The effect of social deprivation on the dynamic of SARS-CoV-2 infection in France:

Stephanie Vandentorren, Sabira Smaili, Edouard Chatignoux, Marine Maurel, Caroline Alleaume, Lola Neufcourt, Michelle Kelly-Irving, Cyrille Delpierre

The effect of social deprivation on the dynamic of SARS-CoV-2 infection in France: a population-based analysis

Stéphanie Vandentorren, Sabira Smaïli*, Edouard Chatignoux, Marine Maurel, Caroline Alleaume, Lola Neufcourt, Michelle Kelly-Irving, Cyrille Delpierre*

Summary

Background Data on health inequalities related to the dynamic of SARS-CoV-2 infection in France are scarce. The aim of this study was to analyse the association between an area-based deprivation indicator and SARS-CoV-2 incidence, positivity, and testing rates between May 2020 and April 2021.

Methods We analysed data reported to the Système d'Information de Dépistage Populationnel surveillance system between May 14, 2020 and April 29, 2021, which records the results of all SARS-CoV-2 tests in France. Residential addresses of tested individuals were geocoded to retrieve the associated aggregated units for the statistical information (IRIS) scale, corresponding to an area comprising 2000 inhabitants relatively homogenous in terms of socioeconomic characteristics. A social deprivation score was assigned to each area using the European Deprivation Index (EDI). We fitted negative binomial generalised additive models to model the age-standardised and sex-standardised ratios for SARS-CoV-2 incidence, positivity rates, and testing rates, and to estimate incidence rate ratios (IRRs) and 95% CIs of their association with EDI quintiles, using the first quintile (least deprived) as the reference category, adjusted for week, population density, and region.

Findings Analyses were based on 70 990 478 SARS-CoV-2 tests, of which 5 000 972 were positive. SARS-CoV-2 incidence was higher in the most deprived areas than the least deprived areas (IRR 1·148 [95% CI 1·138–1·158]) and positivity rates were also higher (IRR 1·283 [1·273–1·294]), whereas testing rates were lower in the most deprived areas than the least deprived areas (IRR 0·905 [0·904–0·907]). SARS-CoV-2 incidence and positivity rates remained higher in the most deprived areas than the least deprived areas during the second and third national lockdowns, and variation in testing rate was observed according to population density.

Interpretation Our results highlight a positive social gradient between deprivation and the risk of testing positive for SARS-CoV-2, with the highest risk among individuals living in the most deprived areas and a negative social gradient for testing rate. These findings might reflect structural barriers to health-care access in France and lower capacity of deprived populations to benefit from protective measures.

Funding None.

Lancet Public Health 2022; 7: e240–49

Published Online February 14, 2022 https://doi.org/10.1016/S2468-2667(22)00007-X

See Comment page e204

*Contributed equally

Santé Publique France, Saint-Maurice, France (S Vandentorren PhD, S Smaïli MSc, E Chatignoux MSc, C Alleaume MSc); **University of Bordeaux, INSERM UMR 1219–Bordeaux Population Health, Bordeaux, France** (S Vandentorren); **CERPOP UMR 1295** (M Maurel MSc, L Neufcourt PhD, M Kelly-Irving PhD, C Delpierre PhD) **and IFERISS** (M Kelly-Irving), **Université Toulouse III Paul Sabatier, INSERM, Toulouse, France**

Correspondence to: Dr Stéphanie Vandentorren, Santé Publique France, Saint-Maurice 94415, France **stephanie.vandentorren@santepubliquefrance.fr**

Introduction

The COVID-19 health crisis has exacerbated existing social inequalities.[1,2] People who are socially deprived have a disproportionately greater risk of SARS-CoV-2 infection, of developing severe COVID-19, and COVID-related mortality.[3,4] The underlying mechanisms for this increased risk include differential exposure to the virus, greater susceptibility to infectious diseases and associated complications, and unequal access to care.

The social-residential environment can affect the differential exposure to the virus, especially high population densities and overcrowded housing. The social-residential environment can also influence the differential frequency of comorbidities such as diabetes, hypertension, or overweight and obesity, which are more prevalent among people who reside in deprived residential areas.

The first studies in New York showed that inequality in COVID-19 incidence was strongly associated with occupation, which itself is strongly correlated with gender and racial inequalities.[5,6] Lockdowns increased inequalities because people working in front-line jobs, such as essential retail, delivery, and health-care workers were unable to work from home. People at high risk of exposure were those in close contact with patients or with the public.[7]

Such inequalities have been identified in several countries, including some with universal health-care systems. A spatial analysis of the spread and dynamics of COVID-19 in Europe[8] found that the proportion of older people (aged ≥75 years) in the population, gross domestic product per capita, and the unemployment rate were associated with high COVID-19 mortality rates. Another study in Switzerland showed that people living in more socially advantaged areas were more likely to get tested for SARS-CoV-2, and less likely to test positive, be admitted to hospital or intensive care, or to die from COVID-19 than people living in more deprived areas.[9]

Research in context

Evidence before this study

We searched PubMed, WHO COVID-19, and Cairn databases for articles published in English, Spanish, and French between Jan 1, 2020 and Nov 30, 2021, using the search terms "Health inequalities" (social inequalities, gender inequalities, racial inequalities, territorial inequalities, social deprivation, racial disparities, ethnic disparities, differentials, socioeconomic status, socioeconomic position)" and "testing" and "COVID-19". Our search yielded 90 relevant articles. Studies have shown that the ongoing COVID-19 health crisis has exacerbated existing social inequalities in many countries, including some with universal health-care systems. People who are socially deprived have a disproportionately greater risk of SARS-CoV-2 infection, of developing severe COVID-19, and death. The underlying mechanisms for this increased risk include differential exposure to the virus, greater susceptibility to infectious diseases and associated complications, and unequal access to care. However, data on health inequalities in the context of SARS-CoV-2 infection in a country with a strong health-care system such as France remain scarce. No studies have investigated the temporal dynamics of SARS-CoV-2 incidence, positivity, and testing rates at the national level in terms of social inequalities since the pandemic started in France.

Added value of this study

We found that the incidence of SARS-CoV-2 infection and positivity rates were higher, whereas testing rates were lower, in the most socially deprived areas when compared with the least deprived areas. After adjustment for population density, we also highlighted the influence of population density on the risk of infection at the municipality level. These differences were especially marked in densely populated areas and to a lesser extent, in moderately populated areas. By contrast, the incidence of SARS-CoV-2 was lower in sparsely or very sparsely populated municipalities across all levels of deprivation and the positivity rate remained stable by level of deprivation. Our results showed that the differential rate of outcomes between the most and the least deprived areas changed over time according to changes in the measures implemented by the French Government to manage the pandemic, particularly lockdowns. To our knowledge, this is the first study to assess the dynamics of the SARS-CoV-2 pandemic in France in terms of social deprivation using a national COVID-19 surveillance database.

