Received: 8 September 2021 | Revised: 19 March 2022 | Accepted: 26 March 2022

DOI: 10.1111/ppe.12883

SPECIAL ISSUE: INFECTIONS DURING PREGNANCY

Paediatric and Perinatal Epidemiology WILEY

SARS-CoV-2 infections among neonates born to pregnant people with SARS-CoV-2 infection: Maternal, pregnancy and birth characteristics

Emily O'Malley Olsen[1] | Nicole M. Roth[1] | Kathryn Aveni[2] | Pauline Santos[3] | Lindsey Sizemore[4] | Umme-Aiman Halai[5] | Eirini Nestoridi[6] | Jerusha Elana Barton[7] | Evan Mobley[8] | Samantha Siebman[4,9] | Chris Fussman[10] | Deborah Mbotha[11] | Paula Dzimira[12] | Kristin M. Silcox[13] | Salma Khuwaja[14] | Danacamile Roscom[15] | Mamie Lush[16] | Sarah Chicchelly[17] | Camille Delgado-López[18] | Levi Schlosser[19] | Jennifer Read[20] | Sascha R. Ellington[1] | Aron J. Hall[1] | Suzanne M. Gilboa[1] | Van T. Tong[1] | Kate R. Woodworth[1]

[1]Centers for Disease Control and Prevention COVID-19 Response, Epidemiology Task Force, Atlanta, Georgia, USA

[2]New Jersey Department of Health, Trenton, New Jersey, USA

[3]New York State Department of Health, Albany, New York, USA

[4]Tennessee Department of Health, Nashville, Tennessee, USA

[5]Los Angeles County Department of Public Health, Los Angeles, California, USA

[6]Massachusetts Department of Public Health, Boston, Massachusetts, USA

[7]Georgia Department of Public Health, Atlanta, Georgia, USA

[8]Missouri Department of Health and Senior Services, Jefferson City, Missouri, USA

[9]Minnesota Department of Health, Saint Paul, Minnesota, USA

[10]Michigan Department of Health and Human Services, Lansing, Michigan, USA

[11]Washington State Department of Health, Olympia, Washington, USA

[12]Pennsylvania Department of Health, Harrisburg, Pennsylvania, USA

[13]Maryland Department of Health, Baltimore, Maryland, USA

[14]Houston Health Department, Houston, Texas, USA

[15]High Sierra Area Health Education Center, Reno, Nevada, USA

[16]Nebraska Department of Health and Human Services, Lincoln, Nebraska, USA

[17]Kansas Department of Health and Environment, Topeka, Kansas, USA

[18]Puerto Rico Department of Health, San Juan, Puerto Rico

[19]North Dakota Department of Health, Bismarck, North Dakota, USA

[20]Vermont Department of Health, University of Vermont School of Medicine, Burlington, Vermont, USA

Correspondence
Emily O'Malley Olsen, Centers for Disease Control and Prevention, Atlanta, GA, USA.
Email: setnet@cdc.gov

Funding information
This study was performed as regular work of the Centers for Disease Control

Abstract

Background: Multiple reports have described neonatal SARS-CoV-2 infection, including likely in utero transmission and early postnatal infection, but published estimates of neonatal infection range by geography and design type.

Published 2022. This article is a U.S. Government work and is in the public domain in the USA

and Prevention. This work is supported by the Epidemiology and Laboratory Capacity for Prevention and Control of Emerging Infectious Diseases Cooperative Agreement (CK19-1904) and contractual mechanisms

Objectives: To describe maternal, pregnancy and neonatal characteristics among neonates born to people with SARS-CoV-2 infection during pregnancy by neonatal SARS-CoV-2 testing results.

Methods: Using aggregated data from the Surveillance for Emerging Threats to Mothers and Babies Network (SET-NET) describing infections from 20 January 2020 to 31 December 2020, we identified neonates who were (1) born to people who were SARS-CoV-2 positive by RT-PCR at any time during their pregnancy, and (2) tested for SARS-CoV-2 by RT-PCR during the birth hospitalisation.

Results: Among 28,771 neonates born to people with SARS-CoV-2 infection during pregnancy, 3816 (13%) underwent PCR testing and 138 neonates (3.6%) were PCR positive. Ninety-four per cent of neonates testing positive were born to people with infection identified ≤14 days of delivery. Neonatal SARS-CoV-2 infection was more frequent among neonates born preterm (5.7%) compared to term (3.4%). Neonates testing positive were born to both symptomatic and asymptomatic pregnant people.

Conclusions: Jurisdictions reported SARS-CoV-2 RT-PCR results for only 13% of neonates known to be born to people with SARS-CoV-2 infection during pregnancy. These results provide evidence of neonatal infection identified through multi-state systematic surveillance data collection and describe characteristics of neonates with SARS-CoV-2 infection. While perinatal SARS-CoV-2 infection was uncommon among tested neonates born to people with SARS-CoV-2 infection during pregnancy, nearly all cases of tested neonatal infection occurred in pregnant people infected around the time of delivery and was more frequent among neonates born preterm. These findings support the recommendation for neonatal SARS-CoV-2 RT-PCR testing, especially for people with acute infection around the time of delivery.

