

Risk Factors of SARS-CoV-2 Antibodies in Arapahoe County First Responders—The COVID-19 Arapahoe Serosurveillance Study (CASES) Project

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Objectives: Define the seroprevalence and risk factors for SARS-CoV-2 antibodies in Arapahoe County, Colorado first responders (eg, law enforcement, human services, fire departments). **Methods:** Two hundred sixty four first responders were enrolled June to July 2020. SARS-CoV-2 seropositivity was defined as detection of immunoglobulin G (IgG) antibodies to both spike receptor binding domain and nucleocapsid in venous blood by validated enzyme-linked immunosorbent assay. We compared risk factors for being seropositive versus seronegative. **Results:** 4% (11/264) were SARS-CoV-2 seropositive. Seropositive participants were significantly more likely to have lung disease (% seropositive, % seronegative; P -value) (36%, 8%; $P = 0.01$), prior SARS-CoV-2/COVID-19 testing (36%, 8%; $P \leq 0.01$), a prior positive result (18%, less than 1%), and to believe they previously had COVID-19 (64%, 15%; $P < 0.01$). Only 15% of those believing they had COVID-19 had anti-SARS-CoV-2 antibodies. **Conclusions:** Human services employees and individuals with lung disease are at SARS-CoV-2 exposure risk. Few individuals believed they had COVID-19 had prior exposure.

Keywords: antibodies, caseworker, COVID-19, first responder, firefighter, police, SARS-CoV-2

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Clinical Significance: First responders are high risk for SARS-CoV-2 exposure, but few studies have focused on this population. To ensure the health and safety of first responders and the community, factors driving SARS-CoV-2 seropositivity must be investigated. Our findings will inform policies to ensure first responder safety during the COVID-19 pandemic.

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The United States has become the epicenter of the coronavirus disease 2019 (COVID-19) pandemic, with over 6 million cases and 185,000 deaths as of September 2, 2020.¹ Early in the pandemic, health care workers were identified as a higher risk population for COVID-19. Over 150,000 cases of COVID-19 have been identified among health care professionals in the United States² and this population has also been found to have a high seroprevalence of antibodies against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus that causes COVID-19.³ A less well understood, but potentially high-risk group, are first responders including firefighters, police and emergency medical service employees. In the United States, it is assumed that the risk of exposure to SARS-CoV-2 among first responders is similar to health care professionals, but few seroprevalence studies including this population have been conducted.

Information regarding the risk of SARS-CoV-2 exposure among first responders is limited. In New York City by the end of March 2020, it was reported that 11% of emergency medical staff and firefighters were on medical leave for confirmed COVID-19.⁴ A study of firefighters and paramedics in a South Florida fire department found that 9% of study participants were seropositive for SARS-CoV-2 antibodies in April 2020 and 4% were assumed to have had a recent infection.⁵ In addition, 7% of public safety, healthcare, and first response personnel in Detroit, Michigan, as of June 2020⁶ and only 1.5% of first responders in Arizona in May 2020⁷ were found to be seropositive. However, the risk factors for infection among first responders remain unclear. To ensure the health and safety of first responders, both at work and in the community, it is critical to understand exposures to SARS-CoV-2 and the risk factors for seroconversion within this population.

Arapahoe County is one of the largest counties in Colorado, consisting of both urban and rural regions with a population of more than 630,000. We invited first responders from Arapahoe County to participate in our study to assess the presence of SARS-CoV-2 antibodies and to identify risk factors for SARS-CoV-2 seropositivity among this potentially high-risk group.

METHODS

First responders (refer to Table 1 for full list of job titles) working in Arapahoe County were invited to participate in the study which took place between July and August 2020. Emails were sent to the chiefs of all agencies in the county asking for their agreement to participate at the agency level. They were asked to forward an email containing a web-based (REDCap) link to their employees who were then, individually, given the opportunity to indicate their desire to participate in the study. Individuals were eligible to participate in the study if they were employed by an Arapahoe County agency since January 2020, had direct contact with the public, and were 20 to 69 years old. Individuals were screened for COVID-19-related symptoms prior to study entry and would have been excluded from the study, if symptomatic, to protect study staff

TABLE 1. Demographics of CASES Project Participants (N = 264)

