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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-094546
Article Type:	Original research
Date Submitted by the Author:	02-Oct-2024
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Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH, Community-Based Participatory Research

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Seroprevalence and Demographic Characteristics of SARS-CoV-2–Infected Residents of Kibera Informal Settlement, Nairobi, Kenya, during the COVID-19 Pandemic

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ABSTRACT

Introduction

Kenya recorded relatively low numbers of COVID-19 cases during the recent pandemic. The reasons remain unclear especially in informal settlements where implementing containment measures is impractical. A study was conducted in Kibera informal settlement in Nairobi, Kenya's largest slum, to determine the seroprevalence of SARS-CoV-2 and associated demographic characteristics, before vaccination became widespread.

Methods

Demographic data were collected from participants age ≥1 year who reported no current symptoms of COVID-19. Capillary blood (500 µL) was collected into Microtainer® EDTA tubes and transported to the Kenya Medical Research Institute laboratories for SARS-CoV-2 antibody testing using the Standard Q COVID-19 IgM/IgG Combo rapid test and two enzyme-linked immunosorbent assays: Wantai Total Ab (IgM/IgG/IgA) and Platelia SARS-CoV-2 Total Ab (IgM/IgG/IgA).

Results

A total of 438 participants were recruited into the study. Most (79.2%) were age 18–50 years; females (64.2%) exceeded males. More than one third (39.1%) were unemployed; only 7.4% were in formal, full-time employment. Less than one quarter (22.1%) self-reported any underlying health conditions. Nearly two-thirds (64.2%) reported symptoms compatible with COVID-19 in the previous 16 months; only one (0.23%) had been hospitalised with a reported negative COVID-19 test. 370 (84.5%) participants tested positive in any of the three tests. There was no significant difference in SARS-CoV-2 seropositivity across participants' age, sex, presence of underlying health conditions, on medication, or those ever tested for SARS-CoV-2. Multiple logistic regression analysis showed COVID-19 symptoms in the previous 16 months were the only significant independent predictor of seropositivity (p=0.0085).

Conclusion

This study reports high SARS-CoV-2 exposure in Kibera informal settlement with limited morbidity; only recent COVID-19 symptoms were a significant independent predictor of seropositivity. The study confirms other reports of high SARS-CoV-2 exposure with limited morbidity in slum communities. Small blood volumes are convenient for serosurveillance studies in large populations.

Key questions

What is already known on this topic

The COVID-19 pandemic had a limited impact on the African continent, with rates of morbidity and mortality much lower than reported elsewhere. The underlying reasons remain unclear although the high infectious disease burden and demographic age structure have been suggested. High exposure rates to SARS-CoV-2 infection in slum communities have also been reported from other resource-limited countries with less impact than expected, despite warnings of potentially major consequences.

What this study adds

To our knowledge, this is the first serosurveillance study in an informal settlement community in Africa, filling an important gap in existing research. By focusing on this specific setting, the study provides valuable insights that can help collaborate and contextualise findings from previous research conducted in different geographic and socioeconomic environments, including Africa.

How this study might affect research, practice, or policy

This study reports data that could inform future research on factors contributing to the unexpected low COVID-19 morbidity observed in informal settlement communities, despite high exposure rates and the inability to comply with social distancing measures. This study's findings also challenge the assumption that high exposure rates necessarily lead to high morbidity, suggesting the need to further investigate potential protective factors and immune responses. The insights gained from this study could influence policy decisions regarding the allocation of resources and development of targeted interventions for informal settlement communities during public health emergencies. The outcomes may also challenge the one-size-fits-all approach to COVID-19 mitigation measures and encourage policymakers to consider context-specific strategies that account for the unique characteristics and resilience of informal settlement communities. The successful use of capillary blood samples for seroprevalence studies could streamline and expand the reach of future surveillance efforts, making it easier to monitor the spread of COVID-19 and other infectious diseases in hard-to-reach populations.

INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the cause of coronavirus disease 2019 (COVID-19), was first reported in Wuhan, Hubei Province, China, in November 2019 and rapidly spread across China and the world [1]. On 30 January 2020, the World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern, and on 11 March 2020 the WHO Director General declared COVID-19 a pandemic [2]. Although the WHO declared the COVID-19 global health emergency over on 5 May 2023 [3], globally over 775 million cases and more than 7 million deaths from COVID-19 had been reported by 16 June 2024, with more than 127,000 new cases and nearly 2,000 deaths in the previous 28 days [4]. In the African region, more than 9 million confirmed cases and over 175,000 deaths had been reported cumulatively by June 2024, although the numbers of cases and deaths reported in Africa were likely an underestimate due to low testing rates [5]; an assessment by the WHO Regional Office for Africa showed only one in seven (14.2%) COVID-19 infections were being detected [6]. Studies from Kenya and other countries in Africa noted low mortality from COVID-19, despite high exposure rates [7,8].

The modes of transmission of SARS-CoV-2 have been elucidated through detailed case contact studies. Respiratory transmission, with SARS-CoV-2 carried on tiny particles emitted from the respiratory tract, has been established as the clear and dominant route of spread; indirect transmission appears to be of limited importance despite initial concerns [**Error! Reference source not found.**]. The clinical spectrum of COVID-19 varies from asymptomatic or pre-symptomatic infection, mild to moderate illness, to severe and critical illness characterised by respiratory failure and multiple organ dysfunction; varying proportions of infected persons remain asymptomatic [10,11]. Transmission from asymptomatic individuals is estimated to account for more than half of all transmissions [12]. Diagnostic testing using reverse transcriptase polymerase chain reaction (RT-PCR)-based assays performed on respiratory specimens is the reference standard for establishing a microbiological diagnosis of COVID-19 [13] but is constrained by the presence of virus to a few days before infection and a short time after infection. Seroepidemiological studies to detect host antibodies to SARS-CoV-2 are therefore important for estimating disease burden and providing a more complete picture of exposure to SARS-CoV-2 in a population [14].

COVID-19 infection in Kenya

The first confirmed case of COVID-19 was reported in Kenya on 13 March 2020 [15]. Restrictions to mitigate the spread of COVID-19 were instituted in March 2020 and were eased towards the end of 2020 until a second lockdown was instituted in five counties in March 2021; in May 2021, as the number

of cases dropped, lockdown restrictions were again lifted [16]. COVID-19 vaccination was initiated in Kenya in March 2021, with vaccination numbers rising from August 2021 with increased vaccine availability. Kenya actively promoted vaccination through the COVID-19 Vaccination Acceleration Programme [17]; as of 16 May 2023, more than 18 million vaccine doses had been administered with 30.7% of the adult population (≥18 years) fully vaccinated. Kenya planned to vaccinate all adults and teenagers in 2022 and to provide third dose booster shots to all eligible adults [18]. On 11 March 2022, Kenya lifted all COVID-19 restrictions while urging continued personal public health measures; by June 2024, 344,000 cases and 5,700 deaths had been reported since the pandemic started, rates that remained low in comparison with global figures [4].

Available seroprevalence data from Kenya targeting different population groups painted a concerning picture of the COVID-19 pandemic's progression within the country. Studies examining stored samples from blood donors across six regional blood transfusion centres, including the capital city Nairobi, revealed a dramatic rise in SARS-CoV-2 antibody prevalence over time. Seroprevalence increased from 4.3% (95% CI, 2.9–5.8%) in samples collected between April and June 2020 to 48.5% (95% CI, 45.2–52.1%) in samples taken just a year later from January to March 2021 [19,20]. These samples were tested using a non-commercial validated enzyme-linked immunosorbent assay (ELISA) for SARS-CoV-2 IgG against spike protein. The same assay was used to test stored blood from women attending antenatal care services at three hospitals in Kenya between August 2020 and October 2021: seroprevalence rose from 50% (95% CI, 42–58%) in August 2020 to 85% (95% CI, 78–92%) in October 2021 in Nairobi; 31% (95% CI, 25–37%) in May 2021 to 71% (95% CI, 64–77%) in October 2021 in Busia; and from 1% (95% CI, 0–3%) in September 2020 to 63% (95% CI, 56–69%) in October 2021 in Kilifi [21]. Purposive testing of venous blood from healthcare workers between July and December 2020 using the same ELISA showed significant variation in overall seropositivity (20.8%: 17.5%–24.4%). Seroprevalence varied significantly (p<0.001) by site: 43.8% (35.8–52.2%) in Nairobi, 12.6% (8.8–17.1%) in Busia and 11.5% (7.2–17.6%) in Kilifi; only 16 (2%) of the sampled healthcare workers reported acute respiratory symptoms at the time of sample collection [22]. Purposive testing of truck drivers and their assistants, again using the same ELISA, conducted between September and October 2020 showed an overall seropositivity of 7.4%; none reported current or previous symptoms of illness [23]. Truck drivers and their assistants continued to transport essential supplies during the COVID-19 pandemic, placing them at increased risk of being infected and of transmitting SARS-CoV-2 over a wide geographical area. In a study on samples collected from January to March 2020 from rural populations in western Kenya with and without human immunodeficiency virus (HIV) infection, 3.3% had detectable SARS-CoV-2 antibodies, with no difference between participants with and without HIV infection (3.1% vs. 4.0%, p=0.68); this study used

the Platelia SARS-CoV-2 Total Ab assay (Bio-Rad Laboratories, Hercules, California, USA). Participants denied symptoms except for one who reported a cough in the preceding week [24]. In our study, SARS-CoV-2 seroprevalence in an informal settlement in Nairobi was conducted to supplement these data and determine exposure in a community subjected to overcrowding and lack of reliable clean water, housing, health services and waste management facilities, where preventive measures were difficult to apply.

