Background: Risk for transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) to close contacts of infected persons has not been well estimated.

Objective: To evaluate the risk for transmission of SARS-CoV-2 to close contacts in different settings.

Design: Prospective cohort study.

Setting: Close contacts of persons infected with SARS-CoV-2 in Guangzhou, China.

Participants: 3410 close contacts of 391 index cases were traced between 13 January and 6 March 2020. Data on the setting of exposure, reverse transcriptase polymerase chain reaction testing, and clinical characteristics of index and secondary cases were collected.

Measurement: Coronavirus disease 2019 (COVID-19) cases were confirmed by guidelines issued by China. Secondary attack rates in different settings were calculated.

Results: Among 3410 close contacts, 127 (3.7% [95% CI, 3.1% to 4.4%]) were secondarily infected. Of these 127 persons, 8 (6.3% [CI, 2.1% to 10.5%]) were asymptomatic. Of the 119 symptomatic cases, 20 (16.8%) were defined as mild, 87 (73.1%) as moderate, and 12 (10.1%) as severe or critical. Compared with the household setting (10.3%), the secondary attack rate was lower for exposures in health care settings (1.0%; odds ratio [OR], 0.09 [CI, 0.04 to 0.20]) and on public transportation (0.1%; OR, 0.01 [CI, 0.00 to 0.08]). The secondary attack rate increased with the severity of index cases, from 0.3% (CI, 0.0% to 1.0%) for asymptomatic to 3.3% (CI, 1.8% to 4.8%) for mild, 5.6% (CI, 4.4% to 6.8%) for moderate, and 6.2% (CI, 3.2% to 9.1%) for severe or critical cases. Index cases with expectoration were associated with higher risk for secondary infection (13.6% vs. 3.0% for index cases without expectoration; OR, 4.81 [CI, 3.35 to 6.93]).

Limitation: There was potential recall bias regarding symptom onset among patients with COVID-19, and the symptoms and severity of index cases were not assessed at the time of exposure to contacts.

Conclusion: Household contact was the main setting for transmission of SARS-CoV-2, and the risk for transmission of SARS-CoV-2 among close contacts increased with the severity of index cases.

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* Dr. Luo, Dr. D. Liu, Mr. Liao, and Dr. Wu contributed equally.
health care facilities at all levels and of all types in China were obliged to identify COVID-19 cases and report them immediately via the online direct reporting system to Centers for Disease Control and Prevention (CDCs) in China. Upon receiving a report, the CDCs reviewed cases within 2 hours in the online direct reporting system. Once suspected cases (symptomatic, but not yet confirmed by laboratory testing), confirmed cases (symptomatic cases), and asymptomatic infected persons (asymptomatic cases) were verified and reported, the county or district CDCs completed an epidemiologic investigation of these cases within 24 hours, including contact tracing (13, 14). Close contacts are individuals who have had contact, without effective protection regardless of duration of exposure, with 1 or more persons with suspected or confirmed COVID-19 any time starting 2 days before onset of symptoms in persons with a suspected or confirmed case, or 2 days before sampling for laboratory testing of asymptomatic infected persons (14).

For close contact tracing on public transportation, a cell phone database based on the movements of the

**Figure 1.** Study flow diagram.

CDC = Center for Disease Control and Prevention; COVID-19 = coronavirus disease 2019; GZCDC = Guangzhou Center for Disease Control and Prevention; RT-PCR = reverse transcriptase polymerase chain reaction.

* Quarantine period was 14 d after the last unprotected contact with confirmed cases and infected persons.

† Followed until 6 April 2020.
users was developed in China (12). By measuring and recording proximity events between individuals, it can immediately trace close contacts of diagnosed cases upon case confirmation (15). In this way, almost all of the close contacts of public transportation can be traced. A small proportion of close contacts was difficult to trace owing to lack of cell phone data. Detailed information on definitions and close contact tracing is provided in Part 2 of the Supplement.

