ORIGINAL ARTICLE

Prevalence and determinants of SARS-CoV-2 neutralizing antibodies in Lebanon

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Abstract

According to the Lebanese Ministry of Public Health, more than 1,053,000 cases of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection have been confirmed in Lebanon so far. The actual number of cases is likely to be higher. We conducted a serological study from October 2020 to April 2021 to estimate the prevalence of SARS-CoV-2 neutralizing antibodies and identify associated factors. Serum samples as well as demographic, health, and behavioral data were collected from 2,783 subjects. Sera were tested by microneutralization assay. Neutralizing antibodies were detected in 58.9% of the study population. The positivity rate increased over the study period. It was highest among the group who remained at work during the COVID-19 pandemic and in peri-urban areas with limited adherence to preventive measures. Sex and age were associated with positivity. Reported previous COVID-19, exposure to a COVID-19 patient in the family, and attending gatherings were associated with increased prevalence. Not taking any precautionary measures against COVID-19 was a risk factor, whereas precautionary measures such as working from home and washing hands were protective. The high neutralizing antibody seroprevalence rates detected in this study emphasize the high transmission rate of SARS-CoV-2 infection in the community. Adherence to preventive measures and non-pharmaceutical interventions imposed by the government is recommended.

Introduction

Four known seasonal coronaviruses have long been circulating in humans [13]. In December 2019, a novel coronavirus emerged in Wuhan province in China and spread rapidly worldwide, causing more than 424 million confirmed cases, including 5.8 million deaths in 200 countries, as of February 22, 2022 [22]. On March 19, 2020, the World Health Organization (WHO) declared COVID-19 a global pandemic [8]. SARS-CoV-2 can be transmitted through direct contact with infected individuals, droplets, or contaminated surfaces [10].

SARS-CoV-2 infection is accompanied by several disease symptoms, including fever, pharyngitis, cough, dyspnea, headache, myalgia, and smell and taste disturbance [7, 17]. With the absence of targeted treatments and low vaccination rates, non-pharmaceutical interventions have been adopted, such as wearing a face mask, practicing hand hygiene through handwashing and the use of sanitizers, and respecting social distancing and lockdown measures to contain the spread of the virus [23].

Lebanon, like other countries, has been facing the COVID-19 pandemic. On February 21, 2020, the first case of COVID-19 was reported in Lebanon. According to the Lebanese Ministry of Public Health, a total of 1,053,252 confirmed cases, including 10,007 deaths, had been reported as of February 22, 2022 [14]. However, cases without laboratory confirmation as well as asymptomatic and mild cases missed by local surveillance systems were not reported. Therefore, the actual number of cases is likely to be much higher, and the official estimate does not reflect the true disease burden on the society and the level of resulting herd immunity. In addition, a study conducted by Jonsdottir et al.

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in 2021 showed that asymptomatic patients and those with mild disease develop an immune response similar to that seen in severe cases [12].

Population-based seroprevalence studies can provide better estimates of the burden of disease and of mortality rates by taking into account infections that are missed by the surveillance systems. With the rapid spread of SARS-CoV-2, sero-epidemiological studies have been conducted to assess seroprevalence among populations. For instance, the estimated SARS-CoV-2 seropositivity was between 22 and 33% in Guilan Province in Iran in April 2020 [16]. Another study conducted in Gangelt, Germany, in April 2020 showed that 15.5% of the total study participants were seropositive, 22.2% of whom have been asymptomatic [19]. In a population-based study in Geneva, Switzerland, in April-May 2020 targeting randomly selected participants and their household members, 4.8% of the participants were found to have anti-SARS-CoV-2 IgG [20]. A longitudinal study of 1847 workers in three distant locations in a non-SARS-CoV-2-exposed institution in Paris, France, from April 28 to July 31 showed that 11% of participants were positive for IgG against the SARS-CoV-2 N and S proteins, and 9.5% had neutralizing antibodies, detected using pseudo-typed virus assays. SARS-CoV-2 infection may have been asymptomatic in at least 20.9% of immune individuals [6]. The seroprevalence was 34% in Pakistan in May-July 2020 [24], 7.6% in Washington DC, USA, in July-August 2020 [18], and 6.1% in a rural district south India in September 2020 [11]. In a study of healthy blood donors conducted in Jordan, anti-SARS-CoV-2 antibodies were detected in 27.4% of the samples collected from January to June 2020, in September 2020, and in February 2021 [21]. A cross-sectional analytical study conducted from 29 June to 10 August 2020 in Saudi Arabia that included healthcare workers from the largest referral hospitals and quarantine sites, showed that 32.2% were seropositive for SARS-CoV-2 antibodies, 88.3% of whom had never been diagnosed with COVID-19. Seropositivity in that study was based on screening by N protein ELISA and confirming positive samples by S1 ELISA and neutralization assay [2].

