Incidence of SARS-CoV-2 infection among COVID-19 vaccinated and unvaccinated healthcare personnel, first responders, and other essential and frontline workers: Eight US locations, January–September 2021

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Abstract

Background: We sought to evaluate the impact of changes in estimates of COVID-19 vaccine effectiveness on the incidence of laboratory-confirmed infection among frontline workers at high risk for SARS-CoV-2.

Methods: We analyzed data from a prospective frontline worker cohort to estimate the incidence of COVID-19 by month as well as the association of COVID-19 vaccination, occupation, demographics, physical distancing, and mask use with infection risk. Participants completed baseline and quarterly surveys, and each week self-collected mid-turbinate nasal swabs and reported symptoms.

Results: Among 1018 unvaccinated and 3531 fully vaccinated workers, the monthly incidence of laboratory-confirmed SARS-CoV-2 infection in January 2021 was 13.9 (95% confidence interval [CI]: 10.4–17.4), declining to 0.5 (95% CI: 0.4–1.4) per 1000 person-weeks in June. By September 2021, when the Delta variant predominated,
1 | BACKGROUND

COVID-19 vaccines have shown >90% effectiveness in preventing SARS-CoV-2 infection, but estimates of vaccine effectiveness (VE) declined to 66% during B.1.617.2 (Delta) predominance.1–5 Changes in COVID-19 VE estimates associated with changes in predominating variant virus circulation over time may have important implications for infection risk in work and community settings. Particularly at increased risk of SARS-CoV-2 infection are frontline workers, including healthcare personnel, first responders, and essential and other frontline workers who provide direct care and services to the public. Using data from the CDC HEROES-RECOVER Network, a prospective frontline worker cohort, we examined changes in the monthly incidence of COVID-19 by vaccination status, as well as the association of additional factors of occupation, demographics, physical distancing, and mask use with risk of infection. Here, we demonstrate that COVID-19 vaccines dramatically reduced the risk of any SARS-CoV-2 infection among vaccinated adults at high occupational risk of exposure, and substantial protection continues to be evident despite the high prevalence of the Delta variant during recent months.

2 | METHODS

The HEROES-RECOVER Network includes Arizona Healthcare, Emergency Response, and Other Essential Workers Surveillance Study (HEROES) conducted in Phoenix, Tucson, and other noncentrally located areas in Arizona and Research on the Epidemiology of SARS-CoV-2 in Essential Response Personnel (RECOVER) conducted in Miami, Florida, Duluth, Minnesota, Portland, Oregon, Temple, Texas, and Salt Lake City, Utah. Active surveillance is conducted with weekly participant or medical record reports for COVID-19-like illness (CLI) defined as ≥1 symptom of fever, chills, cough, shortness of breath, sore throat, diarrhea, muscle aches, or change in smell or taste.6,7 As rotating questions in weekly surveys, participants reported hours in the past 7 days of direct contact (within 3 ft.) and associated percentage facemask use with people at work, in the community, or in any setting who may have COVID-19. Hours of direct contact and percent facemask use were summarized as monthly averages, and then each week was categorized as above or below the corresponding monthly average. Participants self-collected a mid-turbinate nasal swab each week and at the onset of CLI for SARS-CoV-2 testing by reverse transcription–polymerase chain reaction (RT-PCR) and genomic sequencing, if positive. COVID-19 vaccinations were documented through vaccine cards, electronic medical records, or state immunization registries. Participants were considered fully vaccinated ≥14 days after a second mRNA COVID-19 vaccine dose or a single Johnson & Johnson’s Janssen vaccine dose; unvaccinated participants had no COVID-19 vaccine receipt. Indeterminate vaccination status was defined from one day following a COVID-19 vaccine dose until the participant was fully vaccinated and was excluded from analysis. Participants provided informed consent for study activities, and the study protocol was reviewed and approved by institutional review boards at all participating sites, including Abt Associates and CDC.