From 28 December 2019 to 5 March 2020, 3410 close contacts of 391 index cases (244 in Guangzhou and 147 in other regions) were identified and followed up by the Guangzhou CDC (GZCDC) from 13 January 2020 to 6 March 2020. The close contacts included in this study are the close contacts living in Guangzhou of these 391 index cases during the study period and do not include additional close contacts managed by other regional CDCs in China. Figure 1 shows the flowchart of COVID-19 cases and close contact management.

Our study was based on the data from the work for an ongoing public health response to COVID-19 by GZCDC as required by the National Health Commission of China, and hence individual informed consent was waived. The study was determined not to be human subjects research and therefore was considered exempt from ethical approval after consultation with the ethics committee of GZCDC. Analytical data sets were constructed in an anonymized manner, and all analysis of personally identifiable data took place onsite at the GZCDC.

**Data Collected From the Index Cases**

The information collected for 244 index cases in Guangzhou included demographic characteristics (age and sex), severity, clinical symptoms at onset (fever, dry cough, expectoration, fatigue, myalgia, and diarrhea), radiologic examinations (chest computed tomography), and blood examinations (leukocyte count, lymphocyte percentage, and neutrophilic granulocyte percentage). Clinical data on the 147 index cases from regions other than Guangzhou were unavailable, and therefore their 800 close contacts inside Guangzhou could not be categorized by severity and symptoms of the index cases. In addition, no information on symptoms for 21 index cases in Guangzhou, and thus their 797 close contacts, could be categorized by symptoms of the index cases.

**Exposure Settings of Close Contacts**

Upon identification, information about the setting of exposure to the index case was obtained and classified into 5 categories: household, public transportation, health care settings, entertainment venues or workplaces, and multiple settings. “Multiple settings” indicates exposure in more than 1 contact setting. Index cases were quarantined before diagnosis if they were suspected cases, and household contacts were separated from the index cases before diagnosis was made in the index cases.

**Monitoring and Evaluation of Close Contacts**

After identification, close contacts were quarantined for 14 days from last contact with index cases and followed up clinically after quarantine until 6 April 2020. For example, if an individual was traced on the fourth day after the last unprotected contact, this individual was required to be medically observed for 10 days. The quarantine period was extended for 337 close contacts for whom real-time fluorescence-based

### Table 1. Demographic Characteristics of Index Cases, Close Contacts, and Secondary Cases

| Characteristic                                | Index Cases (n = 391), n (%) | Close Contacts (n = 3410), n (%) | Secondary Cases (n = 127), n (%) |
|-----------------------------------------------|------------------------------|----------------------------------|----------------------------------|
| **Median age (IQR), y***                      | 48.0 (33.5–62.0)            | 38.0 (26.0–51.0)                 | 44.0 (30.0–60.0)                 |
| **Age group***                                |                              |                                  |                                  |
| 0–17 y                                        | 13 (5.3)                     | 357 (10.5)                      | 14 (11.0)                       |
| 18–44 y                                       | 92 (37.7)                    | 1784 (52.3)                     | 50 (39.4)                       |
| 45–59 y                                       | 71 (29.1)                    | 818 (24.0)                      | 29 (22.8)                       |
| ≥60 y                                         | 68 (27.9)                    | 451 (13.2)                      | 34 (26.8)                       |
| **Sex***                                      |                              |                                  |                                  |
| Male                                          | 122 (50.0)                   | 1799 (52.8)                     | 56 (44.1)                       |
| Female                                        | 122 (50.0)                   | 1611 (47.2)                     | 71 (55.9)                       |
| **Localized management**                      |                              |                                  |                                  |
| Yes                                           | 244 (62.4)                   | 3410 (100.0)                    | 127 (100.0)                     |
| No                                            | 147 (37.6)                   | 0 (0.0)                         | 0 (0.0)                         |
| **Methods of identifying cases***             |                              |                                  |                                  |
| Surveillance testing                          | 9 (3.7)                      | 0 (0.0)                         | 0 (0.0)                         |
| Testing individuals with symptoms at a health care facility | 197 (80.7)                  | 0 (0.0)                         | 0 (0.0)                         |
| Testing a close contact†                       | 17 (7.0)                     | 3115 (100.0)                    | 127 (100.0)                     |
| Combination of these methods                  | 21 (8.6)                     | 0 (0.0)                         | 0 (0.0)                         |

IQR = interquartile range.