Implications of all the available evidence

Our findings highlight the need to account for deprivation and other social determinants to adapt strategies and reduce transmission (eg, accessibility of testing or promotion of SARS-CoV-2 vaccines). In the context of increased social inequalities during the current pandemic, our results might encourage health authorities to address these issues more rapidly. Without the consideration of social inequalities, any national prevention policies implemented in response to the pandemic are likely to increase inequalities.

In France, the test, trace, isolate strategy was initiated on May 11, 2020. SARS-CoV-2 RT-PCR diagnostic tests were provided free of charge and without need for prescription. The first national lockdown and closure of schools were implemented between March 17 and May 3, 2020, followed by a second, less stringent lockdown between Oct 29 and Dec 14, 2020, during which schools remained open. The third lockdown from April 3 to May 2, 2021, included reintroduction of public health measures (ie, closure of commerce, curfews, no moving between regions, and teleworking) and school closures, but was less stringent than the second lockdown. Initial studies from France showed that the risk of SARS-CoV-2 infection during the first wave (March to May, 2020) was highest among health-care professionals who had direct physical contact with patients or the general public.[10] Seroprevalence was twice as high in the most socially deprived neighbourhoods of cities, and among people living in collective housing in closed establishments (eg, shelters) and in overcrowded housing.[11] The paucity of data on individual social characteristics in medical records and in surveillance system databases in France makes it difficult to rapidly monitor the evolution of the pandemic with regard to socioeconomic characteristics in the general population.[12] To date, the only available data are from ad-hoc surveys such as the EpiCOV study,[13] which assessed the evolution of social disparities in infection during the early stages of the pandemic and during the first and second lockdowns (from mid-March to early June 2020) in France.[14] Real-time data on the social pattern and dynamics of SARS-CoV-2 infection are not available.

Few international studies[15] have investigated the temporal dynamics of SARS-CoV-2 incidence at the national level in terms of social inequalities since the start of the COVID-19 pandemic. In France, no large-scale studies have investigated social inequalities in relation to prevention policies such as lockdown measures during the COVID-19 pandemic. We aimed to assess the association between neighbourhood social deprivation and SARS-CoV-2 incidence, test positivity rates, and testing rates between May, 2020 and April, 2021 in France.

Methods

Data sources

In this population-based analysis, we used data from the Système d'Information de Dépistage Populationnel (SIDEP) surveillance system, implemented on May 13, 2020. SIDEP is a secure platform that records all SARS-CoV-2 RT-PCR and antigen test results from laboratories, hospitals, pharmacies, nurses, and

For more on **SIDEP** see https://www.aphp.fr/actualite/le-systeme-dinformation-de-depistage-populationnel-si-dep-opere-par-lap-hp-evolue-pour

physicians across France. Information is also collected on sex, age, residential address, and postcode.

An external partner (Etalab) geocoded residential addresses (appendix p 2) to retrieve the associated aggregated units for the statistical information (IRIS) scale, corresponding to an area comprising 2000 inhabitants who are relatively homogenous in terms of socioeconomic characteristics. Hereafter, these units are referred to as areas.

Access to information was controlled and SIDEP data were obtained in accordance with privacy laws (General Data Protection Regulation [EU] 2016/679).

We collected data between May 14, 2020 and April 29, 2021. We used aggregated weekly data counts for analysis. We excluded notifications with missing data on age and sex (appendix p 3).

Outcomes

We computed incidence, positivity, and testing rates in each area *a* and week *w*, stratified by age group and sex, according to group classifications used in the 2017 French population census (0–14, 15–29, 30–44, 45–59, 60–74, ≥75 years).[16] A period of 60 days was used to define two separate SARS-CoV-2 infections in the same person[17,18] to calculate outcomes following the methodology standardised by Santé Publique France (appendix p 3). Incidence, positivity rate, and testing rate were calculated as follows:

$$incidence_{a,w,age,sex} = \frac{\text{number of individuals testing positive in the week for the first time in more than 60 days}}{\text{census population}}$$

$$positivity\ rate_{a,w,age,sex} = \frac{\text{number of individuals testing positive in the week for the first time in more than 60 days}}{\text{number of individuals testing positive or negative who had not tested positive during the previous 60 days}}$$

$$testing\ rate_{a,w,age,sex} = \frac{\text{number of individuals testing positive or negative in the week who had not tested positive during the previous 60 days}}{\text{census population}}$$

Exposure

A social deprivation score was assigned to each area using the European Deprivation Index (EDI; 2015 French version).[19] Scores were calculated as a combination of ten census-based variables aggregated at the area level associated with the individual level of deprivation (proportion of individuals of foreign nationality, proportion of households without a car, proportion of individuals employed as managers or intermediate professionals, proportion of single-parent families, proportion of households with at least two individuals, proportion of non-owner occupied households, proportion of unemployed individuals, proportion of individuals without post-secondary school education, proportion of overcrowded dwellings, and proportion of non-married individuals). Quintiles of the national distribution of EDI scores were computed for metropolitan France, whereby the first quintile (Q1) represents the least deprived areas and the fifth quintile (Q5) represents the most deprived areas.

See Online for appendix

Covariates

Population density was defined at the municipality level according to the definition used by the European Union,[20] which accounts for areas within a municipality where a large number of inhabitants are concentrated in a small area. These densely populated areas are determined by dividing the geographical area into 1 km squares. A densely populated area was defined as a municipality where more than half of the population lives in a single dense area. Population density was categorised into sparsely or very sparsely populated municipalities (>50% of the population living in an area where the density is <300 inhabitants per km²), moderately populated municipalities (>50% of the population living in an area where the density is between 300 and 1500 inhabitants per km²), and densely populated municipalities (>50% of the population living in an area where the density is ≥1500 inhabitants per km²).

Since the region variable might be associated with deprivation and testing for SARS-CoV-2 infection, region was considered as a potential confounder of the association between EDI and SARS-CoV-2 incidence, positivity rates, and testing rates.

