RESEARCH ARTICLE

Seroprevalence of SARS-CoV-2 among high-density communities and hyper-endemicity of COVID-19 in Vietnam

Van Thuan Hoang[1] | Thi Dung Pham[1] | Quoc Tien Nguyen[1] | Duy Cuong Nguyen[1] |
Duc Thanh Nguyen[1] | Thanh Binh Nguyen[1] | Thi Khanh Thu Tran[2] | Trong Lan Phan[3] |
Phan Le Nguyen Vo[4] | Thi Loi Dao[1] | Florence Fenollar[5,6] | Philippe Gautret[5,6]

[1]Thai Binh University of Medicine and Pharmacy, Thai Binh, Vietnam

[2]Thai Binh Province General Hospital, Thai Binh, Vietnam

[3]General Department of Preventive Medicine, Ministry of Health, Ha Noi, Vietnam

[4]People's Committee of Nha Be District, Ho Chi Minh City, Vietnam

[5]Aix Marseille Univ, IRD, AP-HM, SSA, VITROME, Marseille, France

[6]IHU-Méditerranée Infection, Marseille, France

Correspondence
Philippe Gautret, Institut Hospitalo-Universitaire Méditerranée Infection, 19-21 Boulevard Jean Moulin, 13385 Marseille Cedex 05, France.
Email: philippe.gautret@club-internet.fr

Abstract

Objective: To assess the magnitude of active and recovering COVID-19 patients among at-risk communities and to identify the factors associated with positive serology.

Methods: Four hundred and eighty-three close contacts of COVID-19 patients residing in Ho Chi Minh City, Vietnam, during the fourth wave of the COVID-19 epidemic (September and October 2021) were included. Five weeks after exposure to a COVID-19 patient, they underwent a serology test using the BIOSYNEX COVID-19 BSS kit.

Results: The median age of participants was 37 years. A total of 34.6% individuals presented at least one clinical symptom between the time of contact with the COVID-19 patient and inclusion in study. A total of 1.7% unvaccinated individuals tested positive for SARS-CoV-2 using real-time PCR, and 9.5% had evidence of recent infection (positive PCR and/or IgM). A further 26.7% unvaccinated individuals presented evidence of a past infection (positive IgG only). Socio-demographic characteristics, vaccination status and clinical symptoms were not associated with a positive IgM test.

Conclusion: This is the first serosurvey conducted during the fourth wave of the epidemic in Vietnam. It revealed a seropositivity rate higher than in previous studies and confirmed the hyperendemicity of SARS-CoV-2. Testing using rapid serological tests proved to be a reliable, easy-to-use method and enabled a rapid estimation of the burden of COVID-19.

KEYWORDS
COVID-19, high-density communities, SARS-CoV-2, seroprevalence, Vietnam

INTRODUCTION

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), first detected in Wuhan city in the Hubei province of China in December 2019, led to the coronavirus disease 19 (COVID-19) epidemic [1]. Nearly two years after its appearance, the COVID-19 has now spread to 215 countries and territories worldwide, with more than 268 million confirmed cases and five million deaths recorded [2].

Although there are vaccines available to prevent the disease, the epidemic is ongoing and continues to be a global public health concern [3,4]. It is putting significant pressure on healthcare systems, even in developed countries [3,4].

Overcrowding, close contact in enclosed spaces and poor sanitation are known factors that increase the transmission of SARS-CoV-2 [5]. It is, therefore, not surprising that densely populated cities in low- and middle-income countries such as Vietnam are at the heart of the COVID-19 pandemic.

Cramped living conditions allow the virus to spread rapidly with a high risk of community transmission [5,6].

Vietnam reported the first two cases in the country on 23 January 2020 [7]. Since then, Vietnam has experienced four waves of the epidemic, with the number of cases increasing in later waves (Table S1). Prior to April 2021, Vietnam was one of the few countries worldwide that had been less affected by the COVID-19 pandemic. As the result of proactive disease prevention measures, the number of confirmed cases was small and most of them were in people entering the country [8,9]. However, on 27 April 2021, after more than a year since the first case was recorded, Vietnam entered the fourth wave of the epidemic. During the ongoing wave, 1,224,110 confirmed cases and 25,055 deaths were recorded (as of 30 November 2021), representing 99.6% and 99.9% of total cases and deaths in the country, respectively [2]. However, Vietnam still lacks published specialised research on COVID-19 [10].