In an effort to combat the spread of SARS-CoV-2, several vaccines have been developed and continue to be distributed worldwide. In Lebanon, as of February 22, 2022, 41.6% of residents aged 12 years and older had been fully vaccinated with either Pfizer-BioNTech or Oxford-AstraZeneca COVID-19 vaccines. The Lebanese Ministry of Public Health, alongside private companies and not-for-profit organizations, is continuing the effort to vaccinate as many residents as possible. However, the population's herd immunity level is not known due to asymptomatic or mild infections that are potentially missed by the surveillance system.

In addition, there is little data about the prevalence and determinants of functionally relevant neutralizing antibodies that convey sterilizing immunity against SARS-CoV-2 in Lebanon. We therefore conducted a serological study to estimate the prevalence of SARS-CoV-2 neutralizing antibodies among segments of the Lebanese population, including members of the general population, healthcare workers, and first responders. We also sought to determine the risks or protective factors that may be associated with seropositivity.

Materials and methods

Study design and population

A cross-sectional serological study was conducted in Lebanon between October 2020 and April 2021. The minimum required sample size assuming 95% confidence and 50% anticipated frequency is 385. A total of 2,783 subjects above 18 years of age were enrolled from seven governorates: Beirut, North, South, Akkar, Nabatiye, Bekaa, and Baalbak-Hermel, using convenience sampling. Exclusion criteria included unwillingness or inability to provide consent and comply with the study requirements. Among the participants, 1,798 were from the general population, 68 were healthcare workers, and 917 were from the Lebanese Internal Security Forces (ISFs). Signed informed consent was obtained from the participants. Sociodemographic, health, behavior, and COVID-19 exposure data were collected using a tailored questionnaire to identify factors associated with the presence of neutralizing antibodies.

Microneutralization assay

A live virus microneutralization assay (MN), which is considered the gold standard for serological testing, was used in this study. A 3-ml blood sample was collected from each participant. Sera were separated by centrifuging blood at $1,000 \times g$ for 15 min. All serum samples were stored at -20 °C until testing. The sera were tested by MN to detect the presence of SARS-CoV-2 neutralizing antibodies. The MN was conducted as described previously by Perera et al., using Vero-E6 cell monolayers [15]. Briefly, serial twofold dilutions of heat-inactivated sera starting with a dilution of 1:10 were mixed with an equal volume of 100 times the 50% tissue culture infectious dose ($TCID_{50}$/mL) of the SARS-CoV-2 isolate hCoV-19/Egypt/NRC-03/2020. After 1 h of incubation at 37 °C, 35 µl of the virus-serum mixture was added in duplicate to Vero-E6 cell monolayers in 96-well microtiter plates. After 1 h of adsorption, the inoculum was removed by aspiration. The plates were then incubated for three more days at 37 °C and 5% CO_2 in a humidified incubator. A virus back-titration was performed without immune serum to determine the input virus dose. The cytopathic effect (CPE) was read at three days postinfection. The

highest serum dilution that completely protected the cells from CPE was recorded as the neutralizing antibody titer.

Statistical analysis

Data were analyzed using IBM SPSS Statistics v23 software (Armonk, New York, USA) to test for associations using the chi-square test, independent *t*-test, and logistic regression. The chi square test was used to compare seropositivity rates within categorical variables, and the *t*-test was used for continuous variables. Logistic regression was used to calculate adjusted odds ratios, using all variables that were significant in bivariate analysis. A *P*-value < 0.05 was considered statistically significant.

Ethical approval

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of the Lebanese American University (protocol code LAU.SOP.JA3.17/Sep/2020).