KEYWORDS
pregnancy, COVID-19, SARS-CoV-2, perinatal infection

1 | INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection can lead to serious coronavirus disease 2019 (COVID-19) in pregnant people, is associated with preterm birth and poses a potential risk of transmission to the neonate.[1–3] Reports have described perinatal infection, including likely in utero transmission and early postnatal infection.[3,4] The American Academy of Pediatrics (AAP) and the Centers for Disease Control and Prevention (CDC) recommend all neonates born to pregnant people with suspected or confirmed COVID-19 be tested for SARS-CoV-2 by real-time reverse transcription polymerase chain reaction (RT-PCR).[5,6] Factors associated with infection among exposed neonates are unclear. We describe maternal, pregnancy and neonatal characteristics among a surveillance cohort of neonates born to people with SARS-CoV-2 infection during pregnancy and assess characteristics by reported neonatal SARS-COV-2 RT-PCR testing.

2 | METHODS

2.1 | Cohort selection

Pregnant people with laboratory-confirmed SARS-CoV-2 infection from 20 January to 31 December 2020 were retrospectively ascertained through reporting of pregnancy in COVID-19 surveillance and cross-matching COVID-19 surveillance data with local data systems to assess pregnancy status. The data are enhanced through supplemental data sources at the jurisdiction level such as vital statistics, administrative data sets, electronic laboratory reporting and maternal and neonatal medical record review and submitted to the Surveillance for Emerging Threats to Mothers and Babies Network (SET-NET).[7] SET-NET data contain maternal characteristics including demographics, prenatal history and SARS-CoV-2 infection (e.g. timing of infection and severity) as well as neonatal characteristics (e.g. gestational age and SARS-CoV-2 testing). This activity was reviewed by CDC and conducted consistent with applicable federal law and policy.[8]

2.2 | Exposure

Using aggregated SET-NET data compiled through 5 November 2021, we identified neonates who were (1) born to people who were SARS-CoV-2 RT-PCR positive in pregnancy, and (2) tested for SARS-CoV-2 by RT-PCR during the birth hospitalisation. For neonates with extended hospitalisation (>14 days) or whose date of discharge was unknown, only SARS-CoV-2 tests conducted ≤14 days following birth were included to focus on perinatal infections.

2.3 | Statistical analysis

We described neonates by SARS-CoV-2 testing result. We focused on SARS-CoV-2-positive neonates and described maternal characteristics including demographics, COVID-19 disease severity[9] and timing of prenatal infection relative to delivery (determined by date of first positive SARS-CoV-2 or symptom onset if testing date was missing), pregnancy complications (e.g. preeclampsia), gestational age and birthweight. We also described these characteristics among neonates who were tested by SARS-CoV-2 RT-PCR following birth but who tested negative. Because negative results are not reported consistently to all jurisdictions, the group of test-negative neonates may not represent all neonates testing negative. Therefore, we did not perform statistical comparisons between neonates testing positive and negative for SARS-CoV-2. We compared testing status by maternal, birth and neonatal characteristics, including prevalence ratios for neonatal testing adjusted for jurisdiction and days from positive to delivery (Table 2).

3 | RESULTS

Twenty jurisdictions with neonatal testing data available reported 28,771 live-born neonates born to 25,487 pregnant people with SARS-CoV-2 infection (Figure 1). Of neonates, 24,955 (86.7%) had no SARS-CoV-2 testing data available, 26 (0.1%) were tested but had indeterminate or unknown results reported and 3790 (13.2%) had positive or negative SARS-CoV-2 RT-PCR results reported. The proportion known to be tested increased with trimester of infection, with testing performed for 1.4%, 2.9% and 24.1% of neonates born to people with first, second and third trimester infection respectively. The median time from maternal infection to delivery was 75 days (IQR: 20-143) among neonates not known to be tested and 1 day (IQR: 0–9) among those tested.

Of the 3790 neonates with test results, 3226 had only negative RT-PCR results reported and 138 (3.6%) had at least one positive RT-PCR result, representing 0.5% [138/28,771] of live births. Of these 138 neonates, 91 (65.6%) had only positive results and 46 (33.3%) had both positive and negative results (Figure S1).

Synopsis

Study question

What are maternal, pregnancy and neonatal characteristics among neonates born to people with SARS-CoV-2 infection during pregnancy, by neonate SARS-CoV-2 testing results at birth?

What's already known?

Multiple reports have described perinatal SARS-CoV-2 infection, including likely in utero transmission and early postnatal infection. Published estimates of perinatal positivity in neonates range from 0.9% to 2.2% depending on location and methodology.

What this study adds?

This study provides a description of SARS-CoV-2 testing patterns among neonates and evidence of neonatal infection identified through multi-state systematic surveillance. Thirteen per cent of the 28,771 live-born neonates of pregnant people with SARS-CoV-2 infection had reported PCR testing and results; 138 (3.6%) were PCR positive. Nearly all positive neonates were born to people with infection <14 days before delivery.

