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High Prevalence of Anti–Severe Acute Respiratory Syndrome Coronavirus 2 (Anti–SARS-CoV-2) Antibodies After the First Wave of Coronavirus Disease 2019 (COVID-19) in Kinshasa, Democratic Republic of the Congo: Results of a Cross-sectional Household-Based Survey

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(See the Editorial Commentary by Colebunders and Kenyon on pages 891–2.)

Background. In October 2020, after the first wave of coronavirus disease 2019 (COVID-19), only 8290 confirmed cases were reported in Kinshasa, Democratic Republic of the Congo, but the real prevalence remains unknown. To guide public health policies, we aimed to describe the prevalence of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) immunoglobulin G (IgG) antibodies in the general population in Kinshasa.

Methods. We conducted a cross-sectional, household-based serosurvey between 22 October 2020 and 8 November 2020. Participants were interviewed at home and tested for antibodies against SARS-CoV-2 spike and nucleocapsid proteins in a Luminex-based assay. A positive serology was defined as a sample that reacted with both SARS-CoV-2 proteins (100% sensitivity, 99.7% specificity). The overall weighted, age-standardized prevalence was estimated and the infection-to-case ratio was calculated to determine the proportion of undiagnosed SARS-CoV-2 infections.

Results. A total of 1233 participants from 292 households were included (mean age, 32.4 years; 764 [61.2%] women). The overall weighted, age-standardized SARS-CoV-2 seroprevalence was 16.6% (95% CI: 14.0–19.5%). The estimated infection-to-case ratio was 292:1. Prevalence was higher among participants ≥40 years than among those <18 years (21.2% vs 14.9%, respectively; $P < .05$). It was also higher in participants who reported hospitalization than among those who did not (29.8% vs 16.0%, respectively; $P < .05$). However, differences were not significant in the multivariate model ($P = .1$).

Conclusions. The prevalence of SARS-CoV-2 is much higher than the number of COVID-19 cases reported. These results justify the organization of a sequential series of serosurveys by public health authorities to adapt response measures to the dynamics of the pandemic.

Keywords. SARS-CoV-2; serological survey; general population; DRC; Africa.

Coronavirus disease 2019 (COVID-19) is a highly contagious viral infection caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). The infection was first identified in December 2019 in China, but has spread extremely fast worldwide, including in Africa [1]. In the Democratic Republic of the Congo (DRC), the first confirmed COVID-19 case was reported on 10 March 2020, in the capital city of Kinshasa, in a Congolese traveler who lived in Europe and had returned to the DRC. After the first cases, the Congolese government rapidly declared a state of emergency and set up a national multisectoral national committee to design strategies to address the pandemic [1]. Among the public health measures taken to control the spread of the virus, the national lockdown was first

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imposed in Kinshasa and then across the entire country, flights from COVID-19–infected countries were suspended, schools and universities were closed, gatherings of more than 20 people were banned, and there was an obligation to wear masks in public areas [2].

On 19 October 2020, after the first epidemic wave (March to July), the DRC reported 11 078 confirmed COVID-19 cases, with 303 deaths. The capital city of Kinshasa represented 74% (8290) of all notified cases across the country [3]. COVID-19 reported cases in the DRC were much lower than predicted by many researchers, For example, Walker et al [4] suggested that 70 million Africans could be infected by SARS-CoV-2, with more than 3 million deaths. Furthermore, Wells et al [5] estimated that there would be 76 213 155 infections and 319 441 deaths in the absence of physical distancing and any public health measures in the DRC.

Several factors may explain this glaring difference between the prediction and the number of COVID-19 reported cases. First, there was limited capacity to test for SARS-CoV-2, especially in the early stage of the epidemic, but gradually the daily capacity of SARS-CoV-2 polymerase chain reaction (PCR) testing in Kinshasa increased and reached 1000, which is still insufficient. However, there was no saturation of hospital reception capacities or unexplained high mortality during the same period, even if mortality may have been underestimated. Some of the potential factors that could explain this difference are the age pyramid, with a younger population potentially resulting in a greater number of asymptomatic cases; pre-existing immunity due to possible cross-reaction with other tropical infectious diseases or other coronaviruses; environmental factors; and early implementation of measures to control the disease [6, 7].

In the African context, and following the recommendations of the World Health Organization [8], population-based sero-surveillance is important to complete data on the reported cases of SARS-CoV-2 infection in order to assess the real extent of the epidemic and to enable decision makers to adjust public health response measures. Several serological surveys have been carried out in Africa and have shown a high variability of seroprevalence of SARS-CoV-2 across countries, but most were performed in specific population groups, such as blood donors, healthcare workers, or other high-risk populations [9–11]. Apart from epidemiological factors, the difference in reported seroprevalence might be explained by the different types of serological assays used, especially those that are designed to detect a single immunoglobulin G (IgG) antibody, and to their target populations. We recently reported on the challenges of SARS-CoV-2 seroprevalence studies conducted in African countries with commercial tests validated in Europe, the United States, or Asia [12].