From January to September 2021, participants with no prior SARS-CoV-2 infection contributed unvaccinated or fully vaccinated person-time according to standard definitions until SARS-CoV-2 detection, study withdrawal, or the end of the study period. Monthly unadjusted incidence was calculated as the number of infections relative to the observed person-weeks, and 95% Wald confidence intervals were estimated. To examine factors associated with SARS-CoV-2 incidence during the entire observation period stratified by vaccination status, we used stratified Poisson generalized estimating equations to account for repeated measures.8 Each model had the factor of interest as the independent variable, log weeks of exposure as an offset, and participants repeatedly with an independent correlation structure. Statistical significance was defined as a two-tailed p-value < 0.05. A final model examined incidence by vaccination status,
### TABLE 1  Characteristics of health care personnel, first responders, and other essential and frontline workers with reverse transcription–polymerase chain reaction (RT-PCR)-confirmed SARS-CoV-2 infections and percentage receiving one or more doses of COVID vaccine—January–September 2021

| Characteristics | Total participants | SARS-CoV-2 infections | COVID-19 vaccination status |
|-----------------|--------------------|-----------------------|-----------------------------|
|                 | No. Distribution (%) | No. (%) | P-value | No. (%) | No. (%) | P-value |
| All participants| 4549               | 257 (5.6) |         | 1018 (22.4) | 3531 (77.6) |         |
| **Sociodemographic characteristics** | | | | | | |
| Cohort location |                  | | | | | |
| Phoenix, AZ     | 519 (11.4)        | 42 (8.1) <0.0001 | 139 (26.8) | 380 (73.2) <0.0001 |
| Tucson, AZ      | 1320 (29.0)       | 52 (3.9)  | 378 (28.6) | 942 (71.4) |
| Other areas in AZ | 330 (7.3) | 14 (4.2) | 109 (33.0) | 221 (67.0) |
| Miami, FL       | 407 (8.9)         | 44 (10.8) | 162 (39.8) | 245 (60.2) |
| Duluth, MN      | 544 (12.0)        | 18 (3.3)  | 30 (5.5)  | 514 (94.5) |
| Portland, OR    | 551 (12.1)        | 17 (3.1)  | 40 (7.3)  | 511 (92.7) |
| Temple, TX      | 329 (7.2)         | 31 (9.4)  | 59 (17.9) | 270 (82.1) |
| Salt Lake City, UT | 549 (12.1) | 39 (7.1) | 101 (18.4) | 448 (81.6) |
| **Sex** | | | | | | |
| Female          | 2810 (61.8)       | 139 (4.9) 0.0090 | 572 (20.4) | 2238 (79.6) <0.0001 |
| Male            | 1739 (38.2)       | 118 (6.8)  | 446 (25.6) | 1293 (74.4) |
| **Age (years)** |                  | | | | | |
| 18–49           | 3301 (72.6)       | 193 (5.8) 0.3490 | 803 (24.3) | 2498 (75.7) <0.0001 |
| ≥50             | 1248 (27.4)       | 64 (5.1)  | 215 (17.2) | 1033 (82.8) |
| **Race** | | | | | | |
| White           | 4295 (94.4)       | 249 (5.8) 0.0757 | 926 (21.6) | 3369 (78.4) <0.0001 |
| Other           | 254 (5.6)         | 8 (3.1)   | 92 (36.2)  | 162 (63.8) |
| **Ethnicity** | | | | | | |
| Hispanic/Latino | 817 (18.0)        | 54 (6.6) 0.1895 | 282 (34.5) | 535 (65.5) <0.0001 |
| Other           | 3732 (82.0)       | 203 (5.4) | 736 (19.7) | 2996 (80.3) |
| **Occupation** | | | | | | |
| Primary HCP     | 868 (19.1)        | 32 (3.7)  <0.0001 | 56 (6.5)  | 812 (93.5) <0.0001 |
| Nurses and other allied HCP | 1450 (31.9) | 69 (4.8) | 251 (17.3) | 1199 (82.7) |
| First responders | 953 (20.9) | 92 (9.7) | 330 (34.6) | 623 (65.4) |
| Essential and other frontline | 1278 (28.1) | 64 (5.0) | 381 (29.8) | 897 (70.2) |
| **Chronic condition** | | | | | | |
| None            | 3427 (75.3)       | 190 (5.5) 0.5905 | 808 (23.6) | 2619 (76.4) 0.0008 |
| 1 or more       | 1122 (24.7)       | 67 (6.0)  | 210 (18.7) | 912 (81.3) |
| **Direct contact and facemask use** | | | | | | |
| Contact with COVID-19 | | | | | | |
| Hours (n = 4477) | | | | | | |
| Above monthly mean | 1337 (29.8) | 99 (7.4) 0.0009 | 345 (25.8) | 992 (74.2) <0.0001 |
| Below monthly mean | 3140 (70.1) | 154 (4.9) | 624 (19.9) | 2516 (80.1) |
| Percent facemask use (n = 4486) | | | | | | |
| Above monthly mean | 3740 (83.4) | 192 (5.1) 0.0010 | 746 (19.9) | 2994 (80.1) <0.0001 |
| Below monthly mean | 746 (16.6) | 61 (8.2) | 228 (30.6) | 518 (69.4) |