Maternal characteristics are summarised in Table 1. Of SARS-CoV-2 positive neonates with date of maternal infection reported (n = 136), 94.1% were born to people with initial positive testing or symptom onset occurring ≤14 days before delivery and eight neonates were born to people with initial positive SARS-CoV-2 testing >14 days before delivery. Four of these persons remained SARS-CoV-2 positive within 2 days prior to delivery. Per cent positivity among neonates tested for SARS-CoV-2 was 1.1%, 2.5%, 4.1% and 4.6% for those born to people with infection diagnosed >14, 7–14, 3–6 and 0–2 days before delivery respectively. Of neonates testing positive and whose maternal disease severity was known, 47.8% were born to people reported as asymptomatic at COVID-19 diagnosis. Compared to neonates with no testing data reported, tested neonates were more likely to be born to people who were of non-White non-Hispanic race/ethnicity, with third trimester infection, infection ≤14 days before delivery, asymptomatic COVID-19 disease and caesarean delivery (Table 2). Compared to those without testing data, tested neonates were more likely to be born preterm or low birthweight, or have a neonatal intensive care unit admission.

Among the 138 neonates testing positive for SARS-CoV-2, 52.6% were female, 5.3% were small for gestational age (<10th percentile by INTERGROWTH-21st) and 23.9% were born preterm (i.e. <37 weeks gestation), including 5.8% born moderate-to-extremely

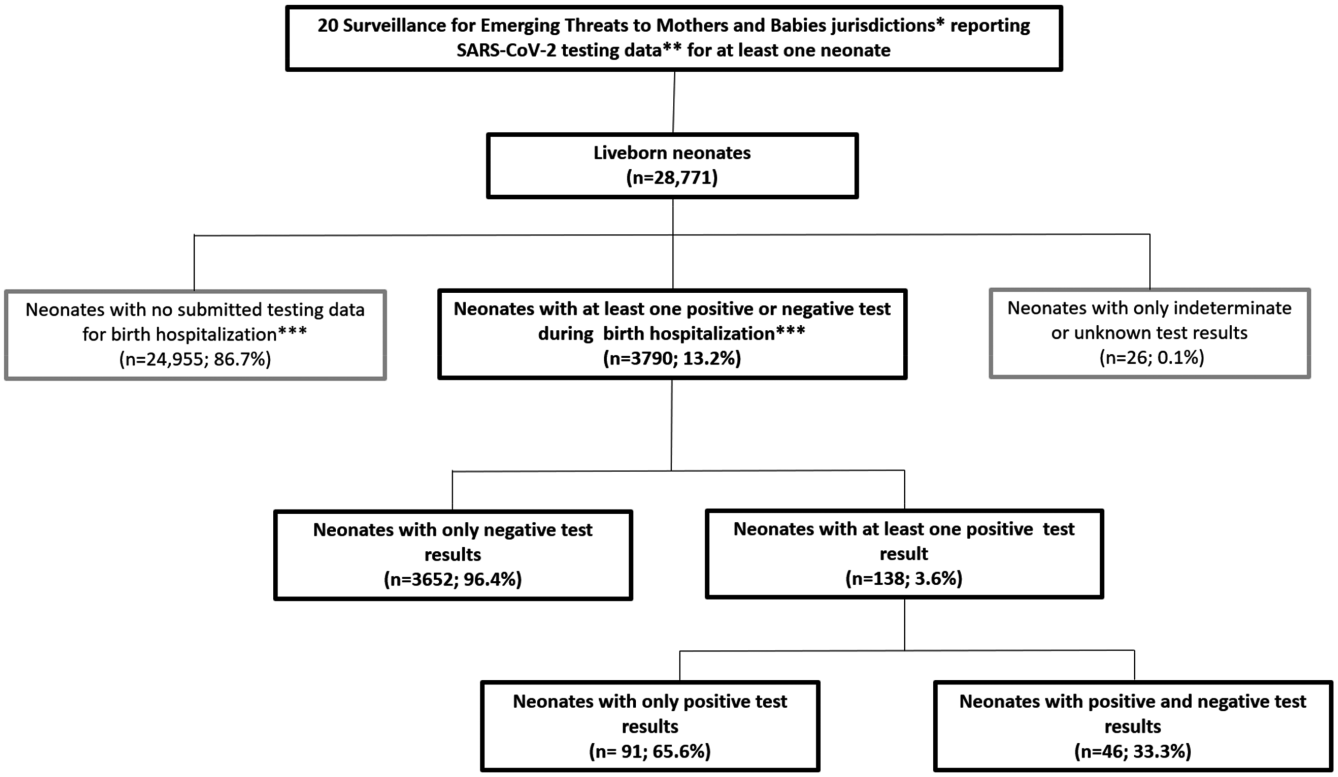

FIGURE 1 Live-born neonates born to pregnant people with SARS-CoV-2 infection – SET-NET, 20 January 2020 through 31 December 2020. *Twenty jurisdictions reporting SARS-CoV-2 laboratory data for at least one neonate: California [excluding Los Angeles County], Georgia, Houston, Kansas, Los Angeles County, Massachusetts, Maryland, Michigan, Minnesota, Missouri, Nebraska, Nevada, New Jersey, New York [excluding New York City], North Dakota, Pennsylvania [excluding Philadelphia], Puerto Rico, Tennessee, Vermont and Washington. **All testing data herein were for SARS-CoV-2 by real-time reverse transcription polymerase chain reaction (RT-PCR). ***The birth hospitalisation period included only SARS-CoV-2 tests conducted ≤14 days following birth

preterm (<34 weeks). Among neonates known to be tested, SARS-CoV-2 per cent positivity was 3.4% among neonates born at ≥37 weeks and 5.7% among neonates born preterm. Timing of first positive RT-PCR testing was available for 137 of the neonates with SARS-CoV-2 infection: six neonates were first tested on the day of birth, 80 on the second day of life (DOL) and 36 on the third DOL (Table 1, Figure S1). Timing of testing was similar for neonates testing negative for SARS-CoV-2.