Age—median [interquartile range]	38 [32–48]
Gender	n (%)
Male	121 (45.8)
Female	143 (54.2)
Race/Ethnicity	n (%)
White, Non-Hispanic/Non-LatinX	211 (79.9)
Black/African American, Non-Hispanic/Non-LatinX	14 (5.3)
Other, Non-Hispanic/Non-LatinX*	10 (3.8)
Hispanic/LatinX	29 (11.0)
Agency	n (%)
Sherriff's Office or Police Department	125 (47.3)
Department of Human Services	91 (34.5)
Fire Department	42 (15.9)
Other†	6 (2.3)
Geographic designation of agency	n (%)
Urban	239 (90.5)
Rural	24 (9.1)
Employment status	n (%)
Full time	246 (93.2)
Part time/Volunteer	14 (5.3)
Agency role	n (%)
Human services/case workers	57 (21.6)
Patrol	51 (19.3)
Firefighter	30 (11.4)
Supervision	25 (9.5)
Investigations	22 (8.3)
Support Services	26 (9.8)
Dispatch	15 (5.7)
Command	10 (3.8)
Detentions/Courts	13 (4.9)
Coroner Staff	7 (2.7)
Medic/EMT	4 (1.5)
Other‡	4 (1.5)
High-risk groups	n (%)
Age 65+	4 (1.5)
Chronic medical condition (including diabetes, high blood pressure, and/or kidney disease)	39 (14.8)
Compromised immune system	14 (5.3)
Heart disease	4 (1.5)
Lung disease	24 (9.1)
Cancer	5 (1.9)
Overweight	60 (23.0)
Obese	10 (3.8)
None of the above	154 (58.3)
Number of high-risk groups, among individuals reporting at least one group (n = 110)	
1	56 (50.9)
2 or more	54 (49.1)

All variables have complete data except (variable [missing n, %]): Age—[1, 0.4%], Geographic designation of agency [1, 0.4%], employment status [4, 1.5%].

*Other Race/Ethnicities Reported include: Mixed, White/Asian, White/East Indian, White/Native American/ American Indian, White/Pacific Islander, Asian, Asian/Pacific Islander.

†Other agencies included: Coroner's Office, Health Department, Office of Emergency Management, Attorney's Office.

‡Other agency roles include: Emergency Management, Victim Assistance Coordinator, Paralegal, Staff trainer/Coach.

and participants. No individuals presenting to the study were symptomatic. Informed consent was obtained from each study participant. All protocol and consent forms were approved by the Colorado Multiple Institutional Review Board (COMIRB).

Interested individuals were asked to come to a central location where they completed a questionnaire. Data on demographics, employment characteristics, high-risk group characteristics, potential SARS-CoV-2 exposures, prior COVID-19 related symptoms, and prior COVID-19/SARS-CoV-2 testing were collected at enrollment (Supplement 1, <http://links.lww.com/JOM/A838>). Participants provided a venous blood draw of up to 3 mL which was collected in BD vacutainer SST tubes (Franklin Lake, NJ). Whole blood was allowed to clot at room temperature. Samples were centrifuged at ~2700 RPM ($1300 \pm 100 \times g$), nine acceleration, nine deceleration, for 10 minutes at 25 °C and the serum removed and stored at -20 °C

until testing was completed. Centrifugation never occurred more than 8 hours after sample collection.

Venous blood draws were tested for immunoglobulin G (IgG) antibodies using an enzyme-linked immunosorbent assay (ELISA) developed at the University of Colorado at Exsera BioLabs. The assay was validated to EUA and CAP/CLIA standards in a compliant laboratory. Validation included testing of over 1000 pre-pandemic normal and 100 PCR-confirmed positive sera. ELISA development was based on the work of Stadlbauer et al⁸ with some modification. In brief, the SARS-CoV-2 receptor binding domain (RBD) was grown in HEK293T cells and the second antigen utilized was Nucleocapsid purified from *Escherichia coli*. All specimens were tested for reactivity to both antigens. To be considered seropositive, antibodies to both the spike RBD and nucleocapsid of SARS-CoV-2 had to be detected. The cut-off for positivity was

based on the aforementioned validation which yielded a specificity of 98.6% and sensitivity of 85%.

