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Risk factors for SARS-CoV-2 transmission in close contacts of adults at high risk of infection due to occupation: results from the contact tracing strategy of the CoVIDA epidemiological surveillance study in Bogotá, Colombia, in 2020–2021

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ABSTRACT

Objectives To estimate the risk factors for SARS-CoV-2 transmission in close contacts of adults at high risk of infection due to occupation, participants of the CoVIDA study, in Bogotá D.C., Colombia.

Setting The CoVIDA study was the largest COVID-19 intensified sentinel epidemiological surveillance study in Colombia thus far, performing over 60 000 RT-PCR tests for SARS-CoV-2 infection. The study implemented a contact tracing strategy (via telephone call) to support traditional surveillance actions performed by the local health authority.

Participants Close contacts of participants from the CoVIDA study.

Primary and secondary outcome measures SARS-CoV-2 testing results were obtained (RT-PCR with CoVIDA or self-reported results). The secondary attack rate (SAR) was calculated using contacts and primary cases features.

Results The CoVIDA study performed 1257 contact tracing procedures on primary cases. A total of 5551 close contacts were identified and 1050 secondary cases (21.1%) were found. The highest SAR was found in close contacts: (1) who were spouses (SAR=32.7%; 95% CI 29.1% to 36.4%), (2) of informally employed or unemployed primary cases (SAR=29.1%; 95% CI 25.5% to 32.8%), (3) of symptomatic primary cases (SAR of 25.9%; 95% CI 24.0% to 27.9%) and (4) living in households with more than three people (SAR=22.2%; 95% CI 20.7% to 23.8%). The spouses (OR 3.85; 95% CI 2.60 to 5.70), relatives (OR 1.89; 95% CI 1.33 to 2.70) and close contacts of a symptomatic primary case (OR 1.48; 95% CI 1.24 to 1.77) had an increased risk of being secondary cases compared with non-relatives and close contacts of an asymptomatic index case, respectively.

Conclusions Contact tracing strategies must focus on households with socioeconomic vulnerabilities to guarantee isolation and testing to stop the spread of the disease.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This study is one of the first to address the risk of transmission depending on close contacts' characteristics and primary cases' sociodemographic features and their impact on transmission dynamics during the first two pandemic peaks in populated city of Latin America.
⇒ The analysis performed in this study proved that contact tracing strategies should focus not only on symptomatic infections but also on socioeconomic disadvantages, given that this population is in higher risk of infection and complication due to COVID-19.
⇒ Limited information regarding the close contacts' socioeconomic features precluded additional analyses, such as determining the impact of close contact sociodemographic characteristics on infection risk and other variables such as isolation and personal protective equipment compliance.

Over 5.5 million COVID-19 deaths have occurred since the onset of the pandemic worldwide.[1] Due to the risk of an increase in the number of cases and deaths, governments and local health authorities have implemented multiple control strategies to mitigate the effects of the pandemic. One of the non-pharmacological strategies that has impacted SARS-CoV-2 transmission the most is contact tracing.[2–4] Test, track and isolation (TTI) strategies have contributed to breaking transmission chains by identifying cases and their contacts, thus reducing rates of transmission and mortality due to COVID-19.[5] Given the transmission patterns of SARS-CoV-2, contacts of infected patients have a higher prevalence of infection compared with those who have not had contact with an infected person. The SARS-CoV-2 that causes the disease has shown high household transmission, representing a risk to susceptible populations such as the elderly (>60 years) and patients with comorbidities. Indeed, previous contact tracing studies reported that the household of the primary case is the setting with the highest risk of COVID-19 transmission.

Although vaccination coverage goals are being reached, new variants with unknown epidemiological behaviour pose an ever-present threat during the pandemic. Additionally, during the economic reopening and relaxed physical distancing measures, directing efforts towards isolating primary cases and their contacts through contact tracing remains one of the main strategies to reduce the spread of the virus.

In Bogotá, Colombia, despite multiple lockdowns and social-distancing measures, the city experienced an aggressive second wave with an increased number of cases and mortality from mid-December 2020 to March 2021. Contact-tracing strategies implemented in Colombia have shown a reduction in mortality between 0.8% and 3.4%.[6] However, the limited capacities of the public health system and socioeconomic vulnerabilities, such as high rates of informal employment, make contact-tracing protocols insufficient and subject to low compliance in some cases.[7] For this reason, the contribution of private–public epidemiological surveillance strategies have been fundamental in the active identification of asymptomatic cases and their contact networks. These strategies include intensified epidemiological surveillance studies such as the CoVIDA project that focused on asymptomatic and mild cases in high-mobility workers during the main pandemic peaks in Bogotá.[8]

The CoVIDA study is the largest intensified sentinel epidemiological surveillance study in Colombia thus far, performing over 60 000 RT-PCR tests for SARS-CoV-2 infection.[8] The study recruited from two main testing centres and home visits in Bogotá and provided results within 48 hours.[9] The CoVIDA study involved a TTI strategy with contact tracing to support traditional surveillance actions performed by the local health authorities. The strategy aimed to identify household-related, social-related and work-related close contacts of primary cases detected by the CoVIDA study and to determine the transmission dynamics of an adult population with high mobility across the city and high risk of infection due to their occupations. The present study aimed to estimate secondary transmission and to identify risk factors among close contacts before the introduction of vaccination against SARS-CoV-2.

