Symptoms and Transmission of SARS-CoV-2 Among Children — Utah and Wisconsin, March–May 2020

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abstract

BACKGROUND AND OBJECTIVES: Limited data exist on severe acute respiratory syndrome coronavirus 2 in children. We described infection rates and symptom profiles among pediatric household contacts of individuals with coronavirus disease 2019.

METHODS: We enrolled individuals with coronavirus disease 2019 and their household contacts, assessed daily symptoms prospectively for 14 days, and obtained specimens for severe acute respiratory syndrome coronavirus 2 real-time reverse transcription polymerase chain reaction and serology testing. Among pediatric contacts (<18 years), we described transmission, assessed the risk factors for infection, and calculated symptom positive and negative predictive values. We compared secondary infection rates and symptoms between pediatric and adult contacts using generalized estimating equations.

RESULTS: Among 58 households, 188 contacts were enrolled (120 adults; 68 children). Secondary infection rates for adults (30%) and children (28%) were similar. Among households with potential for transmission from children, child-to-adult transmission may have occurred in 2 of 10 (20%), and child-to-child transmission may have occurred in 1 of 6 (17%). Pediatric case patients most commonly reported headache (79%), sore throat (68%), and rhinorrhea (68%); symptoms had low positive predictive values, except measured fever (100%; 95% confidence interval [CI]: 44% to 100%). Compared with symptomatic adults, children were less likely to report cough (odds ratio [OR]: 0.15; 95% CI: 0.04 to 0.57), loss of taste (OR: 0.21; 95% CI: 0.06 to 0.74), and loss of smell (OR: 0.29; 95% CI: 0.09 to 0.96) and more likely to report sore throat (OR: 3.4; 95% CI: 1.04 to 11.18).

CONCLUSIONS: Children and adults had similar secondary infection rates, but children generally had less frequent and severe symptoms. In two states early in the pandemic, we observed possible transmission from children in approximately one-fifth of households with potential to observe such transmission patterns.

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Drs Laws, Chancey, Rabold, and Tran conceptualized and designed the study, collected data, conducted the analyses, and wrote and revised the manuscript; Dr Kirking conceptualized, designed, and coordinated the study, provided subject matter expertise, and critically reviewed the manuscript for important intellectual content; Drs Hall, Fry, and Tate provided project leadership and subject matter expertise and reviewed the manuscript for important intellectual content; (Continued)

WHAT'S KNOWN ON THIS SUBJECT: In the limited pediatric coronavirus disease 2019 (COVID-19) literature, researchers suggest that, compared with adults, children may be infected less frequently, have less severe infections, and have a greater proportion of asymptomatic infections. However, more data are needed, particularly among pediatric outpatients with mild illness.

WHAT THIS STUDY ADDS: Among a cohort of household contacts of individuals with COVID-19, the rate of acquiring severe acute respiratory syndrome coronavirus 2 infection was similar between children and adults. Children who developed COVID-19 reported mild symptoms that were less frequent and severe than those experienced by adults.

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As of September 16, 2020, >6.5 million cases of coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), have been reported in the United States.[1] Although children <18 years make up 22% of the US population,[2] they compose 8.3% of reported US cases.[3] This apparent underrepresentation of children among cases is described in the limited pediatric COVID-19 literature, in which researchers suggest that, compared with adults, children may be infected less frequently, have less severe infections, and have a greater proportion of asymptomatic infections.[4–10] Alternatively, these findings may reflect decreased exposures due to mitigation efforts or less frequent testing.

Data are needed to characterize SARS-CoV-2 transmission from children and symptoms of COVID-19, particularly among pediatric outpatients with mild illness. Here, we describe a cohort of pediatric household contacts of individuals with COVID-19. We aimed to assess pediatric rates of secondary infection, characterize transmission patterns, and describe symptoms among children infected with SARS-CoV-2.

METHODS

Study Population

In collaboration with state and local health departments and in the setting of a public health emergency response, the US Centers for Disease Control and Prevention (CDC) conducted a household transmission investigation during March to May 2020 in Milwaukee, Wisconsin, and Salt Lake City, Utah, metropolitan areas. Methods from the full investigation are available at Lewis et al[11]; here, we describe a secondary analysis of the overall household transmission investigation, focused on details related to children in the households. In brief, we approached and enrolled a convenience sample of index case patients with laboratory-confirmed SARS-CoV-2 and their household contacts. Index case patients were identified by local health departments through routine surveillance and contact tracing activities. After completing their own investigation of the reported case, local health department staff described the CDC investigation protocol, asked if the index case patient and household members were interested in participating, and, if so, referred them to the CDC team for study enrollment. Households were eligible for enrollment if the index case patient was within 10 days of his or her first positive test result for SARS-CoV-2 by real-time reverse transcription polymerase chain reaction (RT-PCR) and was at home during enrollment (ie, not hospitalized), with at least one additional household member who was willing to participate. All enrolled index case patients and household contacts were followed prospectively for 14 days.

Data Collection and Laboratory Testing

Index case patients and household contacts were interviewed by using standard questionnaires that captured demographics, medical history, previous SARS-CoV-2 testing, and symptoms since the index case patient's illness onset (Supplemental Information). At study enrollment (day 0), the CDC team visited the household to collect blood and respiratory specimens (nasopharyngeal and self-collected anterior nasal swabs). If a household contact developed new or worsening symptoms, the CDC team conducted an interim visit to collect respiratory specimens from all household members. Five households were selected for intensive swabbing requiring collection of respiratory specimens from all household members during four interim visits regardless of symptom presence. At study close-out (day 14), the CDC team returned to collect blood and respiratory specimens. During the 14-day follow-up, participants completed daily symptom logs, which included temperature checks with study-provided digital thermometers; a parent or guardian used discretion to determine if child(ren) needed assistance.

The City of Milwaukee Health Department Laboratory and the Utah Public Health Laboratory tested respiratory specimens using the CDC 2019-nCoV real-time RT-PCR assay[12] and processed and shipped blood specimens to the CDC for serology testing using the CDC SARS-CoV-2 spike protein enzyme-linked immunosorbent assay (ELISA).[13]

Statistical Analyses

We classified household members as either primary patient or household contact; the primary patient was the household member with earliest symptom onset (and positive SARS-CoV-2 RT-PCR test result). In most (89%) households, the primary patient was the same as the index case patient first identified by the health department. To assess transmission patterns, we excluded households with coprimary patients (with symptom onset ≤2 days of each other), so that each household had one source individual. We categorized household members <18 years as children and classified adult and pediatric household contacts as adult case patients and pediatric case patients, respectively, if they tested positive for SARS-CoV-2 by RT-PCR or had total anti–SARS-CoV-2 antibody titers ≥100 by ELISA at

any point during the study period. Given the low community prevalence early in the pandemic and lag time between exposure and study enrollment, seropositivity was used as a marker of recent acute infection.