* Data on age, sex, and methods of identifying cases were unavailable for 147 index cases outside Guangzhou.

† A total of 295 close contacts were not tested by using reverse transcriptase polymerase chain reaction because the median time from their last contact to the start of quarantine was 24 d, which was longer than the quarantine duration of 14 d, and they had no symptoms during this period.
reverse transcriptase polymerase chain reaction (RT-PCR) testing was delayed.

During the quarantine period, monitoring of clinical symptoms and RT-PCR assay of SARS-CoV-2 nucleic acid was performed approximately every 24 hours. Specimens for RT-PCR testing were obtained from the upper (nasopharyngeal and oropharyngeal swabs) and lower (sputum) respiratory tracts by trained CDC staff and were sent to GZCDC for testing. The RT-PCR testing was performed by qualified staff, and results were identified through open reading frame 1ab (ORF1ab) and nucleocapsid protein (N) in accordance with the protocol established by the Chinese CDC (16). Details of the laboratory processes are provided in Part 3 of the Supplement.

Close contacts who tested positive on RT-PCR and remained symptom-free were released after the quarantine period. Those who developed symptoms but tested negative throughout the quarantine period on RT-PCR received radiologic examinations and serologic COVID-19–specific IgM and IgG examinations. If the examinations were all negative, they were released from quarantine and followed for the development of symptoms by staff in their communities via weekly in-person visits through 6 April 2020. Close contacts who developed symptoms during the follow-up period after release from quarantine were retested.

### Outcomes

The main outcome was COVID-19 infection in close contacts during the follow-up period. These included asymptomatic cases and symptomatic cases, which were defined on the basis of guidelines issued by the National Health Commission of the People’s Republic of China (13, 17).

| Characteristic | Close Contacts, n (%) | Secondary Cases, n (%) |
|---------------|----------------------|------------------------|
| **COVID-19 cases** |                       |                        |
| Asymptomatic (n = 8)* | –                     | 3.7 (3.1–4.4)          |
| Symptomatic (n = 119)* | –                     | 0.2 (0.1–0.4)          |
| Mild | –                     | 3.5 (2.9–4.1)          |
| Moderate | –                     | 20 (16.8)              |
| Severe or critical | –                     | 87 (73.1)              |
| **Number of index cases contacted** |                       |                        |
| 1 | 3206 (94.0) | 117 (92.1) |
| 2 | 128 (3.8)  | 9 (7.1)   |
| ≥3 | 76 (2.2)   | 1 (0.8)   |
| **Exposure setting** |                       |                        |
| Household | 1015 (29.8) | 105 (82.7) |
| Public transportation | 818 (24.0) | 1 (0.8)   |
| Health care settings | 679 (19.9) | 7 (5.5)   |
| Entertainment venues or workplaces | 875 (25.6) | 11 (8.6)  |
| Multiple settings† | 23 (0.7) | 3 (2.4) |
| **RT-PCR testing** |                       |                        |
| Close contacts with ≥1 test‡ | 3115 (91.3) | 127 (100.0) |
| Mean tests (SD), n | 2.8 (2.4) | 2.1 (1.5) |
| **Median time frame (IQR), d** |                       |                        |
| From last contact to quarantine start | 4.0 (1.0–12.0) | 1.0 (0.0–2.0) |
| Duration of quarantine | 10.0 (2.0–14.0) | 2.0 (1.0–5.0)§ |

COVID-19 = coronavirus disease 2019; IQR = interquartile range; RT-PCR = reverse transcriptase polymerase chain reaction.

* Secondary attack rate = (the number of asymptomatic or symptomatic secondary cases/the number of close contacts) × 100%.
† Includes persons who had ≥1 exposure setting.
‡ A total of 295 close contacts were not tested by RT-PCR because the median time from their last contact to the start of quarantine was 24 d, which was longer than the quarantine duration of 14 d, and they had no symptoms during this period.
§ Duration of quarantine does not include isolation once secondary cases are diagnosed; secondary cases were diagnosed a median of 2 d after quarantine.