Mass testing, contact tracing and quarantine of positive cases and close contact persons are currently key methods to prevent transmission and suppress outbreaks in Vietnam [8,9]. In addition, the Vietnamese Ministry of Health has officially announced a '5K' message (in Vietnamese), referring to Khẩu trang (facemask), Khử khuẩn (disinfection), Khoảng cách (distance), Không tụ tập (no gathering), Khai báo y tế (health declaration), to help citizens acclimatise to living safely with the COVID-19 pandemic under 'new normal' conditions (https://covid19.gov.vn/). However, these non-specific measures remain a serious challenge for densely populated cities.

Early detection of people infected with SARS-CoV-2 is an important measure to control the spread of the virus. Currently, the gold standard diagnosis of SARS-CoV-2 infection is real-time reverse transcriptase PCR performed on nasopharyngeal samples. However, this technique is expensive and not always feasible in situations where facilities are lacking. Additionally, diagnoses may be under-reported due to false-negative results [11,12] for several reasons, including sensibility and specificity of diagnostic kits, storage conditions of respiratory samples, presence of interfering substances, testing carried out outside the diagnostic window, use of non-adequately validated assays, insufficient or inadequate materials and practical working conditions in the laboratory [13]. Furthermore, COVID-19 symptoms lack specificity, and mild and asymptomatic cases of COVID-19 may go undocumented. Serological testing offers an essential complementary diagnosis in individuals at high risk of infection due to long-term exposure when RT-PCR test is negative or not performed. Serological tests that identify past infection can be also used to estimate cumulative incidence [14]. Therefore, antibody-based seroprevalence studies are required to estimate population-level exposure to SARS-CoV-2 [15]. In addition, serology rapid test is also an easy method to perform in low- or middle-income countries, right in the community, simple technique, and short time for results [16]. Population-level serological data are essential for understanding the prevalence of subclinical infections and the population's herd immunity to SARS-CoV-2 [17,18]. The proportion of the infected population or recovered from COVID-19 would be an important measure to inform policies at community level, including when and how social distancing can be eased, and prioritising vaccines [19]. Personal serology testing could allow low-risk individuals to return to work, school or university, depending on the potential immune protection produced by a measurable antibody response [20,21].

In Vietnam, some studies on the seroprevalence of SARS-CoV-2 antibodies were conducted, but they were realised during the three previous waves of the epidemic with relatively few COVID-19 cases in the country [17,18,22–24]. Hence, the sero-prevalence was less than 0.5%. However, in the 4th wave of the epidemic, the number of cases accounted for most of the cumulated cases since the outbreak onset. Therefore, the determination of the exposure rate to SARS-CoV-2 needs to be re-evaluated to determine the extent of the epidemic's impact on the community.

Here, we investigate the seroprevalence of SARS-CoV-2 among people in close contact with COVID-19 patients in Ho Chi Minh City (HCMC)—the highest-density region in Vietnam. The objectives of this study were to assess the magnitude of active and recovering COVID-19 cases among at-risk communities and to identify the epidemiological characteristics and factors associated with positive serology.

MATERIALS AND METHODS

Study setting and site selection

Vietnam is a developing country situated in Southeast Asia, with a population of over 98 million living in 63 provinces. Each province is further divided into districts, communes and villages. Each village has an average population between 500 and 2000 [17]. In line with the administrative division, the healthcare system is divided into central hospitals, provincial hospitals, district hospitals and medical centres, as well as primary medical centres within the communes. The Ministry of Health directly manages the provincial health departments and central hospitals. The provincial health department manages the hospitals and medical centres within that province.

This cross-sectional study was conducted in Ho Chi Minh City (HCMC), which is where most cases have appeared in Vietnam since the beginning of the epidemic, especially during the fourth wave of COVID-19 which began on 27 April 2021 (Table S1, Figure S1).

HCMC, formerly known as Saigon, is the largest city in the south of Vietnam (Figure S1). With over 8.9 million inhabitants living within the city itself and over 21 million within its metropolitan area of 20,612 km^2, HCMC is one of the world's most polluted cities and is the second most polluted city in Southeast Asia, just behind Jakarta, Indonesia.

HCMC is a municipality on the same level as Vietnam's provinces, which is subdivided into 22 district-level

sub-divisions, including one city (Thu Duc), 16 urban, and five rural districts. The city's healthcare system is relatively well-developed with a chain of about 100 government-owned hospitals and medical centres and dozens of private clinics. HCMC is also where the first case of COVID-19 was recorded in Vietnam [7].