Results

A total of 2,783 subjects participated in this study. Samples were collected from October 2020 to April 2021, 63% of which were collected between March and April 2021 (Supplementary Fig. S1). Enrollment started in October 2020 and increased until December. However, the number of COVID-19 infections in Lebanon reached a maximum in January 2021, with more than 119,000 reported cases, including 1,627 deaths. Quarantine and mobility restrictions were imposed, thereby limiting our surveillance activity in January and February 2021. The surveillance was resumed in March and April 2021.

The average age of the participants was 38.63 years, with a standard deviation of 12.67. Females constituted 23.5% of participants. The majority of the subjects were college educated (38.7%), 25.1% had reached elementary/intermediate school, 19.6% had reached secondary education, 13.5% were graduates of vocational training, 2.3% had graduate degrees, and 0.9% were uneducated. The majority of the subjects (53.1%) resided in Mount Lebanon, while 13.5%, 12.7%, 10.4%, 4.9%, 3.1%, 1.1%, and 0.8% resided in Beirut, North, South, Bekaa, Akkar, Nabatiye, and Baalbek-Hermel, respectively. Using tobacco products was reported by 60.1% of the participants, 27% reported having a chronic disease, with hypertension being the most common, and 6% reported using medication for chronic disease. None of the participants had received a SARS-CoV-2 vaccine at the time of enrollment. The demographic and health data of the study participants are shown in Table 1.

Table 1 Distribution of the demographic and health data of the study participants

Variable	No. (%)
Age	
Mean = 38.632, standard deviation = 12.67	
Sex*	
Female	654 (23.5)
Male	2128 (76.5)
Educational level	
Not educated	24 (0.9)
Elementary/ intermediate	699 (25.1)
Secondary	545 (19.6)
Undergraduate	1077 (38.7)
Graduate	63 (2.3)
Vocational training	375 (13.5)
Place of residence*	
Beirut	375 (13.5)
Mount Lebanon	1478 (53.1)
South	290 (10.4)
North	353 (12.7)
Bekaa	136 (4.9)
Baalbek Hermel	22 (0.8)
Akkar	87 (3.1)
Nabatiye	31 (1.1)
Current tobacco user	
Yes	1672 (60.1)
No	1111 (39.99)
Chronic disease	
Chest allergy	90 (3.2)
Cardiovascular disease	59 (2.1)
Diabetes	138 (5)
Hypertension	227 (8.2)
Liver disease	3 (0.1)
Kidney disease	8 (0.3)
Blood disease	19 (0.7)
Tumors	7 (0.3)
Immune disease	3 (0.1)
Other	198 (7.1)
Long-term medication use	
Cortisone	22 (0.8)
Immunosuppressor	0 (0)
Chemotherapy	5 (0.2)
Radiotherapy	2 (0.1)
Blood thinners	80 (2.9)
Bronchodilators	61 (2.2)

*Totals do not add up to 2,783 due to missing data

Of the 2,783 participants, 22% reported having COVID-19 in the 3-month period preceding enrolment in the study. The most common symptoms reported during this period were fever (8.7%), sore throat (4.8%), rhinitis (9.6%),

wet cough (0.9%), dry cough (4.5%), difficulty breathing (3.5%), chest pain (2.1%), headache (9.5%), diarrhea (3%), conjunctivitis (0.8%), malaise (12.3%), and loss of taste and smell (6.5% and 7.9%, respectively). 39.5% of the subjects reported being exposed to a COVID-19 patient. This exposure was mainly in the subject's workplace (66.3%) or within the household (58.1%). Among the participants, 9.7% reported attending a social gathering and 2% reported international travel in the 3-month period preceding enrolment. The majority of the participants (92.4%) reported using face masks, 90% practiced social distancing, 3.3% worked from home, 92.4% used disinfectants, 92.8% washed their hands frequently, 4.8% wore gloves, and 4.2% wore face shield. However, 2.5% of the participants did not abide by any of these measures. Sixty-eight subjects (2.4%) were healthcare workers involved in direct patient care, 41 of whom were involved with COVID-19 patients. COVID-19-related symptoms and behaviors among study participants are shown in Table 2.

A total of 1,638 (58.9%) sera tested positive for neutralizing antibodies against SARS-CoV-2. The titer distribution is shown in Fig. 1. Most of the positive sera had a titer of 1:40 (12.5%) or 1:80 (11.4%). Around 14.5% had a titer lower than 1:40, and around 20.3% had a titer higher than 1:80. The overall geometric mean titer (GMT) was 1:24.