### Table 2. Characteristics of 3410 Close Contacts and 127 Secondary Cases

| Characteristic | Close Contacts, n (%) | Secondary Cases, n (%) |
|---------------|----------------------|------------------------|
| **COVID-19 cases** |                       |                        |
| Asymptomatic (n = 8)* | –                     | 3.7 (3.1–4.4)          |
| Symptomatic (n = 119)* | –                     | 0.2 (0.1–0.4)          |
| Mild | –                     | 3.5 (2.9–4.1)          |
| Moderate | –                     | 20 (16.8)              |
| Severe or critical | –                     | 87 (73.1)              |
| **Number of index cases contacted** |                       |                        |
| 1 | 3206 (94.0) | 117 (92.1) |
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| Household | 1015 (29.8) | 105 (82.7) |
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| Entertainment venues or workplaces | 875 (25.6) | 11 (8.6)  |
| Multiple settings† | 23 (0.7) | 3 (2.4) |
| **RT-PCR testing** |                       |                        |
| Close contacts with ≥1 test‡ | 3115 (91.3) | 127 (100.0) |
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| **Median time frame (IQR), d** |                       |                        |
| From last contact to quarantine start | 4.0 (1.0–12.0) | 1.0 (0.0–2.0) |
| Duration of quarantine | 10.0 (2.0–14.0) | 2.0 (1.0–5.0)§ |

COVID-19 = coronavirus disease 2019; IQR = interquartile range; RT-PCR = reverse transcriptase polymerase chain reaction.

* Secondary attack rate = (the number of asymptomatic or symptomatic secondary cases/the number of close contacts) × 100%.
† Includes persons who had ≥1 exposure setting.
‡ A total of 295 close contacts were not tested by RT-PCR because the median time from their last contact to the start of quarantine was 24 d, which was longer than the quarantine duration of 14 d, and they had no symptoms during this period.
§ Duration of quarantine does not include isolation once secondary cases are diagnosed; secondary cases were diagnosed a median of 2 d after quarantine.

### Table 2. Characteristics of 3410 Close Contacts and 127 Secondary Cases

| Characteristic | Close Contacts, n (%) | Secondary Cases, n (%) |
|---------------|----------------------|------------------------|
| **COVID-19 cases** |                       |                        |
| Asymptomatic (n = 8)* | –                     | 3.7 (3.1–4.4)          |
| Symptomatic (n = 119)* | –                     | 0.2 (0.1–0.4)          |
| Mild | –                     | 3.5 (2.9–4.1)          |
| Moderate | –                     | 20 (16.8)              |
| Severe or critical | –                     | 87 (73.1)              |
| **Number of index cases contacted** |                       |                        |
| 1 | 3206 (94.0) | 117 (92.1) |
| 2 | 128 (3.8)  | 9 (7.1)   |
| ≥3 | 76 (2.2)   | 1 (0.8)   |
| **Exposure setting** |                       |                        |
| Household | 1015 (29.8) | 105 (82.7) |
| Public transportation | 818 (24.0) | 1 (0.8)   |
| Health care settings | 679 (19.9) | 7 (5.5)   |
| Entertainment venues or workplaces | 875 (25.6) | 11 (8.6)  |
| Multiple settings† | 23 (0.7) | 3 (2.4) |
| **RT-PCR testing** |                       |                        |
| Close contacts with ≥1 test‡ | 3115 (91.3) | 127 (100.0) |
| Mean tests (SD), n | 2.8 (2.4) | 2.1 (1.5) |
| **Median time frame (IQR), d** |                       |                        |
| From last contact to quarantine start | 4.0 (1.0–12.0) | 1.0 (0.0–2.0) |
| Duration of quarantine | 10.0 (2.0–14.0) | 2.0 (1.0–5.0)§ |

COVID-19 = coronavirus disease 2019; IQR = interquartile range; RT-PCR = reverse transcriptase polymerase chain reaction.