We aimed to describe the prevalence of IgG antibodies to SARS-CoV-2 in the general population of Kinshasa in order to understand to what extent the virus has spread after the first epidemic wave.

METHODS

Study Design and Participants

The 2020 Appui à la Riposte Africaine à l'Epidémie COVID-19 (Support for the African Response to COVID-19 [ARIACOV]) survey was a household-based seroprevalence survey conducted between 22 October 2020 and 8 November 2020 in Kinshasa. The sampling frame used the health divisions of the city. Kinshasa is divided into 35 health zones, which are divided, in turn, into 380 health areas, with an estimated total population of 12 117 417 inhabitants (Système National d'Information Sanitaire [National Health Information System]). A health zone is defined as an operational unit, which supports 100 000 to 150 000 inhabitants and is delimited taking into account the geographical, cultural, and economic accessibility of the population. It could be a geographical space contained within the limits of a territory or an administrative commune comprising a population of approximately 100 000 to 250 000 people in urban areas. Kinshasa is divided in 35 health zones for 26 administrative communes based on the number of population within each administrative commune (unit). A 3-stage design was used to randomly select 292 households (Supplementary Figure 1). First, 14 of 35 health zones (divided into 2 strata corresponding to the eastern and western regions of the city) were selected with a probability to be selected proportional to the number of households in each zone. Then, within each zone, 3 health areas were randomly selected and finally 8 households were selected within each health zone. To balance the groups, all the residents were invited to participate in the study in 50% of households and, among the remaining 50%, only the residents aged 18 years and older were invited to participate.

During the study, all individuals with a suspicion of COVID-19 infection were referred for polymerase chain reaction (PCR) testing and patient care to the COVID-19 reference center. All staff involved in the study were tested by PCR prior to the survey and followed infection, prevention, and control recommendations. Community-based mobilization for the survey was performed in a 2-step process. The study team met with local leaders and key stakeholders a few weeks prior to the start of the survey and also visited each selected cluster to directly mobilize the community about the survey. Participants were told that the survey was about COVID-19/SARS-CoV-2 and that they would be tested for antibodies if they agreed to participate.

A smartphone application (Epicollect 5; Imperial College, London, UK) was used for listing household members and recording answers from the questionnaires. The individual questionnaires collected socioeconomic (eg, common yard vs single-family home, presence of hand-washing device) and behavioral information (eg, absence from Kinshasa), as well as a history of symptoms associated with COVID-19, history of hospitalization, previous history of SARS-CoV-2 tests (recall period starting March 2020), and contact with patients with

COVID-19. Interviews were done in French (official language of the DRC) or in any of the 4 national languages (Kikongo, Lingala, Swahili, or Tshiluba).

Ethics approval was obtained from the Comité d'Ethique de l'Ecole de Santé Publique de Kinshasa (protocol no. ESP/CE/156/2020). All adults and children (≥10 years) were informed about the study objectives and procedures. Adults provided written consent to participate in the study and to be tested for SARS-CoV-2 serology prior to starting the interview. Written parental consent and children assent when aged 10 years or older were obtained prior to enrollment of participants younger than 18 years.

Detection of Antibodies to SARS-CoV-2/COVID-19

Venous blood samples (3–5 mL) were collected from eligible participants in a "red-top tube," which did not contain any additives and transported to the National Institute of Biomedical Research. After centrifugation, serum samples were aliquoted and stored at −20°C until laboratory analysis. Presence of antibodies to SARS-CoV-2 was determined with a previously developed, highly sensitive and specific Luminex-based assay (Luminex Corp, Austin, TX, USA) to simultaneously detect IgG antibodies to 2 viral antigens—that is, recombinant nucleocapsid (NC) and spike (SP) proteins derived from SARS-CoV-2, as previously described [13]. Results were expressed as median fluorescence intensity for 100 beads. Cutoff values were determined with receiver operating characteristic curve analysis from a panel of SARS-CoV-2–negative and –positive plasma samples consisting of European donors before the COVID-19 pandemic and hospitalized PCR-confirmed patients, respectively [13]. Specificity was validated on a panel of 1197 samples from Africa before COVID-19 (99.7% specificity) (Supplementary Table 1). A sample was considered positive for IgG against SARS-CoV-2 if it reacted simultaneously with NC and SP proteins. As several studies have reported a decrease in antibody levels over time, we considered samples with only 1 of 2 antigens above the threshold as "indeterminate" due to the difficulty to discriminate between antibody decline or the lower specificity of single-antigen reaction, as often reported in samples from Africa [12, 14]. Samples with a median immunofluorescence intensity below the cutoff for both antigens were considered negative.