(Continues)
RESULTS

Among 4549 participants, 1020 (22%) were unvaccinated, and 3529 (78%) were fully vaccinated by the end of the observation period (Table 1); 2302 (65%) received Pfizer-BioNTech mRNA, 1144 (32%) Moderna mRNA-1273, and 83 (2%) J&J/Janssen COVID-19 vaccines. Overall, 48% of participants were located in Arizona study sites, 62% female, 73% aged 18–49 years, 95% white, 18% Hispanic, and 25% had at least one chronic medical condition. Approximately half of participants were healthcare workers, 20% were first responders, and 28% were other frontline workers. Participants reported a monthly average of 9 direct contact hours and 97% facemask use with persons known or suspected to have COVID-19; facemask use was lower during contact with coworkers, patients, or the public at work (88%) or in the community (76%) when COVID-19 was not suspected (data not shown). The frequency in which a participant's report was higher or lower than the average is given in Table 1.

Frequency of SARS-CoV-2 infections varied by site and was significantly higher among participants who were male, first responders, and reported lower than average facemask use. Receipt of COVID-19 vaccination also varied by site and was significantly higher among participants who were female, aged ≥50 years, white, non-Hispanic, healthcare personnel, had at least one chronic condition, and reported fewer hours of direct contact and facemask use. All analyses were conducted using SAS Version 9.4 and graphics created using R Version 4.1.
and greater use of facemasks with others at work and in the community (Table 1).

Monthly incidence rates with 95% confidence intervals were plotted for unvaccinated and vaccinated adults during January to September 2021 (Figure 1). Among unvaccinated adults, incidence rates had a W-shaped trend with the highest incidence of SARS-CoV-2 infection in both January (13.9 per 1000 person-weeks, 95% CI 10.4–17.4) and September (during Delta variant predominance) (13.6 per 1000 person-weeks, 95% CI: 7.8–19.4) and a smaller peak in May (3.9 per 1000 person-weeks, 95% CI 1.2–6.6). In contrast, incidence of SARS-CoV-2 infection among fully vaccinated adults remained very low throughout the study period until the Delta variant became predominant with peak incidence in September (4.1 per 1000 person-weeks, 95% CI 1.9–3.8).

First responders had the highest risk of infection, regardless of vaccination status (Table 2). The increased risk of SARS-CoV-2 infection among unvaccinated and vaccinated adults was greatest in Phoenix, Arizona, and Florida; among vaccinated participants, rates were also higher in Texas and Utah. Among vaccinated and unvaccinated participants, infection risk was also increased when reporting above average hours of contact with persons who had confirmed or suspected COVID-19 or below average facemask use during contact. Vaccinated participants similarly had an increased risk when reporting above average hours of COVID-19 contact or below average facemask use during direct contact with people at work or in the community; these patterns were similar for unvaccinated participants but did not reach statistical significance.

The cumulative adjusted incidence of SARS-CoV-2 infection among unvaccinated participants was 7.6 (95% CI 6.4–9.1) compared with 1.9 (95% CI 1.5–2.3) among vaccinated participants, indicating the relative risk of SARS-CoV-2 infection among unvaccinated participants 4.1 (95% CI 3.1–5.3) times higher than fully vaccinated participants.