* Secondary attack rate = (the number of asymptomatic or symptomatic secondary cases/the number of close contacts) × 100%.
† Includes persons who had ≥1 exposure setting.
‡ A total of 295 close contacts were not tested by RT-PCR because the median time from their last contact to the start of quarantine was 24 d, which was longer than the quarantine duration of 14 d, and they had no symptoms during this period.
§ Duration of quarantine does not include isolation once secondary cases are diagnosed; secondary cases were diagnosed a median of 2 d after quarantine.
serologic findings: 1) a positive result for SARS-CoV-2 nucleic acid on RT-PCR; 2) a viral gene identified by gene sequencing that was highly homologous with known SARS-CoV-2; or 3) detectable SARS-CoV-2–specific IgM and IgG in serum, or at least a 4-fold increase in IgG between paired acute and convalescent sera. Symptomatic cases were categorized as mild, moderate, severe, or critical (17) (Part 1 of the Supplement).

Linkage of Secondary Cases to Index Cases
To show the difference between identifying cases through presenting symptoms versus intensive surveillance of a close contact, we attempted to pair every secondary case with their index case and compared their clinical characteristics. If a secondary case was in contact with 2 or more index cases, we linked the secondary case to the earliest index case. Secondary cases were unlikely to have been co–index cases because they did not share the same primary infection exposure as the index case during the contact tracing episode.

Statistical Analysis
The secondary attack rate of COVID-19 was estimated by dividing the number of asymptomatic or symptomatic secondary cases by the number of close contacts for that exposure setting compared with different contact exposure groups. Categorical variables were calculated as numbers (percentages). Skewed and normally distributed continuous variables were calculated as the median (interquartile range [IQR]) or mean (SD), respectively. To minimize the potential for inferential bias and to maximize the decreased statistical power due to exclusion of participants with missing covariate data, we used multiple imputation with chained equations to impute missing covariate values, and 20 data sets were imputed (18). All variables including outcomes were included in the multiple imputation model.

Generalized estimating equations (19) taking into account clustering by index cases were performed to estimate odds ratios (ORs) and 95% CIs for associations of potential factors with the risk for SARS-CoV-2 infection:

\[
S(\beta; \alpha, \phi) = \nabla_{\beta} \left( \frac{\partial \mu_i}{\partial \beta} V_i^{-1}(\alpha)(Y_i - \mu_i) \right) = O_{p},
\]

where \( V_i = \) working covariance matrix \( () \), \( R(\alpha) = \) working correlated matrix, and \( A_i = T \)-dimensional diagonal matrix.

Age (0 to 17 years, 18 to 44 years, 45 to 59 years, or \( \geq 60 \) years), sex, exposure setting, severity of index cases, and symptoms in index cases (fever, dry cough, expectoration, fatigue, and myalgia) were included in the multivariable model.

All analyses were performed by using SAS software, version 9.4, for Windows (SAS Institute). Statistical tests were 2-sided, and \( P \) values less than 0.05 were considered statistically significant.

Role of the Funding Source
The study was funded by the Guangdong Province Higher Vocational Colleges and Schools Pearl River Scholar Funded Scheme, the National Natural Science Foundation of China, the Construction of High-level

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**Figure 2.** Distribution of clusters according to the number of index cases.

In each bar, the light and dark portions indicated the number of index cases outside and inside Guangzhou, respectively.