Statistical Analysis

Statistical analysis was performed using Stata 16 (StataCorp, College Station, TX, USA). Data were checked and analyzed using the svyset commands to take into account the survey design. Descriptive statistics were weighted to take into account the selection probability of the cluster sampling procedure and are presented as proportions with their 95% confidence intervals (CIs) or means with standard deviation. The Pearson's chi-square test was used to compare categorical descriptive outcomes. The overall prevalence estimate was weighted and age-standardized based on available demographic data [15]. Multivariate logistic models were used to assess the association between positive serology and key risk factors. Likelihood ratio tests were performed to determine the significance of each factor in the model. To estimate the total number of SARS-CoV-2 infections in the population, we multiplied the weighted, age-standardized seroprevalence by the population of Kinshasa at the time of the survey and divided this number by the number of reported COVID-19 cases detected by reverse transcription–PCR on 19 October 2020 to estimate the infection-to-case ratio.

RESULTS

Among 292 randomly selected households from 42 clusters, 2400 individuals were eligible; 1607 were present at the time of the survey and 1233 (76.7%) were included in the final analysis (Figure 1, Table 1). Of these, 1080 provided sufficient and compliant samples that were tested for anti–SARS-CoV-2 IgG antibodies against SP and NC proteins. The mean age of participants was 32.4 ± 19.5 years: 461(37.4%) were in the 18–39-year age group, 420 (34.1%) in the 40 and older age group, and 352 (28.6%) in the 0–17-year age group; 764 (61.2%) were women. Most participants (72.2%) resided in a common yard and 668 (54.2%) did not have access to handwashing devices at home. In total, 750 (60.8%) declared having completed secondary studies and 349 (28.3%) were pupils or students. Overall, 659 (53.5%) participants were from the eastern part of the city of Kinshasa.

The overall weighted, age-standardized SARS-CoV-2 seroprevalence was 16.6% (95% CI: 14.0–19.5%) with both anti-IgG against SP and NC proteins. In addition, 17.1% (Table 2) of participants were considered as "indeterminate," as they were positive for SP (n = 43; 23.2%) or NC (n = 142; 76.8%) antibodies only. Based on the observed prevalence, we estimated that a total of 2 426 406 (Supplementary Table 2, Supplementary Figure 1) infections most likely occurred by 19 October 2020 in the general population of Kinshasa for 8290 official reported cases. The ratio of reported cases to estimated infections was 1:292. Seroprevalence was highest among participants 40 years and older (21.2%; 95% CI: 16.6–26.7%), and lowest among children aged between 0 and 17 years (14.9%; 95% CI: 10.4–20.8%). The observed difference was statistically significant ($P < .05$) between age categories, but was not significant between female and male participants (17.7% [95% CI: 13.9–20.9%] vs 15.7% [95% CI: 11.8–20.7%], respectively) (Table 2).

Seroprevalence was higher among participants from the western region of Kinshasa (18.5%; 95% CI: 14.6–23.2) than among those from the eastern area (14.9%; 95% CI: 11.8–18.8%), but the difference was not significant. Among participants who

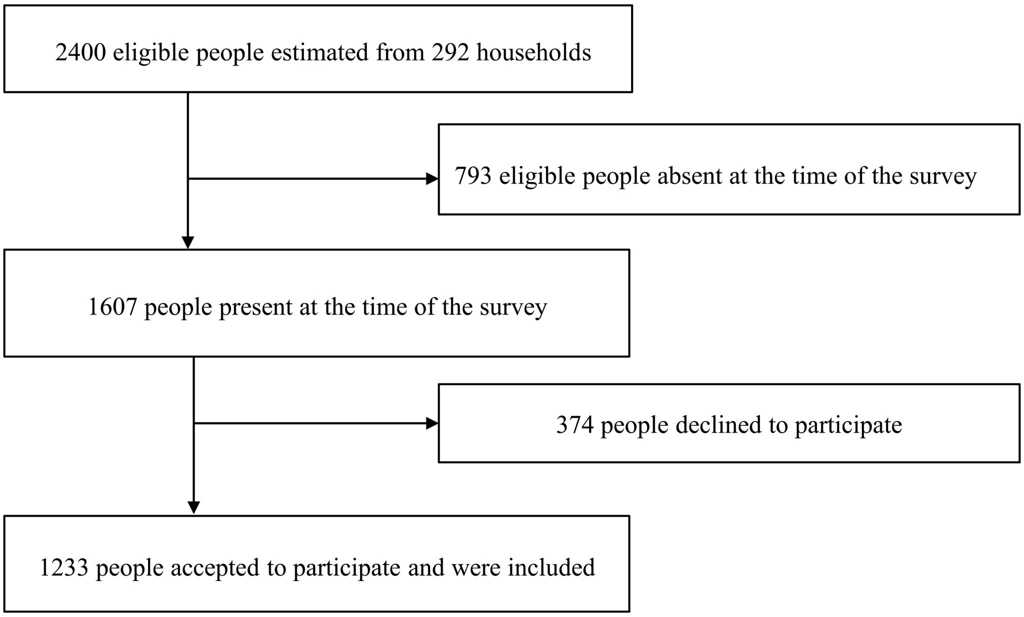

Figure 1. Flowchart of participant inclusion during the SARS-CoV-2 household-based serosurvey. Abbreviation: SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

reported the type of residence, there was no significant difference between residents with a common yard (18.0%; 95% CI: 14.9–21.6%) and those who resided in a single-family home (13.1%; 95% CI: 9.1–18.5%). We investigated the influence of being absent at home on SARS-CoV-2 seroprevalence and observed no significant difference with those still present since March 2020 (13.3% [95% CI: 6.8–4.6%] vs 16.9% [95% CI: 14.2–20.0%], respectively).