**DISCUSSION**

In a prospective cohort of frontline workers, the risk of SARS-CoV-2 infection, regardless of symptoms, was four times higher for unvaccinated adults (7.6 per 1000 person-weeks) compared with vaccinated (1.9 per 1000 person-weeks). Although the rate of infection among vaccinated participants remained below 1 per 1000 person-weeks for the first half of 2021, we observed a concomitant increase in rates with increasing Delta variant prevalence that was pronounced among unvaccinated and modest among vaccinated participants. These findings of continued lower risk of infection among the fully vaccinated relative to the unvaccinated, including during weeks when the Delta variant was predominant, are consistent with previously reported highly protective estimates of COVID-19 VE against infection.2-9.10

A strength of the current analysis is the inclusion of multiple measures of direct contact with known or suspected COVID-19 cases, coworkers, and the public, as well as reported facemask (or other protective equipment) use in these settings. The gap in risk of SARS-CoV-2 infection between unvaccinated and vaccinated adults was heightened by the additional protective benefit of facemask use. Unvaccinated participants reported lower facemask use during hours of direct contact with COVID-19 or with people at work or in the community, consistent with reported lower overall adherence with infection control measures among unvaccinated persons.11 These findings underscore the importance of interpreting differences in incidence estimates by vaccination status in the context of individual physical distancing and facemask use behaviors in addition to observed differences by occupation and site location.

The findings in this study are subject to four key limitations. First, the HEROES-RECOVER participants represent a highly vaccinated population relative to the general population, and the person-time contribution of unvaccinated participants is diminished and may not
| Characteristic                  | Unvaccinated | Fully vaccinated |
|-------------------------------|--------------|-----------------|
|                              | Cumulative incidence* | Relative rate (95% CI) | Cumulative incidence* | Relative rate (95% CI) |
| Sociodemographics             |              |                 |              |                 |
| Cohort location               |              |                 |              |                 |
| Tucson, AZ                    | 5.2          | (Referent)      | 0.7          | (Referent)      |
| Phoenix, AZ                   | 9.7          | 1.8 (1.1–3.0)   | 1.9          | 2.6 (1.3–5.0)   |
| Other areas in AZ             | 4.9          | 0.9 (0.4–1.7)   | 0.8          | 1.0 (0.4–3.1)   |
| Miami, FL                     | 12.4         | 2.3 (1.4–3.7)   | 3.1          | 4.3 (2.1–8.9)   |
| Duluth, MN                    | 3.6          | 0.7 (0.2–1.9)   | 1.1          | 1.5 (0.7–3.1)   |
| Portland, OR                  | 4.2          | 0.8 (0.3–1.8)   | 0.8          | 1.1 (0.5–2.4)   |
| Temple, TX                    | 8.3          | 1.5 (0.8–2.9)   | 2.9          | 4.2 (2.1–7.8)   |
| Salt Lake City, UT            | 6.0          | 1.1 (0.7–1.9)   | 1.6          | 2.2 (1.1–4.3)   |
| Occupation                    |              |                 |              |                 |
| Primary HCP                   | 4.7          | 1 (0.4–2.2)     | 1.1          | 0.9 (0.5–1.5)   |
| Nurses and other allied HCP   | 5.9          | 1.2 (0.8–1.9)   | 1.1          | 0.8 (0.5–1.4)   |
| First responders              | 10.6         | 2.2 (1.5–3.2)   | 2.1          | 1.6 (1.0–2.8)   |
| Essential and other frontline | 4.9          | (Referent)      | 1.3          | (Referent)      |
| Sex                           |              |                 |              |                 |
| Female                        | 6.1          | 0.8 (0.6–1.1)   | 1.2          | 0.7 (0.5–1.1)   |
| Male                          | 7.5          | (Referent)      | 1.6          | (Referent)      |
| Age (years)                   |              |                 |              |                 |
| 18–49                         | 7.1          | 1.2 (0.8–1.8)   | 1.4          | 1.1 (0.8–1.7)   |
| ≥50                           | 5.7          | (Referent)      | 1.2          | (Referent)      |
| Race                          |              |                 |              |                 |
| White                         | 6.8          | 1.3 (0.6–2.7)   | 0.9          | --              |
| Other                         | 6.0          | (Referent)      | 0            | (Referent)      |
| Ethnicity                     |              |                 |              |                 |
| Hispanic/Latinx               | 7.7          | 1.2 (0.8–1.7)   | 1.3          | 1.0 (0.6–1.7)   |
| Other                         | 6.4          | (Referent)      | 1.3          | (Referent)      |
| Chronic condition             |              |                 |              |                 |
| None                          | 6.6          | 0.9 (0.6–1.3)   | 1.3          | 1.0 (0.6–1.4)   |
| 1 or more                     | 7.2          | (Referent)      | 1.3          | (Referent)      |