We described demographics of household contacts, stratified by age. To account for household clustering, we used generalized estimating equations (GEEs) with an independent correlation matrix and logit link to compare secondary infection rates between pediatric and adult contacts. Among pediatric contacts, we calculated unadjusted odds ratios (ORs) and 95% confidence intervals (CIs) using GEEs to assess risk factors for infection. We calculated the serial interval as the number of days between symptom onset of the primary patient and associated secondary case patient.

Among pediatric case patients, we described the timing of RT-PCR and serology results in relation to primary patient and individual symptom onset. To assess the possibility of children transmitting SARS-CoV-2 within households, we calculated the difference in symptom onset in days between all case patients in the same household. On the basis of expected minimum incubation periods, we considered a child as a possible source of transmission if a subsequent case patient developed symptoms >2 days later.[14,15] Community prevalence in these two metropolitan areas was low during this time, and both were under stay-at-home orders, which started soon after study initiation and extended throughout study enrollment, reducing the likelihood of outside exposures.

We categorized symptoms as constitutional (measured or subjective fever, chills, myalgia, and fatigue), upper respiratory (runny nose, nasal congestion, and sore throat), lower respiratory (cough, difficulty breathing, shortness of breath, wheezing, and chest pain), neurologic (headache, loss of taste, and loss of smell), and gastrointestinal (nausea and/or vomiting, diarrhea, and abdominal pain). Among pediatric case patients, we described the frequencies of reporting symptoms and meeting COVID-19 and syndromic surveillance case definitions (coronavirus disease 2019–like illness [CLI][15]; Council of State and Territorial Epidemiologists [CSTE] COVID-19[16]; influenza-like illness [ILI][17]; World Health Organization [WHO] acute respiratory infection [ARI][18]) and calculated positive predictive values (PPVs), negative predictive values (NPVs), and 95% CIs. We used GEEs to compare the symptom frequency and duration between pediatric and adult case patients; those who remained symptomatic at the end of the study period were treated statistically as if their symptoms resolved on day 14.

Ethical Considerations

This protocol was reviewed by CDC and deemed nonhuman subjects research as part of the COVID-19 public health response. All participants provided written consent (or child assent with parental permission) before participation.

RESULTS

Study Population

Individuals from 62 households were enrolled; four households with coprimary patients were excluded (Fig 1). Among the 58 households included (UT: n = 34; WI: n = 24), children resided in 33 (57%). One household had a pediatric primary patient. In total, 188 household contacts were enrolled and included; 68 (36%) were children (Table 1). Of 120 adult contacts, 65 (54%) resided in households with children.

Among 68 pediatric contacts, 37 (54%) were female, 34 (50%) were between 5 and 12 years, and 43 (60%) were non-Hispanic white (Table 1). Nine (13%) children had an underlying medical condition, with asthma the most commonly reported. Most (63%) pediatric contacts were children of the primary patient, whereas 21% were siblings of the (adult) primary patient. Among adult contacts, 74% were between 18 and 49 years, and 49 (41%) had an underlying medical condition. A full description of household characteristics and mitigation measures in the household is available at Lewis et al.[11]

Secondary Infections Among Pediatric and Adult Contacts

Among 68 pediatric contacts, 19 (28%) tested positive for SARS-CoV-2 by RT-PCR or ELISA. Among 120 adult contacts, 36 (30%) tested positive, including 18 of 65 (28%) in households with children and 18 of 55 (33%) in households without childrenunder (Fig 2). There were no significant differences in secondary infection rates between adult and pediatric contacts among all households (OR: 1.11; 95% CI: 0.56 to 2.21) or among households with children (OR: 0.99; 95% CI: 0.51 to 1.90).

Risk Factors for Infection Among Pediatric Contacts

Among the 19 pediatric case patients, the median age was 13 years (range: 3–17; interquartile range [IQR]:10–15 years), 12 (63%) were female, and 14 (74%) were non-Hispanic white. Children of primary patients had increased odds of acquiring infection compared with children in

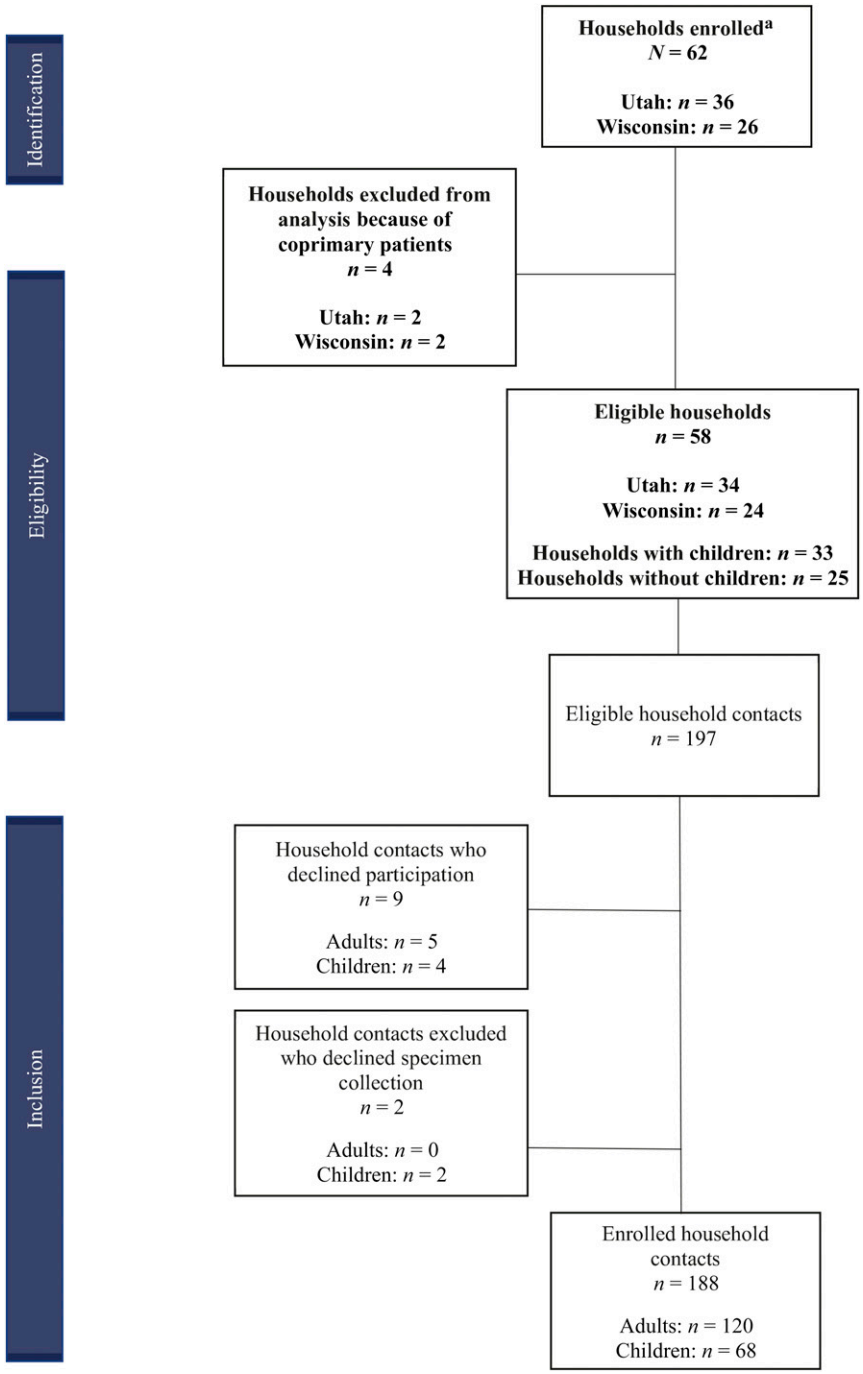

FIGURE 1

Enrollment flowchart. [a] A convenience sample of index cases with laboratory-confirmed SARS-CoV-2 infection was identified by local health departments through routine surveillance and referred to the CDC team for study enrollment.