### Table 3. Exposure Settings and Risk for Transmission Among 3410 Close Contacts

| Characteristic                                      | Secondary Cases, \( n \ (% [95\% CI]) \) | Crude Odds Ratio (95\% CI) | Adjusted Odds Ratio (95\% CI)* |
|----------------------------------------------------|-------------------------------------------|-----------------------------|--------------------------------|
| **Age group (n = 3410)**                            |                                           |                             |                                |
| 0–17 y (n = 357)                                    | 14 (3.9 [1.9–5.9])                       | 1.42 (0.77–2.59)            | 0.78 (0.41–1.50)               |
| 18–44 y (n = 1784)                                  | 50 (2.8 [2.0–3.6])                       | 1.00 (reference)            | 1.00 (reference)               |
| 45–59 y (n = 818)                                   | 29 (3.6 [2.3–4.8])                       | 1.27 (0.80–2.03)            | 1.16 (0.70–1.92)               |
| ≥60 y (n = 451)                                     | 34 (7.5 [5.1–10.0])                      | 2.83 (1.81–4.43)            | 2.34 (1.39–3.97)               |
| **Sex (n = 3410)**                                  |                                           |                             |                                |
| Male (n = 1799)                                     | 56 (3.1 [2.3–3.9])                       | 1.00 (reference)            | 1.00 (reference)               |
| Female (n = 1611)                                   | 71 (4.4 [3.4–5.4])                       | 1.44 (1.00–2.05)            | 1.21 (0.82–1.78)               |
| **Exposure setting (n = 3410)**                     |                                           |                             |                                |
| Household (n = 1015)                                | 105 (10.3 [8.5–12.2])                    | 1.00 (reference)            | 1.00 (reference)               |
| Public transportation (n = 818)                     | 1 (0.1 [0.0–0.4])                        | 0.01 (0.00-0.08)            | 0.01 (0.00-0.09)               |
| Health care settings (n = 679)                      | 7 (1.0 [0.3–1.8])                        | 0.09 (0.04-0.20)            | 0.13 (0.05-0.32)               |
| Entertainment venues or workplaces (n = 875)        | 11 (1.3 [0.5–2.0])                       | 0.11 (0.06–0.21)            | 0.12 (0.04–0.22)               |
| Multiple settings (n = 23)                          | 3 (13.0 [0.0–26.8])                      | 1.30 (0.38–4.45)            | 1.20 (0.32–4.58)               |
| **Severity of index cases (n = 2610)**              |                                           |                             |                                |
| Asymptomatic (n = 305)                              | 1 (0.3 [0.0–1.0])                        | 0.06 (0.01-0.47)            | 0.37 (0.04-3.79)               |
| Mild (n = 576)                                      | 19 (3.3 [1.8–4.8])                       | 0.54 (0.32-0.89)            | 0.56 (0.33-0.94)               |
| Moderate (n = 1469)                                 | 82 (5.6 [4.4–6.8])                       | 1.00 (reference)            | 1.00 (reference)               |
| Severe or critical (n = 260)                        | 16 (6.2 [3.2–9.1])                       | 1.14 (0.67–1.94)            | 1.04 (0.57–1.90)               |
| **Symptoms in index cases (n = 1813)**              |                                           |                             |                                |
| Fever                                              |                                           |                             |                                |
| No (n = 430)                                       | 14 (3.3 [1.6–4.9])                       | 1.00 (reference)            | 1.00 (reference)               |
| Yes (n = 1383)                                     | 92 (6.7 [5.3–8.0])                       | 2.90 (1.73–4.86)            | 1.78 (1.01–3.13)               |
| Dry cough                                          |                                           |                             |                                |
| No (n = 726)                                       | 39 (5.4 [3.7–7.0])                       | 1.00 (reference)            | 1.00 (reference)               |
| Yes (n = 1087)                                     | 67 (6.2 [4.7–7.6])                       | 1.37 (0.95–1.98)            | 1.15 (0.76–1.73)               |
| Expectoration                                      |                                           |                             |                                |
| No (n = 1329)                                      | 40 (3.0 [2.1–3.9])                       | 1.00 (reference)            | 1.00 (reference)               |
| Yes (n = 484)                                      | 66 (13.6 [10.6–16.7])                    | 4.81 (3.35–6.93)            | 4.39 (2.92–6.61)               |
| Fatigue                                            |                                           |                             |                                |
| No (n = 1366)                                      | 76 (5.6 [4.4–6.8])                       | 1.00 (reference)            | 1.00 (reference)               |
| Yes (n = 447)                                      | 30 (6.7 [4.4–9.0])                       | 1.15 (0.77–1.72)            | 0.78 (0.52–1.19)               |
| Myalgia                                            |                                           |                             |                                |
| No (n = 1517)                                      | 88 (5.8 [4.6–7.0])                       | 1.00 (reference)            | 1.00 (reference)               |
| Yes (n = 296)                                      | 18 (6.1 [3.4–8.8])                       | 1.09 (0.67–1.77)            | 0.88 (0.52–1.50)               |