Statistical analysis

We imputed missing data on area codes using the postcode of residential addresses (appendix p 2). We used indirect standardisation to compute age-standardised and sex-standardised ratios for each outcome, stratified by area and week using the national rate (by age group and sex) as the reference. To assess the effect of deprivation on the dynamic of SARS-CoV-2 infection, we fitted successive negative binomial generalised additive models[21] to model standardised ratios per week for incidence, positivity rate, and testing rate. We estimated incidence rate ratios (IRRs) with 95% CIs of the association between each outcome and EDI quintiles (Q1 [least deprived] was used as the reference category). We fitted three models: the first model included EDI quintiles and week; the second model included EDI quintiles and week, and was adjusted for population density (sparsely or very sparsely populated [reference category], moderately populated, and densely populated); and the third model, which was fitted to evaluate the interaction between EDI quintiles and

	Total SARS-CoV-2 tests*	Positive SARS-CoV-2 tests†
Total	70 990 478	5 000 972
Sex		
Male	32 109 488 (45·2%)	2 325 793 (46·5%)
Female	38 880 990 (54·8%)	2 675 179 (53·5%)
Age, years		
0–14	7 274 872 (10·2%)	472 596 (9·5%)
15–29	16 316 329 (23·0%)	1 226 357 (24·5%)
30–44	16 038 167 (22·6%)	1 147 898 (23·0%)
45–59	14 364 443 (20·2%)	1 074 509 (21·5%)
60–74	9 923 649 (14·0%)	637 131 (12·7%)
≥75	7 073 018 (10·0%)	442 481 (8·8%)
EDI quintiles		
1 (least deprived)	10 119 377 (14·3%)	664 240 (13·3%)
2	11 309 720 (15·9%)	735 827 (14·7%)
3	11 956 964 (16·8%)	786 892 (15·7%)
4	14 697 932 (20·7%)	982 447 (19·6%)
5 (most deprived)	22 906 485 (32·3%)	1 831 566 (36·6%)
Population density		
Sparsely or very sparsely populated	21 618 005 (30·5%)	1 426 416 (28·5%)
Moderately populated	20 430 947 (28·8%)	1 413 811 (28·3%)
Densely populated	28 941 526 (40·8%)	2 160 745 (43·2%)

Data are n (%). Data relate to the period May 14, 2020 to April 29, 2021. Counts might include multiple tests for the same individual. EDI=European Deprivation Index. *Cumulative total of individuals who tested positive or negative for SARS-CoV-2 in a week who had not tested positive in the previous 60 days. †Cumulative total of individuals who tested positive for SARS-CoV-2 in a week who had not tested positive in the previous 60 days.

Table: **Distribution of total SARS-CoV-2 tests and positive tests by age, sex, EDI quintile, and population density**

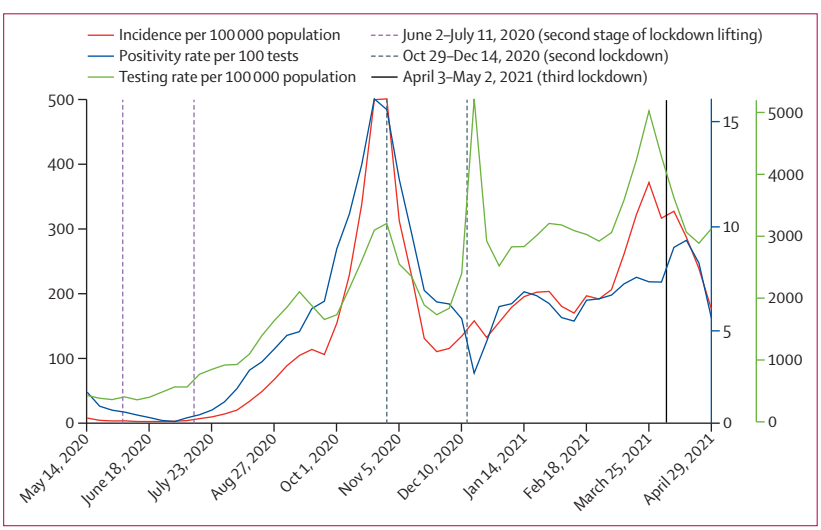

Figure 1: **Weekly dynamics of SARS-CoV-2 incidence, positivity rates, and testing rates in France between May 14, 2020 and April 29, 2021**

population density, included EDI quintiles and week, and was adjusted for population density and the interaction term. All three models were adjusted for region as random intercept to account for the mean region-specific variation during the time period (appendix p 9).

We then stratified analyses by population density category. We calculated sex-standardised and age-standardised ratios for each outcome using the rate (by age group and sex) of each population density category as the reference. Two models were used: the first included EDI quintiles and week (unadjusted), and the second included EDI quintiles, week, and was adjusted for region (appendix p 10).

All generalised additive models used a thin plate spline[22] to model the week variable and a separate smooth function for each EDI quintile.

All statistical analyses were done using R software (version 4.0.4.) and the mgcv package (version 1.8-33).

Role of the funding source

There was no funding source for this study.

Results

Between May 14, 2020 and April 29, 2021, SIDEP received 70 990 478 SARS-CoV-2 test notifications from 47 383 areas, of which 5 000 972 were positive (table). 38 880 990 (54·8%) of 70 990 478 total tests and 2 675 179 (53·5%) of 5 000 972 positive tests were reported among women. Individuals younger than 45 years accounted for 39 629 368 (56·0%) total tests and 2 846 851 (57·0%) positive tests. The least deprived areas (Q1) accounted for 10 119 377 (14·3%) total tests and 664 240 (13·3%) positive tests, and the most deprived (Q5) accounted for 22 906 485 (32·3%) total tests and 1 831 566 (36·6%) positive tests. Densely populated municipalities accounted for 28 941 526 (40·8%) total tests and 2 160 745 (43·2%) of positive tests. We excluded 1 013 180 (1·4%) of 72 354 287 tests and 1182 (2·4%) of 48 566 areas due to a mismatch between the EDI and SIDEP databases, and 350 630 (0·5%) of 72 354 287 tests with missing data on age and sex (appendix p 2).

Figure 1 shows the weekly dynamic of SARS-CoV-2 infection during the study period. SARS-CoV-2 incidence, positivity rates, and testing rates peaked in October, 2020, and April, 2021, leading to the second and third lockdowns, respectively. A peak in the testing rate was also observed in December, 2020.

SARS-CoV-2 incidence was higher in the most deprived areas (Q5) than the least deprived areas (Q1; IRR 1·235 [95% CI 1·224–1·245]). These associations were less strong after adjustment for population density (IRR 1·148 [1·138–1·158]). Adjusted SARS-CoV-2 incidence was higher in moderately populated municipalities (IRR 1·094 [1·089–1·098]) and densely populated municipalities (1·233 [1·228–1·238]), than in sparsely or very sparsely populated municipalities (figure 2; appendix p 11).

The SARS-CoV-2 positivity rate was also higher in the most deprived areas (Q5) than the least deprived areas (Q1; IRR 1·266 [95% CI 1·255–1·276]). After adjustment for population density, these associations were stable and slightly stronger for Q5 than Q1 (IRR 1·283 [1·273–1·294]).

The positivity rate decreased with population density (IRR 0·964 [0·961–0·968] for moderately populated municipalities; 0·963 [0·960–0·967] for densely populated municipalities; figure 2; appendix p 11).

The testing rate was higher in the most deprived areas (Q5) than in the least deprived areas (Q1; IRR 1·004 [1·002–1·006]), but lower in moderately deprived areas (0·987 [0·984–0·989] for Q2; 0·977 [0·975–0·979] for Q3). After adjustment for population density, testing rate decreased with deprivation (IRR 0·905 [0·904–0·907] for Q5) and increased with population density (1·154 [1·152–1·156] for moderately populated municipalities; 1·305 [1·302–1·307] for densely populated municipalities (figure 2; appendix p 11).