3.1 | Comment

3.1.1 | Principal findings

Jurisdictions reported SARS-CoV-2 RT-PCR results for only 13.3% of neonates known to be born to people with SARS-CoV-2 infection during pregnancy. Neonates born to people with infection closer to delivery, with third trimester infection and with preterm delivery were more likely to have reported testing. Although the data are descriptive, these results provide evidence of neonatal infection identified through multi-state systematic surveillance data collection. Among neonates born to people with COVID-19 during pregnancy and known to be tested for SARS-CoV-2, neonatal infection was uncommon, occurring in 3.6%. However, we suspect this overestimates true per cent positivity because negative results are less frequently reported to health departments; the true percentage likely lies between 3.6% and 0.5% (the total neonates testing PCR positive among all live births), which is consistent with other studies.[10,11] Neonatal infection was more frequent among tested neonates born to people diagnosed with COVID-19 close to delivery (<7 days) and among preterm neonates. Neonatal positivity occurred regardless of maternal symptom status.

3.1.2 | Strengths of the study

SET-NET is a large, geographically diverse cohort of pregnant people with laboratory-confirmed SARS-CoV-2 infections. The linked longitudinal surveillance allows for ascertainment of infection during pregnancy and follow-up to the birth hospitalisation using existing data sources including laboratory reporting.

TABLE 1 Maternal demographics, maternal disease characteristics and neonatal characteristics among neonates with reported perinatal SARS-CoV-2 real-time polymerase chain reaction (RT-PCR) test results – SET-NET, 20 jurisdictions[a], 29 March 2020 – 31 December, 2020 and reported by 5 November 2021

	Neonate RT-PCR test results ($N = 3790$)[b]		
	Positive[c]	Negative[d]	Per cent positivity
n (%)	138 (3.6%)	3652 (96.4%)	3.6%
Maternal characteristics			
Age in years	$N = 133$	$N = 3620$	
Median (IQR)	29.3 (24.9–34.6)	29.0 (24.7–33.8)	
<25	36 (27.1%)	957 (26.4%)	3.6%
25–34	65 (48.9%)	1971 (54.4%)	3.2%
≥35	32 (24.1%)	692 (19.1%)	4.4%
Not reported, *n* (%)	5 (3.6%)	32 (0.9%)	
Race/ethnicity	$N = 122$	$N = 3497$	
Hispanic	64 (52.5%)	1703 (48.7%)	3.6%
Black, non-Hispanic	18 (14.8%)	566 (16.2%)	3.1%
White, non-Hispanic	34 (27.9%)	944 (27.0%)	3.5%
Multiple or other[e] race, non-Hispanic	6 (4.9%)	284 (8.1%)	2.1%
Not reported, *n* (%)	16 (11.6%)	155 (4.2%)	9.4%
Underlying conditions			
Any underlying condition(s)[f]	$N = 124$	$N = 3319$	
One or more	59 (47.6%)	1554 (46.8%)	3.7%
None reported	65 (52.4%)	1765 (53.2%)	3.6%
Missing, *n* (%)	14 (10.1%)	333 (9.1%)	4.0%
Hypertensive disorders of pregnancy[g]	$N = 96$	$N = 2721$	
Yes	16 (16.7%)	361 (13.3%)	4.2%
No	80 (83.3%)	2360 (86.7%)	3.3%
Not reported, *n* (%)	38 (28.4%)	605 (18.2%)	5.9%
Trimester of infection	$N = 137$	$N = 3635$	
First	1 (0.7%)	73 (2.0%)	–
Second	2 (1.5%)	236 (6.5%)	–
Third	134 (97.8%)	3326 (91.5%)	3.9%
Not reported, *n* (%)	1 (0.7%)	17 (0.5%)	–
Timing of pregnant person's first positive RT-PCR test (days prior to delivery)	$N = 136$	$N = 3620$	
Median (IQR)	1 (0–3)	1 (0–10)	
>14	8 (5.9%)	751 (20.7%)	1.1%
7–14	9 (6.6%)	344 (9.5%)	2.5%
3–6	19 (14.0%)	441 (12.2%)	4.1%
0–2	100 (73.5%)	2084 (57.6%)	4.6%
Not reported, *n* (%)	2 (1.4%)	32 (0.9%)	–
Maternal disease severity[h]	$N = 90$	$N = 2091$	
Asymptomatic	43 (47.8%)	882 (42.2%)	4.6%
Mild	29 (32.2%)	788 (37.7%)	3.5%
Moderate/severe	10 (11.1%)	307 (14.7%)	3.2%
Critical	8 (8.9%)	114 (5.5%)	6.6%
Not enough information, *n* (%)	48 (34.8%)	1561 (42.7%)	3.0%
Delivery type	$N = 134$	$N = 3375$	
Vaginal	74 (55.2%)	2141 (63.4%)	3.3%
Caesarean	60 (44.8%)	1234 (36.6%)	4.6%
Not reported, *n* (%)	4 (2.9%)	277 (7.6%)	–
Infant characteristics			
Gestational age at birth	$N = 138$	$N = 3537$	
Median weeks (IQR)	38.8 (37.1–39.6)	39.0 (37.6–39.9)	
Term (≥37 weeks)	105 (76.1%)	2995 (84.7%)	3.4%
Preterm (<37 weeks)	33 (23.9%)	542 (15.3%)	5.7%
Late preterm (34–36 weeks)	24 (17.4%)	386 (10.9%)	5.9%
Moderate-to-extremely preterm (<34 weeks)	9 (5.8%)	156 (3.8%)	5.5%
Not reported, *n* (%)	0 (0%)	115 (3.1%)	–
Neonate Sex	$N = 137$	$N = 3648$	
Female	72 (52.6%)	1790 (49.1%)	3.9%
Male	65 (47.4%)	1858 (50.9%)	3.4%
Not reported, *n* (%)	1 (0.7%)	4 (0.1%)	–
Weight in grams at birth	$N = 132$	$N = 3183$	
Low birthweight (<2500 g)	18 (13.6%)	357 (11.2%)	4.8%
Normal birthweight (≥2500 g)	114 (4%)	2826 (88.8%)	3.9%
Not reported, *n* (%)	6 (4%)	469 (13%)	1.3%
Small for gestational age[i]	$N = 132$	$N = 3164$	
Yes	7 (5.3%)	205 (6.5%)	3.3%
No	125 (94.7%)	2959 (93.5%)	4.1%
Not reported, *n* (%)	6 (4.3%)	488 (13.4%)	1.2%