*Adjusted for age, sex, exposure settings, severity of index cases, and symptoms in index cases.
†Includes close contacts with more than 1 exposure setting (household, public transportation, health care setting, workplaces and entertainment venues).
‡A total of 800 close contacts could not be categorized by severity of index cases owing to lack of data.
§A total of 1597 close contacts could not be categorized by symptoms in index cases owing to lack of data.

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### RESULTS

#### Characteristics of Close Contacts and COVID-19 Cases

We collected data from 3410 close contacts in Guangzhou who were linked to 391 index cases (244 index cases in Guangzhou and 147 in other regions). Table 1 shows demographic characteristics of index cases, close contacts, and secondary cases. Among 3410 close contacts, 1799 (52.8%) were male, and the median age was 38.0 years (IQR, 26.0 to 51.0 years). Of these 3410 close contacts, 127 (3.7% [95\% CI, 3.1% to 4.4%]) were secondarily infected; 8 (0.2% [CI, 0.1% to 0.4%]) were asymptomatic, and 119 (3.5% [CI, 2.9% to 4.1%]) were symptomatic. Of the 119 symptomatic cases, 20 (16.8%) presented with mild symptoms, 87 (73.1%) with moderate symptoms, and 12 (10.1%) with severe or critical symptoms. Of the secondary cases, the majority (105 [82.7%]) occurred via household contact (Table 2). The basic characteristics and distribution of clusters in each exposure setting are summarized in Appendix Tables 1 and 2 (available at Annals.org). The distribution of clusters according to the number of index cases is shown in Figure 2.

Because of the lag in identification of close contacts, the median time from last contact to the start of quarantine was 4.0 days (IQR, 1.0 to 12.0 days); thus, the 3410 close contacts were only quarantined for a median of 10.0 days (IQR, 2.0 to 14.0 days) (Table 2; Appendix Figure 1, available at Annals.org). Furthermore, the 127 close contacts in whom asymptomatic or symptomatic cases were diagnosed ended quarantine...
after a median of 2.0 days (IQR, 1.0 to 5.0 days) because most of them received a diagnosis within 2 days of the start of quarantine and were transferred to designated hospitals in a timely manner. For close contacts in whom symptomatic cases were diagnosed, the median time from last contact to symptom onset was 2.0 days (IQR, 1.0 to 3.0 days) (Appendix Figure 2, available at Annals.org). All secondary cases were confirmed by RT-PCR testing, and the mean number of RT-PCR assays was 2.8 (SD, 2.4).

**Exposure Settings and Factors Associated With Risk for Transmission**

Table 3 shows the association between various factors and risk for SARS-CoV-2 infection among close contacts of index cases before and after adjustment. A higher percentage of females than males (4.4% [CI, 3.4% to 5.4%] vs. 3.1% [CI, 2.3% to 3.9%]) were infected, but this difference was not statistically significant on multivariate analysis. In terms of exposure setting, household contacts had a higher risk for secondary infection (10.3% [CI, 8.5% to 12.2%]) than did persons who were exposed in health care settings (1.0% [CI, 0.3% to 1.8%]; OR, 0.09 [CI, 0.04 to 0.20]) and those who were exposed on public transportation (0.1% [CI, 0.0% to 0.4%]; OR, 0.01 [CI, 0.00 to 0.08]).