Of the 1080 participants with blood samples, 741 (68.6%) reported having at least 1 of the 16 symptoms reported to be associated with COVID-19 infection. Among participants who reported no symptoms in the past 8 months, 18.8% (95% CI: 13.3–23.8%) were positive for SARS-CoV-2 IgG SP and NC proteins, but no significant differences were observed among those who reported symptoms. We did not observe associations with a single or a combination of clinical symptoms and seropositivity. We also assessed whether hospitalization could be associated with seroprevalence and observed that the proportion of people who admitted to have been hospitalized before the survey and positive for anti–SARS-CoV-2 antibodies (29.8%; 95% CI: 17.0–46.8%) was significantly higher compared with those who were not hospitalized (16.0%; 95% CI: 13.4–19.0%) (Table 3). None of the households reported deaths with symptoms related to COVID-19.

We then performed multivariate analysis for all parameters with a significant difference of seroprevalence between groups, but no significant association between age, gender, and hospitalization with seroprevalence was found (Table 4).

DISCUSSION

To our knowledge, this is the first serological survey conducted in the general population of Kinshasa after the first wave of the COVID-19 pandemic (March to September 2020). The overall prevalence of anti–SARS-CoV-2 antibodies was 16.6%. Extrapolation to the entire population showed that approximately 2.4 million infections occurred between March and October 2020 in contrast to the 8290 PCR-confirmed cases reported during the same period. We estimated that most cases went unnoticed, with only 1 case detected for every 292 infections.

Seroprevalence in the DRC was higher than that reported in India, Brazil, Switzerland, and Zambia [16–19], but was probably linked to the different age structure or to the early stage of the COVID-19 pandemic, as was the case in Zambia [19]. Several other countries in Africa have reported varying seroprevalences (eg, the prevalence was lower in Kenya, Togo, and Malawi [9, 10, 20], but higher in Niger, the Ivory Coast, and South Sudan [21–23]). This variability could be explained, first, by the fact that most of these studies were carried out in specific populations and, second, apart from the Malawi study, all the other studies reported a seroprevalence using positivity against a single antigen (SP or NC).

Although we observed a trend among age groups, seroprevalence was not significantly associated with age groups in our survey. Indeed, several studies have reported a different distribution of seroprevalence according to age, whereas others did not observe age-related differences—for example, in India, Brazil, and Zambia, seroprevalence was similar between age groups [16, 17, 19]. However, a study conducted in

Table 1. Sociodemographic Characteristics of Participants

	Females	Males	Total
Age, n (%)			
0–17 years	188 (24.9)	164 (34.2)	352 (28.6)
18–39 years	301 (39.9)	160 (33.4)	461 (37.4)
≥40 years	265 (35.2)	155 (33.4)	420 (34.1)
Age, mean ± standard deviation, years	33.4 ± 18.9	30.8 ± 20.2	32.4 ± 19.5
Handwashing device, n (%)			
Present	231 (48.2)	334 (44.3)	565 (45.8)
Absent	248 (51.8)	420 (55.7)	668 (54.2)
Type of residence, n (%)			
Common courtyard	327 (68.3)	563 (74.7)	890 (72.2)
Building	2 (0.4)	1 (0.1)	3 (0.2)
Single-family home	145 (30.3)	184 (24.4)	329 (26.7)
Other	5 (1.0)	6 (0.8)	110 (0.9)
Geographical area, n (%)			
East	410 (54.4)	249 (52.0)	659 (53.5)
West	344 (45.6)	230 (48.0)	574 (46.7)
Number of years residing in Kinshasa, n (%)			
0–4	11 (2.3)	18 (2.4)	29 (2.4)
5–9	6 (1.3)	11 (1.5)	17 (1.4)
10–29	21 (4.4)	22 (2.9)	43 (3.5)
30–69	19 (4.0)	30 (4.0)	49 (4.0)
Always	417 (87.1)	665 (88.2)	1082 (87.8)
Never	5 (1.0)	8 (1.1)	13 (1.1)
Absence from home for >1 month since March 2020, n (%)			
Yes	51 (10.7)	53 (7.0)	104 (8.4)
No	428 (89.4)	701 (93.0)	1129 (91.6)
Number of times absent at night since March 2020, n (%)			
0	397 (82.9)	638 (84.6)	1035 (83.9)
1–4	49 (10.2)	80 (10.6)	129 (10.4)
5–9	10 (2.1)	14 (1.9)	24 (2.0)
≥10	23 (4.8)	22 (2.9)	45 (3.7)
Marital status (participants >15 years), n (%)			
Single	184 (53.6)	273 (44.0)	457(47.4)
Married/living as a couple	139 (40.5)	239 (38.5)	378 (39.2)
Divorced/separated	11 (3.6)	30 (13.6)	41 (4.2)
Widower/widow	9 (2.6)	79 (12.7)	88 (9.1)
Education, n (%)			
None	42 (5.6)	19 (4.0)	61 (4.95)
Primary school	127 (16.8)	98 (20.5)	22 (18.3)
Secondary school	496 (65.8)	254 (53.0)	750 (60.8)
University	89 (11.8)	208 (22.6)	197 (16.0)
Profession, n (%)			
Sales/service	193 (25.6)	52 (10.8)	245 (19.9)
Professional/manager	79 (10.5)	41 (8.6)	120 (9.7)
Pupil/student	189 (25.1)	160 (33.4)	349 (28.3)
Woman/man at home	86 (11.4)	1 (0.2)	87 (7.1)
Construction	1 (0.1)	18 (3.8)	19 (1.5)
Unemployed	126 (16.7)	73 (15.2)	199 (16.1)
Other	80 (10.6)	80 (10.6)	214 (17.4)
Overall, n (%)	754 (61.2)	479 (38.9)	1233