Purpose of the study

This study assessed the prevalence of SARS-CoV-2 antibodies in the residents of Kibera informal settlement in Nairobi, Kenya, one of sub-Sahara Africa's largest slums, before vaccination became widespread, and explored some of the major risk factors for infection. This study also provided an opportunity to determine pathogen exposure in large numbers of persons in a pandemic situation using small blood volumes obtained from fingerprick samples.

MATERIALS AND METHODS

Study site

Kibera informal settlement stands on a 2.5-kilometre square area of land located 5 kilometres southwest of Nairobi's Central Business District. The population is estimated at 170,070, although this may be an underestimate [25]. Residents comprise the major ethnic communities in Kenya [26] with reportedly 116 women for every 100 men [27]. Kibera is governed by area chiefs as the local administrative arm of the government.

Study design

A cross-sectional study was performed to determine SARS-CoV-2 antibody prevalence in Kibera informal settlement, Nairobi, Kenya. The study was conducted between 2 and 13 August 2021 in 10 of the 14 Kibera villages, which provided an adequate representation of the whole settlement. The Cochran sample size formula for larger populations was used to determine sample size [28]. Since the population of Kibera is above 170,000 and approximately 500 people had tested positive for SARS-CoV-2 at the time of the study, a sample size of 389 (~400) participants was determined, a target of 40 participants in each selected village (confidence level 99%; precision 0.01). In each village every fifth household was selected; if a household declined participation, the next household was included. Entry to individual households was facilitated through community health volunteers who were formally assigned to these villages. Participants age 1 year and above who had been resident in Kibera since at least October 2019 were included.

Study methods

Five data collectors, each assigned to two villages, administered a brief questionnaire to each consenting participant, or their parent or legal guardian; data were collected directly into the Open Data Kit system installed in handheld tablets. Data were collected on the following: age, sex, length of residence in Kibera, pregnancy status (for women), main occupation and nature of employment, any underlying health conditions and type of condition, any medications and name of the medication, symptoms suggestive of COVID-19 in the previous 16 months (cough, fever, difficulty in breathing, shortness of breath, new loss of taste and smell), any hospitalisation and date (if known), ever tested for SARS-CoV-2, date and result (if known), and COVID-19 vaccination(s) and date (if known). Five laboratory staff accompanying the data collectors collected 500 µL of capillary blood from each participant by fingerprick into a Microtainer® EDTA tube. Blood samples were transported to the Kenya Medical Research Institute (KEMRI) laboratories for same-day testing on whole blood using the Standard Q COVID-19 IgM/IgG Combo rapid test (SD Biosensor Inc, Suwon, Gyeonggi, Republic of Korea). At the KEMRI laboratories, blood was separated the same day and plasma samples stored at –80 °C for further testing with two enzyme-linked immunosorbent assays (ELISAs): Wantai Total Ab (IgM/IgG/IgA) ELISA for SARS-CoV-2 (Wantai Biological Pharmacy Enterprise Co. Ltd, Beijing, China), and Platelia SARS-CoV-2 Total Ab (IgM/IgG/IgA) Assay (Bio-Rad Laboratories Inc, California, USA). The SARS-CoV-2 antibody tests selected in this survey were commercial tests approved for use in Kenya at the time of the study. Test performance is described in a separate paper [**Error! Reference source not found.**]. Individuals with positive test results in any of the three tests were considered positive (for the ELISAs, optical density ≥1.0) and indeterminate ELISA results as negative (optical density 0.9–0.99). PCR or antigen testing was not performed in any of the study participants. Each participant was assigned a unique identification number; data files and blood sample labelling did not include participant names to ensure anonymity. Individuals who met the case definition of COVID-19 infection [30] at the time of recruitment were not included in the study and were referred to a nearby health facility for further investigation and management. The research teams followed government regulations for the prevention of COVID-19 transmission during data collection [31].

Statistical analysis

Data were entered into Excel, then cleaned and analysed using SAS version 9.4 (SAS Institute Inc). Frequency and percentages were used to present the data; Pearson's chi-square test was used to examine the association between seropositive results and various demographic and health-related factors, including age, sex, employment status, presence and types of underlying health conditions, on any type of medication, COVID-19 vaccination, previous symptoms compatible with COVID-19 and those ever tested for SARS-CoV-2. A simple logistic regression estimated the crude odds ratio (COR) for each variable

found to be significantly associated with seropositivity in the chi-square test (≤0.20). Multiple logistic regression was used to calculate the adjusted odds ratio (AOR), controlling for the effects of multiple variables simultaneously. The COR and AOR were calculated to quantify the strength of the associations between the variables and seropositive status.

RESULTS

Demographic data

A total of 438 participants consented to answer the questions and have a blood sample collected by fingerprick; one participant refused to divulge her occupation. Table 1 shows the information collected from the participant questionnaire. Most participants (79.2%) were between age 18 and 50 years; only 4.8% were age ≤17 years and 16% were age ≥50 years. Females exceeded males across the 18–50 years age group by a ratio of 2:3, but males exceeded females in the <18 years and >50 years age groups. Eleven female participants were pregnant; two were uncertain of their pregnancy status. Of the 419 participants age ≥16 years (the official age for employment in Kenya [32]) more than one third (39.1%) were unemployed; by far the greatest number of unemployed participants were women in the 18–50 years age group (74.4% of unemployed participants). Less than one quarter (22.1%) of participants self-reported any type of underlying health condition; the most common was cardiovascular disease, including hypertension (9.1% of all participants); only 14 (3.2%) participants reported underlying respiratory disease (including asthma). Underlying health conditions were most common in females in the 18–50 years age group (43.8% of all participants). Less than one fifth (16%) of participants were taking one or more medications at the time of the survey; these included therapeutic drugs as well as vitamins and symptomatic treatments. Four of the 18 participants with HIV infection reported not taking antiretroviral medication. Only 1 (0.23%) of the 281 (64.2%) participants reporting symptoms suggestive of COVID-19 in the previous 16 months had been hospitalised; he reported a negative SARS-CoV-2 test at that time. Only 19 (63%) of the 30 participants who reported receiving vaccination against SARS-CoV-2 had received two doses. Most participants could not recall exact dates of vaccinations, but most received vaccinations between 1 April and 28 July 2021, within 4 months of the survey; one reported receiving vaccination in March 2021 and one in August 2021.

Serological results in relation to demographic data

The collection of an adequate volume of blood by fingerprick required lancets of sufficient depth (at least 1.8 mm; we used 2 mm); smaller lancets used initially did not produce an adequate flow of capillary blood for collection of the full 500 µL. Due to inadequate sample collection, there was

insufficient sample in 72 participants to conduct the Platelia SARS-CoV-2 Total Ab Assay, the last test to be conducted. Comparison of performance between the three diagnostic tests (Wantai ELISA, Platelia ELISA and the rapid diagnostic test) are described in a separate paper [**Error! Reference source not found.**]. In summary, the Wantai ELISA showed greater percentage positive results (82.6%) compared with the rapid test (51.8%) and the Platelia ELISA (69.7%); of the rapid test results, 23 were IgM positive, 151 were IgG positive, 53 were both IgM and IgG positive. Specificities of the rapid test and Platelia SARS-CoV-2 Total Ab Assay using the Wantai ELISA as the reference test were high (>90%). There was no significant difference in percentage positive results across participants' age, sex, presence of underlying health conditions, on any type of medication, or those ever tested for SARS-CoV-2; there was a significant difference in percentage positive results according to participants' employment status (p=0.0176), COVID-19 symptoms in the previous 16 months (p=0.0099), and vaccination status (p=0.0561); this last variable was included in the multiple logistic regression analysis because of the p-value of ≤0.20. The previously hospitalised participant tested negative with the rapid test but tested positive with the two ELISAs. The results of multiple logistic regression analysis showed that having had COVID-19 symptoms in the previous 16 months was the only significant independent predictor of seropositivity in this population (p=0.0085) [Table 2].