households in which the primary patient was not their parent (OR: 17.28; 95% CI: 2.36 to 126.8). There were no significant differences in the odds of acquiring infection by age, sex, race–ethnicity, underlying medical conditions, number of household members, household size, or ratio of children to bedrooms and bathrooms. No children were hospitalized, and none died. The median serial interval among pediatric case patients was 5 days (IQR: 4–9 days), and the median symptom duration was 10 days (IQR: 6–14 days), although 2 children were still experiencing symptoms at the end of the study period (Table 2).

Transmission Patterns in Households With Children

In Fig 3, we display serial intervals and transmission patterns in households with children. There was potential for transmission from children in 12 households, ie, there were susceptible household contacts >2 days after illness onset of the first infected child in the house (Fig 3A; households A–F and I–N). Of 10 households with potential for child-to-adult transmission, 2 (20%; households K and M) represent possible transmission from child to adult. Of 6 households with potential for child-to-child transmission, 1 (17%; household L) represents possible transmission between children. In household L, the first infected child (girl; 14 years) was a caretaker for her infected mother and may have transmitted SARS-CoV-2 to her sibling (girl; 10 years). In households with no pediatric case patients (Fig 3B), 9 of 39 (23%) adult contacts tested positive for SARS-CoV-2.

RT-PCR Results in Pediatric Case Patients

The single pediatric primary patient had an respiratory specimen positive for SARS-CoV-2 by RT-PCR collected before study enrollment and did not seroconvert during the study period (Fig 4; child A1).

Among the 19 pediatric case patients, 15 (79%) had respiratory specimens positive for SARS-CoV-2 by RT-PCR collected before or during the study period (Fig 4). One

TABLE 1 Demographic, Clinical, and Household Characteristics of Pediatric and Adult Household Contacts (N = 188) of Primary Patients With COVID-19

Characteristic	Pediatric Contacts (n = 68), n (%)	Adult Contacts in All Households (n = 120), n (%)	Adult Contacts in Households With Children (n = 65), n (%)
Sex			
Male	31 (46)	61 (51)	28 (43)
Female	37 (54)	59 (49)	37 (57)
Age, y			
<1	2 (3)	—	—
1–4	8 (12)	—	—
5–12	34 (50)	—	—
13–17	24 (35)	—	—
18–49	—	88 (73)	51 (78)
50–64	—	26 (22)	12 (18)
≥65	—	6 (5)	2 (3)
Race–ethnicity			
Non-Hispanic white	43 (63)	71 (59)	41 (63)
Non-Hispanic Black	4 (6)	20 (17)	3 (5)
Hispanic (any race)	11 (16)	21 (18)	14 (22)
Non-Hispanic Asian	5 (7)	5 (4)	5 (8)
Non-Hispanic American Indian	1 (1)	3 (3)	2 (3)
Non-Hispanic multiracial	4 (6)	0 (0)	0 (0)
State			
Wisconsin	21 (31)	41 (34)	17 (26)
Utah	47 (69)	79 (66)	48 (74)
Underlying medical conditions			
Any medical condition	9 (13)	49 (41)	24 (37)
Chronic lung disease	7 (10)	26 (22)	11 (17)
Asthma	7 (10)	24 (21)	9 (15)
Diabetes	1 (1)	4 (3)	2 (3)
Cardiovascular disease	0 (0)	17 (14)	6 (9)
Kidney disease	0 (0)	2 (2)	0 (0)
Liver disease	0 (0)	2 (2)	0 (0)
Immunocompromising condition	0 (0)	2 (2)	1 (2)
Neurodevelopmental disability	0 (0)	2 (2)	1 (2)
Other chronic condition	1 (1)	9 (8)	6 (9)
Relationship to primary patient			
Spouse or partner	—	33 (28)	25 (38)
Child	43 (63)	17 (14)	8 (12)
Sibling	14 (21)	16 (13)	11 (17)
Parent	—	24 (20)	13 (20)
Extended family	9 (13)	11 (9)	5 (8)
Housemate	2 (3)	19 (16)	3 (5)
No. household members			
2–4	24 (35)	66 (55)	26 (40)
5–6	21 (31)	30 (25)	17 (26)
≥7	23 (34)	24 (20)	22 (34)
Square footage per household member			
<500	30 (44)	59 (49)	26 (40)
≥500	38 (56)	61 (51)	39 (60)
No. persons per bedroom			
≤1	27 (40)	61 (51)	34 (52)
>1	41 (60)	59 (49)	31 (48)
No. persons per bathroom			
≤1	6 (9)	15 (13)	7 (11)
>1	62 (91)	105 (88)	58 (89)

—, not applicable.

child was asymptomatic at the time of first positive test by RT-PCR but developed symptoms 2 days later (Fig 4A; child H2); among the remaining 14 pediatric case patients with respiratory specimens positive for SARS-CoV-2 by RT-PCR, the median time between symptom onset and RT-PCR positive test result was 2 days (IQR: 1–6 days); specimens from 3 of these children were RT-PCR–positive for SARS-CoV-2 on the day of symptom onset. At day 14, 3 (16%) children had repeat RT-PCR SARS-CoV-2–positive specimens collected, indicating that length of RT-PCR positivity was at least 14 days in those children.

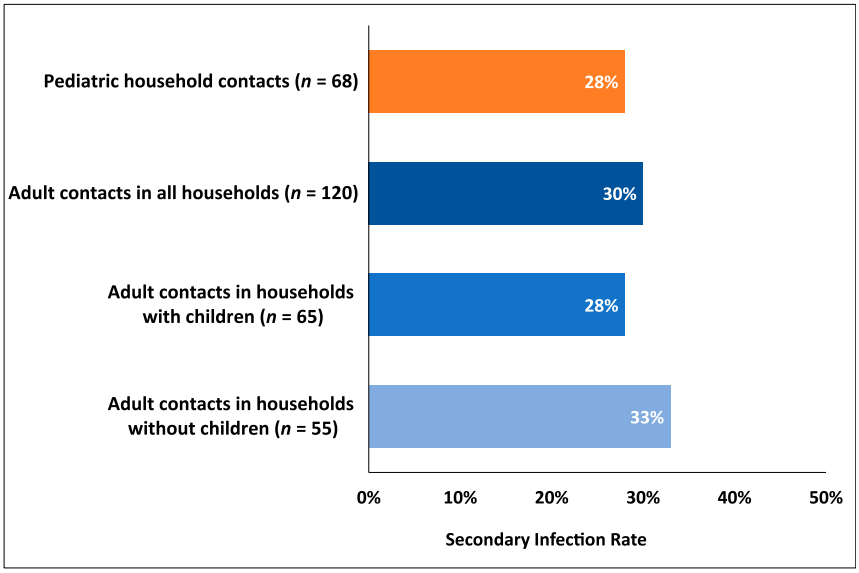

FIGURE 2
Secondary infection rates of SARS-CoV-2 among pediatric and adult household contacts (N = 188).

