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Changing Disparities in Coronavirus Disease 2019 (COVID-19) Burden in the Ethnically Homogeneous Population of Hong Kong Through Pandemic Waves: An Observational Study

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Background. Disparities were marked in previous pandemics, usually with higher attack rates reported for those in lower socioeconomic positions and for ethnic minorities.

Methods. We examined characteristics of laboratory-confirmed coronavirus disease 2019 (COVID-19) cases in Hong Kong, assessed associations between incidence and population-level characteristics at the level of small geographic areas, and evaluated relations between socioeconomics and work-from-home (WFH) arrangements.

Results. The largest source of COVID-19 importations switched from students studying overseas in the second wave to foreign domestic helpers in the third. The local cases were mostly individuals not in formal employment (retirees and homemakers) and production workers who were unable to WFH. For every 10% increase in the proportion of population employed as executives or professionals in a given geographic region, there was an 84% (95% confidence interval [CI], 1–97%) reduction in the incidence of COVID-19 during the third wave. In contrast, in the first 2 waves, the same was associated with 3.69 times (95% CI, 1.02–13.33) higher incidence. Executives and professionals were more likely to implement WFH and experienced frequent changes in WFH practice compared with production workers.

Conclusions. Consistent findings on the reversed socioeconomic patterning of COVID-19 burden between infection waves in Hong Kong in both individual- and population-level analyses indicated that risks of infections may be related to occupations involving high exposure frequency and WFH flexibility. Contextual determinants should be taken into account in policy planning aiming at mitigating such disparities.

Keywords. COVID-19; disparities; socioeconomic; intervention; work from home.

Disparities in disease burden have been noted in many pandemics, from the 1918 flu pandemic to the ongoing coronavirus disease 2019 (COVID-19) pandemic [1–6]. Most studies were conducted in ethnically heterogenous settings and reported higher mortality rates for ethnic minorities who are often in lower socioeconomic positions and socially disadvantaged [1–3]. Despite a body of neighborhood-level evidence, which had largely been derived from assessing aggregated mortality statistics and neighborhood census data [4–6], there is scant evidence on individual-level associations between socioeconomic characteristics and exposure risks of confirmed cases.

Before the widespread availability of effective vaccines conferring sterilizing immunity and definitive treatments specific to COVID-19, governments will still depend on travel restrictions and physical distancing to slow the spread of infection [7, 8]. Shifting risks of infections would be expected as consequences of these measures. For example, a decreased share of imported cases would be expected with tightening restrictions targeting inbound travelers. Physical-distancing measures, such as restrictions on mass gatherings, closure of nonessential businesses, and encouraging work-from-home (WFH) practice, can shift exposure risks outside of households from social to work settings [9] and can leave essential workers, particularly socioeconomically disadvantaged people, more vulnerable to infection [10]. Therefore, a dynamic characterization of differences in exposure and related association with control measures would improve our understanding of disparities.

Here we describe the changing socioeconomic patterning of infections through 3 epidemic waves of COVID-19 in the ethnically homogeneous and developmentally advantaged

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population of Hong Kong (GDP [gross domestic product] per capita, 48 713.5 US dollars in 2019) [11]. We first characterized the dynamic pattern of age, occupation, and the inferred likelihood of WFH arrangements of confirmed COVID-19 cases. We then used spatially aggregated data to assess associations between incidence of local cases and socioeconomic characteristics. We evaluated relations between socioeconomic position and WFH arrangements based on weekly telephone surveys conducted from May through August.

METHODS

Data Sources

We obtained data on all laboratory-confirmed COVID-19 cases in Hong Kong from the Department of Health, which included age, sex, occupation, origin of infection (ie, imported or locally acquired), date of reporting, and locations that cases had visited [12]. Cases who were close contacts of imported and local cases were classified as local cases. Early in the pandemic, COVID-19 detections were mainly targeted symptomatic inbound travelers from high-risk countries/regions (since 21 January), inpatients (since 31 January), adult outpatients with respiratory symptoms (since 19 February), and contacts of confirmed cases. COVID-19 tests were further extended to all outpatients with respiratory symptoms since 9 March and asymptomatic inbound travelers since 20 March [7].

