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COVID-19

Seroprevalence of COVID-19 infection in the Emirate of Abu Dhabi, United Arab Emirates: a population-based cross-sectional study

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Abstract

Background: The United Arab Emirates (UAE) was the first country in the Middle East to report severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection. Serosurveys are essential to understanding the extent of virus transmission. This cross-sectional study aims to assess the seroprevalence of SARS-CoV-2 infection in the Emirate of Abu Dhabi.

Methods: Between 19 July and 14 August 2020, 4487 households were selected using a random sample stratified by region and citizenship of the head of household (UAE citizen or non-citizen). A cluster sample of 40 labour camps was selected. Data on socio-demographic characteristics, risk factors and symptoms compatible with coronavirus disease 2019 (COVID-19) were collected. Each participant was first tested by Roche Elecsys® Anti-SARS-CoV-2 assay, followed, when reactive, by the LIAISON® SARS-CoV-2 S1/S2 IgG assay.

Results: Among 8831 individuals from households, seroprevalence was 10·4% [95% confidence intervals (CIs) 9·5–11·4], with higher seroprevalence in Abu Dhabi and Al Ain regions compared with those in Al Dhafra. In households, we found no sex difference and UAE citizens had lower seroprevalence compared with those of other nationalities. Among 4855 workers residing in labour camps, seroprevalence was 68·6% (95% CI 61·7–74·7), with higher seroprevalence among workers from Southeast Asia. In households, individuals with higher body mass indexes demonstrated higher seroprevalences than individuals with normal weight. Anosmia and ageusia were strongly associated with seropositivity.

Conclusions: The majority of household populations in the Emirate of Abu Dhabi remained unexposed to SARS-CoV-2. In labour camps, SARS-CoV-2 transmission was high. Effective public health measures should be maintained.

Key words: Serosurvey, UAE, labour camps, households

Key Messages

- This is the first regional report on severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) seroprevalence in the United Arab Emirates and the Middle East with >13 000 participants.
- We found a low seroprevalence among residents of households in the Emirate of Abu Dhabi that is comparable to those of other population-based serosurveys.
- Conversely, we observed substantially higher seroprevalence in labour camps, reflecting the high efficiency of SARS-CoV-2 spread in congregate working settings.

Introduction

The World Health Organization recommends that countries should conduct periodic severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) serosurveys. These population-based seroprevalence studies are vital for evaluating the proportion of the population that possess antibodies against the virus, including asymptomatic individuals. Moreover, serosurveys can help to determine those individuals who lack antibodies and thus are potentially susceptible to the infection. Such data are crucial for public health efforts to minimize the impact of the coronavirus disease 2019 (COVID-19) outbreak.[1]

To date, few population-based serosurveys on SARS-CoV-2 have been conducted worldwide, and most studies have been conducted in countries with homogeneous populations.[2–5] The United Arab Emirates (UAE) has a unique socio-demographic structure comprising a large community of expatriates originating from >200 nationalities, most of whom are engaged in the labour work sector. The first confirmed case of COVID-19 in the country was reported on 29 January 2020.[6] As of 14 January 2021, the UAE has reported 242 969 confirmed cases, including 26 423 active cases, 215 820 recovered cases and 726 deaths.[7] The UAE government has issued guidelines advising quarantine for individuals who may have been in contact with someone infected and has regularly broadcasted messages to the public emphasizing the use of facemasks, hand hygiene and maintenance of social distancing. Furthermore, countrywide drive-through SARS-CoV-2 polymerase chain reaction (PCR) testing has been intensified, with 15.7 tests per 1000 of the population as of 13 January 2021.[8]

The present study aimed to assess the seroprevalence of SARS-CoV-2 infection in the Emirate of Abu Dhabi, UAE. The Abu Dhabi Public Health Center has planned periodic cross-sectional serosurveys among a representative sample of the general population, including households and labour camps. We report the findings from the first cross-sectional survey that was conducted between 19 July and 14 August 2020, using an orthogonal testing algorithm that employs two sequentially independent serological tests. This approach was adopted to increase the positive predictive value of a positive result.[9]

Methods

Study design and setting

This cross-sectional study was conducted in the Emirate of Abu Dhabi—the largest among the seven federal emirates of the UAE—which has a total estimated population of 2 566 525 individuals.[10] We separately surveyed cluster samples of households and of labour camps from three regions in the Emirate of Abu Dhabi (Abu Dhabi, Al Ain and Al Dhafra), considering that labour-camp workers exhibit different socio-demographic characteristics compared with the household population. Overall, there are 374 357 workers in 233 labour camps in the Emirate of Abu Dhabi. The UAE government mandates that work establishments with $\geq$50 workers provide accommodation for those workers. The accommodation must be well lit, air-conditioned and well ventilated, with each individual allocated at least 3 square metres of space. In addition, there should be a medical service room, prayer room and laundry room.[11]

Household sampling

The household survey was administered to a two-stage sample obtained from the Emirate of Abu Dhabi population; workers living in camps were excluded from this survey. In the first stage, sampling was stratified by region and the head of household's citizenship (UAE citizen or non-citizen) according to the Statistics Centre of Abu Dhabi (SCAD). In the second stage, a cluster sample of households was selected from each stratum. The number of households in each stratum was estimated assuming the average household sizes reported by SCAD (citizen households were assumed to have 12 members and non-citizen households were assumed to have 4 members). Alternate households were selected from each stratum in each region according to the study targets. If a household was unwilling to participate in the study or if the household doorbell was not answered, the next household was selected instead. All residents in the sampled households were invited to participate in the study, irrespective of age or prior COVID-19 infection. The exclusion criteria included the refusal to provide informed consent or contraindication to venipuncture.The sampling plan targeted a total sample size of 4247 households from an estimated 446 883 households in the total population. This sample size can adequately estimate the proportion of households having at least one seropositive member with 95% confidence and an error of estimation of 1·5%, assuming that 20% of households have at least one seropositive member. The target and actual sample sizes are shown in Supplementary Table S1, available as Supplementary data at *IJE* online. A total of 8831 participants in 4487 households were involved in this study, representing 0.4% and 1.0% of the total household population and total number of households in the Emirate of Abu Dhabi, respectively. This level of sampling coverage is comparable to that in analogous COVID-19 population-based seroprevalence studies, e.g. the ENE-COVID Study[2] in Spain and the SEROCoV-POP study[3] in Geneva that sampled, respectively, 0.1% and 0.6% of their total target populations and 0.2% and 0.7% of their total numbers of households (Supplementary Materials, available as Supplementary data at *IJE* online).

Labour-camp sampling

A cluster sample of labour camps was selected from each region to estimate the prevalence of seropositive workers with 95% confidence and an error of estimation of 1·5%, assuming a seropositivity rate between 20% and 30%. Camps with fewer than five workers were excluded. Overall, 40 camps were selected from the three regions. Approximately 15% of the workers were randomly selected from each of the sampled camps. A list of labour-camp workers present during the study visit was ordered alphabetically by last name. If one of the selected workers was unable to participate in the study, another worker listed after or before the first worker was selected instead.

Data collection

Fieldwork was conducted by trained interviewers who were responsible for data collection using an electronic data-capture tool (Explorance Blue, Montreal, Canada) with electronic devices. Blood samples were collected by registered nurses and phlebotomists. All fieldwork members underwent infection-control training and were provided with personal protective equipment. After obtaining informed consent, the interviewers used the electronic data-capture tool (Study questionnaire, Supplementary Materials, available as Supplementary data at *IJE* online) to collect data on socio-demographics, possible risk factors and clinical symptoms compatible with COVID-19.

