^b	Unadjusted rate difference per 100 (95% CI)	Adjusted rate difference per 100 (95% CI) ^d
Rural residence								
No	86,419	85.6	40,568	46.9	1 (ref)	1 (ref)	0.0	0.0
Yes	14,590	14.4	5,628	38.6	0.82 (0.80 to 0.85)	0.86 (0.83 to 0.88)	−8.4 (−9.2 to −7.5)	−6.6 (−7.4 to −5.7)
Public health unit region of residence^e								
South West	12,371	12.2	4,769	38.6	0.75 (0.72 to 0.78)	0.78 (0.76 to 0.81)	−12.9 (−14.1 to −11.8)	−10.8 (−11.9 to −9.7)
Central West	21,508	21.3	9,553	44.2	0.86 (0.84 to 0.89)	0.86 (0.83 to 0.88)	−7.1 (−8.1 to −6.2)	−7.4 (−8.4 to −6.5)
Central East	28,455	28.2	12,619	44.4	0.86 (0.84 to 0.88)	0.85 (0.82 to 0.87)	−7.2 (−8.1 to −6.3)	−7.9 (−8.8 to −7.0)
Greater Toronto Area	19,904	19.7	10,266	51.6	1 (ref)	1 (ref)	0.0	0.0
Eastern	13,610	13.5	6,925	50.9	0.99 (0.96 to 1.02)	1.00 (0.97 to 1.03)	−0.6 (−1.7 to 0.5)	0.08 (−1.0 to 1.2)
North West	1,700	1.7	709	41.7	0.81 (0.75 to 0.88)	0.92 (0.85 to 0.99)	−9.8 (−12.2 to −7.3)	−3.8 (−6.2 to −1.4)
North East	3,461	3.4	1,355	39.2	0.76 (0.72 to 0.80)	0.86 (0.81 to 0.91)	−12.6 (−14.4 to −10.8)	−6.8 (−8.6 to −5.0)
Marginalization Indices								
Residential instability quintile								
1 (least unstable)	20,305	20.1	9,433	46.5	1 (ref)	1 (ref)	0.0	0.0
2	18,981	18.8	8,796	46.3	1.00 (0.97 to 1.03)	1.01 (0.98 to 1.04)	−0.2 (−1.2 to 0.8)	0.2 (−0.8 to 1.1)
3	19,248	19.1	8,841	45.9	0.99 (0.96 to 1.02)	1.05 (1.02 to 1.08)	−0.6 (−1.5 to 0.5)	2.5 (1.5 to 3.4)
4	18,932	18.7	8,431	44.5	0.96 (0.93 to 0.99)	1.11 (1.07 to 1.14)	−1.9 (−2.9 to −0.9)	5.2 (4.2 to 6.3)
5 (most unstable)	23,543	23.3	10,695	45.4	0.98 (0.95 to 1.01)	1.18 (1.14 to 1.22)	−1.1 (−2.0 to −0.1)	7.9 (6.7 to 9.0)
Material deprivation quintile								
1 (least deprived)	22,946	22.7	12,728	55.5	1 (ref)	1 (ref)	0.0	0.0
2	20,529	20.3	10,206	49.7	0.90 (0.87 to 0.92)	0.95 (0.93 to 0.98)	−5.7 (−6.6 to −4.7)	−2.9 (−3.8 to −1.9)
3	18,710	18.5	8,438	45.1	0.81 (0.79 to 0.84)	0.89 (0.86 to 0.91)	−10.4 (−11.3 to −9.4)	−6.4 (−7.5 to −5.3)
4	18,388	18.2	7,695	41.9	0.76 (0.74 to 0.78)	0.83 (0.80 to 0.86)	−13.5 (−14.5 to −12.5)	−9.4 (−10.6 to −8.2)
5 (most deprived)	20,436	20.2	7,129	34.9	0.63 (0.61 to 0.65)	0.70 (0.67 to 0.73)	−20.6 (−21.5 to −19.7)	−15.6 (−17.0 to −14.3)
Dependency quintile								
1 (least dependent)	33,054	32.7	15,943	48.2	1 (ref)	1 (ref)	0.0	0.0
2	21,133	20.9	9,655	45.7	0.95 (0.92 to 0.97)	1.00 (0.97 to 1.02)	−2.6 (−3.5 to −1.7)	−0.3 (−1.1 to 0.5)
3	17,021	16.9	7,728	45.4	0.94 (0.91 to 0.96)	1.00 (0.97 to 1.02)	−3.0 (−3.9 to −2.0)	−0.3 (−1.2 to 0.7)
4	15,492	15.3	6,762	43.7	0.91 (0.88 to 0.93)	0.97 (0.95 to 1.00)	−4.5 (−5.5 to −3.5)	−1.1 (−2.1 to −0.2)
5 (most dependent)	14,309	14.2	6,108	42.7	0.88 (0.86 to 0.91)	0.98 (0.95 to 1.01)	−5.6 (−6.7 to −4.6)	−0.9 (−1.9 to 0.2)
Ethnic concentration quintile								
1 (lowest concentration)	14,458	14.3	5,997	41.5	1 (ref)	1 (ref)	0.0	0.0
2	16,410	16.2	7,433	45.3	1.10 (1.06 to 1.13)	1.01 (0.97 to 1.05)	4.0 (2.9 to 5.1)	0.4 (−0.7 to 1.5)
3	18,268	18.1	8,940	48.9	1.18 (1.14 to 1.22)	1.01 (0.97 to 1.04)	7.6 (6.5 to 8.7)	0.5 (−0.7 to 1.7)
4	22,102	21.9	10,725	48.5	1.17 (1.13 to 1.21)	0.97 (0.94 to 1.01)	7.2 (6.1 to 8.2)	−1.3 (−2.4 to −0.1)
5 (highest concentration)	29,771	29.5	13,101	44.0	1.06 (1.03 to 1.10)	0.95 (0.91 to 0.98)	2.6 (1.6 to 3.6)	−2.9 (−4.1 to −1.7)

Abbreviations: BMI, body mass index.