The interaction between EDI quintiles and population density groups (model 3) was significant (p<0·0001) for SARS-CoV-2 incidence, positivity rate, and testing rate (appendix pp 12–13); therefore, we analysed the association between deprivation and each outcome stratified by population density (figure 3). A social gradient (ie, higher incidence in more deprived areas) was found for the SARS-CoV-2 incidence in moderately and densely populated municipalities. In contrast, incidence was lower in all quintiles compared with Q1 in sparsely or very sparsely populated municipalities. The adjustment for region did not change the results. A social gradient was also found for the positivity rate (figure 3) in moderately and densely populated municipalities. In the unadjusted model, for sparsely or very sparsely populated municipalities, the positivity rate was lower for all quintiles when compared with Q1. All the associations remained unchanged after adjustment for region, with the exception of sparsely or very sparsely populated municipalities, where the associations were not significant with the exception of that for Q5 (IRR 1·023 [1·001–1·046]; appendix p 15). In adjusted models, an inverse social gradient was found for the testing rate in sparsely or very sparsely populated municipalities (IRR 0·939 [0·935–0·943) and moderately populated municipalities (0·901 [0·897–0·905] for Q5 compared with Q1). In both models, for densely populated municipalities, the testing rate was only lower in Q5 compared with Q1 (IRR 0·929 [0·925–0·932]; appendix p 15).

Weekly dynamics of SARS-CoV-2 incidence, positivity rates, and testing rates by EDI quintile are presented in the appendix (p 31). Between May 14 and 20, 2020, SARS-CoV-2 incidence was 17% (95% CI 0·4–36·0; IRR 1·170 [95% CI 1·004–1·364]) higher in sparsely or very sparsely populated municipalities for Q5 than Q1 and 32% (15–51; IRR 1·319 [1·150–1·513]) higher in moderately populated municipalities for Q5 than Q1 (appendix p 16). The incidence differential across EDI quintiles then decreased to the lowest level in the week of Oct 1–7, 2020 (figure 4), whereby incidence was 31% (29–33; IRR 0·689 [0·668–0·711]) lower in Q5 than Q1 in sparsely populated municipalities, and 23% (21–25; IRR 0·771 [0·752–0·791]) lower in Q5 than Q1 in moderately populated municipalities (appendix p 16). From Nov 5, 2020, the incidence remained higher in Q5 than Q1 (IRR 1·050 [1·026–1·073]; appendix p 18) in moderately populated municipalities, but fluctuated in sparsely populated municipalities. In densely populated municipalities, the incidence was higher in Q5 than Q1 for the whole study period. However, the incidence differential reached a peak in the week of June 25–July 1, 2020 and the week of Nov 26–Dec 2, 2020 (end of the second lockdown; figure 4). SARS-CoV-2 incidence remained higher in Q5 than in Q1 until the last week of the study in densely populated municipalities (48% [43–54]; IRR 1·482 [1·429–1·538]; appendix p 20).

Between May 14 and 20, 2020, the positivity rate was 7% (–7 to 24; IRR 1·073 [95% CI 0·929 to 1·239]) higher in Q5 than Q1 in sparsely or very sparsely populated municipalities, however this difference was not significant, and 40% (95% CI 24 to 59; IRR 1·404 [1·237 to 1·593]) higher in moderately populated municipalities (appendix p 21). The positivity rate differential across EDI quintiles then decreased reaching the lowest level in the week of Oct 8–14, 2020 and increased thereafter (figure 4). From Oct 29, 2020 (second lockdown) onwards, the positivity rate was higher in Q5 than in Q1 in moderately populated municipalities. In sparsely populated municipalities, the positivity rate remained lower in Q5 than in Q1 until the week of Dec 3–9, 2020 (figure 4), and remained similar thereafter. The positivity rate in densely populated municipalities was higher in Q5 than Q1 for the whole study period. The differential rate between EDI quintiles peaked at 39% (95% CI 32 to 46; IRR 1·390 [1·319 to 1·465]) during the week of July 9–15, 2020, and decreased

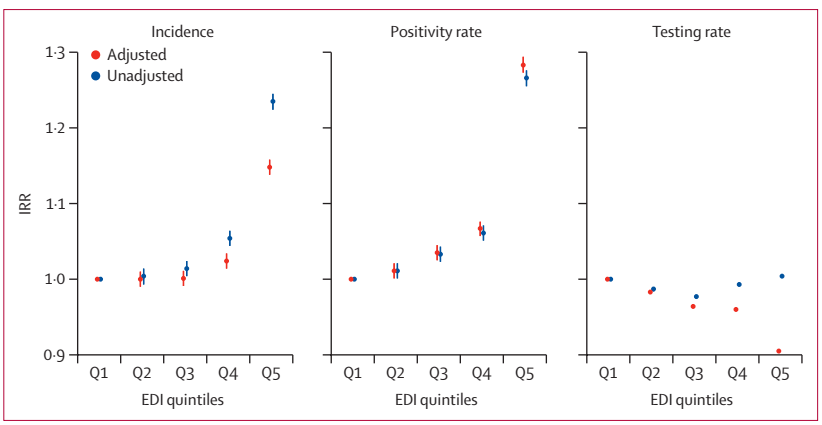

Figure 2: **IRRs of the association between EDI quintile and SARS-CoV-2 incidence, positivity rates, and testing rates**

Q1 represents the least deprived areas (reference category) and Q5 represents the most deprived areas. The unadjusted model estimated IRRs and 95% CIs of the association of each outcome (incidence, positivity rate, and testing rate) with EDI adjusted for week and region as random-intercept. The adjusted model estimated IRRs of the association of each outcome with EDI adjusted for week, population density (sparsely or very sparsely municipalities [reference category], moderately populated municipalities, and densely populated municipalities), and for region as random-intercept. An IRR of less than 1 indicates a negative association and an IRR of more than 1 shows a positive association. 95% CIs were narrow and thus are provided in the appendix (p 11). IRR=incidence rate ratio. EDI=European Deprivation Index. Q=quintile.