Blood sampling

Collection and processing

On recruitment into the study, 6- to 8-mL peripheral venous blood samples from each adult participant and 3- to 4-mL samples from each child aged <14 years were collected. The samples were kept at 15–25°C until delivery within 24 h of collection to the National Reference Laboratory and the Sheikh Khalifa Medical City Laboratory Institute. At the laboratories, the serum was separated from the whole blood and tested using the Roche Elecsys® Anti-SARS-CoV-2 assay (Roche Diagnostics, Rotkreuz, Switzerland). Samples that tested positive were then aliquoted into two cryovials and stored at −80°C for further analysis using the Diasorin Liaison® SARS-COV-2

S1/S2 IgG (DiaSorin, Saluggia, Italy) (Analytical methods, Supplementary Materials, available as Supplementary data at *IJE* online).

Statistical analysis

Data were analysed using SPSS statistical software (IBM Corp, Version 26.0, Armonk, NY) and Stata statistical software (StataCorp, Version 15.1, College Station, TX). We used the complex survey analysis functions to consider the survey designs (stratification and clustering). Because the age-group distribution in the official census from SCAD did not differentiate between camp workers and households in the population, we were unable to perform post-stratification standardized weighting to adjust for differences in the distributions of the age groups between the sample studied in households and camps and their respective population. Having adopted an orthogonal testing algorithm, we also adjusted the final seroprevalence estimates for the sensitivity and specificity of the used tests (Supplementary Materials, available as Supplementary data at *IJE* online).

Demographic data are expressed as numbers and percentages. The prevalence of seropositivity is expressed as a percentage with 95% confidence intervals (CIs). The associations between seroprevalence and possible risk factors and symptoms were analysed using the Chi-square test in the univariate model and expressed as odds ratios (ORs) with 95% CI; these associations were also evaluated in a multiple logistic-regression model adjusting for confounders and expressed as adjusted ORs (aORs) with 95% CI.

Results

Seroprevalence according to socio-demographic characteristics

Households

Data were collected from 8831 individuals living in 4487 households (Figure 1A). The crude positivity rate based on the first test result was 11·3%. The estimated seroprevalence after adjusting for the sampling design and test characteristics for all participants in households was 10·4% (95% CI 9·5–11·4) (Table 1A). Abu Dhabi and Al Ain showed higher seroprevalence compared with that in Al Dhafra. The middle age groups (20–29, 30–39 and 40–49 years) demonstrated higher seroprevalence than the younger or older age groups; however, this difference was not observed after adjusting for potential confounders, including region, sex, occupation and nationality. Similarly, although males showed higher seroprevalence than females, this difference was not observed after adjusting for potential confounders. UAE citizens accounted for

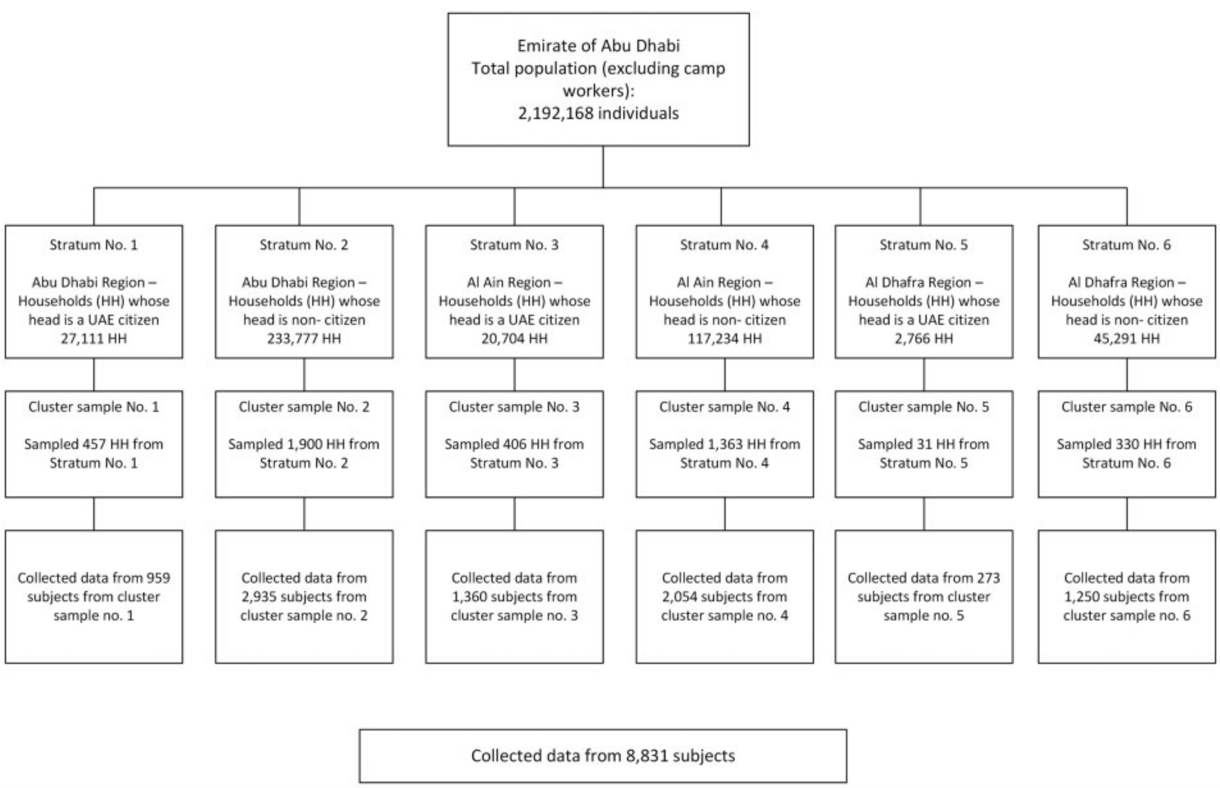

Figure 1A Flowcharts describing the sampling frame from (A) households and (B) labour camps