METHODS

Study population

The CoVIDA study was the largest intensified sentinel epidemiological study performed in Colombia during the COVID-19 pandemic. It included high-mobility occupations (including healthcare workers and essential service workers that because of their occupations had to keep their activities during lockdowns in the two first pandemic peaks) in Bogotá, Colombia. Detailed methods of the CoVIDA project are described elsewhere.[8] The CoVIDA contact-tracing strategy included Bogotá residents with positive RT-PCR test results (primary cases) identified between 1 August 2020 and 14 March 2021. The daily inclusion of participants to perform contact tracing was determined according to the capacity of the CoVIDA project contact centre (approximately 50 contact tracing procedures per day). Data from primary cases were collected before SARS-CoV-2 testing and included (a) sociodemographic characteristics such as sex, age and socioeconomic strata; (b) variables related to occupation; and (c) protective measures such as handwashing and facemask use. Data about symptomatic COVID-19 infection were recorded according to national public health guidelines. Upon invitation to participate in the study, telephonic informed consent was obtained to perform the data collection, RT-PCR testing and contact tracing in case of a positive test result.

Epidemiological investigation and contact tracing

Protocols for contact tracing in the CoVIDA study followed international,[10 11] national and local guidelines (online supplemental figure 1).[12] Trained healthcare workers (tracers) performed the contact-tracing procedures. On positive RT-PCR test result, primary cases were informed via a telephone call. They were also provided with recommendations for isolation and warning signs of severe COVID-19 within 48 hours of RT-PCR sampling. According to protocol, contact tracing was performed within 24 hours after notification of the positive test result.

The contact-tracing protocol included a structured questionnaire about activities and close contacts within the 14 days prior to the onset of symptoms for symptomatic participants or 14 days prior to the RT-PCR swab sampling for SARS-CoV-2 for asymptomatic participants. A close contact was defined as someone the primary case had been within 2 m (6 feet) of for a period longer than 15 min (online supplemental appendix 1). The primary case delivered information to identify close contacts and was asked for information to establish whether the close contact fulfilled the case definition (online supplemental appendix 1). Data regarding the name and telephone number of close contacts were collected to invite them to participate in the study as part of the contact-tracing strategy. Close contacts' information regarding sex, age, presence of symptoms related to COVID-19 and previous COVID-19 testing results were obtained from the primary case during the contact tracing procedure. Personal data regarding participants' infection status were not disclosed unless expressly authorised by the primary case. If the contact reported a recent (ie, within the past 14 days) molecular, antigenic or serologic test for SARS-CoV-2, the CoVIDA project did not perform an additional test, and the case was labelled as self-reported. Close contacts who did not report recent testing for SARS-CoV-2 were eligible for testing and contacted by the CoVIDA contact tracing centre to participate in the study. Contacts who entered the study provided sociodemographic information, as the primary case did, and underwent laboratory testing for SARS-CoV-2 using RT-PCR tests with nasopharyngeal swab sampling, following the same protocols as the primary case. RT-PCR samples were processed by the Gencore Sequencing Centre of Universidad de Los Andes following the international Berlin protocol and using the U-TOP COVID-19 detection kit for one-step, real-time RT-PCR.[13] The same protocols for the test result information were followed with close contacts (online supplemental figure 1). In the case of a positive RT-PCR test, the close contact was labelled as a secondary case.

When the CoVIDA contact centre could not reach close contacts, information regarding their SARS-CoV-2 testing results was updated using registries provided by the Health Secretary of Bogotá. In Colombia, it is mandatory to report SARS-CoV-2 infection. Therefore, close contacts were labelled as secondary cases when they had a positive test result within the 14 days before/after contact tracing was performed for the primary case. After this procedure, close contacts with negative and no test result information were classified as uninfected/untested. This complementary information about SARS-CoV-2 status was only used to calculate secondary attack rate (SAR). No additional information about other sociodemographic features was included in the database.

Statistical analysis

Characteristics of primary, secondary and uninfected/untested cases were described as relative and absolute frequencies and medians with IQR as appropriate. A positive SARS-CoV-2 result by the identified close contact was labelled as a secondary case and used as the dependent variable. Primary cases and close contact characteristics were compared using the χ^2 test for discrete variables and the Wilcoxon rank-sum test for continuous variables.

Given that one participant could have been reported as a close contact by more than one primary case, secondary cases were assigned to the primary case that first reported the contact using the time when contact tracing was performed. Whenever a close contact was reported simultaneously by two primary cases on the same day, the contact was assigned to the primary case with the earliest symptom onset (in the case of symptomatic infections) or to the one with the earliest RT-PCR swab sampling date (in the case of asymptomatic infections).

SAR was estimated by dividing the number of secondary cases (ie, close contacts with positive SARS-CoV-2 tests) by the number of close contacts according to variables of interest (sex, age group, type of contact, type of relationship) and primary case's characteristics (socioeconomic strata, healthcare regime, household size, symptomatic primary case, primary case occupation). A generalised linear model based on a hierarchical model with binomial link function considering clustering by primary cases was used to estimate ORs for associations between sociodemographic characteristics of close contacts and primary case characteristics using a hierarchical conceptual model with backward elimination.[14] The proximal level was composed of risk factors inherent to close contacts (sex, age group, type of contact and, type of relationship to the primary case), and the distal level was composed by primary case characteristics (occupation, socioeconomic strata, household size, type of healthcare insurance and symptomatic infection). Variables with a p value≤0.20 at each level of analysis were retained in the model and controlled by close contacts' age and sex. In the final model, variables that were statistically associated ($p<0.05$) with the outcome were included.[8]

Confirmed SARS-CoV-2 primary cases identified by the CoVIDA project, means of the number of close contacts reported, means of secondary cases and means of SAR were mapped at the community level using the planning zone unit (UPZ, by its acronym in Spanish), which is the smallest geographical administrative unit used in Bogotá. Data analyses were performed using Stata version 17.0 (StataCorp LLC, USA).