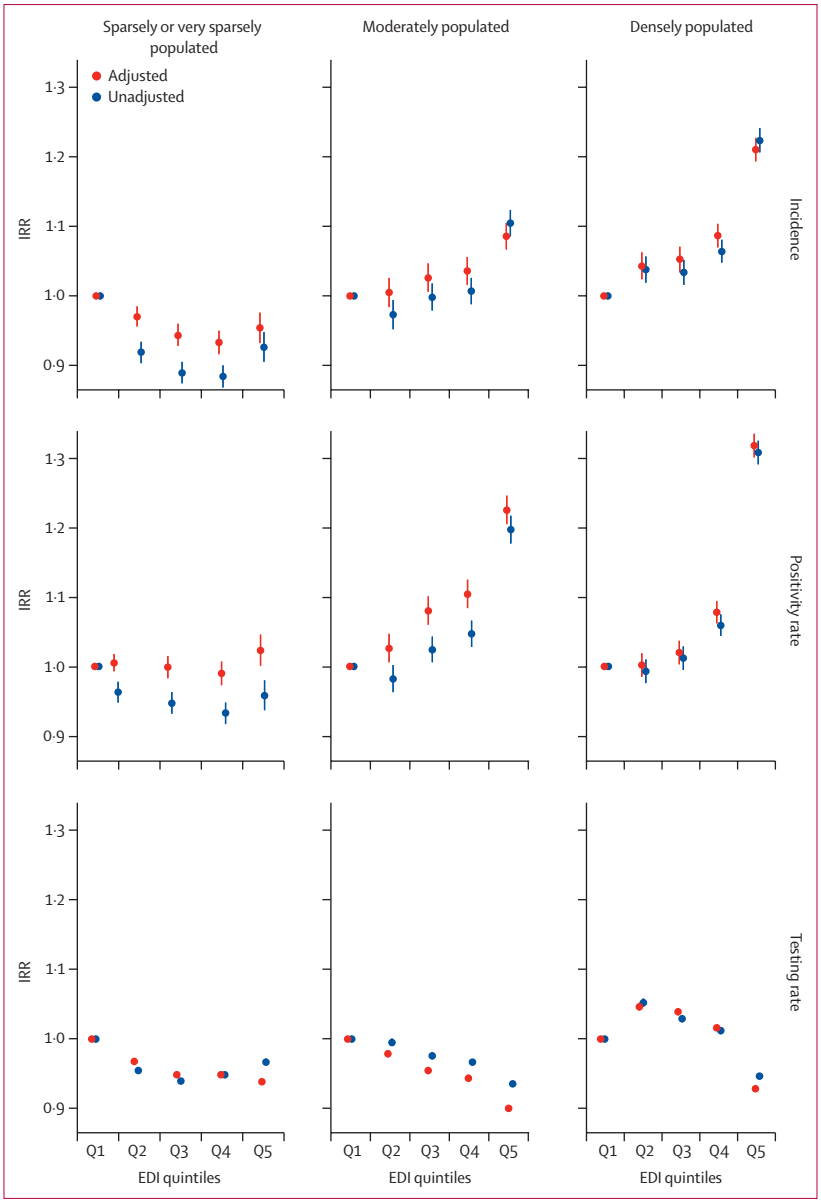

Figure 3: **IRRs of the association between EDI quintiles and SARS-CoV-2 incidence, positivity rate, and testing rates, stratified by population density category**

Q1 represents the least deprived areas (reference category) and Q5 represents the most deprived areas. The unadjusted model estimated IRRs (with 95% CIs) of the association of each outcome (incidence, positivity, and testing rates) with EDI quintile from stratified analyses, with a separate model per each population density group (densely populated, moderately populated, and sparsely or very sparsely populated municipalities) adjusted for week. The adjusted model estimated IRRs (with 95% CIs) of the association of each outcome with EDI from stratified analyses, with a separate model per each population density group (densely populated, moderately populated, sparsely or very sparsely populated municipalities) adjusted for week and adjusted for region as random intercept. An IRR of less than 1 shows a negative association and an IRR of more than 1 shows a positive association. 95% CIs were narrow and thus are provided in the appendix (pp 15–16). IRR=incidence rate ratio. EDI=European Deprivation Index. Q=quintile.

thereafter before increasing again 2 weeks before the second lockdown until the last week of the study (51% [47 to 56]; IRR 1·511 [1·467 to 1·557]; appendix p 25).

Overall, the testing rate was lower in Q5 than Q1 in sparsely or very sparsely populated municipalities and moderately populated municipalities, during the second lockdown. The testing rate remained lower or similar to Q1 thereafter, with the exception of the week of April 29 to May 5, 2021, when the testing rate was 12% (10–14; IRR 1·119 [95% CI 1·098–1·139]) higher in Q5 than Q1 in sparsely or very sparsely populated municipalities and 14% (12–17; IRR 1·142 [1·118–1·166]) higher in Q5 than Q1 in moderately populated municipalities (appendix p 26). In densely populated municipalities, the testing rate was higher in Q5 than Q1 until the week of July 23–29, 2020. Thereafter, the testing rate was lower in Q5 than Q1 with the exception of during the second lockdown, and the week of April 29 to May 5, 2021, when rates were similar between both quintiles.

Discussion

In this study of data from the French COVID-19 national surveillance-testing database, we found that between May, 2020 and April, 2021, in densely and moderately populated municipalities, SARS-CoV-2 incidence and positivity rates were higher and testing rates were lower in the most socially deprived areas compared with the least deprived areas. In contrast, in sparsely or very sparsely populated municipalities, compared with Q1, SARS-CoV-2 incidence and testing rates were lower in all deprivation quintiles and the positivity rate remained stable across deprivation quintiles. With regard to the analysis of the weekly dynamics of incidence, positivity, and testing by EDI quintile and population density group, our results showed that the differential rate between the most and the least deprived areas varied over time according to changes in the measures implemented by the French Government to manage the pandemic, especially lockdowns.

Our findings are consistent with previous studies in the USA,[23,24] India,[25] England,[26] and Switzerland.[9] In France, the EpiCoV study highlighted the association of housing conditions (overcrowding) and urban density on the circulation of the virus.[11] The associations observed between deprivation and SARS-CoV-2 incidence and positivity rates might be the result of various potential factors. People living in the most deprived areas have a higher probability of living in overcrowded housing, which is a risk factor for contamination and COVID-19-related mortality.[27] These individuals are also less likely to be employed as managers or intermediate professionals or to have a higher level of education than people who live in the least deprived areas, which exposes them to occupations that are associated with a higher risk of infection. Individuals residing in more deprived areas are more likely to have a lower level of health literacy[28] and are less likely to benefit from preventive measures implemented by the government. People living in densely populated communities were also often living in overcrowded housing, which meant they were less able to protect themselves during lockdowns. These