DISCUSSION

This study confirmed the expected high exposure to SARS-CoV-2 (84.5%) in residents of Kibera slum at the mid-point of the COVID-19 pandemic. Although nearly two-thirds of participants (62.4%) reported COVID-like symptoms, only one had been hospitalised and recovered. There was no significant association of SARS-CoV-2 infection with age, sex, underlying health conditions, being on any type of medication, having been previously tested for SARS-CoV-2; significant associations were found with employment status, COVID-19 vaccination and previous symptoms compatible with COVID-19, but multiple regression analysis showed an association only with previous symptoms suggestive of COVID-19. The categories <18 years of age and not applicable for employment status (<16 years) have wide confidence intervals, indicating uncertainty about the true value of the odds ratio; this may also be contributed to by the low participant numbers in these categories. In addition, numbers of vaccinated participants were small. The high exposure in this population could be linked to the fact that a large proportion are casual labourers who walk up to 15 kilometres daily in search of work and mix with populations in other areas; other groupings were also at risk due to the high population density resulting in high likelihood of transmission. The overall seroprevalence in our study is similar to that of women who attended antenatal care services in Nairobi (84.5% vs 85%) at a similar time frame (August 2021 vs

October 2021) [21], which was conducted at the national referral hospital close to the Kibera slum. However, in our female population, seroprevalence was only 33.3% in the 18–30 years age group, and 34.9% in the 31–50 years age group, implying the population groups were different and suggesting the need for further investigation.

The reasons for low rates of severe disease in this infected population are unclear. Several explanations have been proposed for the overall low morbidity and mortality from COVID-19 in Africa, including the high infectious disease burden on the African continent and the demographic age structure [33,34,35,36,37]. According to the United Nations, the over 1 billion slum dwellers worldwide are mostly confined to three regions, including sub-Saharan Africa [38]. For residents of urban slums, the difficulty in implementing COVID-19 preventive measures due to severe overcrowding was recognised early [39,40] but the predicted high caseload and mortality rates from community transmission were not apparent, especially in Africa's slums [41,42,43].

This study supports seroprevalence studies in urban slums outside Africa that showed high exposure to the virus as well as low morbidity, with differing associated factors. Malani *et al* in a comparative study of slum and non-slum areas in Mumbai, India, showed markedly higher proportions of positive tests in slum areas (54.1%) than in non-slum areas (16.1%), with lower infection fatality in slums (0·076%) than in non-slums (0·263%) [44]. Nirala *et al* in a study across 10 different slums in Patna, India, found a seropositivity rate of 31.5% (95% CI: 27.9–35.1) with seropositive status significantly associated with age 18–30 years, male gender, high-risk occupations (autorickshaw drivers, rickshaw pullers, street vendors), below poverty line economic status, residing in a hut or kutcha house (makeshift dwelling) and COVID-like symptoms in the preceding one month [45]. A study by Raqib *et al* comparing slum and non-slum areas in Bangladesh showed seroprevalence was positively associated with limited years of formal education (AOR = 1.61; 95% CI = 1.43, 1.82), lower income (AOR = 1.23; 95% CI = 1.03, 1.46), overweight (AOR = 1.2835; 95% CI = 1.26, 1.97), diabetes (AOR = 1.67; 95% CI = 1.21, 2.32) and heart disease (AOR = 1.38; 95% CI = 1.03, 1.86) [46]. However, in a study by George *et al* in a large slum in South India with a reported overall COVID-19 seroprevalence of 57.9% (95% CI 53.4–62.3), age, education, occupation and presence of reported co-morbidities were not significantly associated with seroprevalence [47]. The discrepancies between high seroprevalence, low morbidity and varying underlying factors suggest the need for further research to understand the potential protective factors and immune responses that may be at play in these informal settlements. The informal community in our study may have distinct characteristics that sets it apart from other slum populations examined in previous research. Factors such as community resilience, social support networks and environmental conditions

may vary from place to place and could play a role in mitigating the impact of COVID-19 and influencing the observed lack of associations with reported risk factors.

Co-morbidities associated with severe COVID-19 have also been examined in other populations. Martono Fatmawati *et al* reviewed nine studies from Asia and Europe that showed risk factors for severe COVID-19 included age, gender, chronic comorbidities, cardiovascular disease, diabetes, hypertension, kidney failure, cancer and a history of smoking [48]. Wang *et al* using self-reported data from a survey of adults in the United States reported that individuals with underlying health conditions were more likely to become infected with SARS-CoV-2 and have more severe post-infection symptoms [49]. Kompaniyets *et al* in a cross-sectional study of children age ≤18 years in the United States reported underlying health conditions, such as type 1 diabetes, cardiac and circulatory congenital anomalies and obesity, were more associated with severe COVID-19 or death [50]. Costa *et al* in a review of published data up to June 2020 reported patients with metabolic disorders including obesity, diabetes, cardiovascular disease and liver disease faced a higher risk of SARS-CoV-2 infection and were associated with a significantly worse outcome [51]. Wu *et al* in a review of published papers up to April 2020 reported diabetes increased the mortality of patients with COVID-19 [52]. However, the findings from our study challenge the assumptions that COVID-19 risk factors are necessarily linked to severity of disease. Males have also been reported to be at higher risk of severe illness and increased mortality than females [53,12]; this was as well not evident in our study.

Our study also explored the use of small blood volume samples collected through fingerprick. We found fingerprick sampling a convenient and acceptable way of conducting a serosurvey across a large population that included small children, and for evaluating new technologies. Testing kits used for serosurveys should therefore utilise whole blood or plasma separated from capillary blood. Our study used three tests concurrently to detect antibodies to SARS-CoV-2: one rapid test and two ELISA tests. Since the start of the COVID-19 pandemic, molecular testing for SARS-CoV-2 virus using RT-PCR-based assays performed on respiratory specimens has been central to disease management and control [14]. Tests for SARS-CoV-2 antigens on clinical specimens using immunoassays and rapid tests have also been used but are limited by sub-optimal sensitivity [53,55]. Molecular and antigen tests are constrained by detection of virus to a few days before infection and a short time after infection. In a systematic review of longitudinal studies of RT-PCR test results in symptomatic SARS-CoV-2 infections, the highest percentage of virus detection in nasopharyngeal swabs by PCR was 89% between 0 and 4 days post-symptom onset, dropping to 54% (95% CI 47 to 61) after 10–14 days [56]. Tests for detecting antibodies to SARS-CoV-2 applicable outside research laboratory settings include rapid tests using lateral flow immunology and ELISA tests. In a study by Guo *et al* using an ELISA based on recombinant viral

nucleocapsid protein, the median time to IgM and IgA antibody detection after symptom onset was 5 (IQR 3–6) days, while IgG was detected at 14 (IQR 10–18) days [57]. Zhao *et al*, using an ELISA prepared from recombinant antigen containing the receptor binding domain of SARS-CoV-2 spike protein, reported median times from symptom onset to total antibody, IgM and IgG seroconversion were 11, 12 and 14 days, respectively [58]; the presence of antibodies was <40% among patients within 1 week of onset, and rapidly increased to 100% (total antibody – 94.3% (IgM), 79.8% (IgG)) by day 15 after onset; there were also negative antibody findings in 7% patients, possibly due to blood samples not taken at an appropriate time after symptom onset. In a report by Qu *et al* using a IgG/IgM chemiluminescent immunoassay with combined nucleocapsid protein and spike glycoprotein antigens, seroconversion time of IgG antibody was earlier than that of IgM antibody: 97.6% of patients (40/41) were positive with IgG and 87.8% (36/41) with IgM, with a median time of seroconversion for IgG at 11 days (8–16 days) and for IgM at 14 days (8–28 days) after disease onset. The level of IgG antibody reached the highest concentration on day 30, while the highest concentration of IgM antibody appeared on day 18, but then began to decline [59]. Hoffman *et al* found no statistical difference between testing samples taken from PCR-confirmed COVID-19 cases between 9 and 17 days and 18 and 29 days for either IgM or IgG seropositivity [60]. Generally, IgM is produced first with a later switch towards IgG production, but studies on SARS-associated coronaviruses suggest that IgM and IgG often develop at around the same time [61,62]. In general, detection of antibodies is better in samples taken >14 days after onset of disease, due to the time taken for antibody development [63,64]. Reported duration of antibody after natural confirmed infection is variable, including >6 months [65], up to 20 months in unvaccinated adults in the United States after confirmed COVID-19 infection [66], and more than 2 years in patients in Wuhan, China [67]. It is therefore probable that most natural infections occurring within the previous 16 months in our study population were detected, although the relevance of the IgM and IgG antibody findings is unclear.