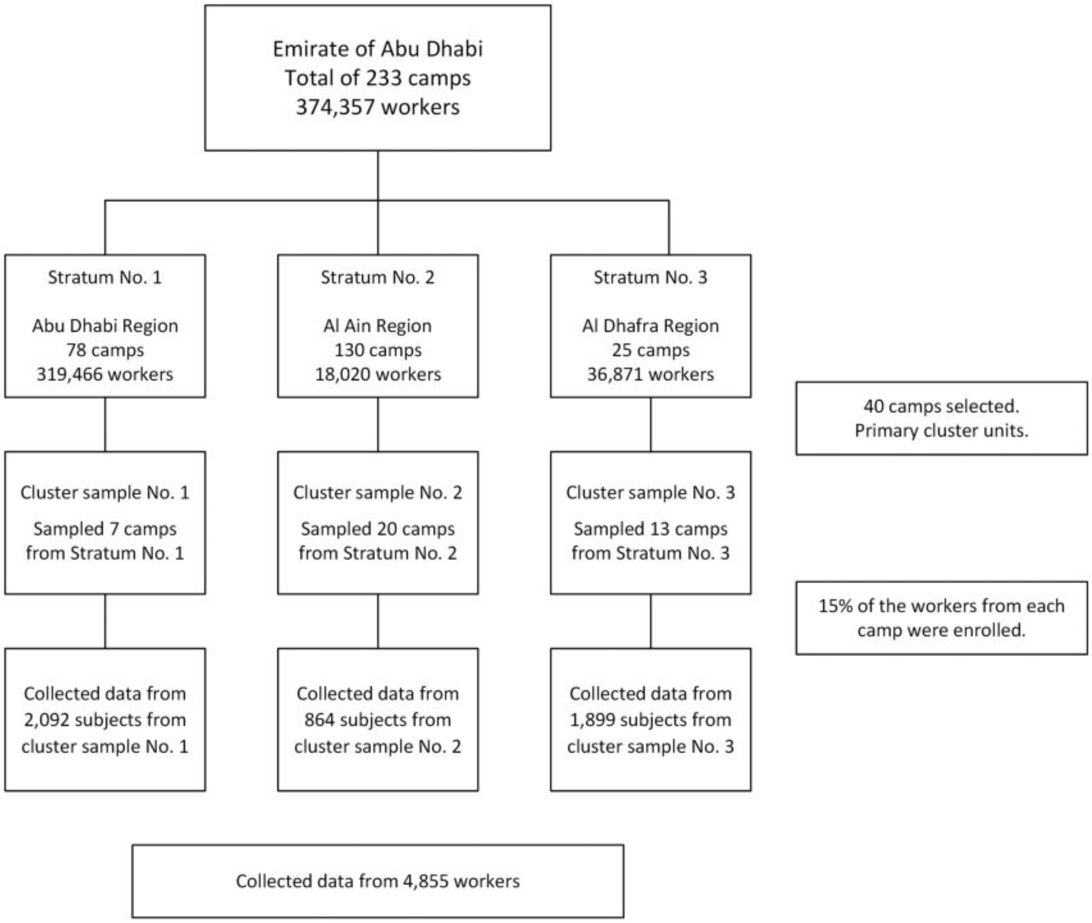

Figure 1B Flowchart describing the sampling frame from labor camps.

21·0% of all participants and had lower seroprevalence (3·4%, 2·2–5·2) compared with that of other nationalities (12%, 10·9–13·3). Among non-UAE citizens, Southeast Asian and Far East Asian individuals showed higher seroprevalence.

Labour camps

We selected 40 camps from the three regions of the Emirate of Abu Dhabi and randomly sampled 4855 workers (Figure 1B). The crude positivity rate based on the first test was 73·8%. The estimated seroprevalence for all labour-camp workers after adjusting for the sampling design and test characteristics was 68·6% (61·7–74·7) (Table 1B). No differences were observed across age groups or regions. However, labour-camp workers residing in small camps (comprising 5–99 workers) showed higher seroprevalence compared with medium- and large-sized camps. Compared with Arab workers, workers from Southeast Asia, Far East Asia and Africa showed higher seroprevalence. In particular, workers from Southeast Asia exhibited a 90·9% seroprevalence [aOR = 12·1 (3·9–37·1)]. Workers in the construction sector demonstrated the highest seroprevalence estimates [83·6%; aOR = 5·2 (2·9–9·4)].

Seroprevalence according to self-reported risk factors

Households

In households, the odds of having SARS-CoV-2 antibodies were five times higher [aOR = 5·2 (3·1–8·2)] (Figure 2 and Supplementary Table S2A, available as Supplementary data at *IJE* online) in individuals who self-reported a history of contact with persons with COVID-19 than those who had not. Individuals with higher body mass indexes (BMIs) demonstrated higher seroprevalences. Individuals who self-reported experiencing neurological diseases had higher seroprevalence [aOR = 5·3 (1·1–24·8)]. However, no other co-morbidities were associated with higher seroprevalence. Furthermore, individuals who self-reported receiving an influenza vaccine in the previous season demonstrated lower seroprevalence than those who did not receive the vaccine. However, this difference was not observed after adjusting for potential confounders.

Table 1A Estimated seroprevalence of SARS-CoV-2 and general characteristics of 8831 participants from households

	Number (%) of participants	Positive on first serology test Adjusted for sampling design, % (95% CI)	Both tests are positive (orthogonal algorithm) Adjusted for sampling design and test characteristics, % (95% CI)	Unadjusted OR	*P*	Adjusted OR[a]	*P*
All participants	8831 (100)	11·3 (10·3–12·4)	10·4 (9·5–11·4)	NA	NA		NA
Age (years)							
0–4	193 (2·2)	5·4 (1·4–18·2)	5·6 (1·4–18·7)	1·0 (0·2–4·4)	0·997	0·8 (0·1–6·6)	0·843
5–9	1142 (12·9)	3·4 (1·7–6·6)	3·5 (1·7–6·8)	0·6 (0·2–1·6)	0·294	0·6 (0·2–2·1)	0·415
10–19	975 (11·0)	5·4 (3·7–7·7)	5·1 (3·5–7·5)	0·9 (0·5–1·9)	0·823	0·8 (0·3–2·5)	0·758
20–29	2227 (25·2)	12·2 (9·9–15)	12·0 (9·7–14·9)	2·3 (1·2–4·5)	0·013	1·9 (0·9–4·1)	0·106
30–39	2393 (27·1)	14·1 (12·3–16·2)	13·0 (11·2–15·0)	2·5 (1·3–4·8)	0·004	1·6 (0·8–3·4)	0·180
40–49	1258 (14·2)	12·5 (10·5–14·8)	10·8 (9·1–12·9)	2·1 (1·1–3·9)	0·029	1·2 (0·6–2·6)	0·566
50–59	454 (5·1)	10·4 (8·1–13·4)	9·7 (7·4–12·7)	1·8 (0·9–3·6)	0·085	1·3 (0·6–2·8)	0·514
≥60	191 (2·2)	6·6 (4·0–10·9)	5·6 (3·1–9·9)	Reference	NA	Reference	NA
Region							
Abu Dhabi	3498 (39·6)	13·1 (11·6–14·8)	11·8 (10·4–13·4)	4·2 (2·3–7·5)	<0·001	3·2 (1·8–5·7)	<0·001
Al Ain	3298 (37·3)	12·7 (11·0–14·7)	12·2 (10·5–14·1)	4·37 (2·4–7·9)	<0·001	3·0 (1·7–5·3)	<0·001
Al Dhafra	2037 (23·1)	3·2 (1·9–5·4)	3·1 (1·7–5·2)	Reference	NA	Reference	NA
Sex							
Female	4045 (45·8)	7·1 (5·9–8·4)	6·5 (5·3–7·8)	Reference	NA	Reference	NA
Male	4788 (54·2)	14·2 (12·8–15·7)	13·1 (11·7–14·6)	2·2 (1·7–2·7)	<0·001	1·3 (1·0–1·7)	0·089
Nationality							
UAE national	1858 (21·0)	3·6 (2·4–5·5)	3·4 (2·2–5·2)	Reference	NA	Reference	NA
Others	6975 (79·0)	13·1 (11·9–14·3)	12 (10·9–13·3)	3·9 (2·5–6·1)	<0·001	1·8 (1·0–3·0)	0·039
Education level							
No school	721 (8·4)	12·9 (9·7–16·9)	12·5 (9·4–16·7)	1·1 (0·6–2·2)	0·782	2·0 (0·9–4·4)	0·093
Primary school	2330 (27·1)	12·7 (10·4–15·5)	12·1 (9·8–15·0)	1·1 (0·6–2·0)	0·856	2·1 (1·0–4·3)	0·050
Secondary school	2202 (25·6)	11·2 (9·6–13·0)	9·9 (8·4–11·5)	0·8 (0·5–1·6)	0·589	1·3 (0·7–2·6)	0·454
College/university	3059 (35·6)	10·0 (8·6–11·5)	9·2 (7·9–10·7)	0·8 (0·4–1·5)	0·430	1·1 (0·6–2·1)	0·819
Master/PhD	283 (3·3)	13·4 (8·0–21·6)	11·5 (6·7–19·2)	Reference	NA	Reference	NA
Ethnicity							
Arab	4661 (52·9)	5·1 (4·2–6·3)	4·7 (3·9–5·9)	Reference	–	Reference	NA
Southeast Asian	3067 (34·8)	21·2 (19·1–23·6)	19·5 (17·5–21·8)	4·8 (3·7–6·2)	0·599	2·9 (2·2–4·0)	<0·001
Far East Asian	761 (8·6)	11·8 (8·3–16·4)	10·7 (7·5–15·1)	2·4 (1·5–3·7)	0·009	2·1 (1·3–3·6)	0·004
African non-Arab	255 (2·9)	6·6 (3·7–11·3)	5·8 (3·0–10·7)	1·2 (0·6–2·5)	0·102	0·9 (0·3–2·3)	0·793