Study population

Inclusion criteria: Close contacts of COVID-19 patients residing in HCMC during the fourth wave of the COVID-19 epidemic (Table S1) were eligible to participate in our study. A 'close contact' of a COVID-19 case is defined as someone who has been in contact with a person who has been diagnosed as positive with SARS-CoV-2 by real-time PCR, within a distance of two metres for at least 15 min, or someone who has been in the same room as such a person for at least 2 h during the contagious period (48 h before the onset of symptoms or diagnosis) (https://covid19.gov.vn/) [17].

During the three previous waves of the epidemic, all patients, regardless of their clinical presentation, were treated in hospital. An epidemiological study was also carried out to trace all close contacts of the patient and these individuals were quarantined in medical facilities [8]. During this fourth outbreak, all medical facilities in HCMC were overwhelmed, so patients who were positive for SARS-CoV-2 but who were asymptomatic or presented with mild symptoms were treated at home. Close contacts of the patient were also quarantined and monitored in their homes for 14 days and were recommended to strictly follow the '5K' message publicised by the Ministry of Health, including wearing a mask.

The sample size was calculated with $Z\alpha = 1.96$ for a 95% confidence interval, a predicted acceptable margin of error of $d = 0.04$, and a 25.0% estimated seroprevalence rate. The minimum sample size needed for the study was 450 persons.

Rapid antigen, serology testing and data collection

During the quarantine period, participants underwent a rapid diagnostic test (RDT) BIOSYNEX® COVID-19 Ag BSS performed by medical doctors, according to the manufacturer's recommendations. The BIOSYNEX COVID-19 Ag BSS test is a qualitative membrane-based immunoassay that uses highly sensitive monoclonal antibodies to detect the nucleocapsid protein of SARS-CoV-2 in nasopharyngeal swab. The sensibility and specificity of this test are 87.2% [66.3%–97.4%] and 99.9% [99.4%–100%], respectively [25].

Five weeks after individuals came into contact with a COVID-19 patient (time needed to detect anti-SARS-CoV-2 antibodies, when present [26]), a SARS-CoV-2 serology test was performed by medical doctors using the BIOSYNEX COVID-19 BSS (IgG/IgM)® (Biosynex, Illkirch-Graffenstaden, France), targeting the receptor-binding domain (RBD) of the spike surface protein of SARS-CoV-2 [16].

This assay was performed following the instructions of the respective manufacturers, with 10 µl of finger-prick whole blood, and read after ten10 min. The sensibility and specificity of this test are 97.4% [86.2%–99.9%] and 99.3% [96.2%–99.9%], respectively [27].

Interviews were conducted with each study participant to collect information about age, gender, chronic conditions, vaccination against COVID-19, and symptoms.

Analysis

STATA software version 16.0 (Copyright 1985–2015 StataCorp LLC, http://www.stata.com) was used for statistical analysis. Descriptive statistics were calculated and presented as numbers and percentages for qualitative variables, and medians and interquartiles for quantitative variables.

Unadjusted associations between IgM seropositive tests using multiple factors, including sociodemographic characteristics (gender, ≤16 years), vaccination status against COVID-19, and clinical symptoms between time of contact with the COVID-19 patient and the serology test, were analysed by univariable analysis. Multivariate analysis was carried out using a logistical regression model. This was used to estimate the adjusted odds ratios of factors regarding the seropositive test. The results were presented by odds ratio (OR) with a 95% confidence interval (95% CI). Results with a p value ≤0.05 were considered to be statistically significant.

RESULTS

Socio-demographic characteristics of the studied population

Of the 500 people who were invited to participate, nine refused to participate and the serology test results were invalid for eight participants. Ultimately, 483 participants were included in our study; 253 (52.4%) male participants and 230 (47.6%) female participants. The median age of participants was 37 years (range = 3–78 years). A total of 48 (9.9%) were children under the age of 16. Hypertension was the most frequent comorbidity (45/483, 9.3%), followed by chronic cardiac diseases (28/483, 5.8%) and chronic respiratory diseases (24/483, 5.0%). At the time of testing, 63 individuals (13.0%) had been vaccinated against COVID-19, with at least one dose at least 14 days before inclusion (Table 1).