Serologic studies that assess prior infection and immunity to infectious diseases are essential for epidemiologic studies, ongoing surveillance, vaccine studies and potentially for risk assessments of healthcare workers, and provide an indication of previous as well as recent exposure in a population. Surveillance therefore remains fundamental to understanding the evolution of SARS-CoV-2 infection, the risk factors for severe disease, and the impact of vaccination and public health and social measures [68]. Although hospital admissions and severe outcomes from COVID-19 have substantially decreased since the start of the pandemic, COVID-19-related deaths remain substantial: in the United States, COVID-19 still ranks as the 10th most common cause of death. The percentage of positive tests for SARS-CoV-2, a key indicator of community spread, reached peak levels of 12.9% in January 2024 [69]. Since disease mitigation measures implemented in many countries severely affected the global economy and financial

markets [70], and substantially impacted the inadequately prepared health systems in Africa [71], health systems need to be vigilant of emerging SARS-CoV-2 variants and the possibility of new surges in cases and deaths. As WHO recommends countries transition from emergency mode to managing COVID-19 alongside other infectious diseases, providing a more complete picture of the total number of people infected with SARS-CoV-2 remains an important measure for guiding public health responses [72]. The recent establishment of a global network to detect and monitor novel coronaviruses of public health importance will facilitate early detection, risk assessment, and response to coronavirus-related health challenges [73]. Well-designed surveillance systems remain core to monitoring acute viral respiratory infections to inform public health measures, health system capacities, impact of vaccination programmes and other control measures [74].

Conclusions

This study reports high SARS-CoV-2 exposure in a slum community in Nairobi, Kenya, with limited morbidity; only recent COVID-19 symptoms were a significant independent predictor of seropositivity. This study confirms other reports of high SARS-CoV-2 exposure with limited morbidity in slum communities. The study also supports the convenient use of small blood volumes for conducting population serosurveys. Use of serological assays to conduct seroprevalence studies will continue to remain important as more robust tests are developed. Public health systems would greatly benefit from serosurveillance to supplement and strengthen existing COVID-19 case-based infectious disease surveillance strategies [75].

Study limitations

This study was conducted during the working week during working hours, which may explain the low number of male participants of working age and low number of those formally employed. The tests used were limited by availability of approved tests at the time.

Acknowledgements

Approval for the study was obtained from the Amref Health Africa Ethics and Scientific Review Committee, from the National Commission for Science, Technology and Innovation, and from the Nairobi Metropolitan Services, Ministry of Health. Verbal permission to conduct the study was obtained from five area chiefs administering the 10 Kibera villages. The study was funded by American Tower Corporation.

Author contributions

Conceptualisation: JYC, SK, SM, JM, JO; Methodology: JYC, SK, SM, SMM, LK, JK, NL, JC, RO, AM; Analysis: JYC, RS, MH; writing—original draft preparation: JYC, RS, MH; writing—review and editing: JYC, SK, JM, SM, SMM, RS, MH, MP, JS, JO. All authors have read and agreed to the published version of the manuscript.

Competing interests

All authors declare they have no competing interests.

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Table 1. Seroprevalence of antibodies to SARS-CoV-2, by sociodemographic and other participant characteristics

Overall	*n*	positive (%)	
	438	370 (84.5)	
Variables	*n* (%)	positive [% (95% CI)]	*p* (chi-square test)
Age			
≤17	21 (4.8)	14 [3.2 (1.54–4.9)]	0.0670
18–30	173 (39.5)	146 [33.3 (28.9–37.8)]	
31–50	174 (39.7)	153 [34.9 (30.5–39.4)]	
>50	70 (16)	57 [13.0 (9.9–16.2)]	
Sex			
Female	281 (64.2)	241 [55.0 (50.3–59.7)]	0.3185
Male	157 (35.8)	129 [29.5 (25.2–33.7)]	
*Employment status*undisclosed was not included in the calculation of significance*			
Unemployed	164 (39.1)	137 [31.4 (27.0–35.7)]	0.0176
Self-employed	102 (24.3)	82 [18.8 (15.1–22.4)]	
Casual/part-time	88 (21.0)	83 [19.0 (15.3–22.7)]	
Student	34 (8.1)	27 [6.2 (3.9–8.4)]	
Formal/regular	31 (7.4)	28 [6.4 (4.1-8.7)]	
Not applicable (<16 years)	18	12 [2.7 (1.2–4.3)]	
Undisclosed	1	1 [0.23]	
Underlying health conditions			
No	341 (77.9)	287 [65.5 (61.1–70.0)]	0.7364
Yes	97 (22.1)	83 [19.0 (15.3–22.6)]	
Types of underlying health conditions	*(% of all participants)*		
Cardiovascular disease	40 (9.1)	32 [7.3 (4.9–9.8)]	0.4123
Stomach ulcer	25 (5.7)	20 [4.6 (2.6–6.5)]	0.5246
HIV	18 (4.1)	17 [3.9 (2.1–5.7)]	0.2330
Respiratory disease	14 (3.2)	12 [2.7 (1.2–4.3)]	0.8964
Diabetes	11 (2.5)	10 [2.3 (0.9–3.7)]	0.5506
On medication			
No	343 (78.3)	291 [66.4 (62.0–70.9)]	0.6888
Yes	95 (21.7)	79 [18.0 (14.4–21.7)]	
COVID-19 symptoms (previous 16 months)			
No	157 (35.8)	142 [32.4 (28.0–36.8)]	0.0099
Yes	281 (64.2)	228 [52.1 (47.4–56.8)]	
Ever tested for SARS-CoV-2			
No	371 (84.7)	311 [71.0 (66.7–75.3)]	0.3787
Yes	67 (15.3)	59 [10.3–16.7)]	
Previous SARS-CoV-2 test			
Tested with negative result	54 (80.6)	48 [71.6 (60.6–82.7)]	*
Tested with positive result	4 (6.0)	4 [6.0 (0.1–11.8)	
Tested with unknown result	9 (13.4)	7 [10.4 (2.0–18.0)]	
COVID-19 vaccination			
No	408 (93.2)	341 [77.9 (74.0–81.8)]	0.0561
Yes	30 (6.8)	29 [6.6 (4.3–9.0)]	

* = no chi square possible due to a negative value in the tested negative category

Table 2. Predictors of positivity to SARS-CoV-2 antibodies (*n*=437)

Variables	COR* (95% CI)	*p*	AOR† (95% CI)	*p*
Age				
<18	0.4 (0.1–1.0)	0.0853	0.4 (0.0–5.0)	0.5574
18–30	1		1	
31–50	1.3 (0.7–2.5)		1.2 (0.6–2.3)	
>50	0.8 (0.4–1.7)		0.7 (0.3–1.6)	
Employment status				
Unemployed	1	0.0320	1	0.1739
Self-employed	0.8 (0.4–1.5)		0.9 (0.4–1.7)	
Casual/part-time	3.3 (1.2–8.8)		3.2 (1.2–8.7)	
Student	0.8 (0.4–1.5)		0.8 (0.3–2.1)	
Formal/regular	1.8 (0.5–6.5)		1.8 (0.5–6.6)	
Not applicable (<16 years)	0.8 (0.3–1.9)		1.2 (0.1–19.9)	
COVID-19 symptoms (previous 16 months)				
No	1	0.0121	1	0.0085
Yes	0.5 (0.3–0.8)		0.4 (0.2–0.8)	
COVID-19 vaccination				
No	0.2 (0.0–1.3)	0.0893	0.2 (0.0–1.3)	0.0822
Yes	1		1	

*Crude odds ratio; †Adjusted odds ratio

BMJ Open

Seroprevalence and demographic characteristics of SARS-CoV-2- infected residents of Kibera Informal Settlement during the COVID-19 pandemic in Nairobi, Kenya. A cross-sectional study

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2024-094546.R1
Article Type:	Original research
Date Submitted by the Author:	20-Feb-2025
Complete List of Authors:	Carter, Jane; Amref Health Africa, Regional Laboratory Programme Khamadi, Samoel; Kenya Medical Research Institute, Centre for Virus Research Mwangi, Joseph; Kenya Medical Research Institute, Centre for Virus Research Muhula, Samuel; Amref Health Africa, Learning and Impact Munene, Stephen; Amref Health Africa, Regional Laboratory Programme Kanyara, Lucy; Kenya Medical Research Institute, Centre for Virus Research Kinyua, Joyceline; Kenya Medical Research Institute, Centre for Virus Research Lagat, Nancy; Kenya Medical Research Institute, Centre for Virus Research Chege, Judy; Kenya Medical Research Institute, Centre for Virus Research Oira, Robert; Kenya Medical Research Institute, Centre for Virus Research Maiyo, Alex; Kenya Medical Research Institute, Centre for Virus Research Stewart, Roy; University Medical Centre Groningen, Department of Health Sciences, Community & Occupational Medicine Postma, Maarten; UMCG, Department of Health Sciences; UMCG, Department of Economics, Econometrics and Finance Stekelenburg, Jelle; Medisch Centrum Leeuwarden, Department of Obstetrics and Gynaecology; Universitair Medisch Centrum Groningen, Department of Health Sciences, Global Health Osur, Joachim; Amref International University, Office of the Vice Chancellor van Hulst, Marinus; Martini Hospital, Clinical Pharmacy; UMCG, Department of Health Sciences
Primary Subject Heading:	Epidemiology
Secondary Subject Heading:	Public health
Keywords:	COVID-19, EPIDEMIOLOGY, PUBLIC HEALTH, Community-Based Participatory Research

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Seroprevalence and demographic characteristics of SARS-CoV-2-infected residents of Kibera Informal Settlement during the COVID-19 pandemic in Nairobi, Kenya. A cross-sectional study

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ABSTRACT

Objectives To assess the prevalence of SARS-CoV-2 antibodies in the residents of Kibera informal settlement in Nairobi, Kenya, before vaccination became widespread, and explore demographic and health-related risk factors for infection.