(Continued)

Table 1A Continued

	Number (%) of participants	Positive on first serology test Adjusted for sampling design, % (95% CI)	Both tests are positive (orthogonal algorithm) Adjusted for sampling design and test characteristics, % (95% CI)	Unadjusted OR	*P*	Adjusted OR[a]	*P*
European	55 (0·6)	3·1 (0·7–12·5)	3·2 (0·7–12·9)	0·7 (0·2–3·0)	0·473	0·7 (0·1–3·4)	0·611
Americas	19 (0·2)	NA	NA	NA	NA	NA	NA
Occupation							
Healthcare	388 (6·1)	7·3 (3·7–13·9)	6·3 (3·4–11·4)	Reference	–	Reference	NA
None	1153 (18·3)	8·8 (6·5–11·7)	8·2 (6–11·2)	1·3 (0·6–2·8)	0·012	1·5 (0·7–3·1)	0·307
Service	754 (11·9)	17·5 (14·1–21·6)	16·3 (13–20·3)	2·9 (1·4–5·8)	0·010	2·0 (1·0–4·1)	0·054
Housewife	640 (10·1)	8·8 (6·2–12·2)	8·0 (5·6–11·4)	1·3 (0·6–2·8)	0·741	1·2 (0·6–2·6)	0·612
House worker	436 (6·9)	3·2 (1·8–5·8)	3·0 (1·5–5·7)	0·5 (0·2–1·2)	0·011	0·3 (0·1–0·8)	0·022
Office	414 (6·6)	16·3 (11·4–22·8)	13·5 (9·4–19·1)	2·3 (1·1–5·0)	<0·001	1·9 (0·9–4·0)	0·113
Transportation industry	386 (6·1)	20·8 (15·9–26·7)	19·2 (14·6–25·0)	3·5 (1·7–7·3)	0·637	1·5 (0·7–3·2)	0·338
Teacher	316 (5·0)	4·4 (2·5–7·8)	4·5 (2·6–8·0)	0·7 (0·3–1·7)	0·281	1·0 (0·4–2·4)	0·996
Worker	251 (4·0)	13·3 (9·0–19·2)	13·4 (8·9–19·4)	2·3 (1·0–5·0)	<0·001	1·8 (0·8–3·9)	0·161
Security	235 (3·7)	8·3 (4·8–14·1)	7·6 (4·2–13·6)	1·2 (0·5–3·0)	0·614	1·0 (0·4–2·6)	0·984
Sales	232 (3·7)	24·6 (16·6–35·0)	23·0 (15·0–33·8)	4·4 (1·9–10·2)	0·041	2·0 (0·9–4·7)	0·091
Labourer	201 (3·2)	24·8 (17·8–33·3)	23·4 (16·7–31·8)	4·5 (2·1–9·7)	0·129	2·2 (1·0–4·8)	0·063
Food industry	126 (2·0)	27·8 (16·4–43·0)	24·0 (13·5–39·0)	4·6 (1·8–12·0)	0·073	2·0 (0·8–5·3)	0·165
Manager	114 (1·8)	15·2 (8·6–25·6)	15·6 (8·8–26·3)	2·7 (1·1–6·9)	0·171	2·4 (0·9–6·3)	0·070
Businessman	104 (1·6)	10·2 (5·0–19·6)	10·1 (4·8–19·8)	1·7 (0·6–4·6)	0·927	1·0 (0·3–2·9)	0·998
Other	564 (8·9)	16·6 (12·1–22·3)	15·2 (10·8–21·1)	2·6 (1·2–5·7)	0·293	2·1 (0·9–4·6)	0·073

[a]Logistic regression adjusting for age, region, sex, education, nationality, ethnicity, occupation and contact with COVID-19.

CI, confidence interval; OR, odds ratio; NA, not applicable.

Table 1B Estimated seroprevalence of SARS-CoV-2 and general characteristics of 4855 workers from labour camps

	Number (%) of participants	Positive on first serology test Adjusted for sampling design, % (95% CI)	Both tests are positive (orthogonal algorithm) Adjusted for sampling design and test characteristics, % (95% CI)	Unadjusted OR	*P*	Adjusted OR[a]	*P*
All participants	4855 (100)	73·8 (66·2–80·2)	68·6 (61·7–74·7)	NA	NA	NA	NA
Age (years)							
18–29	1779 (36·7)	74·1 (65·1–81·4)	69·5 (60·6–77·3)	Reference	NA	Reference	NA
30–39	1933 (39·8)	74·1 (66·3–80·5)	68·3 (61·6–74·2)	0·9 (0·7–1·1)	0·61	1·0 (0·8–1·3)	0·89
40–49	883 (8·2)	73·5 (66·2–79·6)	67·7 (61·3–73·4)	0·9 (0·6–1·2)	0·58	1·0 (0·6–1·6)	0·89
50–59	243 (5·0)	72 (62·1–80·1)	68·4 (58·8–76·7)	0·9 (0·6–1·2)	0·73	1·2 (0·5–2·5)	0·62
≥60	17 (0·3)	58·8 (34·5–79·4)	58·9 (34·6–79·5)	0·6 (0·2–1·7)	0·37	NA	NA
Region							
Abu Dhabi	2092 (43·1)	74·9 (58·8–86·2)	68·2 (54·2–79·7)	Reference	NA	Reference	NA
Al Ain	864 (17·8)	76·0 (61·2–84·4)	71·8 (58·2–82·4)	1·1 (0·5–2·7)	0·68	1·5 (0·8–3·1)	0·19
Al Dhafra	1899 (39·1)	71·6 (64·4–77·9)	67·5 (60·6–73·7)	0·9 (0·4–1·8)	0·92	1·1 (0·6–2·2)	0·58
Camp size (number of workers)							
Small (5–99)	63 (1·3)	90·5 (80–95·7)	87·4 (76·2–93·9)	Reference	NA	Reference	NA
Medium (100–999)	1338 (27·6)	67·8 (59·1–75·3)	63·3 (55·4–70·5)	0·2 (0·1–0·5)	0·002	0·3 (0·1–0·7)	0·011
Large (≥1000)	3454 (71·1)	75·9 (65·7–83·7)	70·3 (61·2–78·0)	0·3 (0·1–0·8)	0·018	0·5 (0·2–1·2)	0·14
Education							
No school	435 (8·9)	77·9 (65·8–86·6)	71·3 (61·1–79·9)	Reference	NA	Reference	NA
Primary school	1871 (38·5)	81·5 (74·7–86·8)	76·2 (70·0–81·4)	1·2 (0·9–1·7)	0·09	1·2 (0·9–1·6)	0·14
Secondary school	1821 (37·5)	72·6 (65·0–79·0)	67·5 (60·6–73·8)	0·8 (0·6–1·1)	0·25	0·7 (0·5–1·0)	0·06
College/university	705 (14·5)	55·0 (46·9–62·8)	50·4 (43·3–57·5)	0·4 (0·2–0·6)	<0·001	0·3 (0·2–0·5)	<0·001
Masters/PhD	22 (0·4)	40·9 (20·8–64·5)	40·9 (20·8–64·6)	0·2 (0·1–0·7)	0·015	0·2 (0·09–0·8)	0·02
Ethnicity							
African (non-Arabs)	264 (5·4)	5.7 (2.2–14.0)	5·5 (2·2–13·4)	12·3 (7·1–21·3)	<0·001	11·8 (3·4–39·9)	<0·001
Arabs	201 (4·1)	1·0 (0.5–2.2)	0·9 (0·4–1·9)	Reference	NA	Reference	NA
Far East Asians	192 (3·9)	3.1 (0.7–11.9)	2·8 (0·6–10·8)	4·9 (3·0–8·2)	<0·001	4·9 (1·4–17·2)	0·01
North Americans	1 (0·01)	(NA, NA)	0·0	0 (NA, NA)	0·66	1·0 (NA, NA)	NA
Southeast Asians	4197 (86·4)	77·0 (71·5–81·7)	90·9 (82·1–95·5)	13·5 (9·1–20·0)	<0·001	12·1 (3·9–37·1)	<0·001
Occupation							
Cleaning	136 (2·8)	77·9 (59·0–89·6)	68·5 (53·4–80·5)	3·1 (2·1–4·9)	<0·001	2·1 (1·3–3·4)	0·001
Construction	115 (2·4)	92·1 (85·3–95·9)	83·6 (76·8–88·8)	7·3 (4·2–12·8)	<0·001	5·2 (2·9–9·4)	<0·001
Food industry	215 (4·4)	70·7 (56·4–81·8)	67·1 (54·1–77·9)	2·9 (2·0–4·3)	<0001	2·4 (1·6–3·6)	<0·001
Helper	207 (4·3)	80·2 (73·7–85·4)	74·0 (67·4–79·7)	4·1 (2·7–6·1)	<0·001	2·8 (1·8–4·4)	<0·001