Direct contact and facemask use

Contact with COVID-19

| Hours                        | Unvaccinated | Fully vaccinated |
|------------------------------|--------------|-----------------|
|                              | Cumulative incidence* | Relative rate (95% CI) | Cumulative incidence* | Relative rate (95% CI) |
| Above monthly mean           | 9.8          | 1.8 (1.3–2.6)   | 2.6          | 2.7 (1.8–3.9)   |
| Below monthly mean           | 5.3          | (Referent)      | 0.9          | (Referent)      |
| Percent facemask use         |              |                 |              |                 |
| Above monthly mean           | 6.1          | (Referent)      | 1.3          | (Referent)      |
| Below monthly mean           | 12.7         | 2.1 (1.3–3.3)   | 2.2          | 1.7 (0.8–3.9)   |

Contact with people at work

| Hours                        | Unvaccinated | Fully vaccinated |
|------------------------------|--------------|-----------------|
|                              | Cumulative incidence* | Relative rate (95% CI) | Cumulative incidence* | Relative rate (95% CI) |
| Above monthly mean           | 5.9          | 0.8 (0.5–1.1)   | 1.1          | 0.7 (0.5–1.0)   |
| Below monthly mean           | 7.8          | (Referent)      | 1.6          | (Referent)      |

(Continues)
TABLE 2 (Continued)

| Characteristic | COVID-19 vaccination status | Unvaccinated | Fully vaccinated |
|----------------|-----------------------------|--------------|-----------------|
|                | Cumulative incidence*       | Relative rate (95% CI) | Cumulative incidence* | Relative rate (95% CI) |
| Percent facemask use |                              |              |                  |
| Above monthly mean | 6.0                          | (Referent)   | 1.2              | (Referent)   |
| Below monthly mean | 8.0                          | 1.3 (1.0–1.9) | 2.0              | 1.7 (1.1–2.7) |
| Contact with people in the community |                              |              |                  |
| Hours            |                              |              |                  |
| Above monthly mean | 6.5                          | 1 (0.7–1.3)  | 1.2              | 1 (0.7–1.4)  |
| Below monthly mean | 6.7                          | (Referent)   | 1.3              | (Referent)   |
| Percent facemask use |                              |              |                  |
| Above monthly mean | 6.2                          | (Referent)   | 1.1              | (Referent)   |
| Below monthly mean | 7.8                          | 1.3 (0.9–1.8) | 1.9              | 1.9 (1.3–2.7) |

Abbreviations: AZ, Arizona; CI, confidence interval; COVID-19, coronavirus disease 2019; FL, Florida; HCP, healthcare personnel; MN, Minnesota; OR, Oregon; TX, Texas; UT, Utah.

Unadjusted cumulative incidence was calculated as the number of cases relative to the observed person-weeks using stratified Poisson generalized estimating equations to account for repeated measures.

Occupation categories: primary HCP (physicians, physician assistants, nurse practitioners, dentists), other allied HCP (nurses, therapists, technicians, medical assistants, orderlies, and all others providing clinical support in inpatient or outpatient settings), first responders (firefighters, law enforcement, corrections, emergency medical technicians), essential and other frontline workers (workers in hospitality, delivery, and retail; teachers; all other occupations that require contact within 3 ft. of the public, customers or coworkers as a routine part of their job).

Each week, participants were asked to report hours of direct contact (within 3 ft.) of others and percent of these hours wearing a facemask in the past 7 days in one of the following scenarios: with persons who have confirmed or suspected COVID-19, people at work, or people in the community.

indicate statistical significance for all analyses. Second, if COVID-19 vaccination reduces nasal viral RNA load, the sensitivity of virus detection by RT-PCR could be reduced and underestimate incidence in the vaccinated. Third, self-collection of specimens or shipping delays, though rare, could compromise specimen quality and further lead to reduced RT-PCR sensitivity and underestimation of incidence. Fourth, the prospective study design is reliant upon participant adherence to weekly specimen collection and symptom reporting that is rarely perfect. However, HEROES-RECOVER has maintained a very high level of adherence to weekly symptom reporting and swab collection (median 100%; interquartile range 82%–100%).

