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Seroprevalence and risk factors of exposure to COVID-19 in homeless people in Paris, France: a cross-sectional study

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Summary

Background During the COVID-19 lockdown period from March 17 to May 11, 2020, French authorities in Paris and its suburbs relocated people experiencing recurrent homelessness to emergency shelters, hotels, and large venues. A serological survey was done at some of these locations to assess the COVID-19 exposure prevalence in this group.

Methods We did a cross-sectional seroprevalence study at food distribution sites, emergency shelters, and workers' residences that were provided medical services by Médecins Sans Frontières in Paris and Seine-Saint-Denis in the Ile-de-France region. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibody seropositivity was detected by Luciferase-Linked Immunosorbent Assay and Pseudo Neutralization Test. Sociodemographic and exposure related information was collected via a verbal questionnaire to analyse risk factors and associations with various COVID-19 symptoms.

Findings Between June 23 and July 2, 2020, 426 (52%) of 818 individuals recruited tested positive in 14 sites. Seroprevalence varied significantly by type of recruitment site (χ^2 $p < 0.0001$), being highest among those living in workers' residences (88.7%, 95% CI 81.8–93.2), followed by emergency shelters (50.5%, 46.3–54.7), and food distribution sites (27.8%, 20.8–35.7). More than two thirds of COVID-19 seropositive individuals (68%, 95% CI 64.2–72.2; 291 of 426) did not report any symptoms during the recall period. COVID-19 seropositivity was strongly associated with overcrowding (medium density: adjusted odds ratio [aOR] 2.7, 95% CI 1.5–5.1, $p = 0.0020$; high density: aOR 3.4, 1.7–6.9, $p < 0.0001$).

Interpretation These results show high exposure to SARS-CoV-2 with important variations between those at different study sites. Living in crowded conditions was the strongest factor associated with exposure level. This study underscores the importance of providing safe, uncrowded accommodation, alongside adequate testing and public health information.

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Introduction

A nationwide lockdown was implemented in France between March 17 and May 11, 2020, to contain the spread of COVID-19. Important differences in seroprevalence were observed between regions: from only 1–3% in the least affected area (Nouvelle Aquitaine) to 9–11% in Ile-de-France, the region that includes Paris.^{1–3} Differences in professions and living conditions also created uneven COVID-19 exposure risk,^{4–9} with those experiencing homelessness particularly exposed to the disease.

In France, an estimated 900 000 people do not have permanent housing, of which 250 000 are experiencing recurrent homelessness (up to 50 000 in Ile-de-France), up to 10 000 are estimated to be permanently living in the streets in Ile-de-France, with 3500 in Paris.¹⁰ Poor sanitary conditions in shared housing, shelters, and encampments often make COVID-19 prevention measures such as physical distancing and self isolation challenging.¹¹ People experiencing homelessness might have underlying medical conditions that put them at a higher risk of developing

severe illness from COVID-19, and some suffer from substance abuse or mental health issues.^{12,13}

During the nationwide lockdown in France, French authorities (assisted by non-governmental entities) relocated people living in the streets or camps into emergency shelters, usually reassigned hotels, to reduce widespread transmission. Some people were hosted temporarily in large venues such as gymnasiums before reaching these shelters.

Between March and June, 2020, Médecins Sans Frontières provided medical care and hygiene promotion to some of France's relocation venues and to migrant workers' residences, including the provision of PCR-based COVID-19 testing. However, France's true COVID-19 infection rate in this group remained unknown: testing was not uniformly available and many with mild symptoms or asymptomatic infections were never tested. Serological surveys (serosurveys) were considered a surveillance alternative that could help determine the true extent of exposure, map disease distribution, and identify hotspots

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Research in context

Evidence before this study

We searched PubMed, MEDLINE, *medRxiv*, *bioRxiv*, Social Science Research Network, Scopus, and Google Scholar from Jan 1 to Oct 10, 2020, for peer-reviewed articles, preprints, research reports, and grey literature published on the seroprevalence of SARS-CoV-2 antibodies. We used the terms “seroprevalence,” “anti-SARS-CoV-2,” “IgG antibodies,” “covid antibodies” and “homeless,” “precarious housing,” “vulnerable,” “migrant,” “risk factors,” “risks,” “comorbidity,” “underlying condition” and similar terms, in English and French, up to Oct 10, 2020. A few small US-based studies have been done (a clinical description of this group in a safety net hospital, an outbreak investigation in three shelters, and a PCR prevalence study in a single shelter), some mathematical modelling studies (UK, USA) including people who are homeless are available but we found no previous COVID-19 seroprevalence survey in a population of homeless people or otherwise living in precarious housing. In Europe, several seroprevalence surveys were available (in Austria, Belgium, Denmark, France, Iceland, Luxembourg, Spain, and Switzerland) but many were sampled from and generalised their results to the total population, and some were done in only small populations. None of these studies specifically disaggregated analysis to describe the temporarily or chronically homeless, and none included information on potential risk factors, protection factors, or comorbidities. Some surveillance data describing COVID-19 in the homeless was found in the UK (National Health Service) and USA (Centers for Disease Control and Prevention), although testing modalities were unclear (and assumed to be PCR rather than serology). Other

surveillance data from French and European cohorts of homeless people or those living in precarious housing is absent.