(Continued)

Table 1B Continued

	Number (%) of participants	Positive on first serology test	Both tests are positive (orthogonal algorithm)	Unadjusted OR	*P*	Adjusted OR[a]	*P*
		Adjusted for sampling design, % (95% CI)	Adjusted for sampling design and test characteristics, % (95% CI)				
Industrial	1359 (28·2)	82·7 (76·0–87·8)	76·8 (69·5–82·7)	4·7 (3·6–6·3)	<0·001	3·6 (2·6–4·8)	<0·001
Labourer	822 (17·0)	77·6 (64·9–86·6)	72·1 (60·1–81·7)	3·7 (2·8–5·0)	<0·01	2·9 (2·1–4·0)	<0·001
Machine operator	131 (2·7)	69·4 (61·9–76·1)	67·2 (59·8–73·9)	3·0 (1·9–4·6)	<0·001	2·7 (1·7–4·4)	<0·001
Mechanic	112 (2·3)	77·6 (70·7–83·4)	73·3 (67·0–78·9)	4·0 (2·4–6·5)	<0·01	3·6 (2·2–6·1)	<0·001
Other	453 (9·4)	62·4 (48·4–74·6)	58·1 (45·3–70·0)	2·2 (1·4–2·7)	<0·001	1·7 (1·2–2·4)	<0·001
Security	246 (5·1)	43·9 (26·0–63·5)	40·7 (24·0–59·8)	Reference	NA	Reference	NA
Service	643 (13·3)	72·3 (64·7–78·8)	67·7 (59·6–74·9)	3·0 (2·2–4·1)	<0·001	2·3 (1·7–3·3)	<0·001
Supervisor	150 (3·1)	52·6 (43·9–61·2)	48·1 (39·6–56·6)	1·3 (2·0–9·9)	<0·001	1·5 (1·0–2·3)	<0·001
Transportation	230 (4·7)	72·1 (60·4–81·5)	67·9 (57·8–76·7)	3·0 (2·1–4·5)	<0·001	2·7 (1·8–4·0)	<0·001

[a]Logistic regression adjusting for age, region, sex, education, nationality, ethnicity, occupation and contact with COVID-19.
CI, confidence interval; OR, odds ratio; NA, not applicable.

Labour camps

Similar to households, labour-camp workers who self-reported a history of contact with individuals with COVID-19 had higher seroprevalence than those without contact [78·9% (75·3–82·2); aOR = 2·1 (1·6–2·7)] (Figure 2 and Supplementary Table S2B, available as Supplementary data at *IJE* online). Further, current smokers among labour-camp workers showed lower seroprevalence [57·8% (50·8–64·6)] than non-smokers [aOR = 0.56 (0.4–0.6)]. The seroprevalences among labour-camp workers were similar among different BMI categories, comorbidities and chronic medications.

Seroprevalence according to clinical characteristics

Households

In households, individuals who reported having no symptoms showed a low seroprevalence of 9·9% [8·9–10·9; aOR = 0·4 (0·3–0·7)] (Figure 3 and Supplementary Table S3A, available as Supplementary data at *IJE* online). Conversely, individuals who self-reported experiencing any symptom compatible with COVID-19 showed higher seroprevalence than those who did not [23·5% (17·2–31·1); aOR = 2.5 (1·6–3·9)]. Specifically, individuals who self-reported having high fever, fatigue, anosmia, ageusia, myalgia, sore throat and diarrhoea had higher seroprevalence than those who did not. For example, 59·2% of those who self-reported ageusia were seropositive [aOR = 15·8 (5·7–43·5)].

Labour camps

In the labour camps, workers who reported having any symptom compatible with COVID-19 had higher seroprevalence than those without reported symptoms [78·6% (71·4–84·4) v/s 66·8% (59·8–73·1); aOR = 1·8 (1·4–2·3)] (Figure 3 and Supplementary Table S3B, available as Supplementary data at *IJE* online). Of note, 88·9% of those who self-reported anosmia were seropositive [aOR = 3·8 (1·8–7·9)]. Additionally, 87·7% of those who self-reported ageusia were seropositive [aOR = 3·6 (2·2–5·9)].

Discussion

The results of this study provide important insight into the status of the COVID-19 outbreak in the Emirate of Abu Dhabi. Almost 6 months from the start of the pandemic and towards what appeared to be the end of the first wave, our analysis reveals that almost 10% of the Abu Dhabi population residing in households had evidence of past