Iran reported that the prevalence of COVID-19/SARS-CoV-2 varied by age group [24]. In Switzerland, seroprevalence was significantly lower among young children (5–9 years) and older people (≥65 years) than for other age groups [18]. Only limited data on the kinetics of antibodies in children are available and most tests were validated on samples of adults with symptoms. However, antibody titers and kinetics in children exposed to SARS-CoV-2 are most likely similar to those in adults [25].

On the basis of our pilot study that showed a low agreement between the results of commercially available antibody-detection

Table 2. Prevalence of SARS-COV-2 by Sociodemographic Characteristics: Kinshasa, Democratic Republic of the Congo, 2020

		Participants					
		Seropositive[a]		Indeterminate[b]		Seronegative	
	Participants Tested, n	n (%)	95% CI (%)	n (%)	95% CI (%)	n (%)	95% CI (%)
Age							
0–17 years	281	39 (14.9)[c]	10.4–20.8	31 (10.8)[c]	7.2–15.9	211 (75.1)[c]	67.7–80.1
18–39 years	428	53 (13.7)[c]	10.1–18.3	82 (18.5)[c]	15.5–23.2	293 (68.5)[c]	62.3–73.0
≥40 years	371	75 (21.2)[c]	16.6–26.7	72 (19.9)[c]	15.4–25.4	224 (60.4)[c]	52.7–64.8
Geographic area							
East	617	79 (14.9)	11.8–18.8	116 (19.5)	16.0–23.6	422 (68.4)	61.0–70.0
West	463	88 (18.5)	14.6–23.2	69 (14.4)	11.0–18.8	306 (66.1)	61.7–72.1
Gender							
Male	417	59 (15.7)	11.8–20.7	72 (17.0)	13.1–21.9	286 (68.6)	61.4–72.6
Female	663	108 (17.7)	13.9–20.9	113 (17.2)	14.0–20.9	442 (66.7)	61.2–69.9
Handwashing device							
Yes	486	86 (18.2)	14.4–22.7	94 (19.1)	15.2–23.6	306 (63.0)	57.4–67.8
No	594	81 (15.3)	12.0–19.3	91 (15.4)	12.2–19.3	422 (71.0)	64.6–73.6
Type of residence							
Common yard	777	131 (18.0)	14.9–21.6	136 (17.3)	14.3–207	510 (65.6)	60.6–68.7
Single-family home	300	36 (13.1)	9.1–18.5	49 (16.9)	12.4–22.6	215 (71.7)	63.5–75.9
Number of years residing in Kinshasa							
0–4	24	3 (18.6)	5.2–48.8	6 (23.0)	8.6–48.9	15 (62.5)	33.0–79.9
5–9	16	0 (0.0)	…	3 (12.5)	3.0–39.5	13 (81.3)	60.5–97.0
10–29	39	7 (18.2)	7.5–37.9	5 (16.7)	5.6–40.4	27 (69.2)	44.0–81.6
30–69	43	12 (30.7)	16.9–49.0	7 (16.4)	6.9–34.5	24 (55.8)	35.4–69.7
Always	945	144 (16.2)	13.5–19.3	160 (16.9)	14.2–19.9	641 (67.8)	35.4–69.7
Never	13	1 (6.2)	0.7–39.3	4 (38.8)	12.4–72.3	8 (61.5)	23.9–82.5