Clinical features of participants

A total of 167 (34.6%) presented at least one clinical symptom between the time of contact with the COVID-19 patient and inclusion in the study. A cough was the most frequent symptom (104/483, 21.5%). In addition, anosmia, ageusia and fever were reported in 99 participants (20.5%), 82 participants (17.0%) and 93 (19.3%) participants, respectively.

TABLE 1 Socio-demographic characteristic of the studied population

Characteristics	N = 483	%
Gender		
Male	253	52.4
Female	230	47.6
Age		
Median	37	
Interquartile	25–48	
Rang	3–78	
Children (≤16 years)		
Yes	48	9.9
No	435	90.1
Chronic conditions		
Hypertension	45	9.3
Chronic cardiac diseases	28	5.8
Chronic respiratory diseases	24	5.0
Diabetes	12	2.5
Cancer	1	0.2
Immunodepression	1	0.2
Vaccination against COVID-19 at least 14 days before the serology test		
Yes	63	13.0
No	420	87.0

TABLE 2 Clinical symptoms

Clinical symptoms	N = 483	%
At least one symptom	167	34.6
Fever	93	19.3
Cough	104	21.5
Expectoration	36	7.5
Rhinitis	60	12.4
Sore throat	54	11.2
Anosmia	99	20.5
Ageusia	82	17.0
Dyspnoea	39	8.1
Myalgia	38	7.9
Arthralgia	14	2.9
Nausea/vomiting	24	5.0
Diarrhoea	50	10.4
Fatigue	72	14.9

Fifty individuals (10.4%) reported diarrhoea and 24 (5.0%) reported nausea or vomiting (Table 2).

Results of SARS-CoV-2 antigen and serology test

During quarantine, all close contact persons were tested for SARS-CoV-2 by a rapid antigen test. Eight (1.7%) were positive, and confirmed as having SARS-CoV-2 infection by real-time PCR, carried out by the HCMC Centre for Disease Control.

Five weeks after contact with the COVID-19 patient, 206 close contact persons had a positive serology test for IgM and/or IgG; hence the seroprevalence of SARS-CoV-2 was 42.6%. Specifically, 51 (10.5%) were positive by IgM (with or without IgG), of whom five reported having been vaccinated and seven were positive by PCR (Table 3). Hence, 46 (9.5%) individuals had evidence of a recent infection without vaccination. In addition, 155 persons were positive for IgG only, of whom 26 were vaccinated and one was positive by PCR. Hence 129 (26.7%) individuals had evidence of a past infection without vaccination.

Factors associated with a positive IgM SARS-CoV-2 serology test

In univariate and multivariate analysis, socio-demographic characteristics, vaccination status and clinical symptoms were not associated with a positive IgM serology test (Table 4).

DISCUSSION

Currently, in Vietnam, all COVID-19 patients are anonymously recorded by the Ministry of Health, after being confirmed with SARS-CoV-2 infection using real-time polymerase chain reaction (RT-PCR) methods. Viral testing is recommended for symptomatic patients or individuals with a suspected history of exposure or living in an endemic area. However, the clinical manifestations of COVID-19 vary widely, from asymptomatic to severe illness and death. The rate of people who are asymptomatic reported in a meta-analysis ranges from 4 to 41%, depending on studied population size [28]. Asymptomatic patients are likely to remain undetected and they can be a source of silent transmission within the community, making it difficult to control the disease. Despite the capacity of viral transmission being 42% lower among asymptomatic versus symptomatic patients, asymptomatic and subclinical symptomatic patients are a significant concern in the controls of current COVID-19 pandemic [28]. In our study, we did not see a relation between seropositivity and the presence or absence of symptoms.

TABLE 3 Results of serology test

Results	N = 483	%
IgM and/or IgG positive	206[30]	42.6
IgM positive and IgG negative	33[2]	6.8
IgM negative and IgG positive	155[25]	32.1
IgM positive and IgG positive	18[3]	3.7
IgM negative and IgG negative	277[31]	57.3

Note: Superscripts indicate number of persons vaccinated against COVID-19.