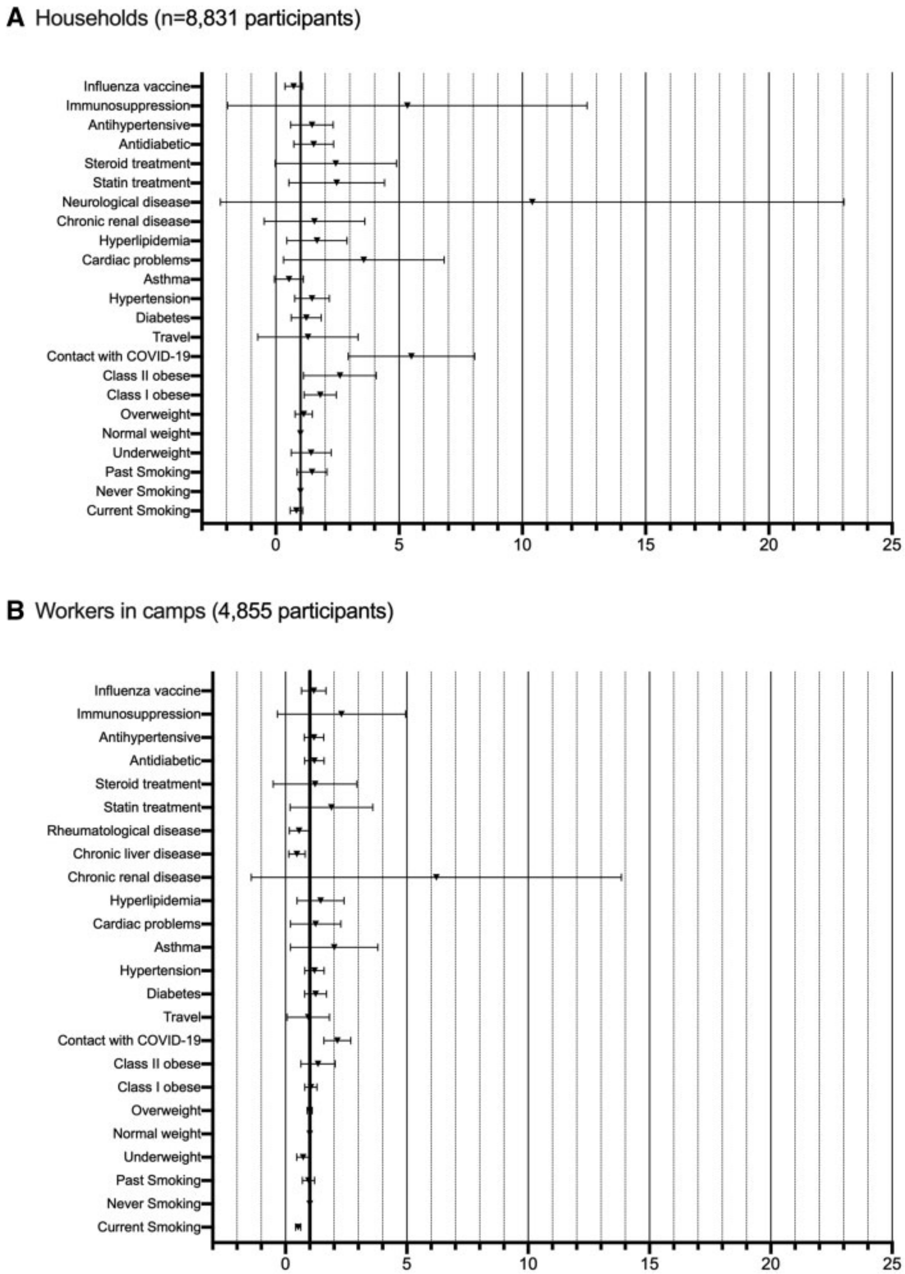

Figure 2 Association of SARS-CoV-2 seroprevalence with self-reported risk factors by households (A) and camp workers (B)

Adjusted odds ratios (with 95% confidence intervals) for sampling design and test characteristics, controlled for age, region, sex, education, nationality, ethnicity, occupation and contact with COVID-19 in a logistic-regression model. A risk factor for which the odds ratio 95% confidence intervals cross the value of 1 (solid horizontal line) is not associated with seropositivity.

exposure or immune response to SARS-CoV-2. Conversely, we found higher SARS-CoV-2 seropositivity estimates of 68·6% among labour-camp workers.

The low estimated seroprevalence among residents of households in Abu Dhabi is comparable to other population-based studies suggesting that a large majority of the population worldwide appears to have remained unexposed to SARS-CoV-2.[2,3,12] The countrywide lockdown and adherence to social distancing in the few months prior to the study are potential contributors to the observed low seroprevalence.

Unlike the earlier population-based studies in Geneva and Spain that excluded institutionalized populations (i.e. persons who were not members of households), this study presents findings from a densely populated area (i.e. labour camps) where congregate living and adherence to social distancing are major challenges for reducing viral transmission. Among 382 US navy-service members aboard an

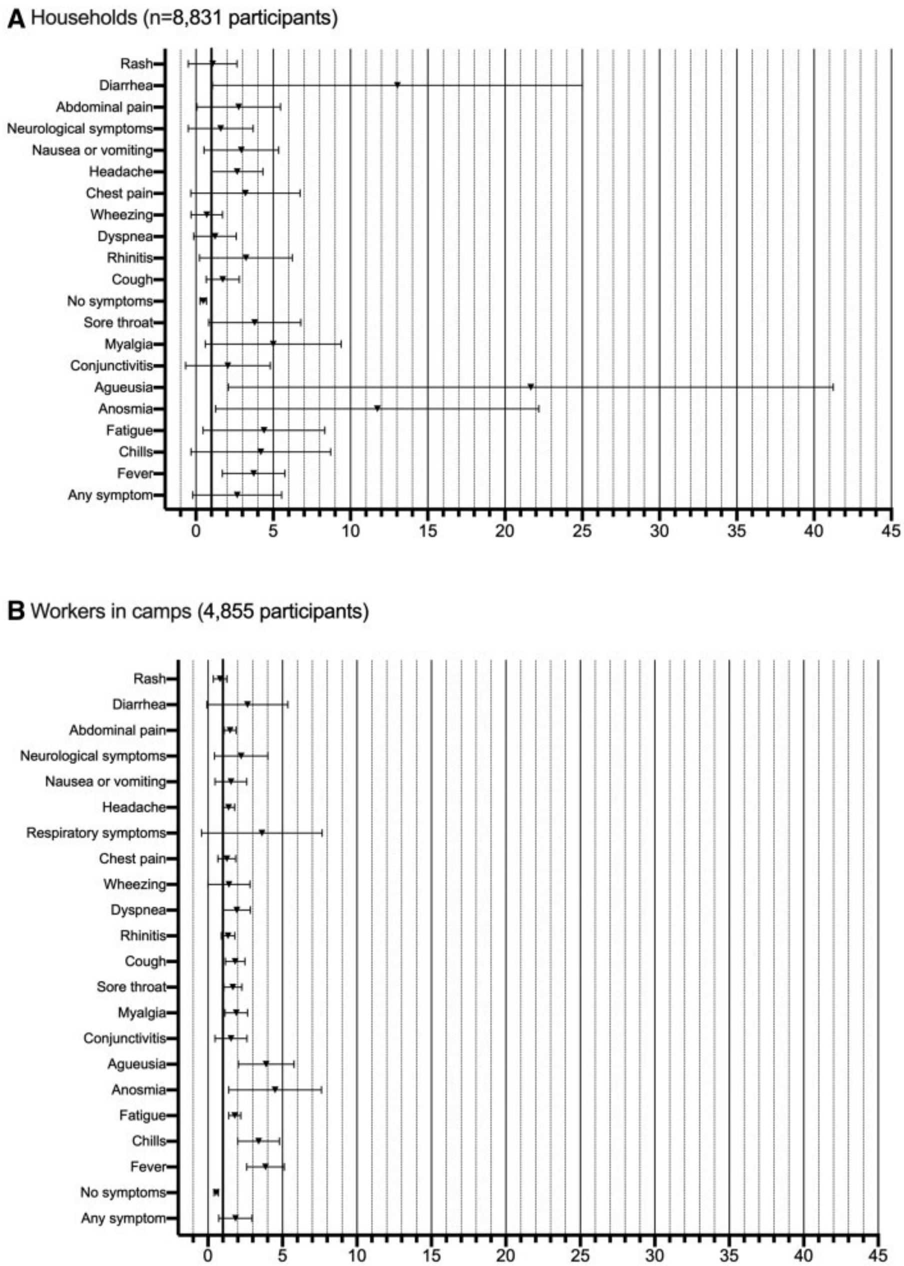

Figure 3 Association of SARS-CoV-2 seroprevalence with self-reported preceding clinical symptoms by households (A) and camp workers (B)

Adjusted odds ratios (with 95% confidence intervals) for sampling design and test characteristics, controlled for age, region, sex, education, nationality, ethnicity, occupation and contact with COVID-19 in a logistic-regression model. A symptom for which the odds ratio 95% confidence intervals cross the value of 1 (solid horizontal line) is not associated with seropositivity.