Sensitivity analysis

We performed a comparison of the characteristics of primary cases and close contacts using as dependent variable the outcome (SARS-CoV-2 test result) for close contacts, only including individuals with defined results (self-reported or RT-PCR test results provided by the CoVIDA project). This procedure was performed to assess possible differences in distribution of secondary cases in participants with a defined infection status. Both sensitivity and bivariate analysis were conducted, and results were compared with discard misclassification bias.

Patient and public involvement

Key information regarding the study aims and procedures were relayed to the participants via telephone call. Each participant received their test results via phone call and email. The results of the contact tracing were individually discussed with each participant, resolving questions mainly related to the risk of exposures by close contacts.

RESULTS

During the study period, 1257 contact-tracing procedures were performed (see figure 1A). A total of 5551 close contacts were identified. After duplicate elimination (ie, close contacts reported simultaneously by more than 1 primary case), 1050 secondary cases (21.0%) and 3931 (78.9%) negatives/untested cases were found (figure 1B). Among secondary cases, 406 were identified with RT-PCR by the CoVIDA study and 639 were self-reported. Among

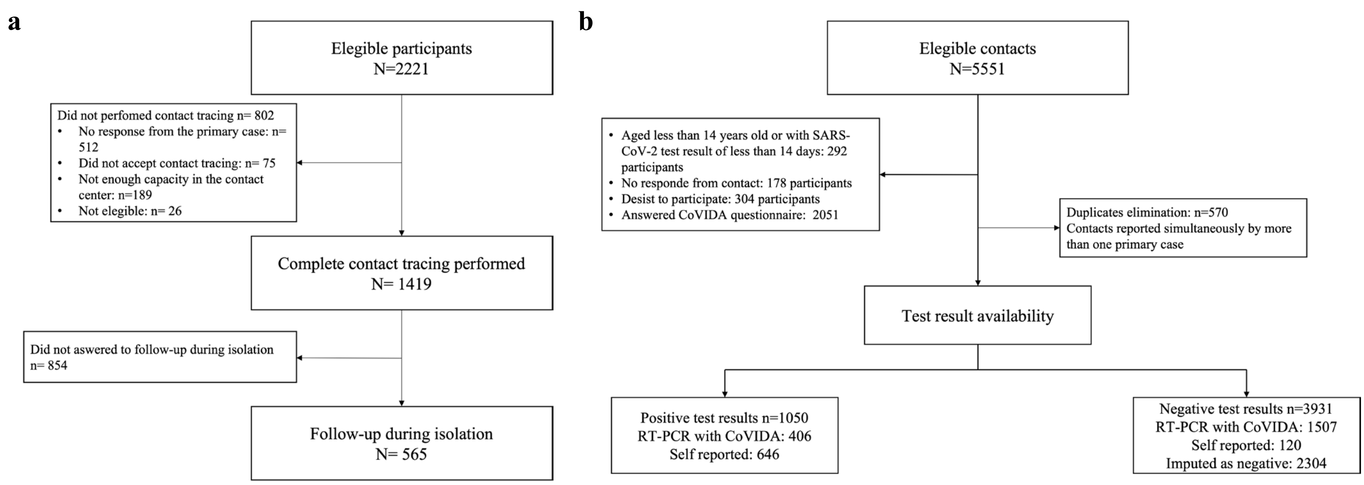

Figure 1 Flowchart of included participants. (A) Primary cases. (B) Eligible close contacts.

negative/untested contacts, 1507 were identified by the CoVIDA study, 120 were self-reported and 2304 were imputed as negative after updating records using the District Health Secretary of Bogotá registries.

Of the primary cases, 50.8% (n=638) were female, and 60.1% (n=755) were aged between 30 and 59. The most frequently reported occupation was costumer/general services, at 21.6% (n=272). Of primary cases, 49.3% (n=619) belonged to middle-low socioeconomic strata and 42.9% (n=539) reported at least one COVID-19-related symptom. Contributory healthcare insurance was reported by 83.3% (n=1034) of primary cases. Close contact with a confirmed COVID-19 case was reported by 26.6% (n=329). Of primary cases, 64.7% (n=811) reported handwashing less than 10 times a day, and 60.4% (n=757) reported a handwashing duration of less than 30s. Always using facemasks was reported by 82.6% (n=1035) of primary cases, and 50% (n=628) reported three or more cohabitants (see table 1). The places and activities most frequented by primary cases prior to testing or symptom onset were home-related (n=581, 46.5%), work-related (n=3326, 26.1%) and family gatherings (n = 262, 21.0%; see table 2).

Sociodemographic characteristics of identified close contacts and secondary cases are shown in table 3. Of close contacts identified, 52.3% (n=2604) were female, and 43.8% (n=1546) were aged between 30 and 59. Most close contacts were identified as a primary case household member (81.0%, n=3949), 10.1% (n=491) as social-related close contacts and 9% (n=491) as work-related contacts. Of close contacts, 65.3% (n=3219) were labelled as relatives, 21.4% (n=1053) as non-relatives and 13.3% (n=655) as spouses. Significant differences were noted between the proportion of secondary cases and negative/untested contacts in household members (86.8% secondary cases vs 79.4% negative cases, p<0.001), according to the type of relationship (20.6% secondary cases vs 11.4% negative cases were reported as spouses, p<0.001).

Regarding characteristics of primary cases, most identified close contacts were associated with primary cases of middle-low socioeconomic strata (50.0%, n=2476), with contributory healthcare regime (84.0%, n=4162), and 56.7% (n=2809) were linked to primary cases with households of more than three inhabitants. When comparing the close contact status and characteristics depending on the primary case, a higher proportion of secondary cases in the middle-low socioeconomic strata group (p=0.004), those with primary cases with a household of more than three inhabitants (p=0.048), and a higher proportion of secondary cases linked to symptomatic primary cases (p<0.001) were found. Regarding primary case occupation, those working in contact with customers/general services reported 20.8% (n=1031) of close contacts. We found a higher frequency of secondary cases among those with primary contacts that were police/military/firefighters (5.2% vs 3.7%) and informally employed or looking for a job (17.3% vs 11.3%).