Serology Results in Pediatric Case Patients

Among the 19 pediatric case patients, 17 had at least 1 available serum specimen; all tested positive for SARS-CoV-2 antibodies by ELISA during the study period (Fig 4B). These children had a median of 13 days between symptom onset and seropositivity (IQR: 7–16 days) and median of 17 days between primary patient symptom onset (ie, exposure) and seropositivity (IQR: 16–24 days). Sixteen had paired sera; 9 of 16 (56%) revealed evidence of seroconversion during the study period.

Four pediatric case patients tested positive by serology only (Fig 4; children B1, C1, M1, and N1). All 4 displayed COVID-19 symptoms during or shortly before the study period but after the primary patient's symptom onset. One (child N1) seroconverted during the study period, consistent with recent acute infection. Two children (B1 and C1) had an initial RT-PCR positive test result 16 days after the primary patients' symptom onset, and symptoms resolved on the day of or 1 day before study enrollment. Child M1 had serum collected on day 14 only, preceded by symptoms consistent with acute infection.

Symptoms Among Pediatric Household Contacts

Among the 19 pediatric case patients, all reported at least one symptom. Upper respiratory and neurologic symptoms (both 84%) were the most commonly reported symptom categories (Fig 5). The most commonly reported individual symptoms were headache (79%), sore throat (68%), rhinorrhea (68%), and nasal congestion (63%). Less than one-half of pediatric case patients reported any gastrointestinal symptoms (42%), cough (42%), loss of smell (32%), loss of taste (21%), or measured fever (16%). In general, the majority of symptoms had low PPVs; the highest PPV was for measured fever (PPV: 100%; 95% CI: 44% to 100%), although it was only reported by 3 pediatric case patients (Table 3). The highest NPVs were in neurologic symptoms (NPV: 93%; 95% CI: 81% to 97%), specifically, headache (NPV: 91%; 95% CI: 78% to 96%) and upper respiratory symptoms (NPV: 90%; 95% CI: 75% to 97%). COVID-19 and syndromic surveillance case definitions had low PPVs and high NPVs (CSTE COVID-19 [NPV: 93%; 95% CI: 81% to 98%]; CLI [NPV: 89%; 95% CI: 77% to 95%]; WHO ARI [NPV: 90%; 95% CI: 74% to 97%]).

When comparing pediatric (n = 19) and adult (n = 36) case patients, children had a lower frequency of reporting most symptoms (Fig 6). Pediatric case patients were significantly less likely to report lower respiratory symptoms (OR: 0.17; 95% CI: 0.04 to 0.82), cough (OR: 0.15; 95% CI: 0.04 to 0.57), loss of taste (OR: 0.21; 95% CI: 0.06 to 0.74), and loss of smell (OR: 0.29; 95% CI: 0.09 to 0.96) than adult case patients and more likely to report sore throat (OR: 3.4; 95% CI: 1.04 to 11.18). Pediatric case patients experienced a shorter duration of symptoms, in comparison with adults (median of 10 vs 16 days; $\beta = -6.5$; 95% CI: -10.1 to -2.9); this difference may be more pronounced because 2 (11%) children, compared with 14 (39%) adults, remained symptomatic at the end of the study period.

DISCUSSION

In this investigation, we followed a cohort of pediatric and adult household contacts of individuals with COVID-19 over time to assess their symptoms, determine if they acquired SARS-CoV-2 infection, and describe household transmission patterns. Our investigation is novel in that we describe outpatient children with COVID-19, who otherwise may not have been tested, and compare them with children who did not acquire infection

TABLE 2 Risk Factors Associated With SARS-CoV-2 Infection Among Pediatric Household Contacts (N = 68)

Characteristics of Pediatric Household Contacts	SARS-CoV-2–Positive Children (n = 19)	SARS-CoV-2–Negative Children (n = 49)	OR[a] (95% CI)
Age, y, *n* (%)			
<5	2 (11)	8 (16)	0.35 (0.06 to 1.91)
5–12	7 (37)	27 (55)	0.36 (0.13 to 1.05)
13–17	10 (53)	14 (29)	Reference
Sex, *n* (%)			
Male	7 (37)	24 (49)	0.61 (0.16 to 2.37)
Female	12 (63)	25 (51)	Reference
Race–ethnicity, *n* (%)			
Non-Hispanic white	14 (74)	29 (59)	Reference
Other	5 (26)	20 (41)	0.52 (0.10 to 2.64)
Underlying medical conditions, *n* (%)			
Any medical condition	4 (21)	5 (10)	2.35 (0.51 to 10.89)
Asthma	2 (11)	5 (10)	1.10 (0.12 to 10.47)
Relationship to primary patient, *n* (%)			
Child	18 (95)	25 (51)	17.28 (2.36 to 126.8)
Sibling, extended family, or housemate	1 (5)	24 (49)	Reference
Attended school in the 2 wk before primary patient onset, *n* (%)			
Yes	7 (37)	15 (31)	1.32 (0.39 to 4.46)
No	12 (63)	34 (69)	Reference
Attended day care in the 2 wk before primary patient onset, *n* (%)			
Yes	1 (5)	2 (4)	1.31 (0.11 to 15.50)
No	18 (95)	47 (96)	Reference
No. household members, *n* (%)			
2–4	8 (42)	16 (33)	Reference
5–6	8 (42)	13 (26)	1.23 (0.27 to 5.53)
≥7	3 (16)	20 (41)	0.29 (0.08 to 1.13)
Square footage per household member, *n* (%)			
<500	5 (26)	25 (51)	0.34 (0.08 to 1.50)
≥500	14 (74)	24 (49)	Reference
No. persons per bedroom, *n* (%)			
≤1	8 (42)	19 (39)	Reference
>1	11 (58)	30 (61)	0.87 (0.25 to 3.10)
No. persons per bathroom, *n* (%)			
≤1	3 (16)	3 (6)	Reference
>1	16 (84)	46 (94)	0.35 (0.05 to 2.50)
Serial interval, d, median (IQR)	5 (4–9)	—	—
Duration of symptoms,[b] d, median (IQR)	10 (6–14)	—	—

—, not applicable.

[a] Unadjusted ORs and 95% CIs were calculated by using GEEs with an independent correlation matrix and logit link to account for clustering within households.