Added value of this study

Although evidence has shown the increased risk that homeless people and those living in precarious housing face, this is the first data-driven description of the effect of the pandemic on one of the continent’s most exposed groups during the early days of the outbreak. In Europe, there is a complete scarcity of prevalence data for this group (PCR testing or otherwise), and serosurveys are a particularly useful tool to capture the magnitude of an epidemic in a population. Our study used high-quality, reliable assays, and a statistically robust survey methodology to measure prevalence and characterise this population’s risk factors for disease.

Implications of all the available evidence

Crowded housing potentially posed an enormous risk to vulnerable individuals. The findings of this study can guide European and other governments’ disease control planning; if they can find ways to house people in less crowded, better ventilated spaces, prioritising individual rather than congregate settings, substantial transmission could be avoided. The high asymptomatic seroprevalence underscores the limitations of syndromic surveillance in this group to policy makers, and public health and surveillance measures targeting risk factors such as age and crowded living conditions might be more effective. Future studies in this vulnerable population should assess the potential reinfections and improve knowledge about duration of protective immunity.

in the high-risk group being served by Médecins Sans Frontières.^{14,15} Several national COVID-19 seroprevalence studies have been undertaken in France;^{2,3,9} however, at the time of writing, none have yet focused on those experiencing homelessness despite recommendations from French health authorities.¹⁶ We present results from a serosurvey done to better understand overall exposure and risk factors among the population using sites served by Médecins Sans Frontières in Ile-de-France and to help prepare for subsequent waves of disease.

Methods

Study design and participants

We did a cross-sectional study to assess severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) antibody seropositivity prevalence. Participants were recruited at sites that were provided medical services by Médecins Sans Frontières in Paris and the Parisian suburb of Seine-Saint-Denis, located in the Ile-de-France region.

The inclusion sites were grouped into three categories: (1) food distribution sites (two sites where Médecins Sans Frontières distributed food to anyone attending the service irrespective of their housing situation),

(2) workers’ residences (two sites served by Médecins Sans Frontières hosting migrants without permanent housing who are considered by the French authorities as homeless), and (3) emergency shelters (ten sites that constituted primarily of hotels where homeless people were relocated during the lockdown). Important definitions associated with homelessness and a site location map are provided in the appendix (pp 10, 12).

Recruitment sites were selected on the basis of survey feasibility (structures still open at the time of the survey, security constraints, site managers’ consent). Within each stratum, the sample per site was calculated in proportion to the site’s expected population. Individuals were randomly selected using simple random sampling when resident lists existed, and systematic random sampling otherwise, using a site-specific sampling interval (I; every Ith person in the line at food distribution, or one adult selected at random every Ith room at residential sites). The random assignment number was generated electronically (MS Excel 2010). To ensure the selected person was included, sites were visited several times at different time periods, including on weekends and evenings. In cases of refusal to participate or

See Online for appendix

absence, the initially selected person was replaced by the next person in line or another adult sharing the room.

People younger than age 18 years or unwilling or unable to consent to the study were excluded from participation.

This study was approved by the Médecins Sans Frontières ethics review board (2044) and by the Comité de Protection des Personnes, Ile de France, Paris (20050–62628). All participants provided written informed consent.

Procedures

A verbal questionnaire was administered by a trained interviewer in the participant's first language. Arabic, English, Farsi, French, Portuguese, and Spanish interviews were done in person. The questionnaire covered the following sections: sociodemographic characteristics, COVID-19 signs and symptoms, residency, life during lockdown, and medical history. The recall period for symptoms and dates was 4 months (ie, March 1, 2020). The questionnaire was pre-tested during a pilot phase and adapted accordingly (appendix pp 17–19). Interviews in other languages were interpreted by phone. Responses were recorded electronically via a Kobo Collect form on a cell phone or tablet.

SARS-CoV-2 serological testing was done using the LuLISA (Luciferase-Linked Immunosorbent Assay; Institut Pasteur, Paris) targeting SARS-CoV-2 nucleoproteins (LuLISA N) or Spike proteins (LuLISA S) to detect immunoglobulin (IgG) antibodies, and a Pseudo Neutralization Test (PNT) to detect neutralising antibodies in human serum.^{17,18} We defined seropositivity as a positive result to any of these antibodies. IgG incidence in patients with PCR-positive COVID-19 is 100% when sampled 15 days after symptom onset.¹⁹ LuLISA specificity has been reported to be between 97% and 100%.¹⁹

Samples were collected as whole blood, maintained in cold chain, centrifuged, and serum refrigerated until the tests were carried out, usually within 3 days.

The primary outcome was seropositivity (seroprevalence in the target groups) and the secondary outcomes were symptoms and risk factors associated with seropositivity.