Figure 2 shows the spatial distribution of primary cases, close contacts, secondary cases and SAR; according to primary cases, close contacts and secondary cases were distributed in the more inhabited localities in Bogotá (SARs were higher in these localities). However, a low number of identified close contacts and high number of close contacts with positive tests were identified in some UPZ, hence the SAR in these were close to 100%. This finding agrees with the cumulative case density and death rate found according to the Health Secretary of Bogotá.[15]

Table 4 shows SAR and logistic regression results according to close contact and primary case features. The highest SAR was found in close contacts aged between 30 and 59 years (SAR=21.5%; 95% CI 19.5% to 23.7%), household close contacts (SAR=25.7%; 95% CI 24.3% to 27.2%), spouses (SAR=32.7%; 95% CI 29.1% to 36.4%), close contacts with primary cases belonging to middle-high and middle-low socioeconomic strata (SAR=23.2%; 95% CI 16.1% to 31.6% and SAR=23.2; 95% CI 21.5% to 24.9%, respectively). Regarding the healthcare regime of the primary case, the highest SAR was observed in the contributory group (21.7%; 95% CI 20.5% to 23.0%). Those close contacts with primary cases

Table 1 Sociodemographic characteristics of identified index cases

Variable	Primary cases N=1257
Sex	
Female	638 (50.8)
Male	619 (49.2)
Age (years)	
14–18	9 (0.8)
19–29	412 (32.8)
30–59	755 (60.1)
>60	81 (6.4)
Occupation	
Healthcare worker	109 (8.7)
Police/military/firefighter	38 (3.0)
Construction worker	16 (1.3)
Costumer/general services	272 (21.6)
Essential office work	211 (16.8)
Informal employment/looking for a job	176 (14.0)
Public/private driver	149 (11.9)
Teacher/auxiliary/student	166 (13.2)
Other occupation*	120 (9.6)
Socioeconomic strata	
High	19 (1.5)
Middle high	30 (2.4)
Middle	161 (12.8)
Middle low	619 (49.3)
Low	364 (29.0)
Very low	64 (5.0)
Report of at least one COVID-19-related symptom	
Yes	539 (42.9)
No	718 (57.1)
Contact with COVID-19	
Yes	329 (26.6)
No	906 (73.4)
Type of healthcare insurance†	
Contributory	1034 (83.3)
Subsidised	115 (9.2)
Not affiliated	198 (8.6)
Frequency of handwashing	
<10 times/day	811 (64.7)
≥10 times/day	442 (35.3)
Duration of handwashing	
≤20 s	757 (60.4)
>20 s	496 (39.6)
Use of facemasks during the day	
Always	1035 (82.6)
Sometimes	205 (16.4)
Never	13 (1.0)
Household size	
≤3	629 (50.0)
>3	628 (50.0)

Missing information on 22 (1.8%) participants regarding contact with COVID-19; 90 (7.2%) participants regarding type of health insurance; 4 (0.3%) participants regarding frequency and duration of handwashing, use of facemasks during the day.
*Other occupations: cooks, musicians, technicians, veterinarians, among others; Socioeconomic strata as defined by the National Department of Statistics (DANE) of Colombia: 1 (very low strata) to 6 (high strata).
†According to health affiliation system in Colombia, people with formal employment are included in the contributory health system, while people working informally and unemployed have subsidised healthcare (public healthcare).

living in households of more than three people had an SAR of 22.2% (95% CI 20.7% to 23.8%). Close contacts of symptomatic primary cases had an SAR of 25.9% (95% CI 24.0% to 27.9%). Close contacts related to primary cases who were informally employed or unemployed (SAR=29.1%; 95% CI 25.5% to 32.8%) had the highest SAR among occupations.

The logistic regression only included observations with complete data. Therefore, the final model included a total of 2177 participants. This analysis showed that close contacts who reported being spouses (OR 3.85; 95% CI 2.60 to 5.70) and relatives (OR 1.89; 95% CI 1.33 to 2.70) of the primary case had higher odds of being secondary cases when compared with non-relatives. In the analysis, characteristics of the primary case, symptomatic primary case, household size and primary case occupations were retained in the model. Close contacts of symptomatic primary cases (OR 1.48; 95% CI 1.24 to 1.77) and those

Table 2 Reported activities or visited place prior to positive result or symptom onset

Reported place or activity	N (%)
Home related	581 (46.5)
Work related	326 (26.1)
Family gathering	262 (21.0)
Grocery shopping	106 (8.5)
Transport to work	66 (5.3)
Use of public transportation	58 (4.6)
Healthcare facility	52 (4.2)
Social event	51 (4.1)
Healthcare facility (healthcare worker)	42 (3.4)
Outdoor activity	19 (1.5)