To identify potential risk factors for SARS-CoV-2 seropositivity, we compared the seropositive and seronegative groups to test whether pre-identified risk factors were more or less likely to be associated with the presence of anti-SARS-CoV-2 antibodies. Exposures of interest included age, sex, race/ethnicity, whether an individual self-identified as being in a high-risk group, frequency of interactions with the public, contact with confirmed or suspected COVID-19 cases, use of personal protective equipment (PPE), prior SARS-CoV-2 testing and results, belief of a prior SARS-CoV-2 infection, and existence and timing of COVID-19 related symptoms. Mann–Whitney *U* test was used to compare median age in seropositive versus seronegative individuals. All other comparisons were performed using a chi-squared or Fisher exact test, where appropriate. Statistical significance was defined as a *P* < 0.05. All analyses were completed using SAS® software, Version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

Participant Characteristics

We enrolled 264 first responders from Arapahoe County. The median age of participants was 38 years old. Slightly more women

than men enrolled, and the majority of individuals identified as White, Non-Hispanic/Non-Latinx (Table 1).

Staff from a sheriff’s office or police department represented the largest number of participants followed by those from the Department of Human Services. Less than 10% of participants worked in a rural area and 95% were employed full-time. In addition to individuals traditionally considered first responders (police, firefighters, EMTs, etc), we allowed enrollment of individuals who worked for the county that had direct contact with the public. As such, over 20% of our enrollees worked as caseworkers or in human services, whom provide services to the county including: adult and senior services, child and adult protective services, food, financial, and medical benefits, as well as other child and community services. The next most common roles included those working in police patrol, and those working as firefighters (Table 1).

To identify whether characteristics of patients considered high-risk for COVID-19 were also associated with SARS-CoV-2 seropositivity among first responders, we asked participants to identify if they had any comorbidities based on previously identified categories. More than half did not identify as belonging to any high-risk group. Among individuals that did report a comorbidity, the most frequently reported were being overweight, having a chronic medical condition including diabetes, high blood pressure, and/or kidney disease, followed by those with lung disease (Table 1).

TABLE 2. Potential COVID-19 Exposures reported by CASES Project Participants (N = 264)

As part of daily responsibilities, respondents interact with public:	<i>n</i> (%)
Always	90 (34.1)
Often	76 (28.8)
Sometimes	70 (26.5)
Rarely	21 (8.0)
Never	7 (2.7)
Times respondents interact with the public for job in an average week?	<i>n</i> (%)
5–7 d/wk	47 (17.8)
3–4 d/wk	129 (48.9)
1–2 d/wk	53 (20.1)
<1 d/wk	35 (13.3)
In past 2 months, close contact with laboratory-confirmed COVID-19 case.	<i>n</i> (%)
Yes	79 (29.9)
No	181 (68.6)
Unknown	4 (1.5)
In past 2 months, close contact with possible but untested COVID-19 case	<i>n</i> (%)
Yes	90 (34.1)
No	167 (63.3)
Unknown	7 (2.7)
If in direct contact with another person possibly exposed to the coronavirus, how often do you use personal protective equipment?	<i>n</i> (%)
Always	157 (59.5)
Often	50 (18.9)
Sometimes	13 (4.9)
Rarely	4 (1.5)
Never	1 (0.4)
Unknown	1 (0.4)
I have not had direct contact	38 (14.4)
COVID-19 test results.	<i>n</i> (%)
Tested positive	3 (1.1)
Tested negative	22 (8.3)
Tested unknown	5 (1.9)
Never tested	234 (88.6)
Regardless of test results, the belief that respondent has had COVID-19.	<i>n</i> (%)
Definitely	9 (3.4)
Very probably	16 (6.1)
Probably	21 (8.0)
Possibly	67 (25.4)
Probably not	110 (41.7)
Definitely not	41 (15.5)

All variables have complete data except where specified.