Statistical analysis

A total target sample of 791 was estimated to detect differences by type of site (strata), assuming that the odds of being seropositive were two times higher in the emergency shelters⁷ and food distribution sites, and three times higher in the workers' residences than the modelled estimates for the general population in France of 12%, with an α error of 0.025 and power of 90%.¹

Summary measures of study participants, seroprevalence estimates, and odds ratios (ORs) and adjusted ORs (aORs) with their 95% CI were calculated by location, type of site, and participant characteristics using the Clopper-Pearson method. Sensitivity analyses for seroprevalence estimates were done by type of site and considered assumptions about diagnostic test performance (appendix p 3). Pairwise Pearson correlation tests were also done on IgG values for

all tests (LuLISA S and N, PNT) alongside Cohen's Kappa test to assess concordance.

Sensitivity analysis of the multivariable models was done with Akaike Information Criteria as comparison criteria.

Categorical variables were compared using Pearson χ^2 tests. *p* values less than 0.05 indicated statistical significance.

Univariable logistic regression analysis investigated seropositivity risk factors by type of site and for all sites combined. To adjust for potential confounding, a multivariable logistic regression model was constructed with random intercepts for specific recruitment sites to account for clustering. The significant risk factors identified in univariable regression were selected as independent variables for the multivariable analysis. Variables were grouped into four categories: (1) sociodemographic characteristics (sex, age, employment before lockdown, language), (2) frequency of movement during lockdown (leaving a residence for work or physical activities, use of public transport, and time spent outside), (3) residence crowding (number sharing a bedroom, kitchen, or bathroom, number of close contacts [>15 min at less than 1 m] inside a residence per day), and (4) adhering to prevention guidance (handwashing, mask wearing, physical distancing, cleaning, and general COVID-19-related recommendations). Key interaction terms were explored for effect modification.

In the multivariable model, we combined variables measuring similar constructs into composite variables: (1) for frequency of movement during lockdown, we combined two variables, categorised into three levels (those who never went out, those who rarely or sometimes went out, and those who went out several times per day); (2) for residence crowding, we created a simple cumulative crowding indicator on the basis of information from four variables, taking into account the number of people sharing the room (0, 1, 2–5, and >5 people), sharing a sanitary facility (0, 1–5, and >5 people), sharing a kitchen (0, 1–5, and >5 people), and number of close contacts per day (0, 1–4, 5–10, >10 people), aggregating these into a score consisting of the sum of these levels, recategorised as low (values ≤ 5), medium (values 6–9), and high (values ≥ 10). For example, an individual sharing the room with no other person (level 1), the kitchen and sanitary facilities with one other person (each of level 2), and who reported on average one close contact per day (level 2) would be assigned an indicator value of seven—representing the medium crowding category. Additionally, we included sociodemographic characteristics (sex, age), known close contact to COVID-positive individuals, a temporary stay in a gymnasium setting during the lockdown before moving to a specific site, and the use of tobacco as potential covariates in the model. We did stepwise backwards selection so that only variables with a *p* value of less than 0.05 based on a likelihood ratio test were retained in the final model. Sensitivity analysis details

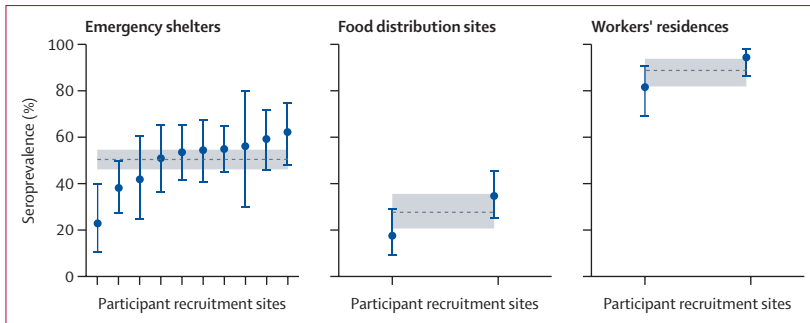


Figure 1: Seroprevalence by type of survey participant recruitment site

Dots in the graph represent seroprevalence point estimates in each study site and vertical lines the 95% CI for the site estimates (ie, extrapolation from those tested to each site's population). Horizontal dashed lines represent the average point estimate per strata (type of recruitment site) and the shadow areas the corresponding 95% CI. Further details regarding seroprevalence by site are presented in the appendix (p 11).

of the multivariable risk factor model are presented in the appendix (appendix pp 3–5).

11 people with uninterpretable serology results were excluded from the analysis. The models excluded individuals with missing data (<5%).

Data were analysed using Stata v.15 software and R (v3.6.2).

Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Overall, 829 people living in 14 facilities were surveyed between June 23 and July 2, 2020, at two food distribution sites, two workers' residences, and ten emergency shelters. Between 10% and 33% of the randomly selected participants were replaced with another participant from the same site due to absence or refusal, probably because of the target group's transient nature, work demands (for those with income-generating opportunities), and the possible confusion between PCR testing and serology testing that might have made some people reluctant to participate. After data cleaning and results consolidation, 818 people (with no duplication) were included in all sites and received serological results from testing (appendix p 11).