Table 3 Sociodemographic characteristics of close contacts

Variable	Total N=4981	Secondary cases n=1050	Test-negative or untested contacts n=3931	P value
Close contact characteristics				
Sex				0.490
Female	2604 (52.3)	539 (51.3)	2065 (52.5)	
Male	2377 (47.7)	511 (48.7)	1866 (47.5)	
Age (years)				0.194
<14	212 (5.9)	43 (5.9)	169 (5.9)	
14–18	204 (5.7)	30 (4.1)	174 (6.0)	
19–29	833 (23.1)	160 (22.0)	673 (23.4)	
30–59	1546 (43.8)	333 (45.7)	1213 (42.1)	
≥60	814 (22.6)	163 (22.4)	651 (22.6)	
No data	1372 (27.5)	321 (30.7)		
Type of contact				<0.001
Household	3949 (81.0)	888 (86.8)	3061 (79.4)	
Work	491 (10.1)	70 (6.8)	421 (10.9)	
Social	238 (9.0)	65 (6.4)	373 (9.7)	
Type of relationship				<0.001
Spouse	655 (13.3)	214 (20.6)	441 (11.4)	
Relative	3219 (65.3)	671 (64.5)	2548 (65.6)	
Non-relative	1053 (21.4)	155 (14.9)	898 (23.1)	
Primary case characteristics				
Socioeconomic strata				0.004
High	70 (1.4)	11 (1.1)	59 (1.5)	
Middle high	125 (2.5)	29 (2.8)	96 (2.5)	
Middle	566 (11.4)	98 (9.4)	468 (12.0)	
Middle low	2476 (50.0)	574 (54.9)	1902 (48.7)	
Low	1484 (30.0)	298 (28.5)	1186 (30.4)	
Very low	227 (4.6)	36 (3.4)	191 (4.9)	
Type of healthcare insurance				0.034
Contributory	4162 (84.0)	904 (86.2)	3258 (83.4)	
Subsidised	401 (8.1)	65 (6.2)	336 (8.6)	
No affiliation	391 (7.9)	80 (7.6)	311 (8.0)	
Household size				0.048
≤3 cohabitants	2145 (43.3)	426 (40.6)	1719 (44.0)	
>3 cohabitants	2809 (56.7)	623 (59.4)	2186 (56.0)	
Symptomatic primary case				<0.001
Yes	1990 (40.2)	516 (49.2)	1474 (37.8)	
No	2964 (59.8)	533 (50.8)	2431 (62.2)	
Primary case occupation				<0.001
Healthcare worker	399 (8.1)	78 (7.4)	321 (8.2)	
Police/military/firefighter	201 (4.1)	55 (5.2)	146 (3.7)	
Construction worker	57 (1.2)	11 (1.1)	46 (1.2)	
Costumer/general services	1031 (20.8)	211 (20.1)	820 (21.0)	
Essential office work	901 (18.2)	198 (18.9)	703 (18.0)	
Informal employment/looking for a job	623 (12.6)	181 (17.3)	442 (11.3)	

Continued

Table 3 Continued

Variable	Total N=4981	Secondary cases n=1050	Test-negative or untested contacts n=3931	P value
Public/private driver	645 (13.0)	96 (9.2)	539 (14.1)	
Teacher/auxiliary/student	593 (12.0)	131 (12.5)	462 (11.8)	
Other occupation*	504 (10.2)	88 (8.4)	416 (10.7)	

Age was missing in 1372 cases (321 missing secondary cases, 1051 negative cases); type of close contact was missing in 303 close contacts; type of relationship was missing for 54 close contacts.
*Other occupations: cooks, musicians, technicians, veterinarians, among others.

of primary cases that were working informally or unemployed had a higher risk of being secondary cases (OR 1.73; 95% CI 1.17 to 2.58). Primary cases' household size was not associated with a higher risk of being a secondary case (OR 1.16; 95% CI 0.97 to 1.38).

Comparison of the characteristics of close contacts with defined test results is shown in online supplemental table 1. No further significant associations between close contacts' characteristics and test results were found, except for close contact age. However, this variable was already included in the main logistic regression model.

Other characteristics, such as close contact occupation, socioeconomic strata, protective measures (eg, handwashing frequency and duration of handwashing), public transportation use and household size can be found in online supplemental table 2. These results were only available for those close contacts who agreed to participate in the CoVIDA project and had confirmed RT-PCR results. Given the proportion of missing data regarding these close contact characteristics, these variables were not included in the logistic regression model.

Online supplemental table 3 shows performance indicators of contact-tracing strategies according to the Colombian Healthcare Ministry standards. The CoVIDA project fulfilled all indicators except for the percentage of contacts tracked with a close contact map. These differences were observed because the CoVIDA contact-tracing centre could make no further communication after reporting the RT-PCR positive test result within the CoVIDA study.

DISCUSSION

To the authors' knowledge, this is one of the first studies approaching risk factors to become a secondary case performed using a contact-tracing strategy in a large city with pronounced social inequities in a developing country in Latin America during the prevaccination period of the COVID-19 pandemic. In our study, the household members, including spouses and relatives, had much higher risk of being secondary cases compared with non-relatives. Furthermore, close contacts who reported at least one COVID-19-related symptom or were linked to a symptomatic primary case had more than a 50% increase in the risk of being a secondary case compared with asymptomatic close contacts. Close contacts of informal or unemployed primary cases had 27% increased risk of being secondary cases compared with close contacts of healthcare workers. These results on risk factors for becoming a secondary case in a large city in a developing country with high social inequity and rates of informal working conditions show that (a) contact-tracing strategies should focus on the household of primary cases and (b) socioeconomic vulnerabilities such as working insecurity could reflect noncompliance with non-pharmacological strategies, such as isolation, because of the intrinsic features of such vulnerabilities.