The majority of participants were seronegative in October and November 2020, and only 8.5% of participants enrolled in October and 2.7% of participants enrolled in November were seropositive. Seropositivity was detected in 16.8% of participants surveyed in December, and it increased to 29.4% in January. In March and April, 83.7% and 84.8% of the participants, respectively, were seropositive. The distribution of seropositivity during the study period is shown in Fig. 2.

The South governorate had the least seropositivity rate among participants. The highest seropositivity rates were found in peri-urban areas and border towns such as Akkar, Baalbek-Hermel, Beqaa, and North. The distribution of seropositivity among governorates is shown in Fig. 3.

The seroprevalence rate was 46% within the general population, 32.4% among healthcare workers, and 89.1% within members of the ISF. The difference in seroprevalence among the various population segments was statistically significant (p-value < 0.001).

All measured variables were analyzed to determine if they were associated with the presence of antibodies. The determinants of seropositivity that continued to be significantly associated following logistic regression analysis among all participants are shown in Table 3. Sex was significantly associated with antibody levels (p-value < 0.0001), where males had higher seropositivity. Reporting previous infection with COVID-19 was associated with seropositivity, but not with antibody levels. Reporting loss of smell was a predictor of positivity for antibodies. Exposure to a COVID-19-positive

Table 2 COVID-19-related symptoms and behaviors among study participants

Variable	No. (%)
Previous COVID-19	
Yes	613 (22.0)
No	2170 (78.0)
Reported symptoms in the preceding 3 months	
Fever	242 (8.7)
Sore throat	133 (4.8)
Rhinitis	268 (9.6)
Wet cough	26 (0.9)
Dry cough	125 (4.5)
Difficulty breathing	98 (3.5)
Chest pain	58 (2.1)
Headache	264 (9.5)
Diarrhea	83 (3)
Conjunctivitis	22 (0.8)
Malaise	342 (12.3)
Loss of taste	181 (6.5)
Loss of smell	221 (7.9)
Contact with a COVID-19 case in the previous three months	
Yes	1099 (39.5)
No	1505 (54.1)
Not sure	179 (6.4)
Place of contact with the COVID-19 case*	
Household	639 (58.1)
Relative	503 (45.8)
Work	729 (66.3)
Neighbor	252 (22.9)
Other	85 (7.7)
Attended a gathering or event	
Yes	269 (9.7)
No	2514 (90.3)
Number of people at gathering or event**	
< 10	40 (14.9)
11-20	35 (13)
21-50	75 (27.9)
51-100	35 (13)
>100	84 (31.2)
Travelled in the previous 3 months	
Yes	57 (2)
No	2726 (98)
Use masks regularly**	
Yes	2621 (92.4)
No	221 (7.6)
Practice social distancing	
Yes	2504 (90)
No	279 (10)
Work from home	
Yes	92 (3.3)
No	2691 (96.7)

Table 2 (continued)

Variable	No. (%)
Use disinfectant	
Yes	2572 (92.4)
No	211 (7.6)
Wash hands frequently	
Yes	2584 (92.8)
No	199 (7.2)
Disregard safety measures	
Yes	69 (2.5)
No	2714 (97.5)
Wear gloves	
Yes	133 (4.8)
No	2650 (95.2)
Wear a face shield	
Yes	116 (4.2)
No	2667 (95.8)
Healthcare worker	
Yes	68 (2.4)
No	2715 (97.6)
COVID-19 related healthcare worker**	
Yes	41 (60.3)
No	27 (39.7)

*Among 1099 subjects with exposure to COVID-19 cases, some participants were exposed to more than one case

**Among 296 subjects who attended a gathering

***Totals do not add up to 2,783 due to missing data

****Among 68 subjects who reported to be healthcare workers

case in the family increased the odds of seropositivity with an odds ratio (OR) of 1.653 (95% confidence interval, 1.359–2.008). Attending gatherings was associated with increased seroprevalence (OR of 1.356; 95% confidence interval, 1.013–1.815). Not taking any precautions against COVID-19 was a risk factor for seropositivity, with an OR of 4.762 (95% confidence interval, 1.534–14.706). Moreover, age was associated with seropositivity (p-value < 0.001), as the mean age of seropositive subjects was 36.7 years, compared to 41.4 years for seronegative subjects. However, reporting sore throat in the 3 months preceding enrolment was inversely correlated with seropositivity, as was international travel. Nonetheless, following COVID-19 precautionary measures such as working from home and washing hands was protective, with an OR of 0.291 (95% confidence interval, 0.171 – 0.496) and 0.586 (95% confidence interval, 0.379–0.908), respectively.