The territory of Hong Kong is divided into 291 tertiary planning units (TPUs), which represent a geographic reference system for town planning purposes [13]. We obtained data on average socioeconomic status in each TPU from the most recent population by census in 2016 [13]. These include the median monthly rent (in Hong Kong dollars [HKD]), median monthly household income (in HKD), the number of people in each age group (binned every 5 years), in each educational level (ie, primary or below, secondary, and tertiary or above), and in each occupation category. In the by-census, occupations were classified into 9 categories, with a detailed list shown in Supplementary Table 1. Detailed definitions of each occupation category are available at https://www.bycensus2016.gov.hk/en/terms-and-definitions.html. We collected data on control measures (ie, travel- and community-based) from local news sources and government press releases (Figure 1A), as previously described [7].

To assess the psychological and behavioral responses of Hong Kong residents to the COVID-19 pandemic, we conducted 21 cross-sectional telephone surveys among Hong Kong adults from 20 January through 28 August 2020 [7, 14]. Random-digit dialing was applied in each survey to phone landline and mobile numbers at a 1:1 ratio. Among these surveys, information on changes in WFH arrangements and WFH hours compared with the previous month was available for 7 surveys conducted between 26 May and 21 August on alternate weeks (ie, 26–29 May, 9–12 June, 23–26 June, 6–10 July, 20–24 July, 4–7 August, and 17–21 August). We also collected information on respondents' socioeconomic characteristics, including age, occupation, educational level, and household incomes. In the questionnaires, occupations were classified into 3 groups—that is, executives and professionals, clerical and service workers, and production

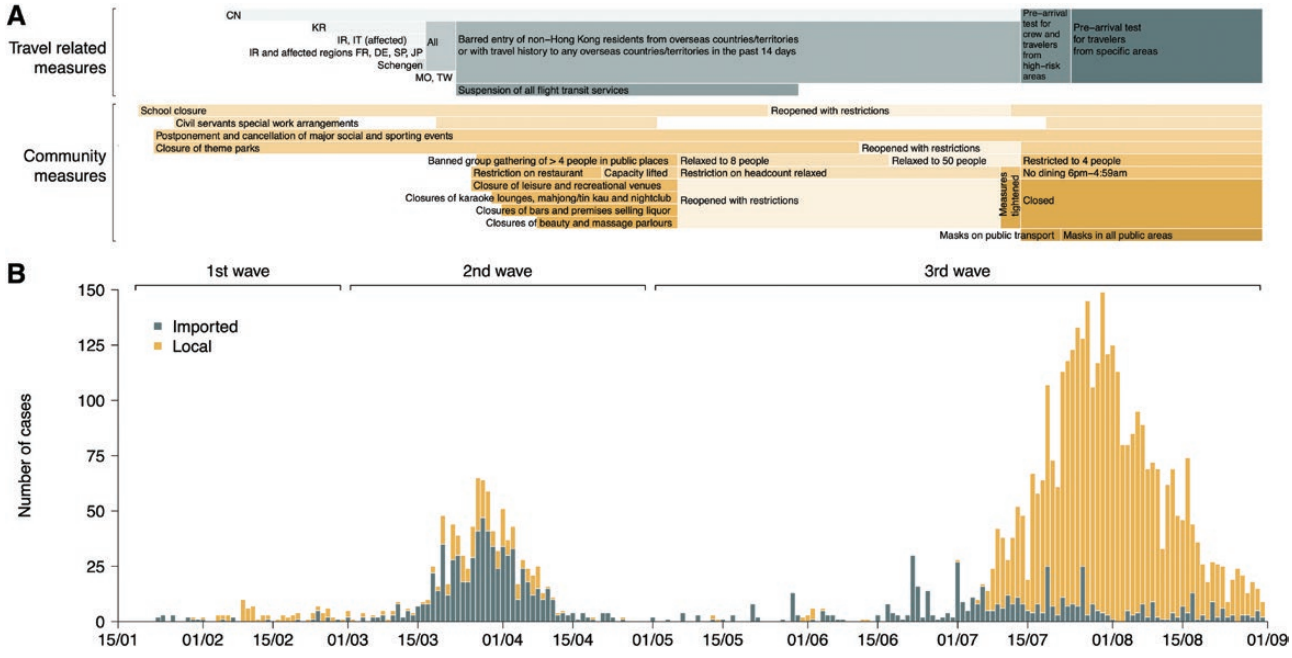

Figure 1. Nonpharmaceutical interventions (*A*) and COVID-19 cases by date of reporting (*B*). The white strips in panel *A* represent absence of the intervention, while shaded areas indicate that stricter interventions were imposed. Abbreviations: CN,mainland China ; COVID-19, coronavirus disease 2019; DE, Germany; FR, France; IR, Iran; IT, Italy; JP, Japan; KR, South Korea; MO, Macao; TW, Taiwan.