Contact tracing as a non-pharmacological measure has targeted household members to stop COVID-19 transmission. Various systematic reviews have found that household members have higher SARs than other close contacts.[16,17] Household SAR can range from 3.9% to 54.9%, with pooled results of 18.1%.[16] In our study, household SAR was 25.7%, more than 10 percentage points higher than in work-related and social-related close contacts, and higher than SARs reported in systematic reviews[16] and other individual studies.[18–20] Differences in the SAR between our study and those found in the literature could be explained by the high-risk population (ie, those with occupations with high mobility during the first pandemic peaks) that was included in our study.[8] Our results suggest that transmission risk is mainly domestic. However, our results and other studies also suggest that people with high mobility occupations, such as police/military/firefighters (OR 3.06, 95% CI 2.48 to 3.77), informal workers (OR 2.65, 95% CI 2.27 to 3.10) and teachers (OR 1.72, 95% CI 1.46 to 2.02) had a higher risk of being infected with SARS-CoV-2 compared with healthcare workers.[8,21]

Also, the higher risk of infection among this population of police/military/firefighters, informal workers and teachers could explain the higher SAR within their close contacts. The other studies examined SAR in the general population rather than among high-risk groups. Within the household, certain conditions could further increase the risk of infection among close contacts. The closer the relationship between the primary case and their close contact, the higher the probability of being infected. In our study, spouses showed the highest SAR (32.7% vs 20.8% in relatives and 15.7% in non-relatives), similar to those reported in the systematic review published by Koh

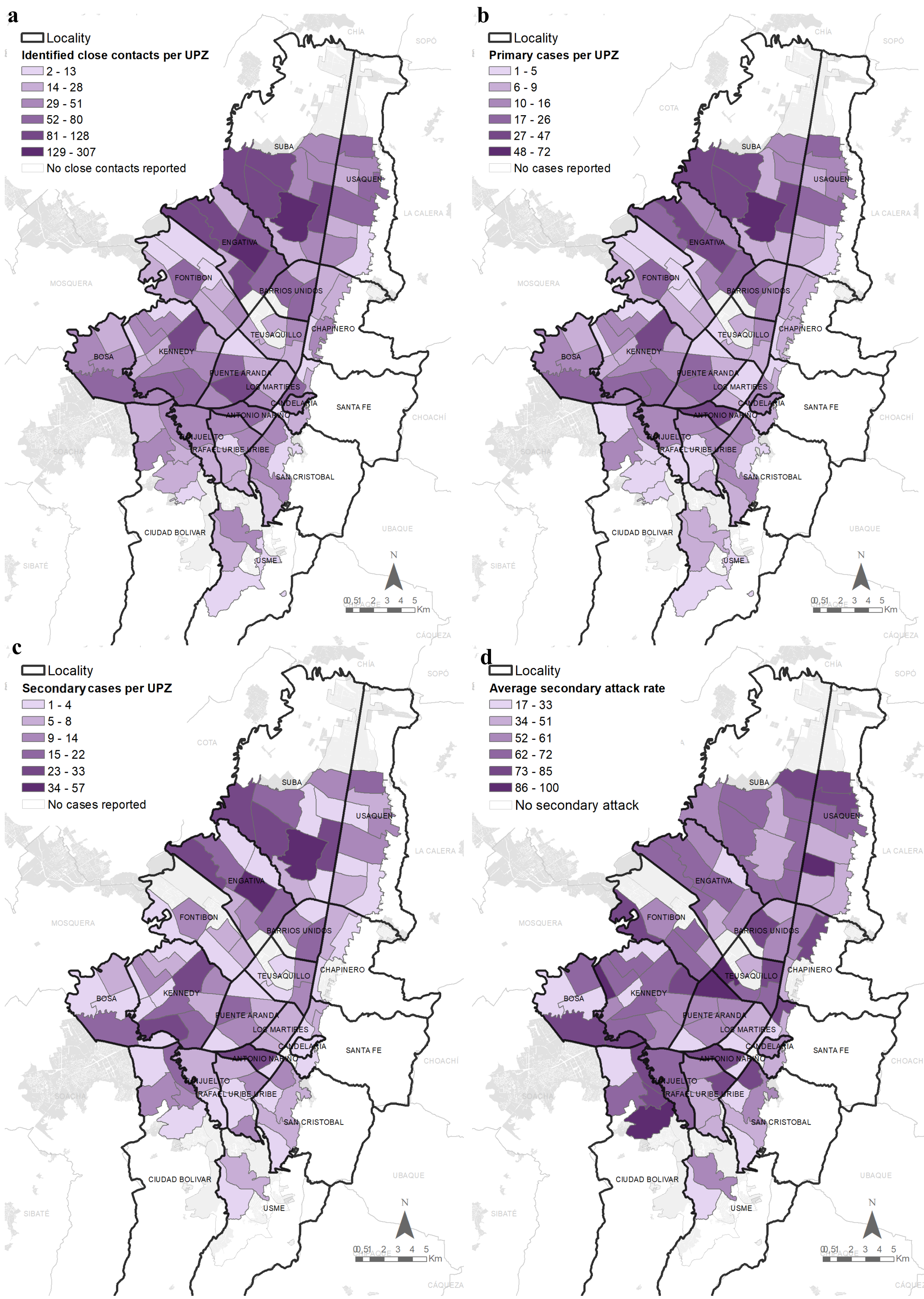

Figure 2 Spatial distribution of primary and close contacts. (A) Primary case. (B) Identified close contacts. (C) Secondary cases. (D) Secondary attack rate. UPZ, planning zone unit.

et al that showed a pooled SAR of 37.5% (95% CI 22.2% to 52.7%).[16] In fact, our study found that, compared with non-relatives, spouses and relatives had a higher risk of being infected. Other studies found similar results, with spouses having at least two times the risk of being infected compared with another household member in