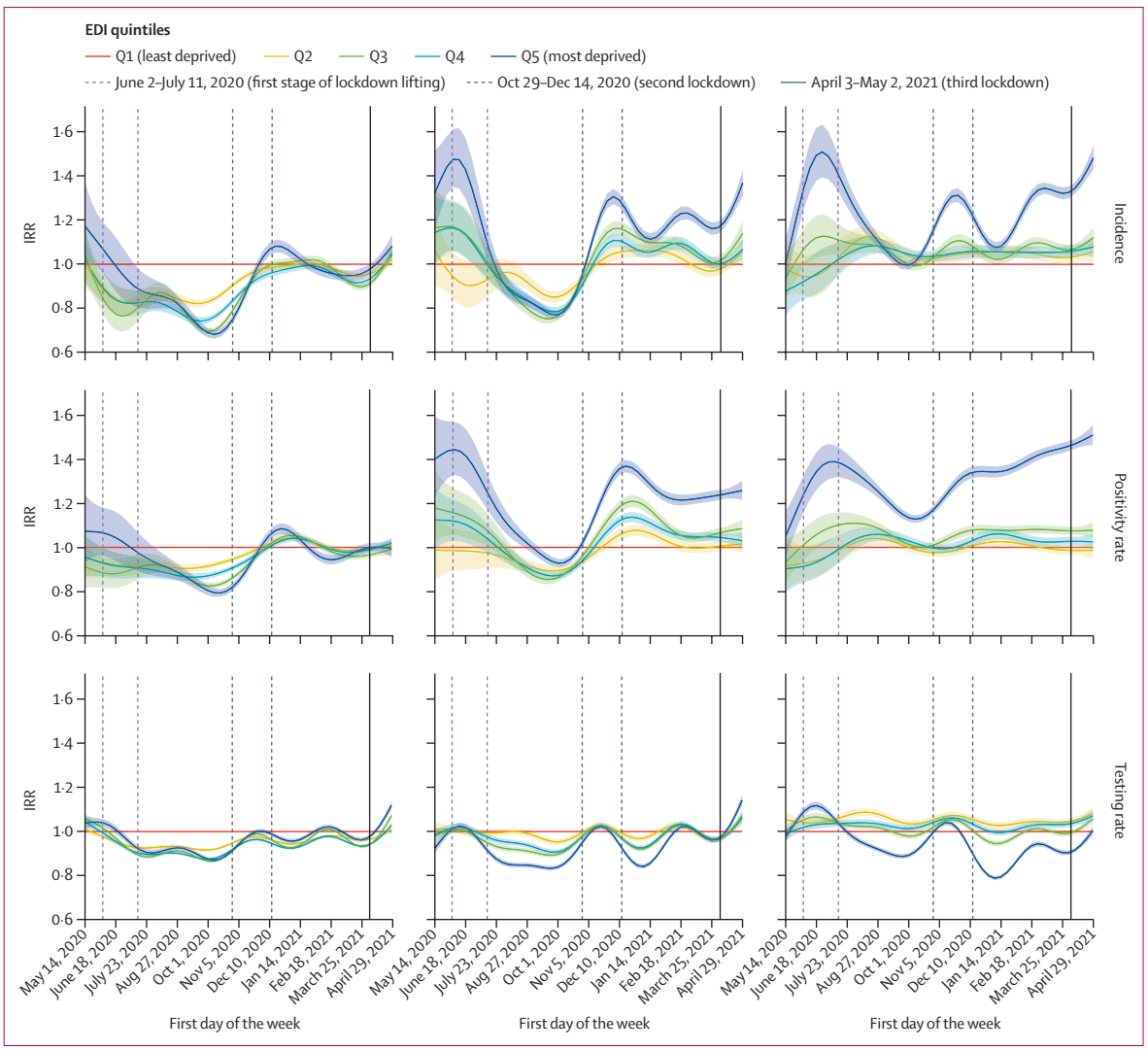

***Figure 4*: Weekly IRRs for the association between EDI quintiles and SARS-CoV-2 incidence, positivity rate, and testing rate, by population density**
IRRs shown are from stratified models of association of outcomes with EDI (Q1 used as a reference) adjusted for week. One model was performed separately within each population density group (sparsely or very sparsely, moderately, densely populated municipalities). An IRR of less than 1 shows a negative association and an IRR of more than 1 shows a positive association. IRRs are shown in the appendix (pp 16–30). IRRs=incidence rate ratios. EDI=European Deprivation Index. Q=quintile.

findings emphasise the importance of structural determinants of health.

Previous studies in the USA on inequalities in access to testing found that ethnic minorities were less likely to be tested.[7,29] A preprint study in New York[30] assessed whether living in a high-income zipcode area was associated with increased rates of COVID-19 testing. Significant disparities were identified in the probability of testing negative for SARS-CoV-2 across various income levels, ranging from 38% in the poorest neighbourhoods by zipcode to 65% in the wealthiest neighbourhoods by zipcode. A study done in in Liverpool (UK) provided substantial evidence on social inequalities in large-scale asymptomatic rapid testing of populations for SARS-CoV-2. The data linkage to novel geospatial data in this study highlighted inequalities in testing outcomes by deprivation, exclusion from internet technologies, and accessibility to test sites.[31]

By adjusting for population density, we highlighted the influence of this factor on the risk of testing positive for COVID-19 at the municipality level. Incidence and testing rates were lower in sparsely or very sparsely populated municipalities than in densely populated municipalities. In the USA, Monnat and colleagues reported that the most rural states had the lowest levels of COVID-19 testing.[32] Moreover, another US study suggested that rural states with the most inhabitants with specific risk factors (eg, hypertension, obesity, diabetes) had the highest SARS-CoV-2 positivity rates and the lowest testing rates.[33] In our study, the positivity rate was higher in sparsely or very sparsely populated municipalities than in more densely populated municipalities. We hypothesise that

people in these areas who went for testing only did so because they had COVID-19 symptoms, and so were more likely to test positive, whereas people living in densely populated municipalities tested more frequently, whether they had symptoms or not, probably because access to testing is easier in those areas. After an initial period wherein there was a limited capacity for SARS-CoV-2 testing, which was mainly reserved for severely ill patients, a new testing policy was implemented in France to systematically test for potential infection with SARS-CoV-2 and enable lifting of the lockdown restrictions on May 11, 2020.[34]

Regarding the influence of region of residence, we observed that the distribution of positive tests and total tests by EDI quintiles differed across regions, justifying the use of the region variable as a confounder in the association between deprivation and outcomes. Adjustment for region in the models did not change our results, with the exception of areas with a lower population density where no social gradient was observed for positivity rates after adjustment. This suggests complex spatiotemporal interactions, at least in lower density areas, which should be further investigated.

Regarding the weekly dynamic of SARS-CoV-2 incidence, positivity rates, and testing rates, we found that during the second and third lockdowns in France, incidence and positivity rates were higher in the most deprived areas than the least deprived areas, in moderately and densely populated municipalities. The differential rates between the two levels of deprivation increased quickly, indicating that social inequalities increased. In contrast, the testing rate was mostly similar between the highest and lowest deprivation quintiles during the second lockdown but higher in the most deprived areas during the third lockdown in moderately populated municipalities. Testing rates were similar across the least and the most deprived deprivation quintiles during the second lockdown in densely populated municipalities, but lower in the most deprived areas than the least deprived areas during the third lockdown. Conversely, in sparsely or very sparsely populated municipalities, SARS-CoV-2 incidence, positivity rates, and testing rates were lower in the most deprived areas than the least deprived areas during the second lockdown. Incidence and testing rates were higher in the most deprived areas during the third lockdown and positivity rates were similar between the highest and lowest deprivation quintiles. A previous study in France showed that lockdowns led to social inequalities in the reduction in COVID-19 infections.[11] Our results might be explained by lower levels of responsiveness among people living in socially deprived areas to COVID-19 national protective measures due to their living conditions. Workers employed in essential sectors are less likely to work from home and continue to be at greater risk of exposure.[35] Additionally, people with low-level qualifications, those on low incomes, and those working informally or illegally are more likely to need to leave their homes to make a living.[36] Socioeconomic inequalities are pervasive with regard to understanding preventive measures and health-care information accessibility and literacy.[37] Importantly, despite free access to testing in France, inequalities in testing rates reflect inequalities in access to care in general, and in preventive health access in particular. The use of health care by a population is dependent on a combination of factors including financial resources, health insurance, the supply of care and of services (public transport), individual characteristics (education, family status, professional status, literacy), and health-care needs (general, physical health, and mental health).