Absence from home for >1 month since March 2020							
Yes	89	10 (13.3)	6.8–24.6	26 (30.4)[d]	20.2–42.9	53 (59.6)	43.8–68.1
No	991	157 (16.9)	14.2–20.0	159 (15.9)[d]	13.4–18.9	675 (68.1)	63.6–70.6
Number of times absent at night since March 2020							
0	917	133 (15.8)	13.1–19.0	148 (16.0)	13.3–19.1	636 (69.4)	64.5–71.8
1–4	109	22 (20.2)	12.8–30.3	27 (24.2)	16.1–34.7	60 (55.0)	44.6–66.1
5–9	21	4 (20.5)	6.6–48.6	5 (25.6)	9.3–53.7	12 (57.1)	29.3–76.8
≥10	33	8 (23.3)	10.6–43.9	5 (17.3)	6.6–38.2	20 (60.6)	45.3–65.6
Marital status (age ≥15 years)							
Single	448	59 (14.6)	11.5–18.4	76 (16.2)	12.5–20.7	313 (69.9)	63.9–74.2
Married/living as a couple	341	61 (19.5)	14.8–25.3	66 (20.2)	15.3–25.7	214 (62.8)	53.9–66.6
Divorced/separated	37	5 (11.5)	3.9–29.6	11 (31.0)	6.7–26.2	19 (51.4)	35.4–76.5
Widower/widow	75	17 (21.8)	12.9–34.5	10 (13.8)	14.8–53.8	48 (64.0)	50.8–76.0
Education (n)							
None	37	8 (25.3)	12.2–45.2	3 (5.9)	1.1–26.6	26 (68.7)	48.8–83.5
Primary school	184	29 (17.4)	11.6–25.3	25 (14.2)	9.1–21.4	130 (68.4)	59.7–76.0
Secondary school	683	103 (16.1)	13.0–19.8	122 (17.9)	14.6–21.6	458 (66.0)	61.6–70.2
University	176	27 (15.8)	10.3–23.5	35 (19.4)	13.3–27.4	114 (64.8)	55.9–72.8
Profession (n)							
Sales/service	220	46 (20.9)	15.2–28.0	58 (26.4)	21.1–35.3	116 (52.7)	43.6–59.2
Professional/manager	111	16 (14.4)	9.2–27.0	19 (17.1)	9.2–27.2	68.5 (68.5)	55.4–77.6
Pupil/student	296	40 (13.5)	10.2–20.3	35 (11.8)	8.0–16.6	221 (74.7)	67.4–79.5
Woman/man at home	81	11 (13.6)	7.7–28.8	11 (13.6)	5.2–20.6	59 (72.8)	60.4–83.9
Construction	19	2 (10.5)	1.7–45.1	3 (15.8)	2.4–33.0	59 (72.8)	50.2–93.7
Unemployed	171	24 (14.0)	10.2–23.9	24 (14.0)	7.7–19.1	123 (71.9)	63.0–79.1
Other	182	28 (15.4)	10.6–23.8	35 (19.2)	14.4–29.1	119 (65.4)	54.1–71.2
Overall	1080	167 (16.6)	14.0–19.5	185 (17.13)	…	728 (67.41)	…

Abbreviations: CI, confidence interval; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

[a]Presence of antibodies to nucleocapsid and spike proteins.

[b]Presence of antibodies to only nucleocapsid or spike protein.

[c]Significant difference at 5%.

[d]Significant difference at 1%.

Table 3. Weighted Proportion of Prevalence of SARS-CoV-2 Stratified by Medical History: Kinshasa, Democratic Republic of the Congo, 2020