workers—based on the above-mentioned 9 classifications (Supplementary Table 1). Detailed survey methods have been previously described [14].

Socioeconomic Characteristics of COVID-19 Cases

We characterized the socioeconomic profile of laboratory-confirmed COVID-19 cases across 3 waves: 18 January–29 February, 1 March–30 April, and 1 May–31 August. We defined imported cases if they had overseas exposure history. We defined local cases as sporadic local cases or close contacts of imported or local cases. As the first wave was relatively small and predominated by imported cases, we combined cases from the first and second waves and compared them with those from the third wave in the following analysis. We performed chi-square and Fisher's exact tests to assess potential difference in the distributions between epidemic waves. If cases were currently employed, we classified their self-reported occupations into the above-mentioned 3 categories in the surveys (Supplementary Table 1); otherwise, we classified them as economically inactive (ie, students, homemakers, retired, or unemployed) or self-employed. We also inferred the likelihood of WFH arrangements based on respondents' self-reported occupations and by assuming that economically inactive individuals could WFH.

Association Between Socioeconomic Characteristics and Incidence

To assess the relationship between socioeconomic factors and incidence at the population level across infection waves, we fitted a Poisson regression model with generalized estimation equations (GEEs) to TPU-specific incidence of confirmed local cases and adjusted for spatial clustering [1]. The TPU-specific exposures were in person-weeks, with exposure time of 14.9 weeks (from 18 January to 30 April) and 17.6 weeks (from 1 May to 31 August) for the first 2 waves and the third wave, respectively. In order to examine if the effects of socioeconomic factors on incidence were different across waves, we included interaction terms between socioeconomic characteristics and waves in the model. Covariables in the model included median monthly rent, proportion with tertiary education (ie, the number of residents >14 years who had attained at least a tertiary-level education divided by the total number of residents >14 years in a given TPU), and proportion of executives and professionals (ie, the number of residents who were employed as managers and administrators, professionals, or associate professionals divided by the total number of employed residents in a given TPU). To keep the model parsimonious, we used the monthly median rent, which was highly correlated with both monthly median income and household size, in the main analysis. Monthly median income was included in the sensitivity analysis. We also adjusted for age-specific population to account for variations in age structure, categorized into 4 groups: 0–19, 20–39, 40–59, and 60 years and older [1].

A case could report multiple locations that were situated in different TPUs, thus leading to overestimation of TPU-specific incidence. We therefore imputed the exposure location of each case by randomly sampling 1 location and aggregated the case into the corresponding TPU in each imputation. We fitted the Poisson model with GEEs to 1000 datasets, each of which contained a unique exposure location for each case. We then calculated the point estimates and 95% confidence intervals (CIs) of covariables following Rubin's rules [15].

Association Between Socioeconomic Characteristics and Work-From-Home Arrangements

To examine the differences in WFH practice among occupations groups in the general public of Hong Kong, we evaluated the distribution of WFH hours in the past week, changes in WFH arrangements compared with the past month, age, educational level, and monthly household income among employed participants in our surveys, by occupation categories. Economically inactive participants were not included in the analysis as information on WFH practice was not collected from them per survey design. We used chi-square tests to examine differences between waves.

RESULTS

Up until 31 August 2020, a total of 4811 COVID-19 cases had been laboratory-confirmed, among which 3556 (74%) were infected locally, while the remaining 1255 cases were determined to have been infected outside Hong Kong. The majority of cases (86%) in the third wave (n = 3773) were locally acquired (Figure 1). Since there were only 95 cases in wave 1, we grouped waves 1 and 2 together in all subsequent analyses.