[b] The symptom duration was not available past study close-out at day 14; n = 2 children were still experiencing symptoms at day 14.

and adults who did. We found that, compared with adults, children acquired infection at similar rates but developed less severe illness. We also found that, among this pediatric population, being the child of a primary patient increased the risk of acquiring infection in the household. Lastly, we observed that children were a possible source of further transmission in approximately one-fifth of households with the potential for such transmission patterns.

At the time of this investigation and until the availability of widespread testing, symptoms consistent with SARS-CoV-2 infection had been the trigger for testing and diagnosis. Our results are similar to other studies,[4,7,9] in that children with COVID-19 often had mild, nonspecific symptoms (sore throat, rhinorrhea, nasal congestion, and headache) that may be challenging to differentiate from other common childhood viral illnesses. In the absence of features commonly associated with COVID-19 in adults (fever, cough, and shortness of breath), children with COVID-19 may not have sought care or did not meet diagnostic testing criteria earlier in the pandemic, thus resulting in underrepresentation in surveillance data. In contrast to the 8.3% of cases reported among children in the United States,[3] 35% of household cases in our study population were in children, most of whom were identified because we tested all household contacts regardless of symptoms.

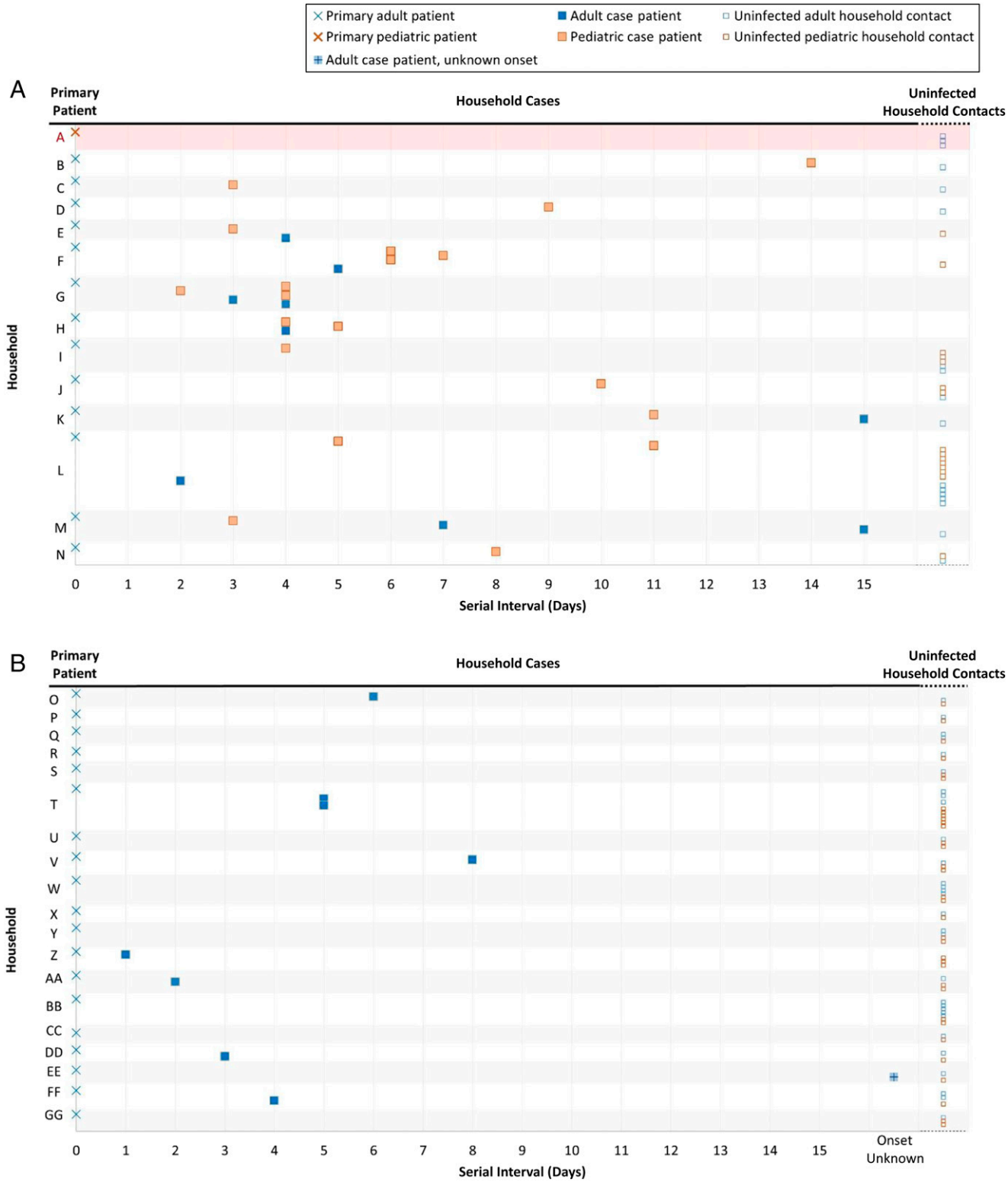

FIGURE 3

Time line of symptom onset of pediatric and adult secondary cases in households with children. We show symptom onset of secondary case patients in households with children relative to primary patient symptom onset. Each household member is represented by a single symbol (X, closed square, or open square). A, Households with at least one child with laboratory-confirmed SARS-CoV-2 infection. B, Households with no infections among children. The study period extended beyond the time line shown. For example, households B, K, and M were followed for 30, 29, and 20 days, respectively.