Table 4 Secondary attack rate and logistic regression for secondary cases

Variable	SAR (%) (95% CI)	Unadjusted OR (95% CI)	P value	Adjusted OR (95% CI)	P value
Close contact characteristics					
Sex					
Male	21.5 (19.9 to 23.2)	1.05 (0.92 to 1.20)	0.490	1.12 (0.94 to 1.33)	0.210
Female	20.7 (19.2 to 22.3)	1.00 (reference)	–	1.00 (reference)	–
Age					
<14 years	20.3 (15.1 to 26.3)	1.00 (reference)	–	1.00 (reference)	–
14–18 years	14.7 (10.1 to 20.3)	0.68 (0.41 to 1.13)	0.136	0.70 (0.41 to 1.21)	0.197
19–29 years	19.2 (16.6 to 22.0)	0.93 (0.64 to 1.36)	0.724	0.95 (0.63 to 1.42)	0.802
30–59 years	21.5 (19.5 to 23.7)	1.08 (0.76 to 1.54)	0.676	1.03 (0.70 to 1.51)	0.889
60 years	20.0 (17.3 to 22.9)	0.98 (0.68 to 1.43)	0.933	0.98 (0.66 to 1.50)	0.889
Type of contact					
Household	25.7 (24.3 to 27.2)	1.00 (reference)	–	1.00 (reference)	–
Work	14.8 (11.6 to 18.5)	0.57 (0.44 to 0.75)	<0.001	1.12 (0.68 to 1.85)	0.647
Social	14.3 (11.3 to 17.7)	0.60 (0.46 to 0.79)	<0.001	0.72 (0.50 to 1.01)	0.069
Type of relationship					
Spouse	32.7 (29.1 to 36.4)	2.81 (2.22 to 3.56)	<0.001	3.85 (2.60 to 5.70)	<0.001
Relative	20.8 (19.5 to 22.3)	1.53 (1.26 to 1.85)	<0.001	1.89 (1.33 to 2.70)	<0.001
Non-relative	15.7 (12.6 to 17.0)	1.00 (reference)	–	1.00 (reference)	–
Primary case characteristics					
Socioeconomic strata					
High	15.7 (8.1 to 26.3)	1.00 (reference)	–	1.00 (reference)	–
Middle high	23.2 (16.1 to 31.6)	1.62 (0.75 to 3.49)	0.217	2.63 (0.93 to 7.45)	0.067
Middle	17.3 (14.3 to 20.7)	1.12 (0.57 to 2.21)	0.738	1.38 (0.55 to 3.47)	0.489
Middle low	23.2 (21.5 to 24.9)	1.62 (0.84 to 3.10)	0.147	2.06 (0.85 to 4.98)	0.108
Low	20.0 (18.1 to 22.2)	1.35 (0.70 to 2.60)	0.373	1.84 (0.76 to 4.49)	0.178
Very low	15.9 (11.4 to 21.3)	1.01 (0.48 to 2.11)	0.977	1.41 (0.53 to 3.74)	0.495
Type of healthcare insurance					
Contributory	21.7 (20.5 to 23.0)	1.00 (reference)	–	1.00 (reference)	–
Subsidised	16.2 (12.7 to 20.2)	0.70 (0.53 to 0.92)	0.010	0.72 (0.51 to 1.02)	0.064
No affiliation	20.5 (16.6 to 24.8)	0.56 (0.72 to 1.20)	0.563	0.58 (0.41 to 0.83)	0.030
Household size					
≤3 cohabitants	19.9 (18.2 to 21.6)	1.00 (reference)	–	1.00 (reference)	–
>3 cohabitants	22.2 (20.7 to 23.8)	1.15 (1.00 to 1.32)	0.048	1.16 (0.97 to 1.38)	0.115
Symptomatic primary case					
Yes	25.9 (24.0 to 27.9)	1.60 (1.39 to 1.83)	<0.001	1.48 (1.24 to 1.77)	<0.001
No	18.0 (16.6 to 19.4)	1.00 (reference)	–	1.00 (reference)	–
Primary case occupation					
Healthcare worker	19.5 (15.8 to 23.8)	1.00 (reference)	–	1.00 (reference)	–
Police/military/firefighter	27.4 (21.3 to 34.1)	1.55 (1.04 to 2.30)	0.030	1.22 (0.73 to 2.05)	0.443
Construction worker	19.3 (10.0 to 31.9)	0.98 (0.49 to 1.99)	0.964	0.73 (0.25 to 1.84)	0.441
Costumer/general service	20.5 (18.0 to 23.1)	1.06 (0.79 to 1.41)	0.699	1.20 (0.82 to 1.73)	0.347
Essential office work	22.0 (19.3 to 24.8)	1.16 (0.86 to 1.55)	0.324	1.14 (0.78 to 1.67)	0.483
Informal employment/looking for a job	29.1 (25.5 to 32.8)	1.69 (1.24 to 2.28)	0.001	1.73 (1.17 to 2.58)	0.006
Public/private driver	14.9 (12.2 to 17.9)	0.72 (0.52 to 1.00)	0.050	0.71 (0.47 to 1.01)	0.108

Continued

Table 4 Continued

Variable	SAR (%) (95% CI)	Unadjusted OR (95% CI)	P value	Adjusted OR (95% CI)	P value
Teacher/auxiliary/student	22.1 (18.8 to 25.6)	1.17 (0.85 to 1.60)	0.336	1.48 (0.99 to 2.24)	0.059
Other occupation*	17.5 (14.2 to 21.1)	0.87 (0.62 to 1.22)	0.421	1.19 (0.78 to 1.83)	0.418

*Other occupations: cooks, musicians, technicians, veterinarians, among others.

a systematic review (pooled risk ratio 2.39; 95% CI 1.79 to 3.19),[16] and similar risk was found in a cohort study performed in China (OR 2.27, CI 95% 1.22 to 4.22).[20] The results explain this fact from the cohort study by Ng *et al*, which showed that sharing a bedroom with a primary case increases the risk of infection more than five times (OR 5.38, 95% CI 1.82 to 15.84).[22]