Information on occupation was available for 67% (n = 3238) of the cases, with no significant difference in the availability of occupation information among imported and local cases ($P = .12$). There were 26.2% (n = 272) and 26.5% (n = 963) cases who were economically inactive in the first 2 waves and the third wave, respectively. The majority (82%) of the imported cases in the first 2 waves were economically inactive individuals including 79% students studying overseas, while the composition shifted towards production workers (23%; 79% of whom were foreign domestic helpers) and executives and professionals (22%; 79% were air or sea crew) in the third wave ($P < .01$) (Figure 2, and Supplementary Figure 1, Supplementary Table 2). Individuals who were not economically active, particularly retirees and homemakers, made up of 33% of local cases and formed 80% (754 out of 943) of those who could WFH during the third wave (Figure 2, Supplementary Figures 1 and 2, Supplementary Table 2). Among local cases who were in formal employment, 70% (1089 out of 1564) did not have WFH flexibility (Figure 2 and Supplementary Table 2). The proportion of cases who were executives and professionals in the third wave (14%) was only one-third that of the first 2 waves (39%; $P < .01$) (Figure 2 and Supplementary Figure 1).

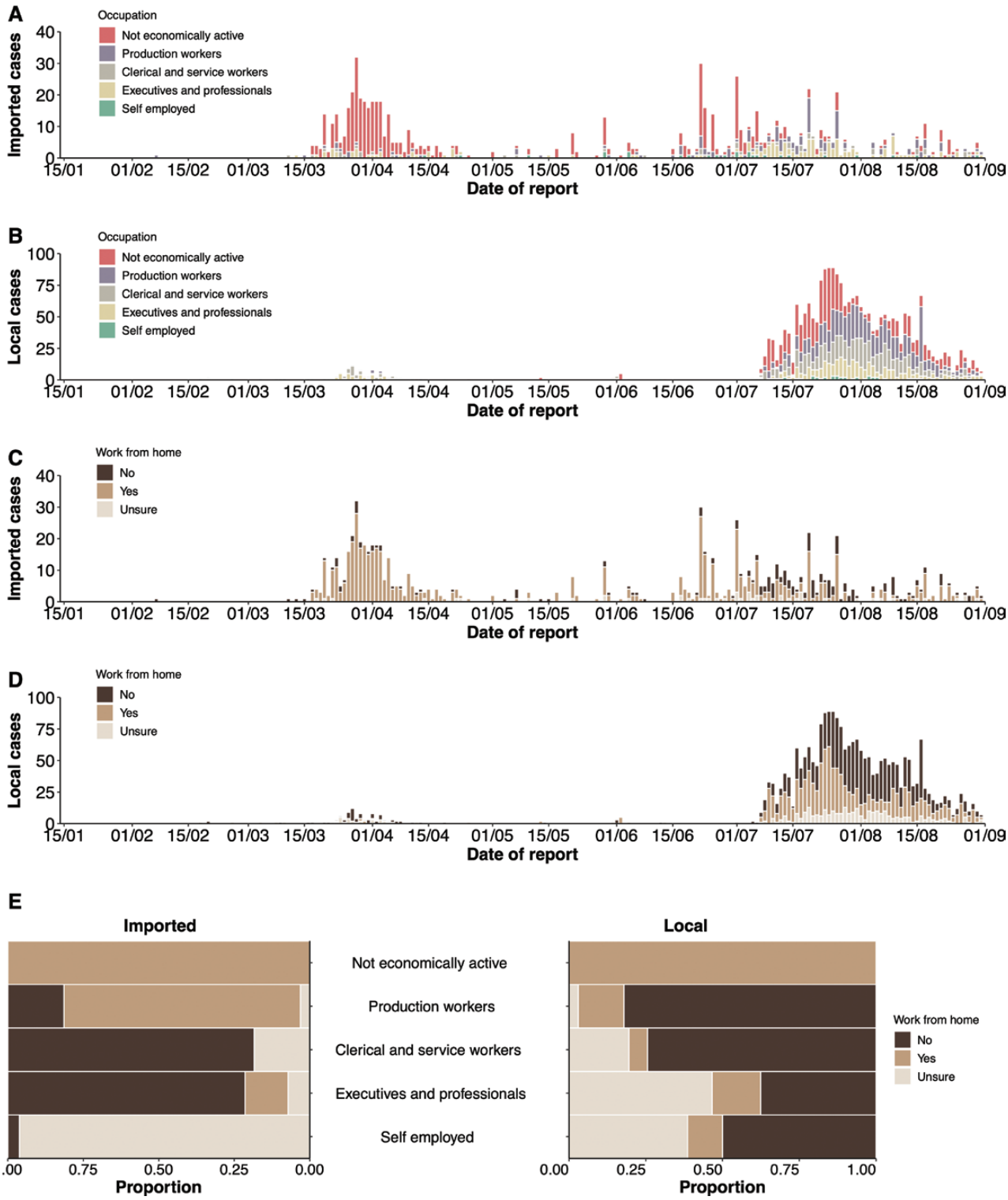

Figure 2. Distribution of occupations and the likelihood of WFH arrangements of confirmed COVID-19 cases. *A* and *B*, Temporal distribution of occupations of imported (*A*) and local (*B*) COVID-19 cases. Occupational groups were classified according to the self-reported occupations. *C* and *D*, Temporal distribution of the likelihood of WFH of imported (*C*) and local (*D*) COVID-19 cases. Cases were classified by WFH allowance according to self-reported occupational groups. *E*, Distribution of the likelihood of WFH by occupational groups and case types across all waves. Abbreviations: COVID-19, coronavirus disease 2019; WFH, work-from-home.

Spatially, 51% and 75% of the 291 TPUs had locally confirmed cases in the first 2 waves and third wave, respectively, with a broader distribution of cases reported in the third wave (Figure 3, Supplementary Figures 3 and 4). A 10% higher proportion of residents employed as executives and professionals in TPUs were associated with an 84% (95% CI, 1–97%) reduction