TABLE 4 Factors associated with positive IgM serology test for SARS-CoV-2

Factors	N = 206 n (%)	Univariate analysis		Multivariate analysis	
		OR [95%CI]	p-value	Adjusted OR [95%CI]	p-value
Gender					
Female	24 (10.4)	Reference	0.93	Reference	0.95
Male	27 (10.7)	1.03 [0.57–1.83]		1.01 [0.57–1.82]	
Children					
No	46 (10.6)	0.98 [0.37–2.61]	0.97	0.88 [0.33–2.39]	0.81
Yes	5 (10.4)				
Vaccination against COVID-19 at least 14 days before the serology test					
No	46 (11.0)	0.70 [0.27–1.84]	0.47	0.66 [0.25–1.77]	0.41
Yes	5 (7.9)				
Clinical symptoms between time of contact with COVID-19 patient and serology test					
No	35 (11.1)	0.85 [0.46–1.59]	0.61	0.81 [0.43–0.53]	0.52
Yes	16 (9.6)				

Indeed, the infectiousness of SARS-CoV-2 depends on the viral load, not on the carrier's symptoms [29]. The false-negative rate of the RT-PCR test is another challenge for the definitive diagnosis and screening of COVID-19 patients [11,12]. Therefore, non-pharmaceutical preventive measures and vaccination against COVID-19 need to be stepped up by the public. Laboratory testing methods also need to be refined to improve sensitivity, specificity and reduce cost of use. Serology may be a better way of estimating the burden of SARS-CoV-2 infection and assessing the impact of the epidemic, thereby allowing preventive measures to be taken for the community. Seroprevalence screening is useful to gain insight into the dynamics of SARS-CoV-2 antibody responses during and after viral transmission. If it is performed regularly, health authorities and policymakers can glean information on seroprevalence rates at any given stage of an outbreak [30]. Contrary to IgM, which is indicative of recent infection, the IgG antibody persists for a long time after virus clearance [31]. Hence, serological monitoring is beneficial when it comes to providing relevant epidemiological data and estimating the cumulative rate of SARS-CoV-2 infection or exposure rate in the population [30–33].

Our study demonstrates high rates of antibodies against SARS-CoV-2 (42.6%) in close contacts of COVID-19 patients, with 9.5% of people presenting evidence of a recent infection without vaccination, and 26.7% presenting evidence of a past infection. The prevalence of SARS-CoV-2 IgM in the surveyed population did not depend on age, sex, clinical symptoms of the patient, or vaccination status, suggesting that all types of individuals were potentially at risk of contamination. SARS-CoV-2 seroprevalence has been shown to depend on the geographical area and the circulation of the virus in the community. In a study by Chau et al., conducted on 148 Vietnamese children and 100 adults during the pre-pandemic phrase of COVID-19, no cases were found to be positive for SARS-CoV-2 antibodies [34]. In August 2020 (during the second phase of the epidemic in Vietnam), 408 healthcare workers at the Hospital for Tropical Diseases in HCMC were enrolled in a serosurvey, including 97 staff who provided direct clinical care to COVID-19 patients and 34 staff whose work involved processing respiratory samples from COVID-19 patients. Their immune status against SARS-CoV-2 was evaluated using the Elecsys Anti-SARS-CoV-2 assay, but no cases were identified [18]. In another study conducted during the second phase of epidemic and including 2,954 high-risk individuals living in communities where cases of COVID-19 had been reported, 27 household contacts and 53 close contacts were identified. IgG antibodies to SARS-CoV-2 were detected in 0.2%, 18.5% and 1.9% cases, respectively [17].

Since April 2020, SARS-CoV-2 serosurveys have been reported from many countries affected by COVID-19 [31–41]. In a recent meta-analysis that included 47 articles covering 399,265 persons from 23 countries, SARS-CoV-2 seroprevalence in the general population varied from 0.4% to 22.1%, with a pooled estimate of 3.4% [30]. This study found that seroprevalence was significantly associated with geographic latitudes and/or climate, income levels, and human development indices, but not with an increasing trend in the number of confirmed cases and deaths [30]. Indeed, the actual number of cases may be higher than the recorded number of cases, as there are patients who go undiagnosed because they are asymptomatic or have mild symptoms.

Our study has some limitations. It was conducted among high-density communities in a COVID-19 hyperendemic region in Vietnam with a modest sample size and cannot be extrapolated to the entire population of Vietnam. Our results showed that the SARS-CoV-2 IgM rate in the population surveyed was not associated with socio-demographic characteristics, vaccination status and clinical symptoms. However, SARS-CoV-2 seroprevalence could be dependent on geographic areas and the circulation of virus in the community which was not evaluated in this monocentric survey [30]. Moreover, SARS-CoV-2 IgM usually appears 5–7 days after onset of symptoms or time of and persists for 5–7 weeks; IgG production is from

day 10–14 and persists for several weeks [42]. In our study, the serology test was conducted 5 weeks after individuals came into contact with a COVID-19 patient and the negative results may be due to testing carried out outside of the diagnostic window. However, this is the first serosurvey conducted during the fourth wave of the epidemic in the country. It showed a higher seropositivity rate than previous studies in the country [17,18,34]. The very high rate of antibodies against SARS-CoV-2 confirms the hyperendemicity of the virus in this area of Vietnam. Testing with rapid serological tests proved to be a reliable and easy-to-use method and made it possible to rapidly estimate the burden of SARS-CoV-2 infection.