TABLE 1 (Continued)

	Neonate RT-PCR test results ($N = 3790$)[b]		
	Positive[c]	Negative[d]	Per cent positivity
Neonatal intensive care unit admission	$N = 115$	$N = 2867$	
Admitted during birth hospitalisation	42 (36.5%)	662 (23.1%)	6.0%
Not admitted to ICU	73 (63.5%)	2205 (76.9%)	3.2%
Not reported, *n* (%)	23 (16.7%)	785 (21.5%)	2.8%
Day of first RT-PCR test following birth[j], in days of life	$N = 137$	$N = 3616$	
1	6 (4.4%)	227 (6.3%)	2.6%
2	80 (58.4%)	2644 (73.1%)	2.9%
3	36 (26.3%)	551 (15.2%)	6.1%
≥4	15 (10.9%)	194 (5.4%)	7.2%

[a]Including California [excluding Los Angeles County], Georgia, Houston, Kansas, Los Angeles County, Massachusetts, Maryland, Michigan, Minnesota, Missouri, Nebraska, Nevada, New Jersey, New York [excluding New York City], North Dakota, Pennsylvania [excluding Philadelphia], Puerto Rico, Tennessee, Vermont and Washington.

[b]Among 28,771 live-born neonates reported to SET-NET, 3790 (13.2%) had a reported SARS-CoV-2 RT-PCR positive or negative test during the birth hospitalisation and within 14 days of delivery.

[c]Neonates with at least one positive RT-PCR during the birth hospitalisation, including neonates with positive and negative RT-PCR results.

[d]Neonates with no positive RT-PCR test and at least one negative RT-PCR test reported.

[e]Other race comprises American Indian or Alaska Native, Native Hawaiian or Pacific Islander, and Asian, Non-Hispanic. These were combined because of small cell sizes that yielded unreliable estimates.

[f]Includes cardiovascular disease, chronic hypertension, chronic lung disease, diabetes mellitus (type 1 or type 2), immunosuppression and obesity (body mass index ≥30 kg/m^2).

[g]Inclusive of preeclampsia, eclampsia or HELLP (haemolysis, elevated liver enzymes and low platelet) syndrome. Does not include chronic hypertension. Hypertensive disorders of pregnancy were only considered underlying conditions for women with third trimester infection.

[h]Categories of disease severity were based on modified National Institute of Health and World Health Organization criteria as described in Galang et al.[9] Pregnant people were considered asymptomatic if reported as having an absence of symptoms using a symptom status variable rather than sole absence of individual symptoms reported. Criteria were applied to classify severity using submitted data including symptoms, intensive care unit admission, invasive ventilation, use of COVID-19 therapies, complications associated with COVID-19 and death.

[i]Defined as weight <10th percentile for sex (presumed female if missing) and gestational age using the INTERGROWTH-21st online percentile calculator http://intergrowth21.ndog.ox.ac.uk. Some gestational ages were reported in completed weeks only (rather than in weeks and days).

[j]For infants with a positive SARS-CoV-2 RT-PCR test result, the day of life of the first positive result.

3.1.3 | Limitations of the data

Limitations of our analysis include the high per cent of neonates without testing results. Testing practices of pregnant people and neonates likely varied over time, by facility and by maternal or neonatal characteristics (e.g. symptoms and intensive care unit admission).[12] Additionally, we were unable to assess route of transmission (e.g. in utero and peripartum), given lack of immunoglobulin-M serology and RT-PCR testing data on sterile specimens (e.g. blood).[13] Lastly, we could not assess infection prevention and control (IPC) measures implemented.