Testing campaigns had a substantial effect on the variations observed in the weekly dynamic of outcomes. In particular, testing increased during the Christmas holidays as a result of encouragement by health authorities. Although the testing rate increased across all levels of deprivation, social inequalities remained, since people living in the most deprived areas were less likely to be tested than those living in the least deprived areas, especially in moderately and densely populated municipalities.

This study has a number of limitations. We used the methodology standardised by Santé Publique France, which considered a period of 60 days for clearance of infection rather than longer durations (eg, 90 days), based on an analysis of the literature and as a conservative choice. The geocoding of residential addresses led to missing data in the area code because of erroneous addresses. The imputation procedure to assign an area code to each individual might have resulted in the misclassification of some area codes. Additionally, we excluded 1·4% of tests and 2·4% of areas due to a mismatch between the EDI and SIDEP databases; the area exclusions were homogeneous over each week of the study period. The use of population estimates from 2017 instead of 2021 might have introduced bias, especially if the structure of the population has evolved differentially during this time period due to deprivation. It is difficult to formally assess such changes sincce population data were not available for 2021. However, we assessed population shifts in the IRIS scale between 2015 and 2017, which showed that the population change increment was only marginally correlated with deprivation (data not shown). Furthermore, the potential bias caused by using data for the 2017 population will not affect the results on the dynamics of the IRRs, but solely results on the mean differences, as population shifts would be low (and non-differential) within a year. Data about living conditions and socioeconomic status are not available in the SIDEP database. Accordingly, since we did not have individual-level socioeconomic data, we used the residence area code of individuals to assign a level of deprivation score to each area. In future studies, we will aim to decipher the independent influence of some of the components of the EDI, especially those that might be particularly relevant

to the risk of testing positive for SARS-CoV-2, such as the proportion of people of foreign nationality or the proportion of overcrowded dwellings. Furthermore, the use of an ecological–social measure of deprivation has been shown to underestimate the social inequalities observed using individual data.[38] Nevertheless, this is the first study to describe the SARS-CoV-2 pandemic dynamic in France with regard to social deprivation using a national exhaustive surveillance COVID-19 testing database. Additional limitations include the inability to include ethnicity data, to account for vaccination uptake, and to link some datasets across systems (eg, hospitalisations and deaths) at the time of our study.

Our results show there were considerable social inequalities in the risk of SARS-CoV-2 infection during the first year of the COVID-19 pandemic in France. To better identify the mechanisms driving such inequalities, data on the living conditions of individuals and their socioeconomic circumstances are urgently needed. Measures of deprivation and other social determinants of health should also be used to enhance transmission reduction strategies (eg, accessibility of testing, promotion of anti-SARS-CoV-2 vaccines). However, these data are rarely collected in health surveillance systems in France, which limits efforts to manage the epidemic fairly.[39] Our study shows the importance of monitoring changes over time when implementing prevention policies, to describe social inequalities in health, and ultimately to address them. Surveillance systems that include social variables should be established in France and elsewhere so that routine reporting of health outcomes according to social factors is possible. Availability of such data would help ensure that the wellbeing of deprived social groups is considered as an integral part of any public health policy, and that research on health inequalities can be directed efficiently towards key questions.

Contributors

SV, SS, CD, and MK-I conceived the study. MM did analysis during the earliest stages of the study. SS did all statistical analyses. EC worked on the methodology to calculate outcomes and programmed the aggregated data and the imputation of area codes. SV, CD, and SS drafted the first version of manuscript. SV, CD, and MK-I did the first bibliography research. CA and LN contributed to writing of the manuscript and the bibliography. EC, CD, MK-I, CA, and LN reviewed the manuscript. All authors contributed to the interpretation of data, and read and approved the final manuscript. SS and EC had access to all of the data and verified the data.

Declaration of interests

We declare no competing interests.

Data sharing

The aggregated data are accessible to researchers upon reasonable request for data sharing to the corresponding author. Requests for data require approval by Santé Publique France.

Acknowledgments

This work is part of the EPIDEMIC consortium cofunded by the French National Research Agency (ANR-20-COVI-0088-01) and the French Region Occitanie (bylaw no 2000-7460). We thank the Data-Labos team at Santé Publique France, Assistance Publique–Hôpitaux de Paris, and Etalab who established the SIDEP surveillance system. We thank Laetitia Huiart, Anne Catherine Viso, and Yann Le Strat for reviewing the manuscript, and Gregoire Deleforterie, Jalpa Shah, Edwige Bertrand, and Laetitia Haroutunian for their help with technical issues. We also thank Jude Sweeney for English translation.