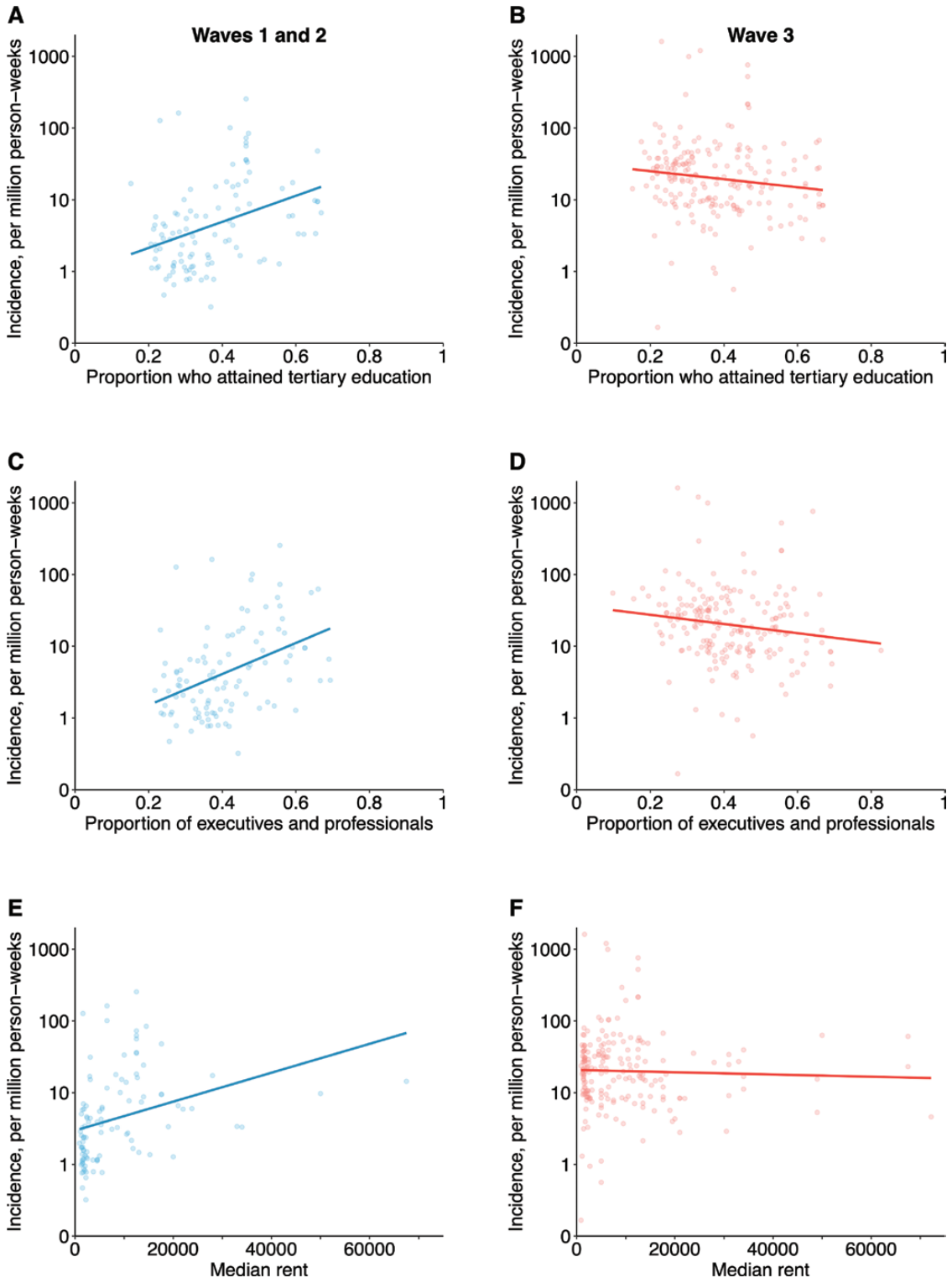

Figure 3. Relationships between socioeconomic status and incidence rate at the TPU level across waves. Panels demonstrate data on the associations between TPU incidence and proportion who attained tertiary education in waves 1 and 2 (*A*) and wave 3 (*B*), the associations between TPU incidence and proportion of executives and professionals in waves 1 and 2 (*C*) and wave 3 (*D*) and the associations between TPU incidence and median rent (in HKD) in waves 1 and 2 (*E*) and wave 3 (*F*). The lines represent the best fitting from linear regression models. Only TPUs with reported local cases were included in the figure and a more complete demonstration can be found in Supplementary Figure 4. Abbreviations: HKD, Hong Kong dollars; TPU, tertiary planning unit.

in the infection incidence in the third wave. In contrast, in the first 2 waves, the same increase was associated with 3.69 times (95% CI, 1.02–13.33 times) higher incidence (Table 1, Figure 3, Supplementary Figure 4). Results from the sensitivity analysis including median monthly income were similar to the main results (Supplementary Figure 5 and Supplementary Table 3).

From 26 May to 21 August 2020, 3594 adult Hong Kong residents (1801 from landline and 1793 from mobile) responded to our telephone surveys; among these, 49% (n = 1766) reported themselves as economically active. Compared with clerical and service workers and production workers, executives and professionals (n = 638; 36%) experienced more WFH time (9.7% of whom reported 40 WFH hours per week; $P < .01$) as well as changes in WFH arrangements throughout the survey period (specifically, 20.8% reported such changes during the previous month; $P < .01$) (Table 2, Supplementary Figure 6).

DISCUSSION

Using individual-level socioeconomic characteristics of confirmed cases, we found the socioeconomic pattern of COVID-19 burden—particularly from an exposure perspective—was reversed between infection waves in Hong Kong. Whereas many cases in the first 2 waves were imported, often in students or business travelers, infections shifted more towards local infections in persons who were not economically active or did not have WFH flexibility in the third waves. Such individual-level socioeconomic disparities in COVID-19 burden were collectively reflected at the population level, where we found an inverse association between incidence and proportion of executives and professionals in a given TPU between pandemic waves. We further found that executives and professionals were more likely to have WFH flexibility and experience frequent changes in WFH practice, compared with production workers, which could have potentially shaped their disparate risks of exposure and infection. One advantage of our study is that we found a consistent pattern at both the individual and population level, which suggests our results are less likely to suffer from ecology fallacy.