Among participants from the general population, sex was significantly associated with antibody levels (p-value < 0.0001), where men had higher seropositivity. Reporting previous infection with SARS-CoV-2 was associated with seropositivity. Exposure to a COVID-19-positive case in the family increased the odds of seropositivity, with an odds ratio of 2.024 (95% confidence interval, 1.605–2.551). However, working from home was protective, with an odds ratio of 0.242 (95% confidence interval, 0.134–0.436). Traveling internationally was inversely correlated. The determinants of seropositivity among the 1,798 participants from the general population are shown in Table 4.

Reporting previous infection with COVID-19 was associated with seropositivity among the 917 participants from the Lebanese ISFs, with an odds ratio of 3.133 (1.635–6.004). As for the healthcare worker participants category, no

Fig. 1 Distribution of neutralizing antibody titers among participants. Titers were measured using a microneutralization assay at a starting serum dilution of 1:10. Sera with no detectable antibody at the 1:10 dilution are given a value of <10. Among the positive sera, the majority of titers were between 1:40 and 1:160.
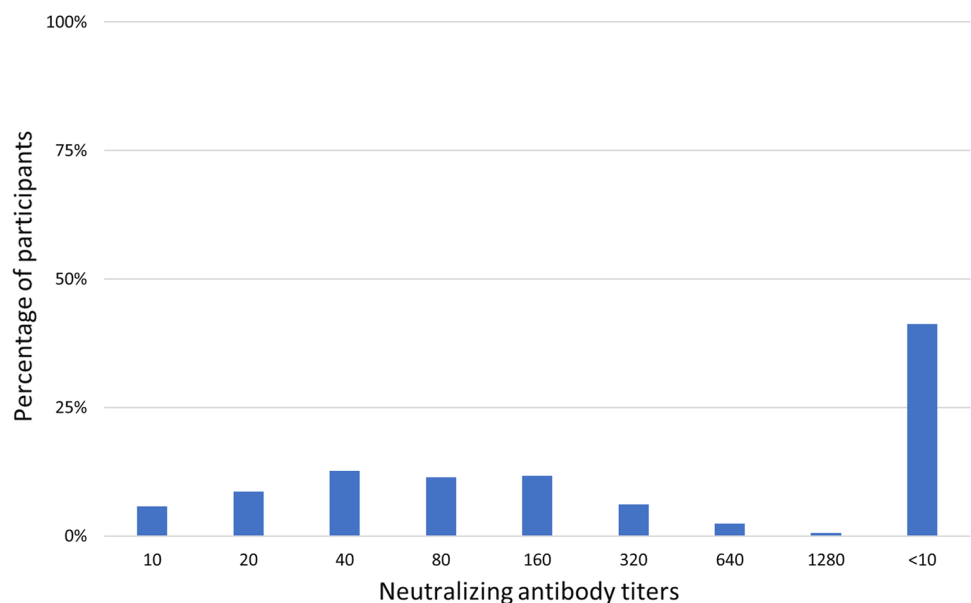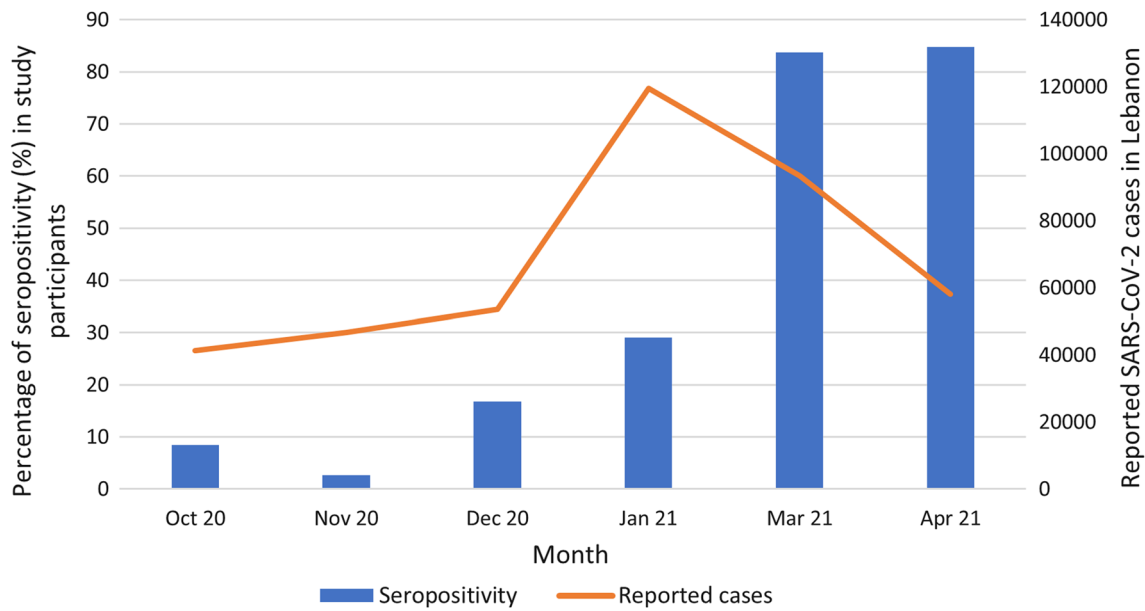
Fig. 2 Distribution of seropositivity over the study period compared to the number of cases reported in Lebanon during those months. The line indicates the number of cases as reported by the Lebanese Ministry of Public Health. Bars indicate the percentage of sera testing positive. The number of cases peaked in January 2020, but seropositivity peaked in March-April 2021.