3.1.4 | Interpretation

Identification of perinatal SARS-CoV-2 infection is influenced by testing practices. Although these data do not represent all perinatal testing practices, they suggest RT-PCR SARS-CoV-2 testing of neonates primarily occurred for those born to people with third trimester infection, especially infection ≤14 days before delivery. These testing patterns are consistent with the idea that transmission via respiratory droplets most likely occurs during the individual's infectious period.[14] Reported testing was also higher among neonates born preterm and neonates with NICU admission. Epidemiologic analyses of neonatal SARS-CoV-2 that rely on laboratory testing results must consider the inherent biases.

Much remains unknown about the mechanisms, frequency and risk factors for transmission of SARS-CoV-2 from a pregnant person to their foetus or neonate. Generally, neonatal positivity was highest among neonates who were most likely to have reported perinatal testing. Nearly all tested neonates born to people with infection occurring >14 days before delivery tested negative. While acknowledging the described biases, our findings that neonates with positive SARS-CoV-2 testing were born to both symptomatic and asymptomatic people support the guidance for neonatal SARS-CoV-2 testing when born to pregnant people with SARS-CoV-2 infection, and counselling for persons who acquire COVID-19 during pregnancy about potential risk to their neonates. Future studies that compare neonates with SARS-CoV-2 infection to a representative sample of neonates without infection are needed to identify risk factors for SARS-CoV-2 infection and other adverse outcomes.

4 | CONCLUSION

Neonatal SARS-CoV-2 testing data are incomplete and may be biased. Neonates born to pregnant people with COVID-19 should be tested for SARS-CoV-2,[5,6] particularly those born to people with infection identified close to delivery and even if the pregnant individual had asymptomatic infection. Additionally, pregnant people should take measures to prevent infection, including COVID-19 vaccination, to protect themselves and their infants.[15]

TABLE 2 Characteristics of people with COVID-19 during pregnancy and their live-born neonates, by neonate SARS-CoV-2 real-time polymerase chain reaction (RT-PCR) testing status—SET-NET, 20 jurisdictions[a], 20 January 2020—31 December 2020 and reported by 5 November 2021

	SET-NET data		Fully imputed data[b]			
	Neonates with no testing data reported	Neonates with one or more perinatal test result reported	Neonates with no testing data reported (%)[c]	Neonates with one or more perinatal test result reported (%)[c]	Proportion of neonates with test data reported (%)[c]	Adjusted Prevalence Ratio (95% CI)[d]
	N = 24,955	*N* = 3816	*N* = 24,955	*N* = 3816	13.3	
Maternal characteristics						
Age in years						
<25	5959	995	24.4	26.3	14.2	1.00 (Reference)
25–34	14,357	2054	58.7	54.4	12.4	0.98 (0.91, 1.05)
≥35	4167	730	17.0	19.3	14.8	1.00 (0.92, 1.09)
Not reported	472	37				
Race/ethnicity						
Asian, non-Hispanic	920	153	3.9	4.3	14.4	1.30 (1.12, 1.51)
Black, non-Hispanic	4162	585	17.2	15.9	12.4	1.20 (1.08, 1.32)
Hispanic	7867	1784	33.2	49.3	18.5	1.41 (1.30, 1.52)
White, non- Hispanic	10,146	984	42.1	26.7	8.8	1.00 (Reference)
Multiple or other race, non-Hispanic	886	139	3.7	3.8	13.6	1.18 (0.99, 1.4)
Not reported	974	171				
Underlying conditions						
One or more underlying conditions[e]	11,580	1812	46.4	47.9	13.65	1.04 (0.98, 1.10)
No underlying conditions	13,375	2004	53.7	52.1	12.92	1.00 (Reference)
Hypertensive disorders of pregnancy[f]						
Yes	884	644	13.3	22.2	33.8	1.08 (0.98, 1.20)
No	9307	2459	86.7	77.8	21.5	1.00 (Reference)
Not reported	746	644				
Trimester of infection[g]						
First	5157	74	20.6	1.8	1.3	1.00 (Reference)
Second	8114	242	33.5	6.4	2.8	2.12 (1.62, 2.76)
Third	10,940	3482	45.9	91.8	23.4	16.61 (13.11, 21.05)
Not reported	744	18				
Maternal symptom status						
Asymptomatic	1674	927	16.5	34.8	24.4	1.00 (Reference)
Symptomatic	11,968	1625	83.5	65.2	10.7	0.72 (0.66, 0.78)
Not reported	11,313	1264				
Timing of pregnant individual's first positive RT-PCR test (days prior to delivery)						
>14 days	19,094	767	80.1	20.3	3.7	1.00 (Reference)
≤14 days	4770	3015	19.9	79.7	37.9	9.94 (9.19, 10.77)
Not reported	1091	34				
Delivery type						
Vaginal	15,711	2232	65.9	61.7	12.5	1.00 (Reference)
Caesarean	7812	1303	34.1	38.3	14.7	1.07 (1.00, 1.13)
Not reported	1432	281				

TABLE 2 (Continued)