Table 1. Associations Between Sociodemographic Factors and COVID-19 Incidence at the Tertiary Planning Unit Level

Factors	Adjusted IRR (95% CI)
Waves 1 and 2	
Tertiary education or above (per 10% increase)	1.44 (.36, 5.76)
Executives and professionals (per 10% increase)	3.69 (1.02, 13.33)
Median monthly rent (per HKD 10 000 increase)[a]	1.09 (1.01, 1.18)
Wave 3	
Tertiary education or above (per 10% increase)	.60 (.06, 5.56)
Executives and professionals (per 10% increase)	.16 (.03, .99)
Median monthly rent (per HKD 10 000 increase)[a]	.96 (.87, 1.06)

Point estimates and 95% confidence intervals (CIs) were calculated from multiple imputations of the exposure location. Age structure of each TPU was also adjusted in the model. Abbreviations: CI, confidence interval; COVID-19, coronavirus disease 2019; HKD, Hong Kong dollars; IRR, incidence rate ratio per unit increase; TPU, tertiary planning unit; USD, US dollars.

[a]HKD: 10 000 ≈ USD 1290.

The COVID-19 pandemic in Hong Kong began with individuals who were likely from the upper or middle class—in particular, students whose families could have afforded sending them to study abroad, resulting in the higher incidence in TPUs with higher socioeconomic status partially through the clusters in entertainment venues [9]. As infections spread more widely in the local community in the third wave along with tightened measures targeting inbound travelers and entertainment venues, the disease burden shifted to socioeconomically disadvantaged individuals and neighborhoods. This unfolding pattern was consistent with the previously reported progress of the COVID-19 pandemic in other countries, such as Germany and India [16–18]. Of note, although we inferred the WFH likelihood for all imported cases, some infections (eg, students) might be due to nonoccupational exposure.

Many studies reported that pandemics—both the current and previous—disproportionally affected socioeconomically disadvantaged neighborhoods and ethnic minorities and hypothesized this to be caused by lower adoption of preventive measures and/or poor living conditions [1, 5, 6]. With detailed information on socioeconomic characteristics (ie, occupation and age) of the confirmed cases, our findings suggest that differences in exposure risks might have accounted for the observed disparities in disease burden. For economically active individuals, their exposure risks were possibly mediated by WFH flexibility, where this was much more available to those in management or professional positions, which are, in turn, generally associated with socioeconomic advantage. Our findings were consistent with the population-level association between higher COVID-19 incidence and lower possibility of social distancing, which has been reported in France and the United States [4–6].

Our findings suggest that economically inactive individuals were also at higher risk of infection. They could have presumably stayed home more but were less constrained by work compared with those who were in formal employment, which might result in behavioral differences compared with economically active individuals who could WFH. Previous studies have often assessed this population with a focus on the population-level unemployment rate, which could be biased towards persons of lower socioeconomic status. However, our results revealed that students, retirees, and homemakers made up a considerable proportion of the COVID-19 cases in Hong Kong, and these groups were less sensitive to the WFH policy. Contact matrix studies have often suggested that the elderly and economically inactive individuals have lower contact intensities compared with the working-age population, which might have underestimated their contributions in simulation models of transmission [19–22]. Our results suggested that transmission may also be associated with the infection risks