Fig. 3 Distribution of seropositivity among the governorates of Lebanon. Bars indicate the percentage of sera testing positive. Beirut and Mount Lebanon are the most densely populated but had lower seropositivity rates.
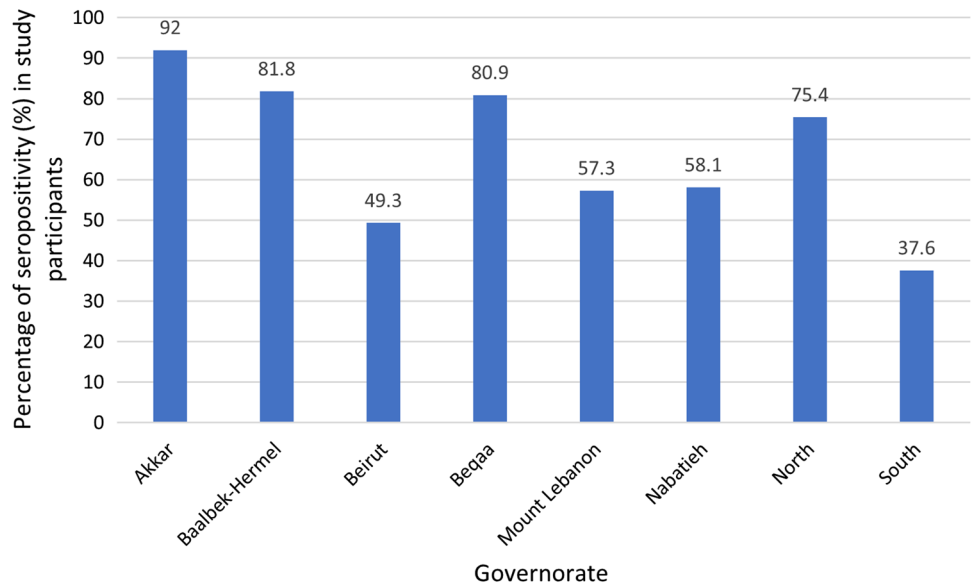
significant variables were identified as determinants of seropositivity.

Discussion

The actual number of COVID-19 cases continues to be underestimated due to asymptomatic cases of infection that are missed by the surveillance systems. Therefore, population-based seroprevalence studies can provide better estimates of the burden of the disease and mortality rates. Furthermore, testing for the presence of neutralizing antibodies rather than binding antibodies provides insights into the presence of functional antibodies that convey sterilizing immunity. Hence, we conducted this study to supplement the data generated by the Lebanese national surveillance system and provide an estimate on sterilizing immunity.