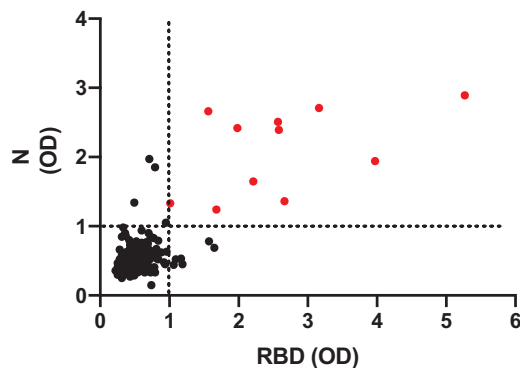


FIGURE 1. Anti-SARS CoV-2 antibodies response. Serum samples from study participants were analyzed for antibodies to the receptor binding domain (RBD) of the spike protein and the nucleocapsid (N) protein by enzyme-linked immunosorbent assay. Shown are the optical density (OD) values for the individual study participants. Only those samples which had an OD above the cut-off were considered positive and are indicated in red.

Participant SARS-CoV-2 Exposures

To identify potential SARS-CoV-2 exposure and behavioral risk factors among first responders, respondents were asked about their interactions with the public, potential exposures to individuals with COVID-19, use of PPE, prior SARS-CoV-2 testing, and belief about the likelihood they had been previously infected. Most individuals interacted with the public either sometimes, often, or always and at least 1 or more days per week. Around one-third of individuals reported close contact with someone with laboratory-confirmed COVID-19 or possible COVID-19 in the two months prior to enrollment and the majority of individuals who were exposed reported using PPE either often or always (Table 2).

For 89% of participants, the testing done during our study was their first SARS-CoV-2 test of any type, and only three individuals (1%) had previously tested positive. Regardless of test results, around 15% of individuals thought their likelihood of having had COVID-19 was probable, very probable, or definite (Table 2).

Risk Factors for SARS-CoV-2 Seropositivity

We chose to use a dual-antigen ELISA to assess antibodies to the SARS-CoV-2 spike receptor binding domain (RBD) and nucleocapsid protein. Of the 264 individuals enrolled, 11 (4%) were reactive for antibodies to both the RBD and nucleocapsid of SARS-CoV-2 (Fig. 1). Of those, five (46%) worked in human services/casework, five (46%) worked in a sheriff's office or police department, and one (9%) worked in a fire department. Among human services employees and caseworkers included in our study, the seroprevalence for SARS-CoV-2 was 6%, while the SARS-CoV-2 seroprevalence for sheriff's office or police department employees and fire department employees was 4% and 2%, respectively. These differences in seroprevalence by employment type were not significant. We compared demographics, health characteristics, and potential SARS-CoV-2 exposure and explanatory variables in seropositive and seronegative individuals and found that there was no association between reactivity and age, sex, or race/ethnicity. Seropositive individuals were significantly more likely to report lung disease ($P = 0.0114$) and marginally more likely to be obese ($P = 0.0563$) (Table 3). Among individuals who reported being in a high-risk group, there was no significant difference in the number of individuals reporting being in one compared with two or more high-risk groups in seropositive compared with seronegative participants ($P = 0.1579$).

There did not appear to be differences between seropositive and seronegative individuals in how regularly they had contact with the public nor their contact with a known or suspected COVID-19 case. Seropositive individuals were significantly more likely to report prior SARS-CoV-2 testing, and a prior positive SARS-CoV-2 test. They were also significantly more likely to report that they believed they probably, very probably, or definitely had COVID-19 prior to enrollment compared with seronegative individuals (Table 3). Among individuals seropositive for anti-SARS-CoV-2 antibodies who believed they probably, very probably, or definitely had COVID-19 previously, two had a prior positive COVID-19 test.

Finally, we asked participants about any symptoms they had experienced in the 3 months prior to antibody testing and compared COVID-19 related symptoms between SARS-CoV-2 seropositive and seronegative participants. Of the 11 seropositive individuals, three (27%) reported never having symptoms. Seropositive participants were significantly more likely to report having any symptoms and were also significantly more likely to report ever having shortness of breath or difficulty breathing, coughing, fever more than 100 °F, chills, rigors, sore throat, loss of taste or smell, gastrointestinal symptoms, and other symptoms within the 3 months prior to testing. Myalgias were also more commonly reported by SARS-CoV-2 seropositive individuals though this was not statistically significant at the $P < 0.05$ level (Table 4).