Design A cross-sectional study.

Setting Kibera informal settlement, Nairobi, Kenya.

Participants Residents of Kibera informal settlement between October 2019 and August 2021, age 1 year and above who reported no current symptoms of COVID-19.

Main outcome measures Associations were determined between SARS-CoV-2 positive tests measured with one rapid test and two enzyme-linked immunosorbent assays and demographic and health-related factors, using Pearson's chi-square test. Crude odds ratio and adjusted odds ratio were calculated to quantify the strength of associations between variables and seropositive status.

Results A total of 438 participants were recruited. Most (79.2%) were age 18–50 years; females (64.2%) exceeded males. More than one third (39.1%) were unemployed; only 7.4% were in formal, full-time employment. Less than one quarter (22.1%) self-reported any underlying health conditions. Nearly two-thirds (64.2%) reported symptoms compatible with COVID-19 in the previous 16 months; only one (0.23%) had been hospitalised with a reported negative COVID-19 test. 370 (84.5%) participants tested positive in any of the three tests. There was no significant difference in SARS-CoV-2 seropositivity across age, sex, presence of underlying health conditions, on medication, or those ever tested for SARS-CoV-2. Multiple logistic regression analysis showed COVID-19 symptoms in the previous 16 months were the only significant independent predictor of seropositivity (p=0.0085).

Conclusion High SARS-CoV-2 exposure with limited morbidity was found in residents of Kibera informal settlement. The study confirms other reports of high SARS-CoV-2 exposure with limited morbidity in slum communities. Reason cited include the high infectious disease burden on the African continent, demographic age structure, and underreporting due to limited testing and lack of access to healthcare services; genetic factors may also play a role. These factors require further investigation.

Strengths and limitations of this study

- This was a community-based serosurveillance study where entry to households and data collection was facilitated by community health volunteers.
- The study relied on self-reported demographic data which is susceptible to recall bias.
- The study collected a small volume of fingerpick blood which was more acceptable than venous blood and is convenient for serosurveillance studies in large populations.
- Capillary blood collected into Microtainer® EDTA tubes had to be transported to the testing site on the same day for testing and processing, so an accessible testing site is required.

INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the cause of coronavirus disease 2019 (COVID-19), was first reported in Wuhan, Hubei Province, China, in November 2019 and rapidly spread across China and the world [1]. On 30 January 2020, the World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern, and on 11 March 2020 the WHO Director General declared COVID-19 a pandemic [2]. Although the WHO declared the COVID-19 global health emergency over on 5 May 2023 [3], globally more than 777 million cases and more than 7 million deaths from COVID-19 had been reported by 5 January 2025, with more than 161,000 new cases and nearly 3,000 deaths in the previous 28 days [4]. In the African region, more than 9.5 million confirmed cases and more than 175,000 deaths had been reported cumulatively by 5 January 2025, although the numbers of cases and deaths reported in Africa are likely an underestimate due to low testing rates [5]; an assessment by the WHO Regional Office for Africa showed only one in seven (14.2%) COVID-19 infections were being detected [6]. Studies from Kenya and other countries in Africa noted low mortality from COVID-19, despite high exposure rates [7,8].

The modes of transmission of SARS-CoV-2 have been elucidated through detailed case contact studies. Respiratory transmission, with SARS-CoV-2 carried on tiny particles emitted from the respiratory tract, has been established as the clear and dominant route of spread; indirect transmission appears to be of limited importance despite initial concerns [**Error! Reference source not found.**]. The clinical spectrum of COVID-19 varies from asymptomatic or pre-symptomatic infection, mild to moderate illness, to severe and critical illness characterised by respiratory failure and multiple organ dysfunction; varying proportions of infected persons remain asymptomatic [10,11]. Transmission from asymptomatic individuals is estimated to account for more than half of all transmissions [12]. Diagnostic testing using reverse transcriptase polymerase chain reaction (RT-PCR)-based assays performed on respiratory specimens is the reference standard for establishing a microbiological diagnosis of COVID-19 [13] but is constrained by the presence of virus to a few days before infection and a short time after infection. Seroepidemiological studies to detect host antibodies to SARS-CoV-2 are therefore important for estimating disease burden and providing a more complete picture of exposure to SARS-CoV-2 in a population [14].

COVID-19 infection in Kenya

The first confirmed case of COVID-19 was reported in Kenya on 13 March 2020 [15]. Restrictions to mitigate the spread of COVID-19 were instituted in March 2020 and were eased towards the end of 2020

until a second lockdown was instituted in five counties in March 2021; in May 2021, as the number of cases dropped, lockdown restrictions were again lifted [16]. COVID-19 vaccination was initiated in Kenya in March 2021, with vaccination numbers rising from August 2021 with increased vaccine availability. Kenya actively promoted vaccination through the COVID-19 Vaccination Acceleration Programme [17]; as of 16 May 2023, more than 18 million vaccine doses had been administered with 30.7% of the adult population (≥18 years) fully vaccinated. Kenya planned to vaccinate all adults and teenagers in 2022 and to provide third dose booster shots to all eligible adults [18]. On 11 March 2022, Kenya lifted all COVID-19 restrictions while urging continued personal public health measures; by June 2024, 344,000 cases and 5,700 deaths had been reported since the pandemic started, rates that remained low in comparison with global figures [4].

Seroprevalence data from Kenya targeting different population groups painted a concerning picture of the pandemic's progression across the country. Studies examining stored samples from blood donors in six regional blood transfusion centres, including the capital city Nairobi, revealed a dramatic rise in SARS-CoV-2 antibody prevalence over time. Seroprevalence increased from 4.3% (95% CI, 2.9–5.8%) in samples collected between April and June 2020 to 48.5% (95% CI, 45.2–52.1%) in samples taken just one year later from January to March 2021 [19,20]. These samples were tested using a non-commercial validated enzyme-linked immunosorbent assay (ELISA) for SARS-CoV-2 IgG against spike protein. The same assay was used to test stored blood from women attending antenatal care services at three hospitals in Kenya between August 2020 and October 2021: seroprevalence rose from 50% (95% CI, 42–58%) in August 2020 to 85% (95% CI, 78–92%) in October 2021 in Nairobi; 31% (95% CI, 25–37%) in May 2021 to 71% (95% CI, 64–77%) in October 2021 in Busia; and from 1% (95% CI, 0–3%) in September 2020 to 63% (95% CI, 56–69%) in October 2021 in Kilifi [21]. Purposive testing of venous blood from healthcare workers between July and December 2020 using the same ELISA showed significant variation in overall seropositivity (20.8%: 17.5%–24.4%). Seroprevalence varied significantly (p<0.001) by site: 43.8% (35.8–52.2%) in Nairobi, 12.6% (8.8–17.1%) in Busia and 11.5% (7.2–17.6%) in Kilifi; only 16 (2%) of the sampled healthcare workers reported acute respiratory symptoms at the time of sample collection [22]. Purposive testing of truck drivers and their assistants, using the same ELISA, conducted between September and October 2020 showed an overall seropositivity of 7.4%; none reported current or previous symptoms of illness [23]. Truck drivers and their assistants continued to transport essential supplies during the COVID-19 pandemic, placing them at increased risk of being infected and of transmitting SARS-CoV-2 over a wide geographical area. In a study on samples collected from January to March 2020 from rural

populations in western Kenya with and without human immunodeficiency virus (HIV) infection, 3.3% had detectable SARS-CoV-2 antibodies, with no difference between participants with and without HIV infection (3.1% vs. 4.0%, *p*=0.68) [24]; this study used the Platelia SARS-CoV-2 Total Ab assay (Bio-Rad Laboratories, Hercules, California, USA). Participants denied symptoms except for one who reported a cough in the preceding week. In our study, SARS-CoV-2 seroprevalence in an informal settlement in Nairobi was conducted to supplement these data and determine exposure in a community subjected to overcrowding and lack of reliable clean water, housing, health services and waste management facilities, where preventive measures were difficult to apply. At the time of the study, Kenya was experiencing wave 4 of the pandemic predominated by the *Delta* variant of concern (VoC) [25].