A population-based cross-sectional study conducted in the UAE between July and August 2020 aimed to determine the seroprevalence of COVID-19 infection. That

Table 3 Determinants of seropositivity among study participants

Variable	Seropositive (%)	p-value	Odds ratio (95% confidence interval)	Odds ratio corrected (95% confidence interval)
Sex				
Male	66.3	<0.0001	2.907 (2.331 – 3.636)	2.941 (2.387 – 3.623)
Female	36.9			
Previous COVID 19				
Yes	88.2	<0.0001	7.218 (5.544 – 9.397)	5.464 (4.049 – 7.407)
No	50.9			
Sore throat in previous 3 months				
Yes	49.2	0.01	0.656 (0.459- 0.939)	0.454 (0.326 – 0.747)
No	59.6			
Loss of smell in previous 3 months				
Yes	84.8	0.025	4.230 (2.895 – 6.179)	1.757 (1.119 – 2.762)
No	56.9			
COVID 19 case in the family				
Yes	71.9	<0.0001	2.305 (1.941 – 2.737)	1.653 (1.359 – 2.008)
No	52.5			
Attended a gathering				
Yes	60.2	0.001	1.560 (1.210 – 2.012)	1.356 (1.013 – 1.815)
No	44.2			
Travel in past 3 months				
Yes	29.8	<0.0001	0.286 (0.161 – 0.507)	0.245 (0.130 – 0.464)
No	59.8			
Work from home				
Yes	27.5	<0.0001	0.250 (0.175 – 0.399)	0.291 (0.171 – 0.496)
No	60.2			
No precautions				
Yes	94.1	<0.0001	11.484 (4.170 – 31.630)	4.762 (1.534 – 14.706)
No	58.2			
Washing hands				
Yes	57.4	<0.0001	0.307 (0.212 – 0.444)	0.586 (0.379 – 0.908)
No	81.4			

study showed that the seroprevalence was 10.4% among 8,831 households and 68.6% among 4,855 workers residing in labor camps. In households, higher seroprevalence was observed among non-UAE citizens and among individuals with higher body mass indices. In workers, higher seroprevalence was observed among workers from Southeast Asia [5]. In Oman, a nationwide cross-sectional study conducted in four cycles (July, August, September, and November 2020) to assess SARS-CoV-2 seroprevalence involving 17,457 participants showed that individuals in close contact with COVID-19 patients had a higher risk of being infected than non-exposed individuals. This is similar to the findings of our study, where having a COVID-19 case in the family was associated with seropositivity. Higher risk of infection was observed among laborers compared to office workers [1]. Hence, exposure in work settings that allow for more person-to-person interactions, such as members of the ISF, is a risk factor for infection. A multicenter cross-sectional study conducted in Egypt from October to December 2020, covering 11,182 healthcare workers from SARS-CoV-2 isolation hospitals, showed a positivity rate of 46.3% among participants, with the highest rate observed among nurses [9]. A study was conducted in KSA in May 2020 to evaluate the seroprevalence of SARS-CoV-2 antibodies among 12,621 healthcare workers in various hospitals, including hospitals dealing with COVID-19 patients. The results showed an overall positivity rate of 2.36%. Comparing seroprevalence between healthcare workers in COVID-19 hospitals and other hospitals showed higher seropositivity among hospitals caring for COVID-19 patients [4]. Another seroprevalence cross-sectional study from KSA, among a total of 11,703 serum samples collected from June to August 2020 and in November 2020, consisting of 5,877 non-COVID patients, 31 infected COVID-19 patients, and 400 healthcare workers, showed an overall seroprevalence of around 11%. Among healthcare workers, 7.5% of seropositive individuals

Table 4 Determinants of seropositivity in the general population

Variable	Seropositive (%)	p-value	Odds ratio (95% confidence interval)	Odds ratio corrected (95% confidence interval)
Sex				
Male	51.3	<0.0001	1.808 (1.481–2.212)	2.138 (1.691–2.702)
Female	36.8			
Previous COVID 19				
Yes	83.1	<0.0001	8.161 (6.036–11.034)	7.576 (5.435– 0.638)
No	37.7			
Sore throat in previous 3 months				
Yes	44.5	0.024	0.923 (0.626–1.361)	0.558 (0.316–0.826)
No	46.5			
COVID 19 case in the family				
Yes	63.4	<0.0001	2.920 (2.387–3.571)	2.024 (1.605–2.551)
No	37.3			
Travel in past 3 months				
Yes	28.8	<0.0001	0.459 (0.250–0.842)	0.247 (0.147–0.585)
No	46.9			
Work from home				
Yes	24.4	<0.0001	0.357 (0.216–0.589)	0.242 (0.134–0.436)
No	47.5			