ACKNOWLEDGEMENTS

REFERENCES

1. Zhu NA, Zhang D, Wang W, Li X, Yang BO, Song J, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med. 2020;382:727–33. https://doi.org/10.1056/NEJMoa2001017

2. COVID Live Update: 268,091,135 Cases and 5,294,887 Deaths from the Coronavirus - Worldometer n.d. [cited 2021 Dec 9]. Available from: https://www.worldometers.info/coronavirus/

3. OECD. The territorial impact of COVID-19: Managing the crisis and recovery across levels of government. OECD n.d. [cited 2021 Dec 9]. Available from: https://www.oecd.org/coronavirus/policy-responses/the-territorial-impact-of-covid-19-managing-the-crisis-and-recovery-across-levels-of-government-a2c6abaf/

4. El Bcheraoui C, Weishaar H, Pozo-Martin F, Hanefeld J. Assessing COVID-19 through the lens of health systems' preparedness: time for a change. Globalization Health. 2020;16:112. https://doi.org/10.1186/s12992-020-00645-5

5. Ahmed SAKS, Ajisola M, Azeem K, Bakibinga P, Chen Y-F, Choudhury NN, et al. Impact of the societal response to COVID-19 on access to healthcare for non-COVID-19 health issues in slum communities of Bangladesh, Kenya, Nigeria and Pakistan: results of pre-COVID and COVID-19 lockdown stakeholder engagements. BMJ Glob Health. 2020;5:e003042. https://doi.org/10.1136/bmjgh-2020-003042

6. Al-Tawfiq JA, Leonardi R, Fasoli G, Rigamonti D. Prevalence and fatality rates of COVID-19: what are the reasons for the wide variations worldwide? Travel Med Infect Dis. 2020;35:101711. https://doi.org/10.1016/j.tmaid.2020.101711

7. Phan LT, Nguyen TV, Luong QC, Nguyen TV, Nguyen HT, Le HQ, et al. Importation and human-to-human transmission of a novel coronavirus in Vietnam. N Engl J Med. 2020;382:872–4. https://doi.org/10.1056/NEJMc2001272

8. Dao TL, Nguyen TD, Hoang VT. Controlling the COVID-19 pandemic: useful lessons from Vietnam. Travel Med Infect Dis. 2020;37:101822 https://doi.org/10.1016/j.tmaid.2020.101822

9. Quach HL, Hoang NA. COVID-19 in Vietnam: a lesson of pre-preparation. J Clin Virol. 2020;127:104379. https://doi.org/10.1016/j.jcv.2020.104379

10. Dao TL, To MM, Nguyen TD, Hoang VT. Mapping COVID-19 related research from Vietnam: a scoping review. Preprints. 2021. https://doi.org/10.21203/rs.3.rs-1461232/v1

11. Wang G, Yu N, Xiao W, Zhao C, Wang Z. Consecutive false-negative rRT-PCR test results for SARS-CoV-2 in patients after clinical recovery from COVID-19. J Med Virol. 2020;92(11):2887–90. https://doi.org/10.1002/jmv.26192

12. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu YI, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet. 2020;395:497–506. https://doi.org/10.1016/S0140-6736(20)30183-5

13. Lippi G, Simundic A-M, Plebani M. Potential preanalytical and analytical vulnerabilities in the laboratory diagnosis of coronavirus disease 2019 (COVID-19). Clin Chem Lab Med. 2020;58:1070–6. https://doi.org/10.1515/cclm-2020-0285

14. Chen Y, Tong X, Wang J, Huang W, Yin S, Huang R, et al. High SARS-CoV-2 antibody prevalence among healthcare workers exposed to COVID-19 patients. J Infect. 2020;81:420–6. https://doi.org/10.1016/j.jinf.2020.05.067

15. Weinstein MC, Freedberg KA, Hyle EP, Paltiel AD. Waiting for certainty on Covid-19 antibody tests — at what cost? N Engl J Med. 2020;383:e37. https://doi.org/10.1056/NEJMp2017739