DISCUSSION

In this study we aimed to identify the seroprevalence and risk factors for detection of anti-SARS-CoV-2 antibodies in Arapahoe County first responders. We found a 4% seropositivity for SARS-CoV-2 antibodies among our participants and almost half of those individuals worked in human services/casework, an under-investigated group that is potentially at high-risk of SARS-CoV-2 exposure. Approximately one-third of first responders reported contact with a confirmed or suspected COVID-19 case but most appeared to be taking steps to protect themselves by using PPE. We sought to identify possible risk factors for SARS-CoV-2 exposure among first responders and found that those with anti-SARS-CoV-2 antibodies were more likely to report lung disease and obesity, were more likely to have been previously tested for SARS-CoV-2 infection, have a previous positive test result, believe they had already had COVID-19, and previously have COVID-19 related symptoms. Understanding the seroprevalence and risk factors for SARS-CoV-2 among this high-risk group is paramount to ensuring their health and safety.

The 4% SARS-CoV-2 seroprevalence in our first responder participants was higher than the 1.5% seroprevalence reported among Arizona first responders,⁷ similar to that of non-healthcare related first responders in Detroit, Michigan which found 5% seropositivity for SARS-CoV-2⁶ but was lower than those found in other studies of US first responders. In New York City as of March 31, 11% of emergency medical staff and firefighters were on medical leave for confirmed COVID-19⁴ and in Florida first responders in April 2020, there was a 9% anti-SARS-CoV-2 seropositivity rate when using an assay that measured both IgM and IgG.⁵ Both regions have some of the highest reported COVID-19 case counts in the country.¹ In addition, first responders in the Florida study were tested for both IgM and IgG anti-SARS-CoV-2 antibodies whereas the assay used to test our participants detected anti-SARS-CoV-2 IgG only. Most individuals will have detectable anti-SARS-CoV-2 IgG within 14 days after initial symptom onset.⁹⁻¹¹ but by not testing for IgM, we may have missed seropositive individuals with more recent infection. IgM testing in this population should be considered in future studies to adequately determine overall recent and long-term seroconversion. We may also be underestimating the number of individuals who had a previous exposure because some individuals may have lost their antibodies

TABLE 3. Characteristics and Potential COVID-19 Exposures for CASES Project Participants by Reactivity Versus Non-Reactivity to Anti-SARS-CoV-2 Antibodies (N=264)

	COVID-19 Antibody Status		P-Value
	Non-Reactives (n = 253)	Reactive (n = 11)	
Participant characteristics			
Age—median[interquartile range]	39 [32,48]	32 [29,45]	0.0963
Sex—male versus female	116 (45.8)	5 (45.5)	0.9795
Race/Ethnicity			0.4894
Black/African American, Non-Hispanic/Non-LatinX	13 (5.1)	1 (9.1)	
Hispanic/LatinX	27 (10.7)	2 (18.2)	
Other, Non-Hispanic/Non-LatinX	10 (4.0)	0 (0.0)	
White, Non-Hispanic/Non-LatinX	203 (80.2)	8 (72.7)	
High Risk Groups			
Age 65+	4 (1.6)	0 (0.0)	1.0000
Chronic medical condition (including high blood pressure and/or diabetes)	36 (14.2)	3 (27.3)	0.2112
Compromised immune system	14 (5.5)	0 (0.0)	1.0000
Heart disease	4 (1.6)	0 (0.0)	1.0000
Lung disease	20 (7.9)	4 (36.4)	0.0114*
Cancer	5 (2.0)	0 (0.0)	1.0000
Overweight	56 (22.1)	4 (36.4)	0.2777
Obese	8 (3.2)	2 (18.2)	0.0592
None of the above	151 (59.7)	3 (27.3)	0.0563
Number of high-risk groups, among individuals reporting at least one group (n = 110)—two or more versus one	48 (52.9)	6 (75.0)	0.1579
COVID-19 exposures			
As part of daily responsibilities, respondents interact with public—often/always versus sometimes/rarely/never	159 (62.8)	7 (63.6)	1.0000
Times respondents interact with the public for job in an average week—3+ d/wk versus <3 d/wk	169 (66.8)	7 (63.6)	1.0000
In the past 2 months, close contact with someone with laboratory-confirmed COVID-19 diagnosis. Yes versus No ^a	75 (30.1)	4 (36.4)	0.7397
In the past 2 months, close contact with someone ill with possibly COVID-19 but not tested. Yes versus No ^a	87 (35.4)	3 (27.3)	0.7518
If in direct contact with another person possibly exposed to the coronavirus, how often do you use personal protective equipment? ^a			0.6736
Always	151 (59.9)	6 (54.5)	
Often/Sometimes/Rarely/Never	37 (14.7)	1 (9.1)	
No contact	64 (25.4)	4 (36.4)	
COVID-19 test results			0.0016*
Not tested/Unknown test result	232 (91.7)	7 (63.6)	
Tested, negative	20 (7.9)	2 (18.2)	
Tested, positive	1 (0.4)	2 (18.2)	
Regardless of test results, the belief that respondent has had COVID-19—definitely/very probably/probably versus possibly/probably not/definitely not	39 (15.4)	7 (63.6)	0.0006*