did not report any previously confirmed infection [3]. The positivity rate in our study was similar to that in Saudi Arabia and lower than that in Egypt. This may be due to different access to personal protective equipment among healthcare workers in different countries. Another cross-sectional serologic survey was conducted in Egypt between August and October 2020 to assess the seroprevalence of SARS-CoV-2 and identify determinants of seropositivity among 888 employees of a major research institution. The results showed that 30% of the participants were seropositive. Age, educational level, and self-reporting of COVID-19-related symptoms such as fever, malaise, headache, dyspnea, dry cough, chest pain, diarrhea, and loss of taste or smell were associated with being seropositive [10]. Although the seropositivity rate in our study was lower during the same time period, similar determinants of testing positive for antibodies were identified.

Lebanon, like the rest of the world, has been affected by the COVID-19 pandemic. The virus spread in almost all Lebanese towns and villages, resulting in the imposition of a total lockdown and severe restrictions to contain the spread of infection. The Lebanese Ministry of Public Health has reported more than a million confirmed COVID-19 cases so far. However, the true burden of COVID-19 on the community has been underestimated. In comparison to the above-mentioned reports, among the 2,783 participants in this study, 58.9% tested positive for neutralizing antibodies against SARS-CoV-2. Seropositivity was detected in 16.8% of the participants surveyed in December, and it increased to 29.4%, 83.7%, and 84.8% of participants in January,

March, and April, respectively. The high seroprevalence rates emphasize the high transmissibility of SARS-CoV-2 in the community, especially since the timing of the study coincided with a major surge in COVID-19 infections and deaths. The seroprevalence rate within the general population was 46.4%. Among healthcare workers, 32.4% were seropositive. Of the 917 participants from the ISF, 89.1% were seropositive. With strict preventive measures in place, the ISF played an important role in protecting citizens and property and were therefore in close contact with infected people and exposed to mass gatherings, which explains the high seropositivity rates detected in our study among this subpopulation.

The South governorate had the lowest seropositivity rate among the seven governorates. The highest seropositivity rates were found in peri-urban areas and border towns such as Akkar, Baalbek-Hermel, Beqaa, and North. This may be linked to the presence of internally displaced people and/or the lack of awareness and lack of adherence to precautionary measures recommended by the Lebanese Ministry of Public Health.

Both sex and age were factors associated with seropositivity. Moreover, reporting previous infection with COVID-19, exposure to a COVID-19 positive case in the family, and attending gatherings were associated with increased seroprevalence. A risk factor increasing seropositivity was not adhering to any precautionary measures against COVID-19, contrary to following COVID-19 precautionary measures, such as working from home and washing hands, which was protective. Of the seropositive

participants, 33% reported not having previous COVID-19 infection or not having been tested previously for COVID-19, and these asymptomatic infection cases were therefore missed by the monitoring authority. None of the measured variables were associated with seropositivity among healthcare workers, and this may be due to the small number of healthcare workers included in our study or other variables that we did not measure.

This study has several limitations. The seroprevalence rates measured may not reflect the herd immunity in Lebanon, as our focus was on sterilizing immunity induced by neutralizing antibodies and not on total binding antibodies. Furthermore, antibody titers may drop over time, and the sterilizing immunity level is therefore expected to drop, especially if transmission rates are lower. An additional effect may be an underestimation of the prevalence rate we reported. Additionally, antibody titers were measured against a single variant of SARS-CoV-2 and hence may not apply to other variants that have evolved since the conclusion of our sampling. Convenience and interrupted sampling may render the data not generalizable at the general population level. However, these limitations have only a minor effect on the direct conclusions of this study.

Conclusions

Our results indicate that the prevalence of neutralizing antibodies in Lebanon following the surge in infection was high, especially among subpopulations that did not strictly abide by the recommended non-pharmaceutical interventions or those whose job requires more person-to-person interactions. Until vaccination rates in Lebanon reach herd immunity levels, adherence to preventive measures and recommended non-pharmaceutical interventions imposed by the government and by the health authorities is important to prevent the further spread of SARS-CoV-2, the causative agent of COVID-19.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00705-022-05470-2.

Declarations

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