		Participants					
		Seropositive[a]		Indeterminate[b]		Seronegative	
	Participants Tested, n	n (%)	95% CI (%)	n (%)	95% CI (%)	n (%)	95% CI (%)
Number of symptoms							
None	324	54 (18.0)	13.3–23.8	48 (15.5)	11.2–21.1	222 (66.5)	59.8–72.6
1 to 2 symptoms	266	42 (16.7)	11.9–22.8	57 (21.2)	15.9–27.7	167 (62.1)	54.9–68.8
3 to 5 symptoms	236	38 (17.5)	12.3–24.2	43 (17.7)	12.6–24.2	155 (64.8)	57.2–71.7
≥5 symptoms	239	30 (13.8)	9.2–20.2	35 (14.1)	9.6–20.2	174 (72.1)	64.7–78.4
Symptoms							
Fever							
No	692	113 (17.6)	14.3–21.3	123 (18.1)	14.9–21.9	456 (64.3)	59.9–68.5
Yes	388	54 (14.8)	11.0–19.8	62 (15.3)	11.5–20.1	272 (69.9)	64.1–75.1
Chills							
No	829	142 (18.3)	15.3–21.8	147 (17.7)	14.7–21.0	540 (64.0)	60.0–67.9
Yes	244	24 (11.2)	7.1–17.1	37 (15.3)	10.6–21.7	183 (73.5)	66.2–79.7
Fatigue/asthenia							
No	844	132 (16.6)	13.8–20.0	152 (17.7)	14.9–21.0	560 (65.6)	61.7–69.4
Yes	232	34 (16.4)	11.3–23.3	32 (14.7)	9.9–21.3	166 (69.9)	61.1–75.7
Muscle pain (myalgia)							
No	832	118 (14.6)	11.9–17.8	148 (17.9)	15.0–21.3	566 (67.5)	63.6–71.2
Yes	240	48 (23.7)	17.6–31.1	36 (14.7)	10.1–20.9	156 (61.7)	53.9–68.9
Sore throat							
No	941	148 (17.0)	14.2–20.2	158 (16.7)	14.0–19.8	635 (66.3)	62.5–69.8
Yes	139	19 (14.0)	8.4–22.4	27 (19.7)	13.0–28.8	93 (66.3)	56.3–75.0
Cough							
No	791	128 (17.2)	14.2–20.7	133 (17.0)	14.1–20.5	530 (65.7)	61.6–69.6
Yes	289	39 (14.8)	10.4–20.7	52 (17.7)	12.7–23.2	198 (67.8)	61.0–74.0
Runny nose (rhinorrhea)							
No	770	122 (16.7)	13.7–20.2	138 (18.2)	15.2–21.8	510 (65.1)	60.9–69.0
Yes	310	45 (16.3)	11.8–22.1	47 (14.3)	10.3–19.5	218 (69.4)	62.9–75.3
Breathing difficulties							
No	1037	163 (16.9)	14.3–19.9	176 (16.9)	14.3–19.9	698 (66.2)	62.6–69.5
Yes	43	4 (8.2)	2.6–23.4	9 (22.5)	10.8–40.9	30 (69.3)	51.0–83.0
Loss of taste and smell (ageusia/anosmia)							
No	929	144 (16.7)	13.9–19.9	162 (14.5)	14.7–20.6	623 (65.9)	62.1–69.5
Yes	141	23 (16.1)	10.2–24.5	23 (15.3)	9.7–23.3	105 (68.6)	59.2–76.7
Chest pain							
No	849	160 (16.8)	14.2–19.9	171 (16.8)	14.2–19.8	678 (66.4)	62.7–69.8
Yes	160	7 (13.3)	6.0–27.2	14 (21.4)	12.1–25.0	50 (65.3)	50.9–77.3
Other respiratory symptoms							
No	1066	12 (16.6)	14.0–19.5	182 (17.1)	14.5–20.0	719 (66.3)	62.8–69.6
Yes	14	2 (15.4)	3.3–49.0	3 (21.4)	5.9–54.3	9 (63.2)	32.5–86.0
Anorexia							
No	917	146 (16.8)	14.1–20.0	162 (17.8)	15.0–21.0	609 (65.4)	61.6–69.0
Yes	163	21 (15.4)	9.6–23.7	23 (13.3)	8.3–20.7	119 (71.3)	62.2–79.0
Headache							
No	690	108 (17.2)	13.9–21.0	121 (17.5)	14.3–21.2	461 (65.3)	60.9–69.5
Yes	390	59 (15.6)	11.7–20.4	64 (16.4)	12.5–21.3	267 (68.0)	62.2–73.3
Nausea/vomiting							
No	959	156 (17.4)	14.7–20.6	159 (16.6)	14.0–19.7	644 (66.0)	62.3–69.5
Yes	121	11 (9.7)	4.9–18.3	26 (21.5)	14.0–31.6	84 (68.8)	58.1–77.9
Abdominal pain							
No	862	193 (17.6)	14.7–21.0	146 (17.1)	14.2–20.3	574 (65.3)	61.4–69.1
Yes	218	25 (12.3)	7.8–18.8	39 (17.5)	12.2–24.3	154 (70.3)	62.4–77.0
Diarrhea							
No	956	103 (16.5)	13.8–19.6	161 (16.9)	14.2–19.9	649 (66.7)	63.0–70.2
Yes	124	21 (17.6)	10.9–27.1	24 (19.1)	12.2–28.7	79 (63.3)	52.8–72.7
Hospitalization							
No	1024	153 (16.0)[c]	13.4–19.0	177 (17.3)	14.7–20.3	694 (66.7)	38.6–70.0
Yes	52	14 (29.8)[c]	17.0–46.8	8 (15.5)	7.0–30.7	30 (54.8)	63.1–70.1

Abbreviations: CI, confidence interval; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

[a]Presence of antibodies to nucleocapsid and spike proteins.

[b]Presence of antibodies to only nucleocapsid or spike protein.

[c]Significant difference at 5%.