	SET-NET data		Fully imputed data[b]			
	Neonates with no testing data reported	Neonates with one or more perinatal test result reported	Neonates with no testing data reported (%)[c]	Neonates with one or more perinatal test result reported (%)[c]	Proportion of neonates with test data reported (%)[c]	Adjusted Prevalence Ratio (95% CI)[d]
	N = 24,955	*N* = 3816	*N* = 24,955	*N* = 3816	13.3	
Infant characteristics						
Gestational age at birth						
Term (≥37 wks)	21,286	3126	89.5	84.2	12.6	1.00 (Reference)
Late Preterm (34–36 weeks)	1744	410	8.0	11.4	17.9	1.15 (1.04, 1.27)
Moderately and Extremely preterm (<34 weeks)	607	165	2.5	4.4	21.1	1.15 (0.94, 1.41)
Not reported	1318	115				
Neonate sex						
Female	12,236	1874	49.3	49.2	13.2	1.00 (Reference)
Male	12,592	1937	50.7	50.8	13.3	0.99 (0.93, 1.05)
Not reported	127	5				
Birthweight						
Low birthweight (<2500 g)	1718	375	7.7	11.6	18.8	1.14 (1.02, 1.27)
Normal birthweight	21,613	2966	92.3	88.4	12.8	1.00 (Reference)
Not reported	1624	475				
Small for gestational age[h]						
Small for gestational age	1201	212	5.5	6.8	16.0	1.06 (0.93, 1.2)
Not small for gestational age	21,701	3110	94.5	93.2	13.1	1.00 (Reference)
Not enough information	2053	494				
Neonatal intensive care unit admission						
Admitted during birth hospitalisation	2165	707	10.1	25.5	27.9	1.55 (1.44, 1.67)
Not admitted	20,407	2301	89.9	74.5	11.2	1.00 (Reference)
Not reported	2383	808				

[a]Including California [excluding Los Angeles County], Georgia, Houston, Kansas, Los Angeles County, Massachusetts, Maryland, Michigan, Minnesota, Missouri, Nebraska, Nevada, New Jersey, New York [excluding New York City], North Dakota, Pennsylvania [excluding Philadelphia], Puerto Rico, Tennessee, Vermont and Washington.

[b]Multiple imputation with a fully conditional specification was conducted and analysed for all variables in the table, with 50 imputations.

[c]Values reflect percentages from the fully imputed data set. No missingness is present in the fully imputed data set.

[d]For each characteristic, the adjusted prevalence ratio (aPR) is calculated using a modified Poisson model with robust standard errors to regress the prevalence of having test data reported on the characteristic and adjusted for jurisdiction and days from maternal SARS-CoV-2 infection to delivery (continuous). The aPRs reflect separate models for each characteristic. For example, Tested (0, 1) = $\beta_{\text{jurisdiction}} + \beta_{\text{days from positive to delivery}} + \beta_{\text{characteristic of interest}}$. Because of sparse data, records from Vermont and North Dakota were excluded from the multivariable models ($n = 8$).

[e]Includes cardiovascular disease, chronic hypertension, chronic lung disease, diabetes mellitus (type 1 or type 2), immunosuppression and obesity (body mass index ≥30 kg/m^2).

[f]Inclusive of preeclampsia, eclampsia or HELLP (haemolysis, elevated liver enzymes and low platelet) syndrome. Does not include chronic hypertension. Hypertensive disorders of pregnancy were only considered as underlying conditions for individuals with third trimester infection.

[g]The multivariable model for trimester of infection was adjusted for reporting jurisdiction only because trimester of infection and days from maternal infection to delivery were too collinear, affecting model convergence and variance estimates.

[h]Defined as weight <10th percentile for sex (presumed female if missing) and gestational age using the INTERGROWTH-21st online percentile calculator http://intergrowth21.ndog.ox.ac.uk. Some gestational ages were reported in completed weeks only (rather than in weeks and days).

ACKNOWLEDGEMENTS

We thank the following persons for their contributions to this project: Savij Apichon, Olga Barer, Emily Barnes, J. Michael Bryan, Melissa Campion, Alex Caraballo Hernandez, Tiffany Chen, Abigail Davis, Valorie Eckert, Tyler Faulkner, Skip Frick, Erika Fuchs, Tahani Hamdan, Elizabeth Harvey, Vivian Hawkins, Celeste Illian, Samir Koirala, Paul Laguna Martínez, Sashawn Lawrence, Shannon Lawrence, Allison Longenberger, Caleb Lyu, Jaimee Maranon, Mariam Marcano Huertas, Raghav Mehta, Glorimar Meléndez Rosario, Cristina Meza, Camille Millar, Nina Mykhaylov, Van Ngo, Aritzay Nieves Colon, Leishla Nieves Ferrer, Patrick Nwachukwu, Natasha Nyquist-Smith, Richard Olney, Lauren Torso Orkis, Nicolle Quintana Paradizo, Joy Rende, Bethany Reynolds, Alison Ryan, Valerie Sánchez Vázquez, Victoria Sanon, Nelida Santos Burgos, Ronda Simpson, Jordan Sontz, Similoluwa Sowunmi, Anam Syed, Ashlyn Torrez, Miguel Valencia-Prado, Stephanie Vicente González, Barbara Warmerdam, Sharon M. Watkins, Robin Williams, Bill Williamson and Heather Wingate. Finally, we thank the COVID-19 Pregnancy and Infant Linked Outcomes Team, the Epidemiology and Surveillance Task Force.

CONFLICT OF INTEREST

All authors have no conflicts of interest to disclose.