Purpose of the study

This study assessed the prevalence of SARS-CoV-2 antibodies in the residents of Kibera informal settlement in Nairobi, Kenya, one of sub-Sahara Africa's largest slums, before vaccination became widespread, and explored some of the major risk factors for infection. This study also provided an opportunity to determine pathogen exposure in large numbers of persons in a pandemic situation using small blood volumes obtained from fingerprick samples.

MATERIALS AND METHODS

Study site

Kibera informal settlement stands on a 2.5-kilometre square area of land located 5 kilometres southwest of Nairobi's Central Business District. The population is estimated at 170,070, although this may be an underestimate [26]. Residents comprise the major ethnic communities in Kenya [27] with reportedly 116 women for every 100 men [28]. Kibera is governed by area chiefs as the local administrative arm of the government.

Study design

A cross-sectional study was performed to determine SARS-CoV-2 antibody prevalence in Kibera informal settlement, Nairobi, Kenya. The study was conducted between 2 and 13 August 2021 in 10 of the 14 Kibera villages, which provided a representation of the whole settlement. The Cochran sample size formula for larger populations was used to determine sample size [29]. Since the population of Kibera is above 170,000 and approximately 500 people had tested positive for SARS-CoV-2 at the time of the study, a sample size of 389 (~400) participants was determined, a target of 40 participants in each selected village (confidence level 99%; precision 0.01). In each village every fifth household was selected;

if a household declined participation, the next household was included. Entry to individual households was facilitated through community health volunteers who were formally assigned to these villages. Participants age 1 year and above who had been resident in Kibera since at least October 2019 were included.

Study methods

Five data collectors, each assigned to two villages, administered a brief questionnaire to each consenting participant, or their parent or legal guardian; data were collected directly into the Open Data Kit system installed in handheld tablets. Data were collected on the following: age, sex, length of residence in Kibera, pregnancy status (for women), main occupation and nature of employment, any underlying health conditions and type of condition, any medications and name of the medication, symptoms suggestive of COVID-19 in the previous 16 months (cough, fever, difficulty in breathing, shortness of breath, new loss of taste and smell), any hospitalisation and date (if known), ever tested for SARS-CoV-2, date and result (if known), and COVID-19 vaccination(s) and date (if known). Five laboratory staff accompanying the data collectors collected 500 µL of capillary blood from each participant by fingerprick into a Microtainer® EDTA tube. Blood samples were transported to the Kenya Medical Research Institute (KEMRI) laboratories for same-day testing on whole blood using the Standard Q COVID-19 IgM/IgG Combo rapid test (SD Biosensor Inc, Suwon, Gyeonggi, Republic of Korea). At the KEMRI laboratories, blood was separated the same day and plasma samples stored at -80 °C for further testing with two enzyme-linked immunosorbent assays (ELISAs): Wantai Total Ab (IgM/IgG/IgA) ELISA for SARS-CoV-2 (Wantai Biological Pharmacy Enterprise Co. Ltd, Beijing, China), and Platelia SARS-CoV-2 Total Ab (IgM/IgG/IgA) Assay (Bio-Rad Laboratories Inc, California, USA). The SARS-CoV-2 antibody tests selected in this survey were commercial tests approved for use in Kenya at the time of the study. Test performance is described in a separate paper [30]. Individuals with positive test results in any of the three tests were considered positive (for the ELISAs, optical density ≥1.0) and indeterminate ELISA results as negative (optical density 0.9–0.99). PCR or antigen testing was not performed for any of the study participants. Each participant was assigned a unique identification number; data files and blood sample labelling did not include participant names to ensure anonymity. Individuals who met the case definition of COVID-19 infection [31] at the time of recruitment were not included in the study and were referred to a nearby health facility for further investigation and management. The research teams followed government regulations for the prevention of COVID-19 transmission during data collection [32].

Statistical analysis

Data were entered into Excel, cleaned and analysed using SAS version 9.4 (SAS Institute Inc). Frequency and percentages were used to present the data; Pearson's chi-square test was used to examine the association between seropositive results and various demographic and health-related factors, including age, sex, employment status, presence and types of underlying health conditions, on any type of medication, COVID-19 vaccination, previous symptoms compatible with COVID-19 and those ever tested for SARS-CoV-2. Simple logistic regression estimated the crude odds ratio (COR) for each variable found to be significantly associated with seropositivity in the chi-square test (≤0.20). Multiple logistic regression was used to calculate the adjusted odds ratio (AOR), controlling for the effects of multiple variables simultaneously. The COR and AOR were calculated to quantify the strength of associations between the variables and seropositive status. Vaccinated individuals were included in the overall analysis as numbers were small (6.8%).

Patients and public involvement

This study was planned, designed and conducted as a shared activity with Kenya's national Virus Research Centre. This included development of the research protocol and study tools, training of data collectors and field laboratory staff, and sample collection. The Virus Research Centre staff conducted all the laboratory tests. The study was discussed with the five area administrative chiefs, and entry to the households was facilitated through the community health volunteers assigned to the study villages. The study results will be presented to the Kibera chiefs, community health volunteers and the participants through a community meeting.

RESULTS

Demographic data

A total of 438 participants consented to answer the questions and to a blood sample collection by fingerprick; one participant refused to divulge her occupation. Table 1 shows the information collected from the participant questionnaire.

Table 1. Seroprevalence of antibodies to SARS-CoV-2 by sociodemographic and other participant characteristics

Overall	*n*	positive (%)	
	438	370 (84.5)	
Variables	*n* (%)	positive [% (95% CI)]	*p* (chi-square test)
Age			
≤17	21 (4.8)	14 [3.2 (1.54–4.9)]	0.0670
18–30	173 (39.5)	146 [33.3 (28.9–37.8)]	
31–50	174 (39.7)	153 [34.9 (30.5–39.4)]	
>50	70 (16)	57 [13.0 (9.9–16.2)]	

Sex			
Female	281 (64.2)	241 [55.0 (50.3–59.7)]	0.3185
Male	157 (35.8)	129 [29.5 (25.2–33.7)]	
Employment status (undisclosed was not included in the calculation of significance)			
Unemployed	164 (39.1)	137 [31.4 (27.0–35.7)]	0.0176
Self-employed	102 (24.3)	82 [18.8 (15.1–22.4)]	
Casual/part-time	88 (21.0)	83 [19.0 (15.3–22.7)]	
Student	34 (8.1)	27 [6.2 (3.9–8.4)]	
Formal/regular	31 (7.4)	28 [6.4 (4.1-8.7)]	
Not applicable (<16 years)	18	12 [2.7 (1.2–4.3)]	
Undisclosed	1	1 [0.23]	
Underlying health conditions			
No	341 (77.9)	287 [65.5 (61.1–70.0)]	0.7364
Yes	97 (22.1)	83 [19.0 (15.3–22.6)]	
Types of underlying health conditions	*(% of all participants)*		
Cardiovascular disease	40 (9.1)	32 [7.3 (4.9–9.8)]	0.4123
Stomach ulcer	25 (5.7)	20 [4.6 (2.6–6.5)]	0.5246
HIV	18 (4.1)	17 [3.9 (2.1–5.7)]	0.2330
Respiratory disease	14 (3.2)	12 [2.7 (1.2–4.3)]	0.8964
Diabetes	11 (2.5)	10 [2.3 (0.9–3.7)]	0.5506
On medication			
No	343 (78.3)	291 [66.4 (62.0–70.9)]	0.6888
Yes	95 (21.7)	79 [18.0 (14.4–21.7)]	
COVID-19 symptoms (previous 16 months)			
No	157 (35.8)	142 [32.4 (28.0–36.8)]	0.0099
Yes	281 (64.2)	228 [52.1 (47.4–56.8)]	
Ever tested for SARS-CoV-2			
No	371 (84.7)	311 [71.0 (66.7–75.3)]	0.3787
Yes	67 (15.3)	59 [10.3–16.7)]	
Previous SARS-CoV-2 test			
Tested with negative result	54 (80.6)	48 [71.6 (60.6–82.7)]	*
Tested with positive result	4 (6.0)	4 [6.0 (0.1–11.8)	
Tested with unknown result	9 (13.4)	7 [10.4 (2.0–18.0)]	
COVID-19 vaccination			
No	408 (93.2)	341 [77.9 (74.0–81.8)]	0.0561
Yes	30 (6.8)	29 [6.6 (4.3–9.0)]	

* = no chi square possible due to a negative value in the tested negative category