Table 4. Association Between Antibodies to SARS-CoV-2 and Risk Factors: Multivariate Logistic Model, Kinshasa, Democratic Republic of the Congo, 2020

Variable	Seropositive[a] Participants, n (%)	Univariate Odds Ratio (95% CI)	Multivariate Odds Ratio (95% CI)
Gender			
Male	59 (14.1)	1	1
Female	108 (16.2)	1.11 (.73–1.68)	1.12 (.73–1.7)
Age			
0–17 years	39(13.9)	1	1
18–39 years	53 (12.4)	.91 (.53–1.55)	.89 (.52–2.52)
≥40 years	75 (20.2)	1.54 (.92–2.57)	1.51 (.91–2.52)
Hospitalization			
Yes	14 (26.9)	1	1
No	153 (14.9)	0.59 (0.30–1.16)	0.60 (0.31–1.17)

Abbreviations: CI, confidence interval; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.
[a]Presence of antibodies to nucleocapsid and spike proteins.

assays validated in Europe, the United States, or Asia on African samples, we recommend the use of a combination of serological tests, targeting 2 or more independent antigens in this context [12]. This is even more important with the advent of mass vaccination. Therefore, assuming that seropositivity against SP and NC proteins is evidence of true seroconversion, we estimated the seroprevalence of antibodies against SARS-CoV-2 at 16.6%. During the first wave (March to September), the majority of notified PCR-confirmed cases came from the western health zone of Kinshasa, but our study showed that seroprevalence was almost similar between the 2 geographic regions studied, thus suggesting that COVID-19 had spread throughout the entire city despite early government actions. Nevertheless, this high seroprevalence was not accompanied by higher mortality rates or saturation of hospital services. The SARS-CoV-2 virus is known for its ability to be transmitted to all ages, but the risk of developing a severe form increases with age and other risk factors, including obesity among younger individuals [26, 27]. Indeed, the age pyramid in the DRC is made up of a large base of young people, with a small number of the elderly, and people aged 65 years and older represent only 3% of the total population [15].

In many studies, seroprevalence is determined using only 1 of the 2 major SARS-CoV-2 antigens [9–11, 16, 28]. This may lead to an overestimation due to cross-reactivity of the SP or NC antibodies against other viral antigens [29] or underestimation by antibody waning [14]. Cross-reactivity can occur with common circulating coronaviruses, as well as other viruses such as dengue [29]. In contrast to anti-SP IgG antibodies, which are sustained over time, the half-life of the SARS-CoV-2 anti-NC IgG response seems to be shorter [14]. Seroprevalence of antibodies against the SP or NC proteins only was 17.1% in our study. The overall seroprevalence in Kinshasa combining all positive and indeterminate groups could thus be higher and reach 32.6%. Seroprevalence based on positivity to 2 different SARS-CoV-2 antigens thus provides most likely minimal estimates, and it is probable that a proportion of the participants with antibodies against a single antigen also represented individuals who had a previous SARS-CoV-2 infection. Nevertheless, most of the population from Kinshasa remains not infected as yet and it is hoped that the spread of SARS-CoV-2 can be maintained until the herd immunity threshold is achieved. This estimated threshold is approximately 50% to 67%, but it could be reached faster by vaccination rather than natural immunization [30, 31].

Evidence of antibodies was found among participants who did not report having symptoms in the past 8 months. Similar findings have been reported in many countries [19, 32]. These data underline the importance of testing asymptomatic individuals before traveling by air or other means of transport connecting different regions, even if they did not report any notion of exposure to SARS-CoV-2.

Our study has several limitations. Based on the assumption that 50% of the population are aged 18 years and younger, we invited all residents from 50% of the households to participate in the study, while only people aged 18 and older were invited to participate in the remaining 50% of households. Participation was only 50% and more women were included, which may limit the generalizability of our findings. Seroprevalence in age groups should be interpreted with caution as the age adjustment was done based on the 2019 population estimation [15]. Additionally, COVID-19–related symptoms that participants had developed in the previous 8 months were reported retrospectively, resulting in a probable recall bias. We also probably missed some recent infections because we only tested the presence of IgG antibodies, as illustrated by the lower sensitivity of our assay on a panel of samples collected between 1 and 30 days after symptom onset, suggesting a possible underestimation of recent infections.

CONCLUSIONS

The results of the first household SARS-CoV-2 serosurvey in Kinshasa show a high seroprevalence and spread in both the eastern and western regions of the city, illustrating that most cases were undiagnosed. These results provide an excellent picture of the extent of the COVID-19 pandemic in Kinshasa after the peak of the first wave, as well as lessons for adjusting the countermeasures. The country is now facing the second wave, which is apparently more contagious than the first one. Our findings therefore support strengthening of the testing capacity for both symptomatic and asymptomatic individuals, strict application of nonpharmaceutical measures, and improvement in the management of severe cases. Finally, we provide evidence of the value of conducting serological surveys at regular intervals in both extended areas of Kinshasa and in other regions of the DRC to better understand the trend of the pandemic, identify the population categories at highest risk for clinical complications, and estimate the herd immunity threshold in order to use vaccines in a cost-effective manner.

Supplementary Data

Supplementary materials are available at *Clinical Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

Notes

Disclaimer. The contents of this document are the authors' opinions and do not necessarily reflect those of the Ministry of Public Health of the DRC government.

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