All values are given as n (%) unless otherwise specified.
 All variables have complete data except (variable [missing no. non-reactive, missing no. reactive]): contact with someone with lab-confirmed COVID-19 [4,0], contact with someone with lab-confirmed COVID-19 [7,0]. Use of personal protective equipment [1,0].
 Chi-square, Fishers Exact, and Mann-Whitney U tests used for comparisons.
^aUnknown responses excluded.
 *P-values <0.05 are considered statistically significant.

over time.^{10,12} We were unable to explore the concept of antibody decay in this study, but it will be the subject of future follow-up work in this cohort.

Among SARS-CoV-2 seropositive individuals, almost half were employed in human services or casework and the rest in protective services (police, firefighters, etc). In the United States, it is estimated that 3.4 million individuals work in protective services (police officers, firefighters, etc) and another 2.1 million in community and social services occupations (probation officers, community health workers, etc), representing a significant number of first line workers at risk of SARS-CoV-2 exposure and COVID-19 development.¹³ Identification of seropositive human service or social workers speaks to the close proximity with which they work

with the public. Forms of transmission of SARS-CoV-2 include respiratory droplets which can be spread when an individual coughs, sneezes, or speaks, transmission through airborne aerosols and indirect transmission through contact with a contaminated surface or object.¹⁴ As part of their occupation, caseworkers may have closer contact with individuals that last for longer periods of time and may be more likely to be exposed to others in an indoor setting, say in the instance of home inspections, compared with other occupations. There was no difference in the frequency of public interaction for caseworkers compared with other occupations among seropositive participants in our study, which is not unexpected as all individuals received training on safety and use of PPE. In addition to individuals who would classically be considered first

TABLE 4. Symptoms Reported by CASES Project Participants by Reactivity Versus Non-Reactivity to Anti-SARS-CoV-2 Antibodies (N=264)

	Non-Reactive (n = 253)	Antibody Reactive (n = 11)	P-Value
Ever any symptoms ^a	116 (45.8)	8 (72.7)	0.0804
Any symptoms 3 months ago (April)	57 (22.5)	6 (54.5)	0.0249*
Any symptoms 2 months ago (May)	39 (15.4)	4 (36.4)	0.0849
Any symptoms 1 month ago (June)	74 (29.2)	5 (45.5)	0.3132
Any of the following symptoms (ever vs never)			
Shortness of breath or difficulty breathing	18 (7.1)	5 (45.5)	0.0011*
Coughing	38 (15.0)	6 (54.5)	0.0037*
Headache	71 (28.2)	5 (50.0)	0.1597
Fever >100 °F	14 (5.6)	6 (54.5)	<0.0001*
Chills	16 (6.3)	4 (36.4)	0.0057*
Repeated shaking with chills (rigors)	7 (2.8)	2 (18.2)	0.0485*
Muscle pain (unrelated to exercise or vigorous activities)	21 (8.5)	3 (27.3)	0.0678
Sore throat	47 (19.0)	5 (45.5)	0.0446*
Loss of taste or smell	8 (3.2)	5 (45.5)	<0.0001*
Gastrointestinal symptoms, such as nausea or diarrhea	43 (17.0)	5 (45.5)	0.0316*
Other symptoms ²	9 (3.6)	3 (27.3)	0.0097*

All values are given as n (%) unless otherwise specified.

All variables have complete data except (variable [missing no. non-reactive, missing no. reactive]): headache [1,1]; fever more than 100° [2,0]; muscle pain [1,0]; sore throat [1,0]; loss of taste or smell [2,0].