Most participants (79.2%) were between age 18 and 50 years; only 4.8% were age ≤17 years and 16% were age ≥50 years. Females exceeded males across the 18–50 years age group by a ratio of 2:3, but males exceeded females in the <18 years and >50 years age groups. Eleven female participants were pregnant; two were uncertain of their pregnancy status. Of the 419 participants age ≥16 years (the official age for employment in Kenya [33]) more than one third (39.1%) were unemployed; the greatest number of unemployed participants were women in the 18–50 years age group (74.4% of unemployed

participants). Less than one quarter (22.1%) of participants self-reported any type of underlying health condition; the most common was cardiovascular disease, including hypertension (9.1% of all participants); only 14 (3.2%) participants reported underlying respiratory disease (including asthma). Underlying health conditions were most common in females in the 18–50 years age group (43.8% of all participants). Less than one fifth (16%) of participants were taking one or more medications at the time of the survey; these included therapeutic drugs as well as vitamins and symptomatic treatment. Four of the 18 participants with HIV infection reported not taking antiretroviral medication. Only 1 (0.23%) of the 281 (64.2%) participants reporting symptoms suggestive of COVID-19 in the previous 16 months had been hospitalised; he reported a negative SARS-CoV-2 test at that time. Only 19 (63%) of the 30 participants who reported receiving vaccination against SARS-CoV-2 had received two doses. Most participants could not recall exact dates of vaccinations, but most received vaccinations between 1 April and 28 July 2021, within 4 months of the survey; one reported receiving vaccination in March 2021 and one in August 2021.

Serological results in relation to demographic data

The collection of an adequate volume of blood by fingerprick required lancets of sufficient depth (at least 1.8 mm; we used 2 mm); smaller lancets used initially did not produce an adequate flow of capillary blood for collection of the full 500 µL. Due to inadequate sample collection, there was insufficient sample in 72 participants to conduct the Platelia SARS-CoV-2 Total Ab Assay, the last test to be conducted. Comparison of performance between the three diagnostic tests (Wantai ELISA, Platelia ELISA and the rapid diagnostic test) are described in a separate paper [30]. In summary, the Wantai ELISA showed greater percentage positive results (82.6%) compared with the rapid test (51.8%) and the Platelia ELISA (69.7%); of the rapid test results, 23 were IgM positive, 151 were IgG positive, 53 were both IgM and IgG positive. Specificities of the rapid test and Platelia SARS-CoV-2 Total Ab Assay using the Wantai ELISA as the reference test were high (>90%). There was no significant difference in percentage positive results across participants' age, sex, presence of underlying health conditions, on any type of medication, or those ever tested for SARS-CoV-2; there was a significant difference in percentage positive results according to participants' employment status (p=0.0176), COVID-19 symptoms in the previous 16 months (p=0.0099), and vaccination status (p=0.0561); this last variable was included in the multiple logistic regression analysis because of the p-value of ≤0.20. The previously hospitalised participant tested negative with the rapid test but positive with the two ELISAs. Simple and multiple logistic regression

analysis showed that having had COVID-19 symptoms in the previous 16 months was the only significant independent predictor of seropositivity in this population (p=0.0085) (Table 2).

Table 2. Predictors of positivity to SARS-CoV-2 antibodies (n=437*)

Variables	Simple logistic regression analysis COR† (95% CI)	p	Multiple logistic regression analysis AOR‡ (95% CI)	p
Age				
<18	0.4 (0.1–1.0)	0.0853	0.4 (0.0–5.0)	0.5574
18–30	1		1	
31–50	1.3 (0.7–2.5)		1.2 (0.6–2.3)	
>50	0.8 (0.4–1.7)		0.7 (0.3–1.6)	
Employment status				
Unemployed	1	0.0320	1	0.1739
Self-employed	0.8 (0.4–1.5)		0.9 (0.4–1.7)	
Casual/part-time	3.3 (1.2–8.8)		3.2 (1.2–8.7)	
Student	0.8 (0.4–1.5)		0.8 (0.3–2.1)	
Formal/regular	1.8 (0.5–6.5)		1.8 (0.5–6.6)	
Not applicable (<16 years)	0.8 (0.3–1.9)		1.2 (0.1–19.9)	
COVID-19 symptoms (previous 16 months)				
No	1	0.0121	1	0.0085
Yes	0.5 (0.3–0.8)		0.4 (0.2–0.8)	
COVID-19 vaccination				
No	0.2 (0.0–1.3)	0.0893	0.2 (0.0–1.3)	0.0822
Yes	1		1	

*The one participant with undisclosed employment status was omitted

†Crude odds ratio; ‡Adjusted odds ratio

DISCUSSION

This study confirmed the expected high exposure to SARS-CoV-2 (84.5%) in residents of Kibera slum at the mid-point of the COVID-19 pandemic. Although nearly two-thirds of participants (62.4%) reported previous COVID-like symptoms, only one had been hospitalised and recovered. There was no significant association of SARS-CoV-2 infection with age, sex, underlying health conditions, being on any type of medication, having been previously tested for SARS-CoV-2; significant associations were found with employment status, COVID-19 vaccination and previous symptoms compatible with COVID-19, but multiple regression analysis showed an association only with previous symptoms suggestive of COVID-19. The categories <18 years of age and not applicable for employment status (<16 years) have wide confidence intervals, indicating uncertainty about the true value of the odds ratio; this may also be contributed to by the low participant numbers in these categories. In addition, numbers of vaccinated

participants were small. The high exposure in this population could be linked to the fact that a large proportion are casual labourers who walk up to 15 kilometres daily in search of work and mix with populations in other areas; other groupings were also at risk due to the high population density in the Kibera slum resulting in high likelihood of transmission. The overall seroprevalence in our study is similar to that of women who attended antenatal care services in Nairobi (84.5% vs 85%) at a similar time frame (August 2021 vs October 2021) [21], which was conducted at the national referral hospital close to the Kibera slum. However, in our female population, seroprevalence was only 33.3% in the 18–30 years age group, and 34.9% in the 31–50 years age group, implying the population groups were different and suggesting the need for further investigation. The reasons for low rates of severe disease in this infected population are unknown. Analysis of data from an ongoing population-based infectious disease surveillance platform showed that in Kibera during the COVID-19 period observed (March 2020–December 2021) all-cause mortality was slightly lower with no significant change in mortality due to leading specific causes of death [34].

Several explanations have been proposed for the overall low reported morbidity and mortality from COVID-19 in Africa despite high infection rates, including the high infectious disease burden on the African continent, demographic age structure [35,36,37,38,39] and underreporting due to limited testing and lack of access to healthcare services [8]. An integrative review concluded that low COVID-19 mortality and morbidity in Africa was largely a result of the combined effect of the younger African population and underreporting of COVID-19 cases [40], although the protective effect of a younger population has been questioned [8]. In our study, the number of participants age >50 years was low (16%) which may also have contributed to the lower rate of severe disease in this population. Genetic factors may also explain the diversity observed in severity of COVID-19 in African populations due to single nucleotide polymorphisms (SNPs) within the SARS-CoV-2 receptor genes; these have been demonstrated to have both detrimental and protective effects across ethnic groups [41]. Indeed, the population of Kibera represents a variety of the ethnic groups found in the eastern Africa region.

According to the United Nations, over 1 billion slum dwellers worldwide are mostly confined to three regions, one being sub-Saharan Africa [42]. For residents of urban slums, the difficulty in implementing COVID-19 preventive measures due to severe overcrowding was recognised early [43,44] but the predicted high caseload and mortality rates from community transmission were not apparent, especially in Africa's slums [45,46,47]. This study supports seroprevalence studies in urban slums outside Africa that showed high exposure to the virus as well as low morbidity, with differing associated factors.

Malani *et al* in a comparative study of slum and non-slum areas in Mumbai, India, showed markedly higher proportions of positive tests in slum areas (54.1%) than in non-slum areas (16.1%), with lower infection fatality in slums (0·076%) than in non-slums (0·263%) [48]. Nirala *et al* in a study across 10 different slums in Patna, India, found a seropositivity rate of 31.5% (95% CI: 27.9–35.1) with seropositive status significantly associated with age 18–30 years, male gender, high-risk occupations (autorickshaw drivers, rickshaw pullers, street vendors), below poverty line economic status, residing in a hut or kutcha house (makeshift dwelling) and COVID-like symptoms in the preceding one month [4949]. A study by Raqib *et al* comparing slum and non-slum areas in Bangladesh showed seroprevalence was positively associated with limited years of formal education (AOR = 1.61; 95% CI = 1.43, 1.82), lower income (AOR = 1.23; 95% CI = 1.03, 1.46), overweight (AOR = 1.2835; 95% CI = 1.26, 1.97), diabetes (AOR = 1.67; 95% CI = 1.21, 2.32) and heart disease (AOR = 1.38; 95% CI = 1.03, 1.86) [50]. However, in a study by George *et al* in a large slum in South India with a reported overall COVID-19 seroprevalence of 57.9% (95% CI 53.4–62.3), age, education, occupation and presence of reported co-morbidities were not significantly associated with seroprevalence [51]. The discrepancies between high seroprevalence, low morbidity and varying underlying factors suggest the need for further research to understand the potential protective factors and immune responses that may be at play in these informal settlements. The informal community in our study may have distinct characteristics that sets it apart from other slum populations examined in previous research including genetic variability. Factors such as community resilience, social support networks and environmental conditions may vary from place to place and could play a role in mitigating the impact of COVID-19 and influencing the observed lack of associations with reported risk factors.