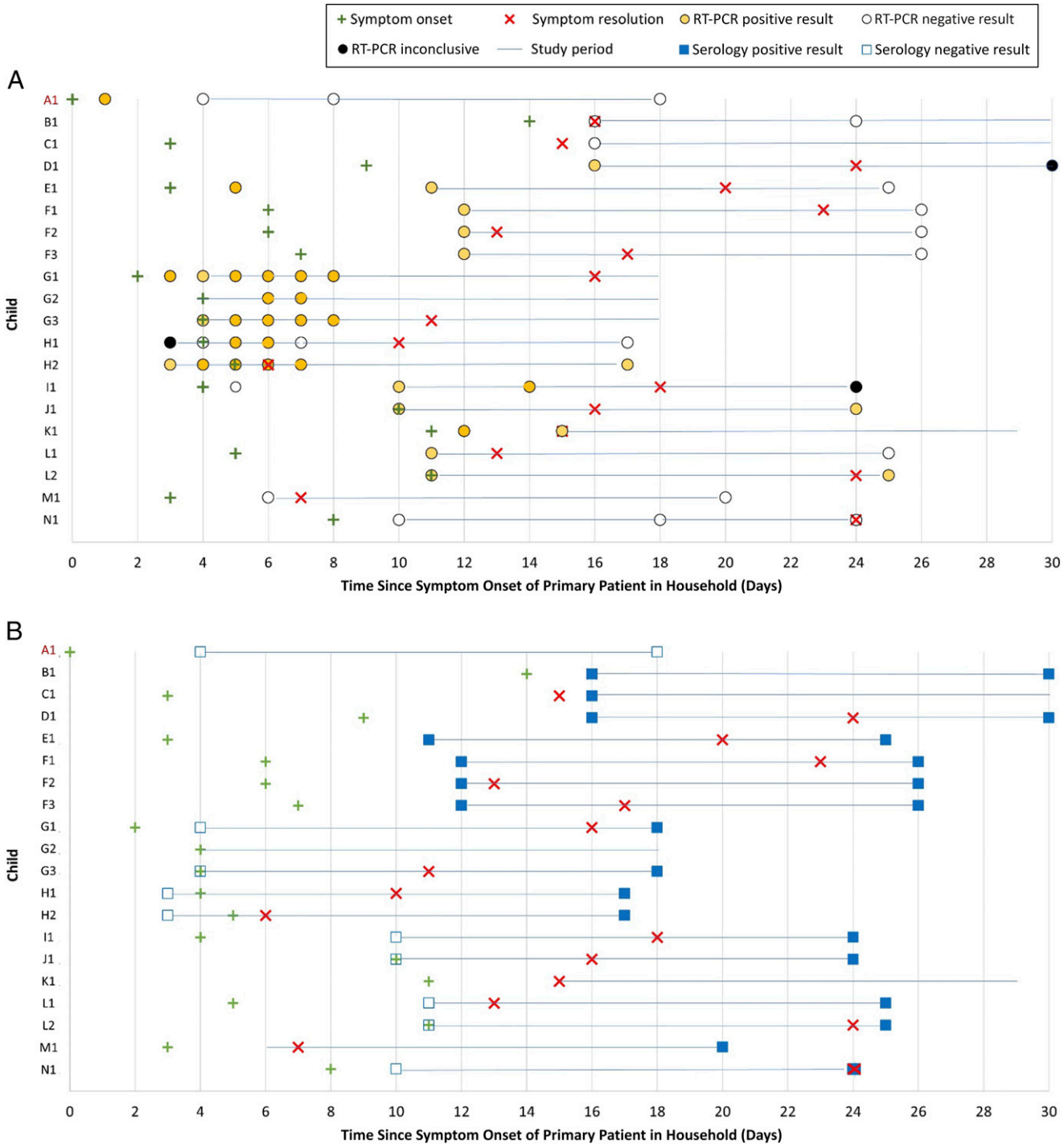

FIGURE 4

Time from symptom onset in primary patient to SARS-CoV-2 RT-PCR and ELISA test results among pediatric case patients. A and B, Results from RT-PCR testing and SARS-CoV-2 ELISA testing, respectively, for each child with laboratory-confirmed SARS-CoV-2 infection, with the letter corresponding to the household (see Fig 3). Symptom onset, symptom resolution, and test results of the pediatric case patient, relative to the primary patient symptom onset, are shown. Only 1 child (A1, in red) was a primary patient. Two children (A1 and G2) continued to have symptoms beyond the study period. Not all children had serological test results at enrollment and study close-out visits.

As schools and daycares reopen, home- and school-based symptom screening strategies are being used to limit transmission.[19,20] However, with most symptoms and case definitions having low PPVs, symptom screening checklists may either be too broad, resulting in unnecessarily restricting access, or too narrow, resulting in failed recognition of disease. Additionally, in recent studies, it is suggested that asymptomatic children

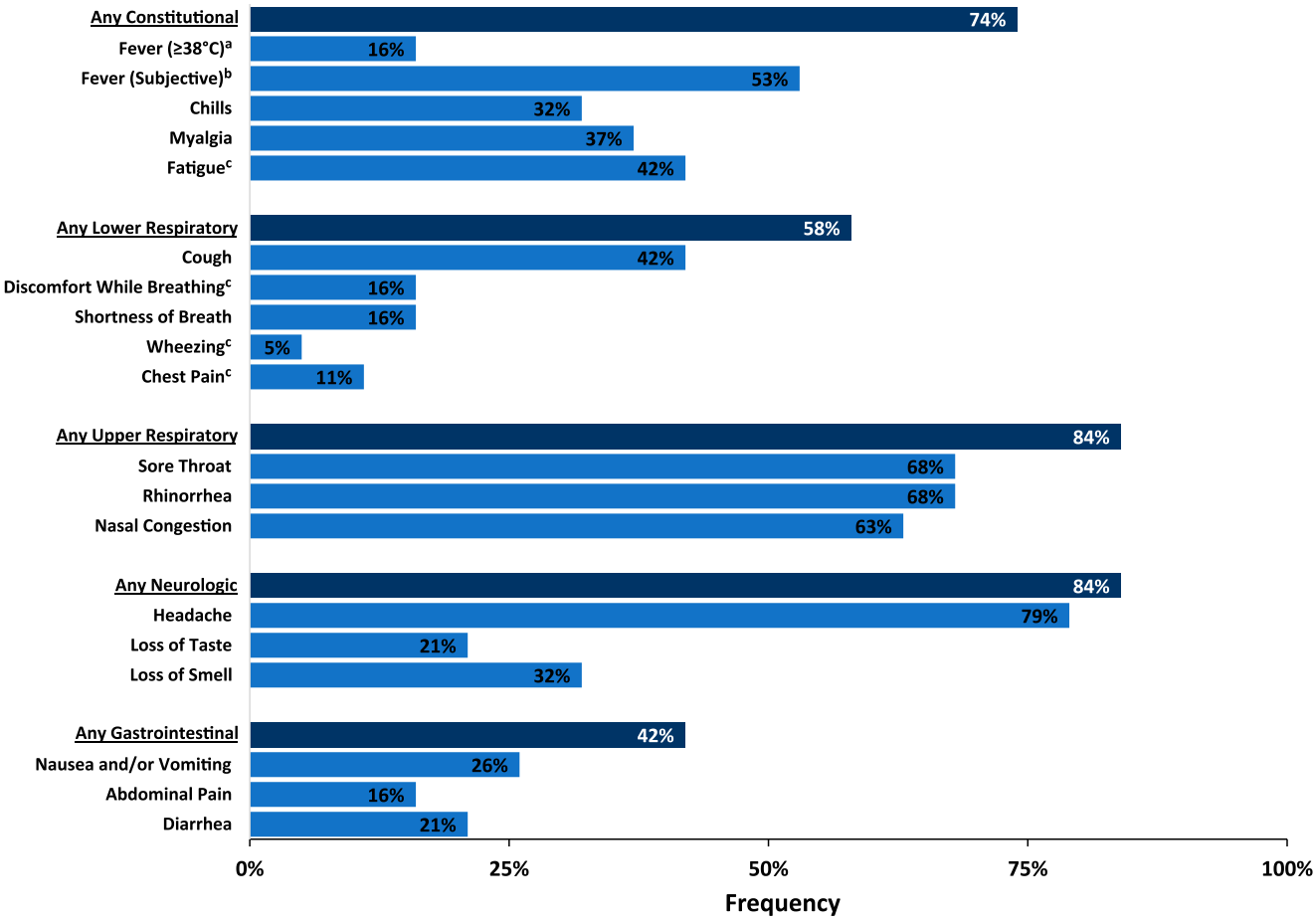

FIGURE 5

Frequency of symptoms among children with laboratory-confirmed SARS-CoV-2 infection (n = 19). [a] Equivalent to 100.4°C. [b] Subjective fever is defined as a fever that is felt (tactile) rather than measured. [c] Symptom was not systematically asked of all participants.