^aExcludes "Other symptoms".

^bOther symptoms include: rash, allergies, sore neck, shingles, light-headedness, acid reflux, nasal drip, fatigue, high pitch ringing in ears, burning/red eyes, lung rattling during inhalation.

*P-values <0.05 considered statistically significant.

responders, studies of COVID-19 high-risk groups, as well as policies created to protect at-risk employees, should include individuals working in human services occupations with frequent public contact.

Older age, as well as several medical conditions, including cancer, chronic kidney disease, chronic obstructive pulmonary disease (COPD), immunocompromised state, heart disease, diabetes, and obesity, have been suggested as underlying conditions that increase risk for development of severe COVID-19.¹⁵ We aimed to identify whether these conditions were also associated with being SARS-CoV-2 seropositive in first responders. We did not see a difference in seropositivity among individuals with and without cancer, immunocompromised state, heart disease, or diabetes and we did not collect data on chronic kidney disease or COPD, though we did ask about general lung disease. Seropositive individuals in our study were more likely to report having lung disease, which is surprising given that these individuals might perceive themselves to be at higher risk for severe disease and therefore more readily protect themselves. In COVID-19 patients, mixed results have been found with regards to lung disease such as COPD or asthma and risk of more severe disease.^{16–21} Multiple reports of clinical characteristics among COVID-19 patients listed individuals with underlying lung disease, such as COPD and asthma,^{22–24} but whether chronic lung diseases are associated with worse outcomes among COVID-19 patients remains unclear.^{16–21} Unfortunately, we did not collect information about the type, history, or severity of lung disease so we were not able to describe this relationship further. We also found that individuals who had anti-SARS-CoV-2 antibodies were more likely to report being obese, though this association was not statistically significant. Our findings are in contrast with a study of first responders in Florida that reported no association between seropositivity for SARS-CoV-2 and self-reported body mass index (BMI). Although we found that obesity was more often reported in SARS-CoV-2 seropositive individuals, only 4% of respondents overall reported being obese. This is substantially lower than national estimates that almost 40% of adults are obese in the United States.²⁵ By relying on individuals to self-identify as obese we may be

underestimating the true prevalence of obesity in our study population. It is likely that we had non-differential misclassification, where most individuals reported less obesity, regardless of their blood test result (which they were unaware of when they reported their obesity status), meaning the true association is likely stronger than what we report here. However, it is also possible that the association between obesity and antibody reactivity may be a result of reporting bias where individuals who were seronegative were less likely to report being obese. The limited number of cases (11 out of 264) did not allow for investigating the association between lung disease or obesity and anti-SARS-2 reactivity in a multivariable regression, potentially including other factors, as for example socio-economic status or age. When investigating associations between BMI and COVID-19, future work should rely on physical measurements rather than self-report of height and weight.

Participants who were SARS-CoV-2 seropositive were more likely to have been tested and to have a positive result, which is in contrast with the study of Arizona first responders that reported no difference between seropositive and seronegative individuals and prior testing.⁷ However, testing overall in this population prior to our study was low. This may have resulted from expensive or hard to find SARS-CoV-2 tests. This may also represent a recruitment bias in our study participants. Individuals with a previous positive SARS-CoV-2 or COVID-19 test may not have felt as inclined to participate in our study, as one of the main benefits to the participant was a free test result. In addition, individuals may have been more likely to have a previous test if they had any COVID-19-like symptoms. If that is the case, we may be underestimating the seroprevalence of SARS-CoV-2 antibodies in first responders in the region. Interestingly, two of the SARS-CoV-2 seropositive individuals had a prior negative and one of the seronegative individuals had a prior positive SARS-CoV-2 test. Unfortunately, we did not collect data on the type or timing of prior testing and therefore cannot make any direct comparisons to our assay.