Even the SAR on work-related and social-related close contacts was higher in our study (14.8% and 14.3%, respectively) compared with other studies. The study by Ng *et al* using data from Singapore found that SAR was 1.3% (95% CI 0.9 to 1.9) for work-related close contacts and 1.3% (95% CI 1.0 to 1.7) for social-related contacts.[22] Non-household-related activities that can increase the risk of infection include meetings, choir and specific activities such as eating, travelling and attendance at a religious event.[16] Our study found that the most reported activities among primary cases were related to the household setting, which can explain the higher SAR obtained in household members compared with other studies.[22]

Other features such as symptoms in both the primary case were the risk factors for being a secondary case in our study. Results show that the household SAR of symptomatic primary cases is higher than that of asymptomatic or presymptomatic cases (RR 3.23; 95% CI 1.46 to 7.14) or contacts exposed to primary cases during the symptomatic period (RR 2.15, 95% CI 1.67 to 2.79), and those with critically severe symptoms (RR 1.61, 95% CI 1.0 to 2.57) and specific symptoms such as dizziness, myalgia and chills had higher risks of infection in a retrospective cohort study.[23] Other symptoms such as fever and expectoration in the primary case have also been identified as risk factors for infection.[19] Another population-based study in China found that close contacts exposed to mild symptomatic and moderate symptomatic cases of COVID-19 had a higher risk of becoming infected (adjusted risk ratio (ARR) 4.0; 95% CI 1.8 to 9.1; ARR 4.3; 95% CI 1.9 to 9.7, respectively). Even though asymptomatic infections have the potential of spreading to others, they appear to have a lower SAR and less probability of infecting others.[19 24] In addition, our findings are consistent with the literature, showing that symptomatic cases had higher transmissibility compared with asymptomatic cases and were more likely to infect their contacts due to a higher viral load.[25]

However, most studies analysing transmission dynamics and risk factors for COVID-19 transmission have been performed in developed and high-income countries, such as China, the USA and Singapore, among others.[20 22 23]

In our study, close contacts with primary cases with informal working conditions or who were unemployed were at higher risk of infection. Although the occupations and socioeconomic vulnerabilities of primary cases and close contacts have not been widely studied, results from other analyses of the CoVIDA project have shown that people in lower socioeconomic strata, with no healthcare coverage, and living in crowded spaces have a higher risk of infection.[7 8 25] Another study conducted in the Netherlands found that occupations related to public transportation, including driving instructors, and others such as hairdressers and aestheticians tested positive more often than healthcare workers.[15] The higher SAR and probability of being a secondary case due to close contact with infected persons with military-related occupations could reflect housing conditions (ie, poor ventilation, crowded spaces, among others) and deficient isolation strategies. Additionally, diverse workplaces employing military and civilian workers can increase transmission rates.[26 27] Our results show that no differences between primary case socioeconomic strata or healthcare regimes affect the probability of being infected. Being linked to a primary case with a larger household resulted in a higher SAR, but these results did not reflect on the multivariate analysis. Although our study did not find differences between age groups or sex, other studies have found that adults, especially people over 60 years old, have a higher risk of infection.[18 19]

Contact tracing is a widely proven non-pharmacological strategy that could dramatically reduce the pandemic spread when performed appropriately.[2 28 29] In fact, this strategy has been shown to reduce mortality by between 48% and 67%[6 30 31] and has proven to be cost-effective in settings such as Colombia and Latin America.[31] Although digital technologies are an appealing way to enact contact-tracing strategies, limited resources in connectivity and ethical concerns place traditional contact tracing as a viable, effective strategy to be used more widely, especially in low-income and middle-income settings.

Our results and those reported in the literature show that contact-tracing strategies should focus on household members. However, containment strategies also depend on isolation compliance. In this matter, social inequities should be addressed. Our study showed that close contacts of primary cases with working insecurity were at higher risk of infection. This has become the reality of thousands of families due to unemployment and precarious working conditions during the pandemic. Latin America is one of the most heavily impacted regions in terms of loss of earnings and hours worked worldwide.[32] This phenomenon results in slower economic growth and higher rates of informal working, widening social inequities and impacting the pandemic containment.[33]

A third pandemic peak and the highest number of cases and deaths were observed after the CoVIDA project finished sample collection. Even though contact tracing was a national policy implemented in Bogotá, testing capacity, time to test, time to test result and isolation compliance were challenging in all PRASS (Prueba, Rastreo y Aislamiento Selectivo Sostenible) and DAR (Detecto, Aislo y Reporto) strategy reports.[34 35] The results of this study can lead to other focal points, such as symptomatic primary cases, households and occupations such as military and informal workers, because their close contacts are at higher risk of becoming secondary cases.

Among the strengths of the study is that it is one of the first to address the risk of transmission depending on close contacts' characteristics and primary cases' sociodemographic features and their impact on transmission dynamics during the first two pandemic peaks in the most populated city in Colombia. However, some limitations must be considered. Even though we validated test results using official registries and updated testing information using registries provided by the Health Secretary of Bogotá for close contacts with provided ID information, there was a large number of close contacts without SARS-CoV-2 test result information. Additionally, limited information regarding the socioeconomic features of close contacts precludes other analyses, such as determining the impact of close contact sociodemographic characteristics on infection risk and other variables such as isolation compliance.

In conclusion, the results of this study suggest focusing contact-tracing strategies on household members, spouses and close contacts of primary cases who are unemployed, working informally or working in the military, who have higher odds of being secondary cases. Contact-tracing strategies must focus on households with socioeconomic vulnerabilities and guarantee isolation and testing in a timely manner. In low-income and middle-income countries such as Colombia, contact tracing should consider social vulnerabilities and occupational hazards derived from these inequalities, besides biological factors such as symptomatic infection, to effectively mitigate the COVID-19 pandemic.

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