Most study participants were men (651 of 818, 80%; 167 women, 20%; sex ratio, 3:9), with no women living in workers' residences. The mean age was 39 years, with half of the population younger than age 35 (401 of 818; 49%). The population recruited at food distribution sites was older than those living in shelters (mean age, 49.0 vs 31.8; $p=0.0011$). Comorbidities were reported for 21% (170 of 818) of participants, most commonly hypertension (68 of 818, 8%) and diabetes (46 of 818, 6%). More than half of the surveyed population reported never smoking (441 of 818, 54%).

Of 818 participants, 124 (15%) were recruited from workers' residences, 543 (66%) from emergency shelters and 151 (18%) from food distribution sites.

Participants recruited at food distribution sites resided in different types of housing: 42% (64 of 151) in their own residence, 26% (39 of 151) in shelters (emergency or other), and 17% (25 of 151) in the streets or in a camp.

Most participants (742 of 818, 91%) were not born in France, and almost a quarter of all participants (186 of 818, 23%) had been residing in France for less than a year. About two thirds (557 of 818, 68%) reported having medical coverage (from the French state system) and almost two thirds (526 of 818; 64%) had a middle school education or lower. Most participants were not working before the lockdown (632 of 818, 77%) except for those surveyed at workers' residences where 60% (74 of 124) had at least some income-generating work before lockdown.

Crowding varied by recruitment site. Workers' residences were the most crowded, with a third (41 of 124, 34%) of participants reported sharing a room with between two and five other individuals and 21% (26 of 124) with more than five individuals. Most participants recruited at emergency shelters shared a room with a second person (309 of 521, 59%), but rarely had to share with more than five individuals (21 of 521, 4%). Nearly half (65 of 151, 43%) of participants recruited from food distribution sites did not share accommodation with anyone (appendix p 13).

More than half of surveyed individuals (426 of 818, 52%) tested positive by any serological test. Seroprevalence varied significantly by type of site ($\chi^2 p<0.0001$; figure 1). It was highest (89%; 95% CI 81.8–93.2) among individuals living in workers' residences, followed by those recruited at emergency shelters (50%; 46.3–54.7), and food distribution sites (28%; 20.8–35.7). Seroprevalence also varied between facilities of the same type: 23–62% in emergency shelters, 18–35% in food distribution sites, and 82–94% in workers' residences. More than a third (37%, 303 of 818) of PNT tests were positive, suggesting that some of the seropositive population might have been protected against COVID-19 at the time of the survey (appendix p 2). Correlation and concordance between the three serology techniques were strong (appendix p 2).

In univariable analysis, seropositivity risk factors were most strongly associated with crowded living conditions, with 4.3 times higher odds of seropositivity (95% CI 2.2–8.4, $p<0.0001$) in those sharing a room with more than five people than those who did not share a room, and 3.1 times higher odds (95% CI 2.0–5.0, $p<0.0001$) in those sharing a bathroom with more than five people than those who did not share (table 1 shows a breakdown by age categories). Seropositivity odds increased with the level of crowding and were much higher for those in medium (OR 3.6, 95% CI 2.0–6.3; $p<0.0001$) and highly crowded (OR 6.7, 3.6–12.5; $p<0.0001$) settings being more likely to test positive than those residing in less crowded settings.

Seropositivity odds were higher among participants who reported a temporary stay in a gymnasium during

lockdown (OR 2.8, 95% CI 1.1–7.2; $p=0.029$; table 1; adjusted (a) OR 3.1, 95% CI 1.2–8.1; $p=0.023$; table 2). There was no significant difference in seropositivity between individuals who, to their knowledge, had close

	Number of seropositive participants	Proportion (95% CI)	OR (95% CI)	p value
Socio-demographic				
Sex				
Male	363/651	56% (51.8–59.6)	1 (ref)	..
Female	63/167	38% (30.4–45.5)	0.5 (0.3–0.7)	<0.0001
Tobacco consumption				
Never smoker	258/441	59% (53.7–63.3)	1 (ref)	..
Previous smoker	40/72	56% (43.4–67.3)	0.9 (0.5–1.5)	0.63
Occasional smoker	38/74	51% (39.4–63.1)	0.7 (0.5–1.2)	0.25
Regular smoker	89/228	39% (32.7–45.7)	0.5 (0.3–0.6)	<0.0001
Residential details				
Type of recruitment site				
Food distribution site	42/151	28% (21.2–35.5)	1 (ref)	..
Workers' residence	110/124	89% (81.8–93.2)	20.4 (10.5–39.4)	<0.0001
Emergency shelter	274/543	50% (46.3–54.7)	2.6 (1.8–3.9)	<0.0001
Change place of residence for confinement				
No	237/468	51% (46–55.3)	1 (ref)	..
Yes	189/350	54% (48.6–59.3)	1.1 (0.9–1.5)	0.34
Transit through gymnasium before or during lockdown				
No	408/794	51% (47.8–54.9)	1 (ref)	..
Yes	18/24	75% (53.3–90.2)	2.8 (1.1–7.2)	0.029
Out of place of residence				
Frequency of leaving place of residence, composite score				
Never	123/192	64% (56.8–70.8)	1 (ref)	..
Sometimes	244/481	51% (46.2–55.3)	0.6 (0.4–0.8)	0.0019
Every day	59/145	41% (32.6–49.2)	0.4 (0.2–0.6)	<0.0001
Time spent outside the residence during confinement				
Never	89/156	57% (48.9–64.9)	1 (ref)	..
Less than 1 h per day	187/349	54% (48.2–58.9)	0.9 (0.6–1.3)	0.46
1–3 h per day	80/161	50% (41.7–57.7)	0.7 (0.5–1.2)	0.19
More than 3 h per day	65/145	45% (36.6–53.3)	0.6 (0.4–1.0)	0.031