may transmit SARS-CoV-2[4,7,9,21]; although none of the children who tested positive for SARS-CoV-2 in our study were asymptomatic, 4 were either presymptomatic or on the day of symptom onset at first positive RT-PCR test result, suggesting that they may have been shedding the virus while not experiencing symptoms. Clinicians and schools should maintain a lower threshold for laboratory testing in children if there is an epidemiological link, especially to a parent with suspected or confirmed COVID-19, including in asymptomatic or mildly symptomatic children. Although challenging, the use of syndromic case definitions and/or use of symptoms with high NPVs for COVID-19 or other infectious diseases of concern may still have utility.

An improved understanding of children's role in the transmission of SARS-CoV-2 is important to better inform prevention recommendations. In studies conducted early in the pandemic, researchers suggested that children were infrequently the primary source of household SARS-CoV-2 infections.[22,23] However, in a more recent study of 153 pediatric index patients, researchers found that older children (10–19 years old) transmitted SARS-CoV-2 to 18.6% of household contacts,[24] and evidence has emerged that children with COVID-19 have similar or higher viral loads compared with adults.[25–27] We were limited in our ability to observe transmission from children, but, among households with the potential for such patterns, we found possible child-to-adult transmission in 20% and possible child-to-child transmission in 17%. Similarly, a case series of 15 households in Chicago, Illinois, suggested both child-to-child and child-to-adult transmission in 13%.[28] We found that children acquired infection at the same rate as adults, at ~30%. Compared to other respiratory viral infections, this is higher than documented secondary transmission rates for Middle East Respiratory Syndrome (4%)[29]

TABLE 3 PPVs and NPVs of Individual Symptoms Among Pediatric Household Contacts (N = 68) of Primary Patients With COVID-19

	SARS-CoV-2–Positive Children (n = 19), n	SARS-CoV-2–Negative Children (n = 49), n	Symptom PPV, % (95% CI)	Symptom NPV, % (95% CI)
Symptoms				
Constitutional	14	10	58 (39 to 76)	89 (76 to 95)
Fever	10	5	67 (42 to 85)	83 (71 to 91)
Measured (≥38°C[a])	3	0	100 (44 to 100)	75 (64 to 84)
Subjective[b]	10	5	67 (42 to 85)	83 (71 to 91)
Chills	6	4	60 (31 to 83)	78 (65 to 86)
Myalgia	7	2	78 (45 to 94)	80 (68 to 88)
Fatigue[c]	8	6	—	—
Lower respiratory	11	5	69 (44 to 86)	85 (72 to 92)
Cough	8	5	62 (36 to 82)	80 (68 to 88)
Discomfort while breathing[c]	3	0	—	—
Shortness of breath	3	1	75 (30 to 95)	75 (63 to 84)
Wheezing[c]	1	0	—	—
Chest pain[c]	2	0	—	—
Upper respiratory	16	21	43 (29 to 59)	90 (75 to 97)
Sore throat	13	6	68 (46 to 85)	88 (76 to 94)
Rhinorrhea	13	16	45 (28 to 62)	85 (70 to 93)
Nasal congestion	12	10	55 (35 to 73)	85 (72 to 92)
Neurologic	16	11	59 (41 to 75)	93 (81 to 97)
Headache	15	10	60 (41 to 77)	91 (78 to 96)
Loss of taste or smell	7	2	78 (45 to 94)	80 (68 to 88)
Loss of taste	4	2	67 (30 to 90)	75 (64 to 85)
Loss of smell	6	2	75 (41 to 93)	78 (66 to 87)
Gastrointestinal	8	16	33 (18 to 53)	75 (61 to 85)
Nausea and/or vomiting	5	5	50 (24 to 76)	76 (63 to 85)
Diarrhea	4	12	25 (10 to 50)	71 (58 to 82)
Abdominal pain	3	6	33 (12 to 65)	73 (60 to 83)
Case definitions				
COVID-19 case definitions				
CLI[d]	14	9	61 (41 to 78)	89 (77 to 95)
CSTE COVID-19[e]	16	10	62 (43 to 78)	93 (81 to 98)
Syndromic surveillance case definitions				
ILI[f]	8	2	80 (49 to 94)	81 (69 to 89)
WHO ARI definition for community-based RSV surveillance[g]	16	22	42 (28 to 58)	90 (74 to 97)

RSV, respiratory syncytial virus; —, not calculated.

[a] Equivalent to 100.4°F.

[b] Subjective fever is defined as a fever that is felt (tactile) rather than measured.

[c] Not included in the list of symptoms asked of all participants; NPVs and PPVs were not calculated.

[d] Fever, cough, or shortness of breath.

[e] At least 1 of the following: cough, shortness of breath, or discomfort breathing; or at least 2 of the following: fever, chills, rigors, myalgia, headache, sore throat, and/or loss of taste or smell.

[f] Fever and (cough and/or sore throat).

[g] Shortness of breath, cough, sore throat, and/or congestion or runny nose.

and pandemic influenza H1N1 (10.3%–20.2%),[30] the latter of which may have had higher attack rates in children than adults. Seasonal influenza secondary attack rates range widely by year, strain type, and age, making direct comparisons difficult.[31–33]

Our investigation was subject to several limitations. We enrolled a small, convenience sample of households in 2 states, which may not be representative of US households; this may result in selection bias and could affect the generalizability of our findings. Among all primary patients, only 1 was a child, which limited our ability to observe transmission from children and may not be reflective of pediatric infection rates in high-transmission areas or when communities and/or schools are open. Although we cannot be certain that the pediatric case patients in our study acquired infection in the household, these communities were under stay-at-home orders for the majority of the study period, reducing the risk of acquiring infection in the community. Our small sample size of children and the resulting wide CIs may have limited our ability to identify differences. The true infection