As part of our survey, we asked first responders to define how likely they thought they were to have already had COVID-19. We found that SARS-CoV-2 seropositive participants were more likely

to believe they had a prior COVID-19 infection when compared with seronegative participants. Overall, 46 (17%) participants thought they probably to definitely had previously had COVID-19, but only seven (15%) were seropositive for anti-SARS-CoV-2 antibodies, denoting a previous infection. An individual's perception of their risk of infection with SARS-CoV-2 has been associated with adoption of protective behaviors (eg, wearing masks, social distancing, improved hand washing).^{26–28} It is possible an individual's perception of past infection may also influence changes in behavior. Individuals who believe they already had COVID-19 may be less likely to follow preventive protocols, assuming protection through immunity. However, we found that a small percentage of individuals who believe they already had COVID-19 had detectable antibodies. It is also unclear at this time how long immunity after infection lasts but there is some evidence that immunity wanes over time¹⁰ and this waning may occur more quickly in individuals with mild illness²⁹ or asymptomatic individuals.¹² Unfortunately, we did not ask about perceptions of future risk nor did we ask about infection prevention behaviors outside of PPE use. It will be important moving forward to remind and support individuals to practice safety measures both at home and in the workplace, regardless of their past infection status.

When asked about the presence of COVID-19 associated symptoms, SARS-CoV-2 seropositive first responders were more likely to report ever having symptoms 3 months prior to testing. Interestingly, there were no associations seen with symptoms present within 1 or 2 months of testing and being SARS-CoV-2 seropositive. This suggests that individuals in our study may have been infected early in the pandemic potentially because of increased risk of infection due to a lack of recognition of the severity of the pandemic, an inadequate supply of PPE, and/or delays in the implementation of prevention protocols for the general population (eg., stay at home order, wearing masks, etc). When broken down by symptom we found that SARS-CoV-2 seropositive participants were more likely to report ever having any of the COVID-19 related symptoms asked about, except for headaches. Headache was the most reported symptom among participants, regardless of their SARS-CoV-2 serostatus, which is consistent with studies of COVID-19 symptoms among health care workers.³⁰ Headaches have been found to be associated with wearing PPE.³¹ Since first responders in our study were all trained on and were, presumptively, wearing proper PPE, we would expect to see similar frequencies of headaches regardless of an individual's previous SARS-CoV-2 exposure status. We also found that 27% of SARS-CoV-2 seropositive participants reported no symptoms in the 3 months prior to testing. This is slightly lower than the current centers for disease control and prevention estimates that 40% of SARS-CoV-2 infections are asymptomatic³² but similar to reports that 29% of frontline health care personnel with SARS-CoV-2 antibodies were asymptomatic.³³ In comparison, over 70% of first responders in Arizona with detection of anti-SARS-CoV-2 IgG antibodies reported having no COVID-19 symptoms.⁷ There is strong evidence that supports presymptomatic transmission of SARS-CoV-2^{34–37} but whether truly asymptomatic individuals can infect others is still up for debate.^{38,39} Regardless, proper training on and continued use of PPE is important for protecting first responders as well as the general population.

One strength of our study was enrollment of individuals from a variety of first responder roles and agencies within Arapahoe County, including those working in both rural and urban areas. We used a validated ELISA assay with a high sensitivity and specificity to test for anti-SARS-CoV-2 IgG antibodies to measure prior infection and were able to report on SARS-CoV-2 serology among human services workers, a previously unidentified potentially high-risk group for exposure to SARS-CoV-2. There were also limitations. We did not collect data on smoking status, a potentially important risk factor for COVID-19. Enrolled individuals identified

predominately as White, Non-Hispanic/Non-Latinx which may have reduced the generalizability of our results, though it is in line with the demographics of individuals employed in protective service and community and social service occupations in the United States.⁴⁰ In addition, our study may have had some selection bias as we had low acceptance of the study in rural areas and so may have an underrepresentation of SARS-CoV-2 seroprevalence in that subregion.

CONCLUSION

We were able to estimate the seroprevalence of SARS-CoV-2 in Arapahoe County first responders and to identify factors that may be driving seropositivity and SARS-CoV-2 exposure in this population. The identification of caseworkers as having similar risk of SARS-CoV-2 exposure compared with other first responders points to a need to analyze types of exposure (eg, limited outdoors vs extensive indoor) among first responder populations, and to ensure their inclusion in future risk assessments. Our findings will help with public health strategies regarding the COVID-19 response and provide guidance towards risk assessments of first responders during this pandemic. To ensure the health and safety of first responders, both at work and in the community, future studies need to continue to identify risk factors for transmission both among first responders and the general population, identify the transmission dynamics of SARS-CoV-2, and elucidate the immune systems response to this virus.

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