aircraft, 60% had reactive antibodies following a COVID-19 outbreak.[13] Similarly, in an adult homeless shelter in Boston, SARS-CoV-2 PCR testing revealed a 36% positivity rate.[14] These findings highlight the high efficiency for SARS-CoV-2 transmission in these settings and calls for implementing effective public health measures. In line with the national screening programme for COVID-19 in the UAE, a comprehensive 6-week screening and testing campaign was conducted in the Musaffah area in Abu Dhabi region, a large industrial area with several labour camps. The campaign delivered streamlined healthcare and support services, including intensified PCR testing and multi-language awareness programmes that utilized popular social figures to convey messages on precautionary measures. Despite the efforts of the UAE and Abu Dhabi government in implementing a structured multidimensional approach to reduce the risk of COVID-19 transmission among this group, challenges do continue to exist. Controlling the transmission in labour camps requires collaboration from the three parties; government, labour communities and employers. Employers and the private sector should support the government in its efforts to control the transmission. Active engagement of employers in contact tracing, regular testing and vaccination campaigns for their employees is crucial. Moreover, interventions targeting crowding in labour camps such as reducing capacity and adding new beds in separate locations may reduce COVID-19 risk, as has been suggested for nursing homes and shelter houses.[15]

In the households survey, we observed regional differences, with seroprevalence estimates in Abu Dhabi and Al Ain that were three times higher than that observed in Al Dhafra. Although Al Dhafra is the largest among the three studied regions, it has a smaller population density. Regional variations in SARS-CoV-2 seroprevalences have been also reported in the USA, with seroprevalence rates of $<5\%$ in the west to $>25\%$ in the north-east.[12] Similarly, in Spain, the SARS-CoV-2 seroprevalence in Madrid was five times higher than that observed in other provinces.[2]

The higher seroprevalence in camp workers in comparison to those in members of households may have several explanations. The studied household individuals and labour-camp workers had different socio-demographic characteristics. Almost all the labour-camp workers were male and the majority were in the age range of 18–40 years old, whereas almost half of the household individuals were female and a significant portion were <20 years old. For these reasons, both gender and age were taken into consideration when calculating the adjusted odds ratio in the figures and tables. Additionally, in contrast to the household individuals who lived in residential villas and apartments, the labour-camp workers resided in highly condensed areas. Camp workers usually have their meals together and are transported to and from their workplace by non-public buses where workers from more than one camp are clustered in the same transportation vehicle. These different living conditions have implications on virus transmission and necessitate tailored public health strategies.

Similar to other serosurveys, we found no sex differences in SARS-CoV-2 seroprevalence. We also found that children and adolescent (0–19 years) and older people ($\geq$60 years) had lower seroprevalence than the other age groups.[2,3,5] The fact that the study was conducted while schools and day-care centres were closed for months could possibly explain the observed low seroprevalence in children. Likewise, the low seroprevalence in the elderly was likely related to decreased social mixing in this age group. In the labour camps, we observed no differences across age groups.

Further, we found that Emirati citizens had lower seroprevalence compared with those of other nationalities. On the other hand, individuals from Southeast Asia showed the highest seroprevalence rates in both households and labour camps. These observed differences are possibly explained by variations in the socio-behavioural characteristics of these different groups. In the USA, residents of non-Hispanic Black and Hispanic neighbourhoods had higher SARS-CoV-2 seropositivity rates when compared with residents of predominantly non-Hispanic White neighbourhoods.[12] Further studies are needed to precisely quantify the observed differences in nationality/ethnicity.

Moreover, we found that workers in the construction sector had the highest seroprevalences. Construction workers are at increased risk for COVID-19 exposure because the nature of their job might not allow them to maintain a physical distance of at least 2 metres. National and international guidelines for workers on construction projects have been published that emphasize the need to take necessary preventive measures against COVID-19.[16–18]

In addition, we found that close contact with individuals with COVID-19 increased the likelihood of viral transmission in both households and labour camps. These findings are consistent with other serosurveys and highlight the importance of public health measures, including contact tracing, quarantine and self-isolation.[2,19]

Remarkably, the present study found that individuals in labour camps who are current smokers had lower SARS-CoV-2 seroprevalence than those who were never-smokers did. However, as we had no data on disease severity, we cannot comment on any association between smoking and infection severity. The issue of smoking and COVID-19 has been scientifically debated over the past few months.[20,21] A lower-than-expected prevalence of smoking among COVID-19-infected patients has been reported in observational studies.[22,23] In contrast, other studies have confirmed an increased risk for severe COVID-19 in those with a history of smoking.[24,25] Additionally, smoking can increase the lung gene expression of the angiotensin-converting enzyme-2 receptor utilized by SARS-CoV-2 to enter the host cell.[26] Although we observed lower SARS-CoV-2 seroprevalence estimates in labour camps among current smokers than those who were never-smokers, that observation was lacking among participants from households. As we rely on participants' self-reporting, it may be possible that some participants did not accurately disclose their smoking status. Taken together, observational data on the relationship between smoking and COVID-19 should be interpreted with caution.

Individuals with higher BMIs are at risk of developing complications with COVID-19.[27] In the households, individuals with higher BMIs were more likely to be seropositive than individuals with normal weight. However, this observation was lacking in labour camps. Additionally, well-known comorbid conditions, such as diabetes and hypertension, were not associated with higher seroprevalences in labour camps. It is possible that rigorous pre-employment health-screening programmes have resulted in excluding those with pre-existing medical conditions.[28]

Consistently with other studies, fever, cough, anosmia and ageusia were among the symptoms with the strongest association with seropositivity.[29,30] These symptoms should be taken into consideration when developing guidelines for case isolation, contact tracing and testing strategies.

A key strength of our study in comparison to other population-based serosurveys (e.g. the Spanish study) is the use of a more sensitive and specific technique to screen for antibodies in contrast to using Point of Care test (POCT) that has lower sensitivity and specificity. In the Spanish study, independent validation of the POCT returned a sensitivity of 82·1% for IgG, whereas the independent validation in our study returned a sensitivity approaching 90% (89·9%) for the first serology testing method (Roche Elecsys® Anti-SARS-CoV-2 assay) (Analytical methods, Supplementary Material, available as Supplementary data at *IJE* online).[2] We also enhanced the specificity by using the orthogonal algorithm—applying a different method that has different epitope targets (LIAISON® SARS-CoV-2 S1/S2 IgG assay). Although this approach increases the positive predictive value for a positive test result (i.e. positive on both tests), negative results should be interpreted with caution, as it takes 7–14 days for the immune system to produce measurable antibodies.

Few limitations exist. First, some participants may have not accurately recalled the answers for all questions in the study questionnaire, resulting in possible recall bias. Second, imprecision with ethnicity classification is probable, as nationality recorded on official documents (e.g. passport) was used as a surrogate for ethnicity. Although we collected data on clinical symptoms compatible with COVID-19, we did not collect data on disease severity. Further, although the overall sample size was large, certain age groups in the household survey might be underrepresented or overrepresented due to the fact that some individuals were either not present in their households during the time of the visit or refused to participate.

In conclusion, our study provides regional estimates on SARS-CoV-2 seroprevalence reflecting wide variations between affected areas. The substantially higher seroprevalence estimates in labour camps reflects the high efficiency of SARS-CoV-2 spread in congregate working settings. The low estimated seroprevalence among residents of households in the Emirate of Abu Dhabi is similar to other serosurveys confirming that majority of individuals are still susceptible for the infection. As the UAE and many other countries have started rolling out COVID-19 vaccines, findings from this study and similar population-based serosurveys are useful for vaccine-prioritization decisions, particularly for highly susceptible communities with lower seropositivity rates. Nevertheless, until vaccination targets are reached, social distancing and public health measures to identify new cases and their contacts are indispensable in the efforts to mitigate this pandemic.

Supplementary data

Supplementary data are available at *IJE* online.