(Table 1 continues in next column)

	Number of seropositive participants	Proportion (95% CI)	OR (95% CI)	p value
(Continued from previous column)				
Out of place residence				
Adherence to prevention guidance				
No adherence	40/85	47% (37.6–56.7)	1 (ref)	..
Partial or full adherence	374/707	53% (49.5–56.2)	1.32 (0.84–2.09)	0.10
Close contacts				
Number of close contacts (at <1 m distance for >15 min) inside place of residence, on average, per day				
None	100/226	44% (38.5–50.1)	1 (ref)	..
1–4	218/411	53% (48.7–57.4)	1.4 (1.2)	0.035
5–10	46/84	55% (45.1–64.1)	1.5 (0.9–2.5)	0.10
More than 10	62/97	64% (54.9–72.0)	2.2 (1.4–3.6)	0.001
Number of people sharing the bedroom				
None	73/182	40% (32.9–47.6)	1 (ref)	..
One other person	202/351	58% (52.2–62.8)	2 (1.4–2.9)	<0.0001
2–5	103/192	54% (46.3–60.9)	1.7 (1.1–2.6)	0.0093
More than 5	40/54	74% (60.3–85)	4.3 (2.2–8.4)	<0.0001
Number of people sharing the shower or bathroom				
None	40/122	33% (24.6–41.9)	1 (ref)	..
1–5	235/447	53% (47.8–57.3)	2.3 (1.5–3.5)	<0.0001
More than 5	150/248	60% (54.1–66.6)	3.1 (2.0–5.0)	<0.0001
Number of people sharing the kitchen				
None	84/194	43% (36.2–50.6)	1 (ref)	..
1–5	206/426	48% (43.5–53.2)	1.2 (0.9–1.7)	0.24
More than 5	136/198	69% (61.7–75.1)	2.9 (1.9–4.3)	<0.0001
Aware of anyone in close contacts that had COVID-19				
No	365/708	52% (47.8–55.3)	1 (ref)	..
Yes	56/100	56% (45.7–65.9)	1.2 (0.8–1.8)	0.40
Crowding in place of residence, composite score				
Low crowding	17/72	24% (14.4–35.1)	1 (ref)	..
Medium crowding	265/506	52% (47.9–56.8)	3.6 (2.0–6.3)	<0.0001
High crowding	135/200	68% (60.5–73.9)	6.7 (3.6–12.5)	<0.0001

Data are n/N (%) unless otherwise specified. OR=unadjusted odds ratio.

Table 1: Risk factors for severe acute respiratory syndrome coronavirus 2 seropositivity, univariable analysis

	aOR (95% CI)	p value
Sex		
Male	1 (ref)	..
Female	0.5 (0.4–0.8)	0.0061
Frequency of leaving place of residence, composite score		
Never	1 (ref)	..
Sometimes	0.6 (0.4–0.8)	0.0036
Every day	0.4 (0.2–0.7)	0.0018
Crowding in place of residence, composite score		
Low crowding	1 (ref)	..
Medium crowding	2.7 (1.5–5.1)	0.0020
High crowding	3.4 (1.7–6.9)	<0.0001
Tobacco consumption		
Never smoker	1 (ref)	..
Previous smoker	0.8 (0.4–1.4)	0.35
Occasional smoker	0.8 (0.4–1.3)	0.32
Regular smoker	0.4 (0.3–0.7)	<0.0001
Transit through gymnasium before or during lockdown		
No	1 (ref)	..
Yes	3.1 (1.2–8.1)	0.023
Type of site (recruitment)		
Food distribution site	1 (ref)	..
Workers' residence	12.0 (5.6–25.6)	<0.0001
Emergency shelter	1.7 (1.1–2.7)	0.025

aOR=adjusted odds ratio.

Table 2: Risk factors for severe acute respiratory syndrome coronavirus 2 seropositivity, multivariable analysis

contacts who had previously had COVID-19 (OR 1.2, 95% CI 0.8–1.8; p=0.40). Lower risk of exposure was primarily associated with more frequent movement during lockdown, with significantly lower odds of infection among those who left the residence sometimes (OR 0.6, 95% CI 0.4–0.8; p=0.0019) or several times daily (OR 0.4, 0.2–0.6; p<0.0001). The risk of seropositivity was also lower in regular smokers than those who never smoked (OR 0.5, 95% CI 0.3–0.6; p<0.0001). We did not find evidence that participants reporting adherence to COVID-19 prevention measures had higher prevalence of SARS-CoV-2 antibodies than those not adhering (OR 1.3; 95% CI 0.8–2.1; p=0.27).