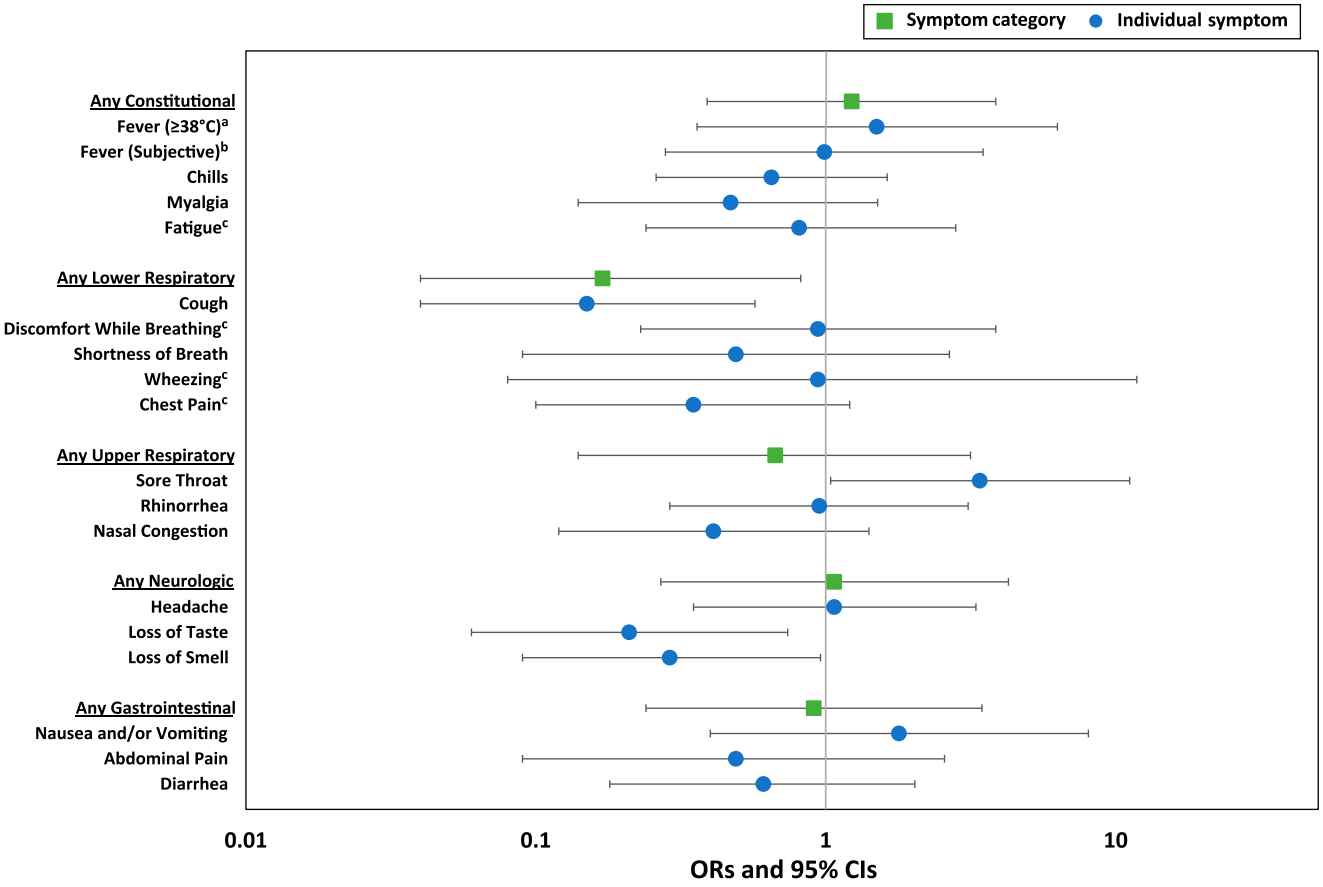

FIGURE 6

ORs for the presence of symptoms, comparing children (n = 19) with adults (n = 36) with laboratory-confirmed SARS-CoV-2 infection. Unadjusted ORs and 95% CIs were calculated by using GEEs with an independent correlation matrix and logit link to account for clustering within households. [a] Equivalent to 100.4°C. [b] Subjective fever is defined as a fever that is felt (tactile) rather than measured. [c] Symptom was not systematically asked of all participants.

rate among children may have been higher than reported because we were unable to collect serum specimens on all pediatric contacts. Because our study period was only 14 days, some household contacts may have developed additional symptoms or acquired infection after the observation period ended. All symptoms were self-reported or, for some children, reported by their parent(s), which may be subject to recall error, and some symptoms were not systematically asked about for all participants. Because of the high prevalence (28%) of SARS-CoV-2 infection among pediatric contacts, the PPVs and NPVs reported here may not be representative of all settings.

With our investigation, we provide additional information about the symptoms of children with COVID-19, time line of exposure and symptom onset to laboratory-confirmed infection, and household transmission patterns. Additional studies are warranted to examine pediatric transmission patterns outside the home in other environments in which children congregate, such as schools, and in areas with higher incidence than was observed during our study period. In these studies, researchers should include assessments of the effectiveness of mitigation efforts. Finally, additional studies on previous exposures to other coronaviruses and duration of SARS-CoV-2 antibodies may be done to shed light on protective factors against future SARS-CoV-2 infections in children.

CONCLUSIONS

In this cohort of exposed household contacts, children acquired SARS-CoV-2 infection at the same rate as adults, and, among pediatric contacts, being the child of an individual with COVID-19 increased the risk of acquiring infection. Children with COVID-19 commonly reported mild symptoms, including headache, sore throat, rhinorrhea, and nasal congestion. Compared with adults, children were less likely to report lower respiratory symptoms, particularly cough, and had a shorter

duration of illness. We observed that children were the potential source of further transmission in approximately one-fifth of households with the opportunity to observe such transmission patterns. With these early pediatric data, we provide insight into the risk of COVID-19 infection and resulting symptom profiles of children with mild illness. Further investigations are warranted to better understand SARS-CoV-2 transmission from children both within and outside the household.

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ABBREVIATIONS

ARI: acute respiratory infection
CDC: US Centers for Disease Control and Prevention
CI: confidence interval
CLI: coronavirus disease 2019–like illness
COVID-19: coronavirus disease 2019
CSTE: Council of State and Territorial Epidemiologists
ELISA: enzyme-linked immunosorbent assay
GEE: generalized estimating equation
IQR: interquartile range
NPV: negative predictive value
OR: odds ratio
PPV: positive predictive value
RT-PCR: reverse transcription polymerase chain reaction
SARS-CoV-2: severe acute respiratory syndrome coronavirus 2
WHO: World Health Organization

Drs Ye and Nabity designed the study, conducted data management, and reviewed the manuscript; Dr Chu, Mr Fajans, Ms Reses, Mr Fox, and Ms Binder conducted data management and reviewed the manuscript; Drs Freeman, Lester, Mills, and Thornburg conducted laboratory specimen analysis and reviewed the manuscript; Drs Lewis, Duca, Dawson, Conners, Gharpure, Buono, Yousaf, Owusu, Wadhwa, Pevzner, Battey, Njuguna, Fields, Salvatore, O'Hegarty, Gregory, Rispens, Dietrich, Marcenac, and Matanock, Ms Yin, Ms Pomeroy, Ms Vuong, and Ms Banks collected data and specimens and reviewed the manuscript; Drs Pray, Westergaard, Dasu, Bhattacharyya, Dunn, and Atkinson-Dunn, Ms Christiansen, Ms Page, Ms Christensen, Ms Kiphibane, and Ms Willardson assisted with household enrollment and reviewed the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the US Centers for Disease Control and Prevention and the Agency for Toxic Substances and Disease Registry.

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