HEROES-RECOVER network completes routine weekly testing for SARS-CoV-2 regardless of symptoms and collects detailed information from participants, allowing for estimation of incidence with laboratory-confirmed outcomes accounting for the impact of individual characteristics and behaviors. The high effectiveness of COVID-19 vaccines (noted in clinical trials and in real-world estimates from this network) translate into substantial decreases in the actual number of adults who are infected following vaccination. Our findings further support the benefit of full vaccination and ongoing interventions to improve vaccine uptake and adherence to infection control measures, such as physical distancing and masking.

ACKNOWLEDGEMENTS

This work is supported by US Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Immunization and Respiratory Diseases Grants 75D30120C08150 and 75D30120C08379. The following are acknowledged: Danielle R. Hunt, Laura J. Edwards, Meghan K. Herring, Tyler C. Morrill, Brandon P. Poe, John Thacker, Tana Brummer, James Carr, Hala Deeb, Sauma Doka, Claire Douglas, Kate Durocher, Tara Earl, Jini Nwando Etoh, Lebanon Gerber, Louise S. Hadden, Ed Hock, Keya Jacoby, Ryan Klein, Lindsay B. LeClair, Nancy McGarry, Kelly Patlan, Steve Pickett, Khaila Prather, Rajabansi Raorane, Alfredo Rodriguez-Nogues, Meghan Shea, Chao Zhou, Abt Associates, Inc.; Tnelda Zunie, Nicole Calhoun, Eric Hoffman, Martha Zayed, Joel Blais, Jason Ettlinger, Angela Kennedy, Jacob Sartor, Natalie Settele, Rupande Patel, Elisa Priest, Jennifer Thomas, Muralidhar Jatla, Madhava Beamer, Michael Mack, Alejandro Arroliga, Baylor Scott & White Health; Gregory Joseph, Preeta Kutty, Alicia M. Fry, Aron Hall, Adam MacNeil, Cria Perrine, L. Clifford McDonald, Vic Veguilla, Stephanie Blakely, CDC; Yolanda Prado, Daniel Sapp, Mi Lee, Chris Eddy, Matt Hornbrook, Donna Eubanks, Danielle Millay, Dorothy Kurdyla, Kristin Blakely, Ambrosia Bass, Kristi Bays, Kimberly Berame, Cathleen Bourdin, Arela Buslach, Stephen Fortmann, Jennifer Gluth, Kenni Graham, Tarika Holness, Kelley Jewell, Enedina Luis, Abreeanah Magdaleno, DeShaun Martin, Joyce Smith-McGee, Martha Perley, Sam Peterson, Aaron Piepert, Krystil Phillips, Joanna Price, Sperry Robinson, Katrina Schell, Emily Schield, Natosa Shirley, Anna Shvinsky, Britta Torgremson-Ojerio, Brooke Wainwright, Shawn Westaway, Kaiser Permanente Northwest; Adam Bissonnette, Elisha Stefanski, Marshfield Clinic Research Institute; Samantha Kendrick, Daniel
Stafki, Jill Dolezilek, Catherine Diluzio Mary Robinson, Leah Hoffman, Kelley Philips, St. Luke’s Regional Health Care System; Zoe Baccam, Drew Baldwin, Genesis Barron, Ed Bedrick, Maiya Ngaybe Block, Dimaye Calvo, Esteban Cardona, Adam Carl, Andrea Carmona, Alisia Coleman, Emily Cooksey, David Dawley, Carly Deal, Stacy Delgado, Kiara Earley, Lynn Gerald, Natalie Giroux, Anna Giudici, Sofia Grijalva, Allan Guildos, Hanna Hanson, Adrianna Hernandez, James Hollister, Theresa Hopkins, Rezswana Islam, Gabriella Jimenez, Krystal Jovel, Sana Kahn, Olivia Kavanagh, Karl Krupp, Karla Ledezema, Sally Littau, Amelia Lobos, James Lopez, Veronica Lugo, Purnima Madhivanan, Jeremy Makar, Taylor Maldonado, Enrique Marquez, Christina Mortensen, Allyson Munoz, Flavia Nakayima Miro, Sandra Norman, Assumpta Nsengiyunva, Kennedy Obrien, Jonathan Perez Leyva, Celia Pikowski, Cynthia Porter, Patrick Rivers, James Romine, Alexa Roy, Jennifer Scott, Priyanka Sharma, Alison Slocum, Saskia Smidt, Gianna Taylor, Isabella Terrazas, Tahlia Thompson, Heena Timisina, Italia Trejo, Jennifer Uhrlaub, Erica Vanover, Mandie White, April Yingst, University of Arizona; Carlos Silvera, Cynthia Beaver, Rachel Reyes, Christian Rojas, Catalina Gonzalez, Testoff, Alex Stewart, Kemi Ogunsina, Aimee Green, Johanna Garibaldi, Nathaly Suarez, Olga Carrera, Hannah Kling, Aimee Green, Johanna Garibaldi, University of Miami; Matthew Bruner, Rachel Brown, Jenna Praggastis, Marcus Sticku, Arlyne Arteaga, Riley Campbell, Madeleine Smith, Adriele Fugal, Maya Wheeler, Gretchen Maughan, Allana Soriano, Nikki Gallacher, Anika Dsouza, Lauren Anderson, Jenna Yo, Iman Ibrahim, Tristen Forbes, Taryn Hunt-Smith, Ryder Jordin, Michael Langston, Timina Powaukee, Daniel Dawson, Kathy Tran, Fiona Tsang, Hannah Whiting, Brock Bourelle, Emilee Eden, Braydon Black, Madison Tallman, Chapman Cox, Derrick Wong, Camie Schaefer, Jeanmarie Mayer, Joseph Stanford, University of Utah.