^a Counts and column percentages from imputation dataset #1 were used for variables with missing information (see Table S2).^b Models were adjusted for maternal age, estimated date of conception, neighborhood income quintile, rural residence, and public health unit region.^c Composite of: asthma, chronic hypertension, diabetes, heart disease, thyroid disease. Sum of individual conditions does not equal the total number of individuals with any condition, as categories were not mutually exclusive.^d Self-reported cannabis, opioid or alcohol use during pregnancy.^e Public health units within each region are provided in Table S1.

during pregnancy [30]. While lower maternal age, smoking, and lower neighborhood income were associated with lower vaccine initiation during the A/H1N1 influenza pandemic [30], the associations were generally smaller in magnitude than what we observed in the COVID-19 pandemic in Ontario. Other studies from the 2009 A/H1N1 influenza pandemic documented significantly lower vaccination rates among pregnant individuals who smoked during pregnancy [31] and lived in rural settings [32], and higher vaccination rates among those with chronic medical conditions [31,32]. These findings are also congruent with patterns generally observed for seasonal influenza and pertussis vaccine coverage during pregnancy, which also vary considerably between individuals of higher and lower socioeconomic status [33,34].

When COVID-19 vaccination was initially recommended for pregnant individuals, it was unclear what the uptake would be, especially amid initial concerns about the use of novel vaccine technologies during pregnancy [35]. Surveys of pregnant people reported decreased intention to become vaccinated, largely due to concerns about potential harm to the fetus [36]; this also continues to be the most commonly-cited reason for low uptake of influenza vaccine during pregnancy [33]. Although substantial evidence on safety of COVID-19 vaccination during pregnancy has accumulated [9–15], our results suggest that there is a subgroup of individuals who are less likely to get vaccinated during pregnancy. Previous studies in the general population have shown that lower socioeconomic status (e.g., lower level of education, poverty, lower household income) are risk factors for COVID-19 infection, confirmed diagnosis, and death, and that socioeconomic determinants play an important role in COVID-19 outcomes [37–40]. Moreover, socioeconomic status is also associated with inequalities in perinatal health; for example, lower socioeconomic position is a risk factor for adverse pregnancy outcomes such as low birth weight and preterm birth [41,42]. Thus, to prevent severe COVID-19-related outcomes among higher-risk subgroups of pregnant individuals and decrease disparities in vaccine coverage, interventions specifically targeted for these subgroups may be required.

Strengths of this study include the large birth population and deterministically linked population-based data sources within a publicly-funded health care system providing ascertainment of COVID-19 vaccinations received during pregnancy and comprehensive sociodemographic and pregnancy-related information. Study limitations include potential underestimation of the number of pregnancies in the later months of the study period, due to lag times in receiving completed birth records from some hospitals and because not all pregnant people undergo prenatal screening [25], which we relied on to identify ongoing pregnancies. Although we had information on a wide range of sociodemographic, health-related, and pregnancy-related factors, decisions about vaccination during pregnancy are likely influenced by other factors that we could not measure, such as frequency and method (virtual versus in-person) of prenatal care visits, or individual knowledge, attitudes, and beliefs. Our assessment of factors associated with COVID-19 vaccine series initiation during pregnancy—which relied on completed pregnancies after April 1, 2021—likely predominantly reflects associations with vaccination during the second and third trimesters of pregnancy; it is possible that some patterns of association may differ for early pregnancy vaccination.

5. Conclusions

Our population-based study in Ontario, Canada found that COVID-19 vaccine coverage with at least one dose remained substantially lower among pregnant individuals than among similarly-aged females in the general population in 2021. Although disparities in coverage across categories of maternal age and

socioeconomic status showed some diminution by the end of 2021, at the population level, persistent gaps could translate into thousands fewer pregnant individuals in specific subgroups not having been vaccinated. We identified several sociodemographic, health-related, and pregnancy-related factors that were associated with initiating COVID-19 vaccination during pregnancy—combined with the growing body of evidence supporting safety of COVID-19 vaccination during pregnancy, these findings can help inform public health strategies to increase COVID-19 vaccine acceptance and coverage in the pregnant population.

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7. Disclaimer

The study sponsors did not participate in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; or the decision to submit the manuscript for publication. Parts of this material are based on data and information compiled and provided by BORN Ontario and the Ontario Ministry of Health; however, the analyses, conclusions, opinions and statements expressed herein are solely those of the authors and do not reflect those of the funding or data sources. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

8. Data sharing

The dataset from this study is held securely by BORN Ontario. Although the dataset cannot be made publicly available, the analytic code may be available on request.

Data availability

The dataset from this study is held securely by BORN Ontario. Although the dataset cannot be made publicly available, the analytic code may be available on request.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: K. Wilson is CEO of CANimmunize Inc, which hosts a national digital immunization record, and is a member of the independent data safety board for the Medicago COVID-19 vaccine trial; there were no other relationships or activities that could appear to have influenced the submitted work.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.vaccine.2023.01.073>.

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