Co-morbidities associated with severe COVID-19 have also been examined in other populations. Martono Fatmawati *et al* reviewed nine studies from Asia and Europe that showed risk factors for severe COVID-19 included age, gender, chronic comorbidities, cardiovascular disease, diabetes, hypertension, kidney failure, cancer and a history of smoking [52]. Wang *et al* using self-reported data from a survey of adults in the United States reported that individuals with underlying health conditions were more likely to become infected with SARS-CoV-2 and have more severe post-infection symptoms [53]. Kompaniyets *et al* in a cross-sectional study of children age ≤18 years in the United States reported underlying health conditions, such as type 1 diabetes, cardiac and circulatory congenital anomalies and obesity, were more associated with severe COVID-19 or death [54]. Costa *et al* in a review of published data up to June 2020 reported patients with metabolic disorders including obesity, diabetes,

cardiovascular disease and liver disease faced a higher risk of SARS-CoV-2 infection and were associated with a significantly worse outcome [55]. Wu *et al* in a review of published papers up to April 2020 reported diabetes increased the mortality of patients with COVID-19 [56]. However, the findings from our study challenge the assumptions that COVID-19 risk factors are necessarily linked to severity of disease. Males have also been reported to be at higher risk of severe illness and increased mortality than females [57,12]; this was also not evident in our study.

Our study also explored the use of small blood volume samples collected through fingerprick. We found fingerprick sampling a convenient and acceptable way of conducting a serosurvey across a large population that included small children, and for evaluating new technologies. Testing kits used for serosurveys should therefore ideally use whole blood or plasma separated from capillary blood. Our study used three tests concurrently to detect antibodies to SARS-CoV-2: one rapid test and two ELISA tests. Since the start of the COVID-19 pandemic, molecular testing for SARS-CoV-2 virus using RT-PCR-based assays performed on respiratory specimens has been central to disease management and control [14]. Tests for SARS-CoV-2 antigens on clinical specimens using immunoassays and rapid tests have also been used but are limited by sub-optimal sensitivity [58,59]. Molecular and antigen tests are constrained by detection of virus to a few days before infection and a short time after infection. In a systematic review of longitudinal studies of RT-PCR test results in symptomatic SARS-CoV-2 infections, the highest percentage of virus detection in nasopharyngeal swabs by PCR was 89% between 0 and 4 days post-symptom onset, dropping to 54% (95% CI 47 to 61) after 10–14 days [60]. Tests for detecting antibodies to SARS-CoV-2 applicable outside research laboratory settings include rapid tests using lateral flow immunology and ELISA tests. In a study by Guo *et al* using an ELISA based on recombinant viral nucleocapsid protein, the median time to IgM and IgA antibody detection after symptom onset was 5 (IQR 3–6) days, while IgG was detected at 14 (IQR 10–18) days [61]. Zhao *et al*, using an ELISA prepared from recombinant antigen containing the receptor binding domain of SARS-CoV-2 spike protein, reported median times from symptom onset to total antibody, IgM and IgG seroconversion were 11, 12 and 14 days, respectively [62]; the presence of antibodies was <40% among patients within 1 week of onset, and rapidly increased to 100% (total antibody – 94.3% (IgM), 79.8% (IgG)) by day 15 after onset; there were also negative antibody findings in 7% patients, possibly due to blood samples not taken at an appropriate time after symptom onset. In a report by Qu *et al* using a IgG/IgM chemiluminescent immunoassay with combined nucleocapsid protein and spike glycoprotein antigens, seroconversion time of IgG antibody was earlier than that of IgM antibody: 97.6% of patients (40/41) were positive with IgG

and 87.8% (36/41) with IgM, with a median time of seroconversion for IgG at 11 days (8–16 days) and for IgM at 14 days (8–28 days) after disease onset. The level of IgG antibody reached the highest concentration on day 30, while the highest concentration of IgM antibody appeared on day 18 but then began to decline [63]. Hoffman *et al* found no statistical difference between testing samples taken from PCR-confirmed COVID-19 cases between 9 and 17 days and 18 and 29 days for either IgM or IgG seropositivity [64]. Generally, IgM is produced first with a later switch towards IgG production, but studies on SARS-associated coronaviruses suggest that IgM and IgG often develop at around the same time [65,66]. In general, detection of antibodies is better in samples taken >14 days after onset of disease, due to the time taken for antibody development [67,68]. Reported duration of antibody after natural confirmed infection is variable, including >6 months [69], up to 20 months in unvaccinated adults in the United States after confirmed COVID-19 infection [70], and more than 2 years in patients in Wuhan, China [71]. It is therefore probable that most natural infections occurring within the previous 16 months in our study population were detected, although the relevance of the IgM and IgG antibody findings is unclear.

Serologic studies that assess prior infection and immunity to infectious diseases are essential for epidemiologic studies, ongoing surveillance, vaccine studies and potentially for risk assessments of healthcare workers, and provide an indication of previous as well as recent exposure in a population. Surveillance therefore remains fundamental to understanding the evolution of SARS-CoV-2 infection, the risk factors for severe disease, and the impact of vaccination and public health and social measures [72]. Although hospital admissions and severe outcomes from COVID-19 have substantially decreased since the start of the pandemic, COVID-19-related deaths remain substantial: in the United States, COVID-19 still ranks as the 10th most common cause of death. The percentage of positive tests for SARS-CoV-2, a key indicator of community spread, reached peak levels of 12.9% in January 2024 [73]. Since disease mitigation measures implemented in many countries severely affected the global economy and financial markets [74], and substantially impacted the inadequately prepared health systems in Africa [75], health systems need to be vigilant of emerging SARS-CoV-2 variants and the possibility of new surges in cases and deaths. As WHO recommends countries transition from emergency mode to managing COVID-19 alongside other infectious diseases, providing a more complete picture of the total number of people infected with SARS-CoV-2 remains an important measure for guiding public health responses [76]. The recent establishment of a global network to detect and monitor novel coronaviruses of public health importance will facilitate early detection, risk assessment, and response to coronavirus-related health

challenges [77]. Well-designed surveillance systems remain core to monitoring acute viral respiratory infections to inform public health measures, health system capacities, impact of vaccination programmes and other control measures [78].

Conclusions

This study reports high SARS-CoV-2 exposure in a slum community in Nairobi, Kenya, with limited morbidity; only recent COVID-19 symptoms were a significant independent predictor of seropositivity. This study confirms other reports of high SARS-CoV-2 exposure with limited morbidity in slum communities. The study also supports the convenient use of small blood volumes for conducting population serosurveys. Use of serological assays to conduct seroprevalence studies will continue to remain important as more robust tests are developed, especially point of care tests. Public health systems would greatly benefit from serosurveillance to supplement and strengthen existing COVID-19 and other case-based infectious disease surveillance strategies [79].

Study limitations

This study was conducted during the working week during working hours, which may explain the low number of male participants of working age and low number of those formally employed. The tests used were limited by availability of approved tests at the time.

Author contributions

Conceptualisation: JYC, SK, SM, JM, JO; Methodology: JYC, SK, SM, SMM, LK, JK, NL, JC, RO, AM; Analysis: JYC, RS, MH; writing—original draft preparation: JYC, RS, MH; writing—review and editing: JYC, SK, JM, SM, SMM, RS, MH, MP, JS, JO. All authors have read and agreed to the published version of the manuscript. JYC is the guarantor.

Patient and public involvement

Patients or the public were not involved in the design, reporting or dissemination plans of our research. Entry to individual households was facilitated through community health volunteers who were formally assigned to these villages.

Ethics statement

Approval for the study was obtained from the Amref Health Africa Ethics and Scientific Review Committee (ESRC), the National Commission for Science, Technology and Innovation (NACOSTI), and the Nairobi Metropolitan Services, Ministry of Health. Verbal permission to conduct the study was obtained from the five area chiefs administering the study villages.

Competing interests

All authors declare they have no competing interests.

Funding

The study was funded by American Tower Corporation, USA. The funder had no role in the study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Data availability

Data are available on reasonable request.

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