16. Mboumba Bouassa R-S, Péré H, Tonen-Wolyec S, Longo JDD, Moussa S, Mbopi-Keou F-X, et al. Unexpected high frequency of unspecific reactivities by testing pre-epidemic blood specimens from Europe and Africa with SARS-CoV-2 IgG–IgM antibody rapid tests points to IgM as the Achilles heel. J Med Virol. 2021;93:2196–203. https://doi.org/10.1002/jmv.26628

17. Hasan T, Pham TN, Nguyen TA, Le HTT, Van Le D, Dang TT, et al. Sero-prevalence of SARS-CoV-2 antibodies in high-risk populations in Vietnam. Int J Environ Res Public Health. 2021;18:6353. https://doi.org/10.3390/ijerph18126353

18. Chau NVV, Toan LM, Man DNH, Thao HP, Lan NPH, Ty DTB, et al. Absence of SARS-CoV-2 antibodies in health care workers of a tertiary referral hospital for COVID-19 in southern Vietnam. J Infect. 2021;82:e36–7. https://doi.org/10.1016/j.jinf.2020.11.018

19. Bubar KM, Reinholt K, Kissler SM, Lipsitch M, Cobey S, Grad YH, et al. Model-informed COVID-19 vaccine prioritization strategies by age and serostatus. Science. 2021;371:916–21. https://doi.org/10.1126/science.abe6959

20. Weitz JS, Beckett SJ, Coenen AR, Demory D, Dominguez-Mirazo M, Dushoff J, et al. Modeling shield immunity to reduce COVID-19 epidemic spread. Nat Med. 2020;26:849–54. https://doi.org/10.1038/s41591-020-0895-3

21. Larremore DB, Bubar KM, Grad YH. Implications of test characteristics and population seroprevalence on "Immune Passport" strategies. Clin Infect Dis. 2021;72:e412–4. https://doi.org/10.1093/cid/ciaa1019

22. Song LH, Hoan NX, Bang MH, Kremsner PG, Velavan TP. Viral and serological testing of SARS-CoV-2 among health care workers and patients in Vietnam. The Lancet Regional Health – Western Pacific. 2021;8:100113. https://doi.org/10.1016/j.lanwpc.2021.100113

23. Hasan T, Thach PN, Anh NT, Hien LTT, An NTM, Thuy DT, et al. The prevalence of SARS-CoV-2 antibodies in quarantine workers and high-risk communities in Vietnam. IJID Regions. 2022;2:137–40. https://doi.org/10.1016/j.ijregi.2021.12.001

24. Nguyen HHH, Nguyen QH, Truong DTT, Dao MH, Le TN, Nguyen HT, et al. Seroprevalence of SARS-CoV-2 neutralizing antibodies among blood donors in Ho Chi Minh City, Vietnam, August–November 2020. Am J Trop Med Hyg 2022;106:891–5. https://doi.org/10.4269/ajtmh.21-0259

25. Ngaba GP, Mireille Kalla GC, Nguedia Assob JC, Njouendou AJ, Jembe CN, Mboudou ET, et al. Evaluation de deux tests de diagnostic antigénique du COVID-19: BIOSYNEX® COVID-19 Ag BSS et BIOSYNEX® COVID-19 Ag+ BSS comparés à la PCR AmpliQuick® SARS-CoV-2. Pan Afr Med J. 2021;39:228. https://doi.org/10.11604/pamj.2021.39.228.30752

26. European Centre for Disease Prevention and Control. Immune responses and immunity to SARS-CoV-2. [cited 2021 Aug 1]. Available from: https://www.ecdc.europa.eu/en/covid-19/latest-evidence/immune-responses

27. Tonen-Wolyec S, Dupont R, Batina-Agasa S, Hayette M-P, Bélec L. Capillary whole-blood IgG-IgM COVID-19 self-test as a serological screening tool for SARS-CoV-2 infection adapted to the general public. PLoS One. 2020;15:e0240779. https://doi.org/10.1371/journal.pone.0240779

28. Byambasuren O, Cardona M, Bell K, Clark J, McLaws M-L, Glasziou P. Estimating the extent of asymptomatic COVID-19 and its potential

for community transmission: systematic review and meta-analysis. Official J Assoc Med Microbiol Infect Dis Canada. 2020;5(4):223–34. https://doi.org/10.3138/jammi-2020-0030