AUTHOR CONTRIBUTIONS
Allison Naleway: Conceptualization; data curation; investigation; methodology. Lauren Grant: Formal analysis; investigation; methodology. Alberto Caban-Martinez: Data curation; investigation. Meredith Wesley: Data curation; formal analysis; investigation. Jefferey Burgess: Conceptualization; data curation; investigation. Kimberly Groover: Data curation; investigation. Manjusha Gaglani: Conceptualization; data curation; investigation. Sarang Yoon: Conceptualization; data curation; investigation. Harmony Tyner: Conceptualization; data curation; investigation. Jennifer Meece: Data curation; investigation. Jennifer Kuntz: Data curation; investigation. Young M. Yoo: Formal analysis; investigation; methodology. Natasha Schaefer-Solle: Data curation; investigation. Joe Gerald: Data curation; investigation. Spencer Rose: Data curation; investigation. Matthew Thiese: Data curation; investigation. Jessica Lundgren: Data curation; investigation. Holly Groom: Data curation; investigation. Josephine Mak: Formal analysis; investigation. Paola Feliciano: Data curation; investigation. Laura Edwards: Data curation; investigation. Karen Lutrick: Data curation; investigation. Kayan Dunnigan: Data curation; investigation. Andrew Phillips: Data curation; investigation. Marilyn Odean: Data curation; investigation. Katherine Ellingson: Data curation; investigation. Karley Respet: Data curation; investigation. Mark Thompson: Conceptualization; investigation; methodology. Ashley Fowlkes: Conceptualization; investigation; methodology.

CONFLICT OF INTEREST
All authors have completed and submitted the International Committee of Medical Journal Editors form for disclosure of potential conflicts of interest. Allison L. Naleway reported institutional funding from Pfizer and Vir Biotechnology for studies unrelated to the submitted work and Jennifer Kuntz receives research funding from Pfizer, Novartis, and Vir Biotechnology for unrelated studies. Matthew S. Thiese reports grants and personal fees from Reed Group and the American College of Occupational and Environmental Medicine, outside the submitted work. No other potential conflicts of interest were disclosed. 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.

PEER REVIEW
The peer review history for this article is available at https://publons.com/publon/10.1111/irv.12956.

DATA AVAILABILITY STATEMENT
The data that support the findings of this study are available from the corresponding author upon reasonable request.

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