The multivariable model is adjusted for sex, frequency of leaving the place of residence, crowding in place of residence, tobacco consumption, transit through gymnasium before or during lockdown, and type of recruitment site. In the multivariable analysis, the odds of seropositivity increased with crowding (medium composite indicator: aOR 2.7, 95% CI 1.5–5.1, p=0.0020; high composite indicator: aOR 3.4, 1.7–6.9, p<0.0001). Seropositivity odds were 12.0 times higher (aOR 12.0, 95% CI 5.6–25.6; p<0.0001) for those in workers' residences, and 1.7 times higher (aOR 1.7, 1.1–2.7; p=0.025) for those in emergency shelters than for those in food distribution sites. Seropositivity odds were lower in people who moved out of their place of residence

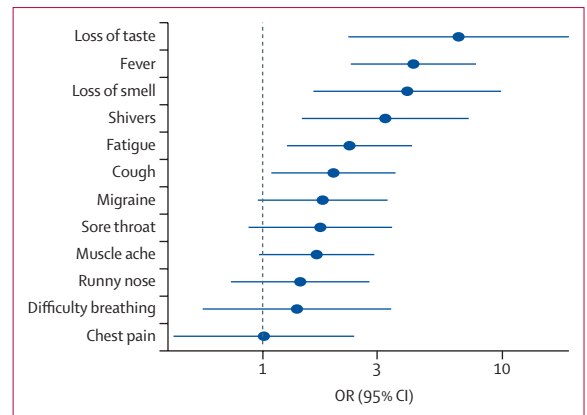


Figure 2: Association of self-reported symptoms (strong vs mild or none) with seropositivity

The original symptoms are presented in the appendix (pp 15–16). OR=unadjusted odds ratio.

several times daily than for those who never left (aOR 0.4, 95% CI 0.2–0.7; p=0.0018), in regular smokers compared to those who never smoked (aOR 0.4, 0.3–0.7; p<0.0001), and among women (aOR 0.5, 0.4–0.8; p=0.0061).

291 of 426 seropositive individuals (68%, 95% CI 64.2–72.2) did not report any symptoms during the recall period (implying a high proportion of asymptomatic infections). However, six of 12 COVID-19 symptoms were significantly associated with seropositivity (figure 2), including loss of taste (OR 6.6, 95% CI 2.3–18.9; p<0.0001), fever (OR 4.3, 2.3–7.8; p<0.0001), loss of smell (OR 4.0, 1.6–9.9; p=0.0038), shivering (OR 3.2, 1.5–7.2; p=0.0042), fatigue (OR 2.3, 1.3–4.2; p=0.0071), and cough (OR 2.0, 1.1–3.6; p=0.033). 25 (11%) of 238 participants with symptoms (135 seropositive and 103 seronegative) reported having received a previous COVID-19 test (PCR), nine had a positive result and seven were admitted to COVID-19 treatment centres.

Sensitivity analysis details on model selection are presented in the appendix (appendix pp 3–5).

Discussion

To the best of our knowledge, this study is the first in Europe to evaluate SARS-CoV-2 exposure in those temporarily or chronically experiencing homelessness (or otherwise living in precarious housing) during the first months of the COVID-19 pandemic. In Ile-de-France, many of these people were not born in the country, could have been undocumented, might not speak French, and might not have access to the same information or state medical services as the rest of the population. Although their access to care was beyond the scope of this survey, understanding the risk and needs of this group is crucial to containing the spread of the pandemic.

Our results show high exposure to COVID-19, with important variability between some sites and groups. They also underscore the danger that overcrowded living situations pose. On the other hand, individuals' frequency

of leaving their residence during lockdown was the most important determinant of protection, possibly due to time spent outdoors under these circumstances (lockdown) and away from indoor exposure to infected people.

Several studies have attempted to estimate the risk of infection in similar populations living in precarious conditions. However, most of the evaluations have estimated prevalence of active infection on the basis of PCR testing, with no study available to our knowledge capturing cumulative exposure measured through the presence of antibodies against SARS-CoV-2, in similar populations. These studies have consistently shown high prevalence of active infection and pointed towards overcrowding and sharing of living spaces as the main risk factors for infection.^{6,7,20} Our findings show much higher seroprevalence compared with the general population, as reported by population-based surveys, which ranged between 9% and 11% in Ile-de-France in May, 2020.^{2,3,9}

The prevalence of asymptomatic or subclinical infections (up to 68%) in a younger population is consistent with other studies^{6,7,21,22} but this fact combined with the very high exposure ratio, calls into question the utility of surveillance measures that only identify symptomatic cases and their contacts. Additional explanations might include difficulties in recalling symptoms and problems of selection, with previously symptomatic individuals potentially less willing or available to participate.