29. Boschi C, Aherfi S, Houhamdi L, Colson P, Raoult D, Scola BL. Isolation of 4000 SARS-CoV-2 shows that contagiousness is associated with viral load, not vaccine or symptomatic status. Emerg Microbes Infect. 2021;10:2276–8. https://doi.org/10.1080/22221751.2021.2008776

30. Rostami A, Sepidarkish M, Leeflang MMG, Riahi SM, Nourollahpour Shiadeh M, Esfandyari S, et al. SARS-CoV-2 seroprevalence worldwide: a systematic review and meta-analysis. Clin Microbiol Infect. 2021;27:331–40. https://doi.org/10.1016/j.cmi.2020.10.020

31. Xu X, Sun J, Nie S, Li H, Kong Y, Liang M, et al. Seroprevalence of immunoglobulin M and G antibodies against SARS-CoV-2 in China. Nat Med. 2020;26:1193–5. https://doi.org/10.1038/s41591-020-0949-6

32. Pollán M, Pérez-Gómez B, Pastor-Barriuso R, Oteo J, Hernán MA, Pérez-Olmeda M, et al. Prevalence of SARS-CoV-2 in Spain (ENE-COVID): a nationwide, population-based seroepidemiological study. Lancet. 2020;396:535–44. https://doi.org/10.1016/S0140-6736(20)31483-5

33. Stringhini S, Wisniak A, Piumatti G, Azman AS, Lauer SA, Baysson H, et al. Seroprevalence of anti-SARS-CoV-2 IgG antibodies in Geneva, Switzerland (SEROCoV-POP): a population-based study. Lancet. 2020;396:313–9. https://doi.org/10.1016/S0140-6736(20)31304-0

34. Chau NVV, Nhan LNT, Nguyet LA, Tu NTK, Hong NTT, Man DNH, et al. Absence of SARS-CoV-2 antibodies in pre-pandemic plasma from children and adults in Vietnam. Int J Infect Dis. 2021;111:127–9. https://doi.org/10.1016/j.ijid.2021.07.072

35. Hallal PC, Hartwig FP, Horta BL, Silveira MF, Struchiner CJ, Vidaletti LP, et al. SARS-CoV-2 antibody prevalence in Brazil: results from two successive nationwide serological household surveys. Lancet Glob Health. 2020;8:e1390–8. https://doi.org/10.1016/S2214-109X(20)30387-9

36. Gallian P, Pastorino B, Morel P, Chiaroni J, Ninove L, de Lamballerie X. Lower prevalence of antibodies neutralizing SARS-CoV-2 in group O French blood donors. Antiviral Res. 2020;181:104880. https://doi.org/10.1016/j.antiviral.2020.104880

37. Fischer B, Knabbe C, Vollmer T. SARS-CoV-2 IgG seroprevalence in blood donors located in three different federal states, Germany, March to June 2020. Euro Surveill. 2020;25. https://doi.org/10.2807/1560-7917.ES.2020.25.28.2001285

38. Percivalle E, Cambiè G, Cassaniti I, Nepita EV, Maserati R, Ferrari A, et al. Prevalence of SARS-CoV-2 specific neutralising antibodies in blood donors from the Lodi Red Zone in Lombardy, Italy, as at 06 April 2020. Euro Surveill. 2020;25:2001031. https://doi.org/10.2807/1560-7917.ES.2020.25.24.2001031

39. Ward H, Atchison C, Whitaker M, Ainslie KEC, Elliott J, Okell L, et al. SARS-CoV-2 antibody prevalence in England following the first peak of the pandemic. Nat Commun. 2021;12:905. https://doi.org/10.1038/s41467-021-21237-w

40. Havers FP, Reed C, Lim T, Montgomery JM, Klena JD, Hall AJ, 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(12):1576. https://doi.org/10.1001/jamainternmed.2020.4130

41. Shakiba M, Nazemipour M, Salari A, Mehrabian F, Nazari SSH, Rezvani SM, et al. Seroprevalence of SARS-CoV-2 in Guilan Province, Iran, April 2020. Emerg Infect Dis. 2021;27:636–8. https://doi.org/10.3201/eid2702.201960

42. Denning DW, Kilcoyne A, Ucer C. Non-infectious status indicated by detectable IgG antibody to SARS-CoV-2. Br Dent J. 2020;229:521–4. https://doi.org/10.1038/s41415-020-2228-9

SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.