References

1 Quinn SC, Kumar S. Health inequalities and infectious disease epidemics: a challenge for global health security. *Biosecur Bioterror* 2014; **12:** 263–73.
2 Bambra C, Riordan R, Ford J, Matthews F. The COVID-19 pandemic and health inequalities. *J Epidemiol Community Health* 2020; **74:** 964–68.
3 Wilkins CH, Friedman EC, Churchwell AL, et al. A systems approach to addressing COVID-19 health inequities. *NEJM Catal Innov Care Deliv* 2021; **2:** CAT.20.0374.
4 Public Health England. Disparities in the risk and outcomes of COVID-19. 2020. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/908434/Disparities_in_the_risk_and_outcomes_of_COVID_August_2020_update.pdf (accessed Oct 25, 2021).
5 Almagro M, Orane-Hutchinson A. JUE insight: the determinants of the differential exposure to COVID-19 in New York city and their evolution over time. *J Urban Econ* 2020; published online Oct 28. https://doi.org/10.1016/j.jue.2020.103293.
6 Vahidy FS, Nicolas JC, Meeks JR, et al. Racial and ethnic disparities in SARS-CoV-2 pandemic: analysis of a COVID-19 observational registry for a diverse US metropolitan population. *BMJ Open* 2020; **10:** e039849.
7 Goldman N, Pebley AR, Lee K, Andrasfay T, Pratt B. Racial and ethnic differentials in COVID-19-related job exposures by occupational standing in the US. *PLoS One* 2021; **16:** e0256085.
8 Amdaoud M, Arcuri G, Levratto N. Are regions equal in adversity? A spatial analysis of spread and dynamics of COVID-19 in Europe. *Eur J Health Econ* 2021; **22:** 629–42.
9 Riou J, Panczak R, Althaus CL, et al. Socioeconomic position and the COVID-19 care cascade from testing to mortality in Switzerland: a population-based analysis. *Lancet Public Health* 2021; **6:** e683–91.
10 Dubost C-L, Pollak C, Rey S. Les inégalités sociales face à l'épidémie de Covid-19: état des lieux et perspectives. Paris: Direction de la recherche, des études, de l'évaluation et des statistiques. https://drees.solidarites-sante.gouv.fr/publications/les-dossiers-de-la-drees/les-inegalites-sociales-face-lepidemie-de-covid-19-etat-des (accessed Oct 25, 2021).
11 Bajos N, Jusot F, Pailhé A, et al. When lockdown policies amplify social inequalities in COVID-19 infections: evidence from a cross-sectional population-based survey in France. *BMC Public Health* 2021; **21:** 705.
12 Khalatbari-Soltani S, Cumming RC, Delpierre C, Kelly-Irving M. Importance of collecting data on socioeconomic determinants from the early stage of the COVID-19 outbreak onwards. *J Epidemiol Community Health* 2020; **74:** 620–23.
13 Bajos N, Counil E, Franck J-E, et al. Social inequalities and dynamics of the early COVID-19 epidemic: a prospective cohort study in France. *BMJ Open* 2021; **11:** e052888.
14 Rahi M, Le Pluart D, Beaudet A, et al. Sociodemographic characteristics and transmission risk factors in patients hospitalized for COVID-19 before and during the lockdown in France. *BMC Infect Dis* 2021; **21:** 812.
15 Dragano N, Hoebel J, Wachtler B, Diercke M, Lunau T, Wahrendorf M. Social inequalities in the regional spread of SARS-CoV-2 infections. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* 2021; **64:** 1116–24 (in German).
16 Institut national de la statistique et des études économiques. Population en 2017. Recensement de la population – Base infracommunale (IRIS). https://www.insee.fr/fr/statistiques/4799309#consulter (accessed Feb 1, 2022).
17 Seow J, Graham C, Merrick B, et al. Longitudinal observation and decline of neutralizing antibody responses in the three months following SARS-CoV-2 infection in humans. *Nat Microbiol* 2020; **5:** 1598–607.
18 Ripperger TJ, Uhrlaub JL, Watanabe M, et al. Orthogonal SARS-CoV-2 serological assays enable surveillance of low-prevalence communities and reveal durable humoral immunity. *Immunity* 2020; **53:** 925–33.

19 Pornet C, Delpierre C, Dejardin O, et al. Construction of an adaptable European transnational ecological deprivation index: the French version. *J Epidemiol Community Health* 2012; **66:** 982–89.

20 Eurostat. Degree of urbanisation. https://ec.europa.eu/eurostat/fr/web/degree-of-urbanisation/background?etrans=en (accessed Oct 25, 2021).

21 Wood SN, Pya N, Säfken B. Smoothing parameter and model selection for general smooth models. *J Am Stat Assoc* 2016; **111:** 1548–63.

22 Wood SN. Thin Plate Regression Splines. *J R Stat Soc Series B Stat Methodol* 2003; **65:** 95–114.

23 Lewis NM, Friedrichs M, Wagstaff S, et al. Disparities in COVID-19 incidence, hospitalizations, and testing, by area-level deprivation—Utah, March 3–July 9, 2020. *MMWR Morb Mortal Wkly Rep* 2020; **69:** 1369–73.

24 Escobar GJ, Adams AS, Liu VX, et al. Racial disparities in COVID-19 testing and outcomes: retrospective cohort study in an integrated health system. *Ann Intern Med* 2021; **174:** 786–93.

25 Das A, Ghosh S, Das K, Basu T, Das M, Dutta I. Modeling the effect of area deprivation on COVID-19 incidences: a study of Chennai megacity, India. *Public Health* 2020; **185:** 266–69.

26 Upshaw TL, Brown C, Smith R, Perri M, Ziegler C, Pinto AD. Social determinants of COVID-19 incidence and outcomes: a rapid review. *PLoS One* 2021; **16:** e0248336.

27 Goutte S, Péran T, Porcher T. The role of economic structural factors in determining pandemic mortality rates: evidence from the COVID-19 outbreak in France. *Res Int Bus Finance* 2020; **54:** 101281.

28 Schillinger D. The intersections between social determinants of health, health literacy, and health disparities. *Stud Health Technol Inform* 2020; **269:** 22–41.

29 Benitez J, Courtemanche C, Yelowitz A. Racial and ethnic disparities in COVID-19: evidence from six large cities. *J Econ Race Policy* 2020; **3:** 243–61.

30 Schmitt-Grohé S, Teoh H, Uribe M. COVID-19: testing inequality in New York City. *SSRN* 2020; published online April 20. https://ssrn.com/abstract=3594306 (preprint).

31 Green MA, García-Fiñana M, Barr B, et al. Evaluating social and spatial inequalities of large scale rapid lateral flow SARS-CoV-2 antigen testing in COVID-19 management: an observational study of Liverpool, UK (November 2020 to January 2021). *Lancet Reg Health Eur* 2021; **6:** 100107.

32 Monnat S. Why coronavirus could hit rural areas harder. March 24, 2020. https://surface.syr.edu/cgi/viewcontent.cgi?article=1065&context=lerner (accessed Oct 25, 2021).

33 Souch JM, Cossman JS. A commentary on rural-urban disparities in COVID-19 testing rates per 100,000 and risk factors. *J Rural Health* 2021; **37:** 188–90.

34 Pullano G, Di Domenico L, Sabbatini CE, et al. Underdetection of cases of COVID-19 in France threatens epidemic control. *Nature* 2021; **590:** 134–39.

35 Messacar D, Morissette R, Deng Z. Inégalités en matière de faisabilité du travail à domicile pendant et après la COVID-19. June 8, 2020. https://www150.statcan.gc.ca/n1/pub/45-28-0001/2020001/article/00029-fra.htm (accessed Oct 25, 2021).

36 Bonacini L, Gallo G, Scicchitano S. Working from home and income inequality: risks of a 'new normal' with COVID-19. *J Popul Econ* 2020; published online Sept 12. https://doi.org/10.1007/s00148-020-00800-7.

37 Okan O, Bollweg TM, Berens EM, Hurrelmann K, Bauer U, Schaeffer D. Coronavirus-related health literacy: a cross-sectional study in adults during the COVID-19 infodemic in Germany. *Int J Environ Res Public Health* 2020; **17:** 5503.

38 Lamy S, Molinié F, Daubisse-Marliac L, et al. Using ecological socioeconomic position (SEP) measures to deal with sample bias introduced by incomplete individual-level measures: inequalities in breast cancer stage at diagnosis as an example. *BMC Public Health* 2019; **19:** 857.

39 Burström B, Tao W. Social determinants of health and inequalities in COVID-19. *Eur J Public Health* 2020; **30:** 617–18.