Overcrowded housing conditions, whether long term or as temporary emergency measures, carry risks during an infectious disease outbreak that should be weighed against the risks of remaining unsheltered. The extent to which these risks can be mitigated in areas of high prevalence, by using masks and hand hygiene in crowded living environments, remains uncertain. In Europe and North America, overcrowding is defined as more than a single person or couple per habitable room.²³ Single-room accommodation and heightened infection prevention methods are important strategies to prevent COVID-19 deaths in homeless populations.²⁴

Our study has several limitations. First, the cross-sectional design makes it extremely difficult to determine when or where participants became seropositive. Additionally, some studies have reported stable antibody concentrations within the first 3 months of recovery,²⁵ whereas others have shown a rapid decrease regardless of disease severity between 3 months and 6 months,²⁶ or after 6 months.²⁷ Therefore, some participants could potentially have tested seronegative despite having been infected before the survey. Previous evaluation of LuLISA tests have shown very high sensitivity and specificity.^{18,19} However, these estimates could be revised in the future when results of other evaluation studies become available. Although we cannot exclude misclassification of some tested samples, our sensitivity analysis showed that even assuming a diagnostic test sensitivity or specificity as low as 70%, seroprevalence estimates by site type remained high (appendix p 3).

The study sites were not randomly selected but were a convenience sample from locations where Médecins Sans Frontières provided medical services during the first wave of the pandemic. Practical considerations such as the survey team's access to a facility and security constraints also affected site selection. Generalising these results to other similar populations (in France or elsewhere) is therefore inappropriate. Participant selection within study sites could have been biased by the relatively high replacement rate (up to a third of individuals) due to absence or refusal to participate. Initially selected individuals could have plausibly been unavailable because of more frequent movement outside of their residence, or those who had previously been tested might have been more likely to refuse to participate. The expected number recruited per site was not always achieved, thus some site types were overrepresented or under-represented. However, crude and weighted prevalence estimates (by initial sampling probability) did not vary substantially (appendix p 11).

Information bias could have also affected results, since questions related to the participants' living conditions, COVID-19 symptoms, or adherence to prevention measures were self-reported. Social desirability bias could also have affected answers (especially when discussing lockdown adherence and prevention measures). Our efforts to mitigate information bias included the use of pre-tested questionnaires, robust training of the study team, and the use of translators to put interviewees more at ease and communicate in their preferred language.

In conclusion, we found high prevalence of exposure to COVID-19 in a population living in precarious conditions in Paris. The main factor associated with the risk of exposure was living in overcrowded conditions; therefore, adequate housing avoiding overcrowding should be provided to people who are homeless or living in precarious housing to reduce the risk of infection with SARS-CoV-2 and developing COVID-19. This is especially important among those with conditions or comorbidities that could entail risk of severe disease along with the implementation of adequate testing strategies, infection prevention and control measures, and public health messaging. Finally, the scarce data demands more detailed epidemiological studies of similarly susceptible groups. Incorporating qualitative information might be particularly useful; however, much more can be done to properly protect those who are unable to safely isolate during a government mandated lockdown.

Contributors

TR, BM, CV, AEL, FJL, WH, CT, and EF conceived the study (developed the research hypothesis, determined the study design, carried out and discussed sampling strategy and sample size calculations). TR, BM, ES, AEL, FJL, JV, EF, and CM developed the study protocol. TR, BM, and CV performed field data collection (blood samples and data questionnaires) and supervised the field study. JV, FA, and SG did the laboratory analyses (serology tests) and JV, FA, SG, BN, FJL, and TR contributed to their interpretation. TR and BN managed the data and did the statistical data analysis. RN, TR, BM, AEL, and FJL did the literature search for the manuscript. BN and TR verified the underlying

data and did additional analyses. All authors interpreted the results, contributed to writing the manuscript, and approved the final version for submission. All authors had full access to all of the data in the study and accept responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests. The Total Foundation provided a broad use grant to Institut Pasteur for COVID-19 research, which funded in part laboratory expenses for this study. The Total Foundation did not contribute to the conception of the study or to the interpretation of results.

Data sharing

Anonymised data collected for the study and a data dictionary will be made available to other researchers following approval of a study proposal by TR (thomas.roederer@epicentre.msf.org) for 5 years from publication. The study protocol, statistical analysis plan, and informed consent forms are also available from TR.