Ethics approval

The institutional review board of the Department of Health, Abu Dhabi approved the study protocol (DOH/CVDC/2020/1301). Written informed consent was obtained from all individuals prior to study participation. Consent for children was obtained from a parent.

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Data availability

Our data are accessible to researchers upon reasonable request to the corresponding author.

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Author contributions

A.R.A. conceived of the study design, wrote the first draft of the manuscript and supervised the project. F.A., S.A., T.Z., H.N., L.A. and M.S.H. participated in the study design. T.Z. designed the sampling plan and implemented the electronic data-collection tool (Explorance Blue). F.A., S.A., H.K. and S.A.M. were the executive coordinators for the project. M.A., D.A., N.A., A.K. and K.H. were responsible for supervising field teams and data collection. L.A., A.E., H.A., N.A.K., B.A. and M.J. were responsible for laboratory analysis. S.S. and T.Z. were responsible for data management. H.N. and T.Z. were responsible for data analysis and interpretation. All authors helped in drafting the manuscript. All authors read and approved the final manuscript.

Conflict of interest

None declared.

References

1. World Health Organization. *Population-based Age-Stratified Seroepidemiological Investigation Protocol for Coronavirus 2019 (COVID-19) Infection*. 2020. https://apps.who.int/iris/handle/10665/332188 (31 January 2021, date last accessed).
2. Pollán M, Pérez-Gómez B, Pastor-Barriuso R *et al.* Prevalence of SARS-CoV-2 in Spain (ENE-COVID): a nationwide, population-based seroepidemiological study. *Lancet* 2020;**396**:535–44.
3. Stringhini S, Wisniak A, Piumatti G *et al.* Seroprevalence of anti-SARS-CoV-2 IgG antibodies in Geneva, Switzerland (SEROCoV-POP): a population-based study. *Lancet* 2020;**396**: 313–19.
4. Havers FP, Reed C, Lim T *et al.* Seroprevalence of antibodies to SARS-CoV-2 in 10 sites in the United States, March 23-May 12, 2020. *JAMA Intern Med* 2020;**180**:1576.
5. Hallal PC, Hartwig FP, Horta BL *et al.* SARS-CoV-2 antibody prevalence in Brazil: results from two successive nationwide serological household surveys. *Lancet Glob Health* 2020;**8**: e1390–98.
6. Al-Mandhari A, Kodama C, Abubakar A, Brennan R. Solidarity in response to COVID-19 outbreak in the Eastern Mediterranean Region. *East Mediterr Health J Rev Sante Mediterr Orient Al-Majallah Al-Sihhiyah Li-Sharq Al-Mutawassit* 2020;**26**:492–4.
7. National Emergency Crisis and Disaster Management Authority. UAE Coronavirus *(COVID-19) Updates*. 2021. https://covid19.ncema.gov.ae/en (14 January 2021, date last accessed).
8. Roser M, Ritchie H, Ortiz-Ospina E, Hasell J. *Coronavirus Pandemic (COVID-19)*. 2021. https://ourworldindata.org/coronavirus (13 January 2021, date last accessed).
9. Centers for Disease Control and Prevention. *Interim Guidelines for COVID-19 Antibody Testing*. 2020. https://www.cdc.gov/coronavirus/2019-ncov/lab/resources/antibody-tests-guidelines.html (31 January 2021, date last accessed).
10. Statistics Centre—Abu Dhabi. Statistical Yearbook of Abu Dhabi. 2020. https://www.scad.gov.ae/Release%20Documents/Statistical%20Yearbook%20of%20Abu%20Dhabi_2020_Annual_Yearly_en.pdf (31 January 2021, date last accessed).
11. Labour Accommodation—The Official Portal of the UAE Government. https://u.ae/en/information-and-services/jobs/labour-accommodation (31 January 2021, date last accessed).
12. Anand S, Montez-Rath M, Han J *et al.* Prevalence of SARS-CoV-2 antibodies in a large nationwide sample of patients on dialysis in the USA: a cross-sectional study. *Lancet* 2020;**396**:1335–44.
13. Payne DC, Smith-Jeffcoat SE, Nowak G *et al.*; CDC COVID-19 Surge Laboratory Group. SARS-CoV-2 infections and serologic responses from a sample of U.S. navy service members—USS Theodore Roosevelt, April 2020. *MMWR Morb Mortal Wkly Rep* 2020;**69**:714–21.
14. Baggett TP, Keyes H, Sporn N, Gaeta JM. Prevalence of SARS-CoV-2 infection in residents of a large homeless shelter in Boston. *Jama* 2020;**323**:2191–92.
15. Brown KA, Jones A, Daneman N *et al.* Association between nursing home crowding and COVID-19 infection and mortality in Ontario, Canada. *JAMA Intern Med* 2021;**181**:229–36.
16. CDC. *Communities, Schools, Workplaces, & Events*. 2020. https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/construction-workers.html (31 October 2020, date last accessed).
17. *Safety and Health Topics | COVID-19 | Occupational Safety and Health Administration*. 2020. https://www.osha.gov/SLTC/covid-19/ (31 October 2020, date last accessed).
18. The Federal Competitiveness and Statistics Authority. The *UAE Government's Initiatives to Combat the COVID-19 Crisis*. 2020. https://fcsa.gov.ae/en-us/Lists/D_Reports/Attachments/49/UAE%20Gov%20Initiatives%20to%20Combat%20Covid-19%20-%20En.pdf (5 November 2020, date last accessed).
19. Steensels D, Oris E, Coninx L *et al.* Hospital-wide SARS-CoV-2 antibody screening in 3056 staff in a tertiary center in Belgium. *Jama* 2020;**324**:195–97.
20. Polverino F. Cigarette smoking and COVID-19: a complex interaction. *Am J Respir Crit Care Med* 2020;**202**:471–72.
21. Rossato M, Russo L, Mazzocut S, Di Vincenzo A, Fioretto P, Vettor R. Current smoking is not associated with COVID-19. *Eur Respir J* 2020;**55**:2001290.
22. Guan W-J, Ni Z-Y, Hu Y *et al.*; China Medical Treatment Expert Group for Covid-19. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med* 2020;**382**:1708–20.
23. Lippi G, Henry BM. Active smoking is not associated with severity of coronavirus disease 2019 (COVID-19). *Eur J Intern Med* 2020;**75**:107–08.
24. Zhao Q, Meng M, Kumar R *et al.* The impact of COPD and smoking history on the severity of COVID-19: a systemic review and meta-analysis. *J Med Virol* 2020;**92**:1915–21.
25. Zheng Z, Peng F, Xu B *et al.* Risk factors of critical & mortal COVID-19 cases: a systematic literature review and meta-analysis. *J Infect* 2020;**81**:e16–25.
26. Cai G, Bossé Y, Xiao F, Kheradmand F, Amos CI. Tobacco smoking increases the lung gene expression of ACE2, the receptor of SARS-CoV-2. *Am J Respir Crit Care Med* 2020;**201**: 1557–59.
27. Chang T-H, Chou C-C, Chang L-Y. Effect of obesity and body mass index on coronavirus disease 2019 severity: a systematic review and meta-analysis. *Obes Rev* 2020;**21**:e13089.
28. Pachman J. Evidence base for pre-employment medical screening. *Bull World Health Organ* 2009;**87**:529–34.
29. Makaronidis J, Mok J, Balogun N *et al.* Seroprevalence of SARS-CoV-2 antibodies in people with an acute loss in their sense of smell and/or taste in a community-based population in London, UK: an observational cohort study. *PLOS Med* 2020;**17**: e1003358.
30. Rudberg A-S, Havervall S, Månberg A *et al.* SARS-CoV-2 exposure, symptoms and seroprevalence in healthcare workers in Sweden. *Nat Commun* 2020;**11**:5064.