AUTHOR CONTRIBUTION

All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

DISCLAIMER

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention (CDC). Of note, SET-NET does not collect data on sex or gender of the birthing individual. We use the term 'maternal' throughout this publication to describe characteristics of birthing individuals, although they may be of any gender. We continue to work through the challenge of finding the most inclusive language that is clear and scientifically accurate.

DATA AVAILABILITY STATEMENT

The SET-NET data are not available at this time.

ORCID

Emily O'Malley Olsen https://orcid.org/0000-0002-5312-7596
Van T. Tong https://orcid.org/0000-0002-3970-1440

REFERENCES

1. Zambrano LD, Ellington S, Strid P, et al. Update: Characteristics of symptomatic women of reproductive age with laboratory-confirmed SARS-CoV-2 infection by pregnancy status — United States, January 22–October 3, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:1641–1647. doi:10.15585/mmwr.mm6944e3
2. Woodworth KR, Olsen EO, Neelam V, et al. Birth and infant outcomes following laboratory-confirmed SARS-CoV-2 infection in pregnancy — SET-NET, 16 Jurisdictions, March 29–October 14, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:1635–1640. doi:10.15585/mmwr.mm6944e2
3. Walker KF, O'Donoghue K, Grace N, et al. Maternal transmission of SARS-COV-2 to the neonate, and possible routes for such transmission: a systematic review and critical analysis. *BJOG*. 2020;127(11):1324–1336. doi:10.1111/1471-0528.16362
4. Fenizia C, Biasin M, Cetin I, et al. Analysis of SARS-CoV-2 vertical transmission during pregnancy. *Nat Commun*. 2020;11(1):5128. doi:10.1038/s41467-020-18933-4
5. American Academy of Pediatrics. FAQs: management of infants born to mothers with suspected or confirmed COVID-19. Published September 2020. Accessed August 26, 2021. https://services.aap.org/en/pages/2019-novel-coronavirus-covid-19-infections/clinical-guidance/faqs-management-of-infants-born-to-covid-19-mothers/
6. Centers for Disease Control and Prevention. Evaluation and management considerations for neonates at risk for COVID-19. Published December 2020. Accessed August 26, 2021. https://www.cdc.gov/coronavirus/2019-ncov/hcp/caring-for-newborns.html
7. Woodworth KR, Reynolds MR, Burkel V, et al. A preparedness model for mother-baby linked longitudinal surveillance for emerging threats. *Matern Child Health J*. 2021;25(2):198–206. doi:10.1007/s10995-020-03106-y
8. C.F.R. part 46.102(l)(2), 21 C.F.R. part 56; 42 U.S.C. Sect. 241(d); 5 U.S.C. Sect. 552a; 44 U.S.C. Sect. 3501 et seq.
9. Galang RR, Newton SM, Woodworth KR, et al. Risk factors for illness severity among pregnant women with confirmed severe acute respiratory syndrome coronavirus 2 infection – Surveillance for Emerging Threats to Mothers and Babies Network, 29 state, local, and territorial health departments, March 29, 2020 -March 5, 2021. *Clin Infect Dis*. 2021;73(Suppl 1):S17–S23. doi:10.1093/cid/ciab432
10. Angelidou A, Sullivan K, Melvin PR, Shui JE, Goldfarb IT, Bartolome R, Chaudhary N, Vaidya R, Culic I, Singh R, Yanni D, Patrizi S, Hudak ML, Parker MG, Belfort MB. Association of maternal perinatal SARS-CoV-2 infection with neonatal outcomes during the COVID-19 pandemic in Massachusetts. *JAMA Netw Open*. 2021;4(4):e217523. doi:10.1001/jamanetworkopen.2021.7523
11. Norman M, Navér L, Söderling J, et al. Association of maternal SARS-CoV-2 infection in pregnancy with neonatal outcomes. *JAMA*. 2021;325(20):2076–2086.
12. Palmsten K, Vazquez-Benitez G, Kharbanda EO. Point: uncertainty about estimating the risks of COVID-19 during pregnancy. *Paediatr Perinat Epidemiol*. 2021:1–3. doi:10.1111/ppe.12773
13. World Health Organization. Definition and categorization of the timing of mother-to-child transmission of SARS-CoV-2. 2012. Accessed August 26, 2021. https://www.who.int/publications/i/item/WHO-2019-nCoV-mother-to-child-transmission-2021.1
14. Quilty BK, Clifford S, Hellewell J, Russell TW, Kucharski AJ, Flasche S, Edmunds WJ. Quarantine and testing strategies in contact tracing for SARS-CoV-2: a modelling study. *Lancet Public Health*. 2021;6(3):e175–e183. doi:10.1016/S2468-2667(20)30308-X
15. Centers for Disease Control and Prevention. COVID-19 vaccines while pregnant or breastfeeding. Updated August 11, 2021. Accessed August 27, 2021. https://www.cdc.gov/coronavirus/2019-ncov/vaccines/recommendations/pregnancy.html

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

How to cite this article: Olsen EO, Roth NM, Aveni K, et al. SARS-CoV-2 infections among neonates born to pregnant people with SARS-CoV-2 infection: Maternal, pregnancy and birth characteristics. *Paediatr Perinat Epidemiol*. 2022;36:476–484. doi:10.1111/ppe.12883