Table 2. Socioeconomic Characteristics and Work-From-Home Arrangements

	All Economically Active Respondents	Executives and Professionals	Clerical and Service Workers	Production Workers	P^a
N	1766	638	816	312	
WFH hours last week					
<10 hours	1291 (73.1)	417 (65.4)	605 (74.1)	269 (86.2)	<.01
10 to 39 hours	236 (13.4)	126 (19.7)	103 (12.6)	7 (2.2)	
≥40 hours	120 (6.8)	62 (9.7)	56 (6.9)	2 (0.6)	
Missing	119 (6.7)	33 (5.2)	52 (6.4)	34 (10.9)	
Change in WFH[b]					
Unchanged	1324 (75.0)	462 (72.4)	610 (74.8)	252 (80.8)	<.01
Changed	276 (15.6)	131 (20.5)	131 (16.1)	14 (4.5)	
Missing	166 (9.4)	45 (7.1)	75 (9.2)	46 (14.7)	
Age group, y					
18–29	399 (22.6)	146 (22.9)	212 (26.0)	41 (13.1)	<.01
30–59	1158 (65.6)	436 (68.3)	512 (62.7)	210 (67.3)	
60 or above	175 (9.9)	45 (7.1)	69 (8.5)	61 (19.6)	
Missing	34 (1.9)	11 (1.7)	23 (2.8)	0 (0.0)	
Educational attainment					
Primary or below	65 (3.7)	3 (0.5)	15 (1.8)	47 (15.1)	<.01
Secondary	664 (37.6)	84 (13.2)	355 (43.5)	225 (72.1)	
Tertiary or above	1026 (58.1)	547 (85.7)	441 (54.0)	38 (12.2)	
Missing	11 (0.6)	4 (0.6)	5 (0.6)	2 (0.6)	
Household income (HKD)[c]					
Less than $10 000	108 (7.1)	21 (3.8)	65 (9.2)	22 (8.5)	<.01
$10 000 to $20 000	134 (8.8)	10 (1.8)	67 (9.5)	57 (22.0)	
$20 000 to $30 000	205 (13.5)	36 (6.5)	100 (14.2)	69 (26.6)	
$30 000 to $40 000	218 (14.3)	61 (11.0)	120 (17.0)	37 (14.3)	
$40 000 to $50 000	166 (10.9)	52 (9.3)	90 (12.8)	24 (9.3)	
$50 000 to $60 000	127 (8.3)	60 (10.8)	58 (8.2)	9 (3.5)	
More than $60 000	394 (25.9)	265 (47.6)	113 (16.0)	16 (6.2)	
Missing	169 (11.1)	52 (9.3)	92 (13.0)	25 (9.7)	

Data are presented as n (%). N = 1766. Abbreviations: HKD, Hong Kong dollars; USD, US dollars; WFH, work-from-home.

[a]By chi-square test for the comparison between executives and professionals, clerical and service workers, and production workers.

[b]Changes in WFH refer to either increase or decrease in hours of working from home in the past week compared with the previous month.

[c]HKD 10 000 ≈ USD 1290.

of contacts, including visiting places with high risk of occurrences of case clusters (eg, dorms and restaurants for retirees, local markets for homemakers and domestic helpers, and bars for students) [9, 23]. In particular, we found that 1 in 7 local cases in the third wave were retirees, one-third of whom were infected in nursing homes. Given their high infection fatality risk [24], it is important to enforce public health measures shielding older adults.

Our work may be limited by a lack of direct information on individual data regarding WFH arrangements. Based on the employment details reported for each case, we were able to infer most (89%) of the WFH possibilities. In addition, we did not assess socioeconomic patterning of disease burden measured by clinical outcomes, given that all confirmed COVID-19 cases would be hospitalized for treatment in Hong Kong and that almost all deceased cases were aged 55 years or older, and the majority (83%) with known occupations were retirees. However, a number of studies have suggested a strong association between higher mortality and lower socioeconomic position or belonging to an ethnic minority group, which was likely to be mediated by disparities in pre-existing conditions, exposures, and access to care [1, 5, 6, 25]. Finally, we did not examine socioeconomically related behavioral factors, such as facemask use and social-distancing practice in different occupational groups, and their potential association with the risk of infection, due to the high adoption rate of mask wearing and social-distancing policies in Hong Kong [7, 14].

By the end of September, Hong Kong had managed to suppress 3 epidemic waves of COVID-19 with a series of control measures targeting travelers and physical distancing in the local community [7, 8]. Our findings for the third wave suggest that people who were less sensitive to these control measures (eg, who cannot WFH or who are economically inactive) may face disproportionally higher risks of infection while maintaining essential services in the community. Moreover, and uniquely, there was a reversal of socioeconomic patterning between the first 2 and third waves. Therefore, contextual determinants should be taken into account in future policy planning aimed at mitigating such disparities.

Supplementary Data

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

Notes

Author Contributions. All authors meet the ICMJE criteria for authorship. The study was conceived by B. J. C. and G. M. L. P. W., E. H. Y. L., J. Y. W., F. H., H. G., J. X., D. C. A., T. W. Y. N., J. Q., T. K. T., and Q. L. helped with data preparation. Data analyses were done by B. Y. B. Y. wrote the first draft of the manuscript, and all authors interpreted data, provided critical review and revision of the text, and approved the final version.

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Potential conflicts of interest. B. J. C. consults for Roche and Sanofi Pasteur. All other authors report no other potential conflicts. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

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