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References

- Salje H, Tran Kiem C, Lefrancq N, et al. Estimating the burden of SARS-CoV-2 in France. *Science* 2020; **369**: 208–11.
- Carrat F, de Lamballerie X, Rahib D, et al. Seroprevalence of SARS-CoV-2 among adults in three regions of France following the lockdown and associated risk factors: a multicohort study. *medRxiv* 2020; Sept 18. <http://medrxiv.org/lookup/doi/10.1101/2020.09.16.20195693> (preprint).
- Le Vu S, Jones G, Anna F, et al. Prevalence of SARS-CoV-2 antibodies in France: results from nationwide serological surveillance. *medRxiv* 2020; Oct 21. <https://doi.org/10.1101/2020.10.20.20213116> (preprint).
- Iversen K, Bundgaard H, Hasselbalch RB, et al. Risk of COVID-19 in health-care workers in Denmark: an observational cohort study. *Lancet Infect Dis* 2020; **20**: 1401–08.
- Houlihan CF, Vora N, Byrne T, et al. Pandemic peak SARS-CoV-2 infection and seroconversion rates in London frontline health-care workers. *Lancet* 2020; **396**: e6–7.
- Karb R, Samuels E, Vanjani R, et al. Homeless shelter characteristics and prevalence of SARS-CoV-2. *West J Emerg Med* 2020; **21**: 1048–53.
- Baggett T, Keyes H, Sporn N, et al. Prevalence of SARS-CoV-2 infection in residents of a large homeless shelter in Boston. *JAMA* 2020; **323**: 2191–92.
- Middleton J, Reintjes R, Lopes H. Meat plants—a new front line in the Covid-19 pandemic. *BMJ* 2020; **370**: m2716.
- Warszawski J, Bajos N, Meyer N, et al. Epidemiology and living conditions associated with Covid-19 (The EpiCov survey). 2020. <https://drees.solidarites-sante.gouv.fr/IMG/pdf/er1167-en.pdf> (accessed Jan 13, 2021).
- Fondation Abbe Pierre. L'État du mal-logement en France 2020. https://www.fondation-abbe-pierre.fr/documents/pdf/reml2020_rapport_complet_web.pdf (accessed Jan 13, 2021).
- Lima NNR, de Souza RI, Feitosa PWG, et al. People experiencing homelessness: their potential exposure to COVID-19. *Psychiatry Res* 2020; **288**: 112945.
- Tsai J, Wilson M. COVID-19: a potential public health problem for homeless populations. *Lancet Public Health* 2020; **5**: e186–87.
- Fazel S, Geddes JR, Kushel M. The health of homeless people in high-income countries: descriptive epidemiology, health consequences, and clinical and policy recommendations. *Lancet* 2014; **384**: 1529–40.
- Peeling RW, Olliaro PL. The time to do serosurveys for COVID-19 is now. *Lancet Respir Med* 2020; **8**: 836–38.
- Eckerle I, Meyer B. SARS-CoV-2 seroprevalence in COVID-19 hotspots. *Lancet* 2020; **396**: 514–15.
- Suzie D. Haute Autorité de Santé: Place des tests sérologiques dans la stratégie de prise en charge de la maladie COVID-19. 2020. https://www.has-sante.fr/upload/docs/application/pdf/2020-05/rapport_indications_tests_serologiques_covid-19.pdf (accessed Jan 26, 2021).
- Goyard S, Balbino B, Chinthrajah RS, et al. A highly sensitive bioluminescent method for measuring allergen-specific IgE in microliter samples. *Allergy* 2020; published online May 14. <https://doi.org/10.1111/all.14365>.
- Grzelak L, Temmam S, Planchais C, et al. A comparison of four serological assays for detecting anti-SARS-CoV-2 antibodies in human serum samples from different populations. *Science Transl Med* 2020; **12**: eabc3103.
- Anna F, Goyard S, Lalanne AI, et al. High seroprevalence but short-lived immune response to SARS-CoV-2 infection in Paris. *Eur J Immunol* 2020; published online Dec 1. <https://doi.org/10.1002/eji.202049058>.
- Schrooyen L, Delforge M, Lebout F, et al. Homeless people hospitalized with COVID-19 in Brussels. *Clin Microbiol Infect* 2021; **27**: 151–52.
- Feaster M, Goh Y-Y. High proportion of asymptomatic SARS-CoV-2 infections in 9 long-term care facilities, Pasadena, California, USA, April 2020. *Emerg Infect Dis* 2020; **26**: 2416–19.
- Lechien JR, Chiesa-Estomba CM, Place S, et al. Clinical and epidemiological characteristics of 1420 European patients with mild-to-moderate coronavirus disease 2019. *J Intern Med* 2020; **288**: 335–44.
- WHO. WHO housing and health guidelines. Geneva: World Health Organization, 2018.
- Lewer D, Braithwaite I, Bullock M, et al. COVID-19 among people experiencing homelessness in England: a modelling study. *Lancet Respir Med* 2020; **8**: 1181–91.
- Gudbjartsson DF, Norddahl GL, Melsted P, et al. Humoral immune response to SARS-CoV-2 in Iceland. *N Engl J Med* 2020; **383**: 1724–34.
- Ibarrondo FJ, Fulcher JA, Goodman-Meza D, et al. Rapid decay of anti-SARS-CoV-2 antibodies in persons with mild Covid-19. *N Engl J Med* 2020; **383**: 1085–87.
- Robbiani DF, Gaebler C, Muecksch F, et al. Convergent antibody responses to SARS-CoV-2 in convalescent individuals. *Nature* 2020; **584**: 437–42.