The secondary attack rate increased with the severity of index cases, from 0.3% (CI, 0.0% to 1.0%) for asymptomatic to 3.3% (CI, 1.8% to 4.8%) for mild, 5.6% (CI, 4.4% to 6.8%) for moderate, and 6.2% (CI, 3.2% to 9.1%) for severe or critical cases ($P$ for trend < 0.001). Manifestation of certain symptoms, such as fever (6.7% [CI, 5.3% to 8.0%] vs. 3.3% [CI, 1.6% to 4.9%]) and expectoration (13.6% [CI, 10.6% to 16.7%] vs. 3.0% [CI, 2.1% to 3.9%]), in the index cases was associated with an increased risk for infection in their close contacts. The frequency of contact and number of index cases contacted were not separately assessed owing to multicollinearity with household contacts; the incidence of COVID-19 by these 2 variables is shown in Appendix Table 3 (available at Annals.org).

**Clinical Characteristics of Index Cases and Secondary Cases**

A total of 121 secondary cases were successfully linked to their 68 index cases, and 6 secondary cases were not successfully linked because their index cases were outside Guangzhou and we had no detailed information for them. Compared with their 68 index cases, the 121 secondary cases were in general clinically milder and were less likely to manifest such common symptoms as fever, cough, expectoration, fatigue, myalgia, and diarrhea (Table 4). Secondary cases were also less likely than index cases to demonstrate radiologic and laboratory alterations related to the infection (Table 4).

| Table 4. Clinical Characteristics of 68 Index Cases and 121 Secondary Cases |
|---------------------------------|-----------------|-----------------|
| Characteristic                  | Index Cases ($n = 68$), n (%) | Secondary Cases ($n = 121$), n (%) |
| Severity*                       |                  |                  |
| Asymptomatic                    | 1 (1.5)          | 8 (6.6)          |
| Mild                             | 5 (7.3)          | 18 (14.9)        |
| Moderate                        | 42 (61.8)        | 84 (69.4)        |
| Severe or critical              | 20 (29.4)        | 11 (9.1)         |
| Hospital admission              |                  |                  |
| Death                           | 0 (0.0)          | 0 (0.0)          |
| Discharge                       | 68 (100.0)       | 121 (100.0)      |
| Highest body temperature†       |                  |                  |
| <37.5 °C                         | 14 (20.6)        | 60 (52.6)        |
| 37.5-38.0 °C                     | 29 (42.7)        | 33 (29.0)        |
| 38.1-39.0 °C                     | 19 (27.9)        | 21 (18.4)        |
| ≥39.0 °C                        | 6 (8.8)          | 0 (0.0)          |
| Symptoms at onset‡              |                  |                  |
| Fever                           | 57 (83.8)        | 55 (46.2)        |
| Dry cough                       | 42 (61.8)        | 43 (36.1)        |
| Expectoration                   | 37 (54.4)        | 19 (16.0)        |
| Fatigue                         | 17 (25.0)        | 14 (11.8)        |
| Myalgia                         | 12 (17.7)        | 5 (4.2)          |
| Diarrhea                        | 9 (13.2)         | 1 (0.8)          |
| Double lung abnormalities on chest CT‡ | 57 (83.8)        | 79 (66.4)        |
| Median blood biochemical index (IQR)$ |                  |                  |
| Leukocyte count, × 10⁶ cells/L  | 5.6 (4.2-7.3)    | 5.3 (4.4-6.5)    |
| Neutrophilic granulocytes, %    | 65.8 (51.1-74.1) | 55.9 (43.0-63.2) |
| Lymphocytes, %                  | 22.9 (9.9-30.8)  | 30.8 (20.1-40.9) |

CT = computed tomography; IQR = interquartile range.
* All cases were updated by progression of their illness, and the most severe condition was their final severity designation.
† Data were unavailable for 3 asymptomatic secondary cases.
‡ Data were unavailable for 7 secondary cases.
§ Estimated from data during hospitalization.
DISCUSSION

We found that the secondary attack rate was less than 4% among close contacts of persons with COVID-19. Secondary infections acquired while using public transportation were rare; in contrast, 1 in 10 household contacts was found to be infected. Moreover, we found that patients with more clinically severe disease were more likely to infect their close contacts than were less severe index cases; asymptomatic cases were least likely to infect their close contacts. Manifestation of certain symptoms, such as expectoration, in index cases was also associated with an increased risk for infection in their close contacts.

The secondary attack rate of COVID-19 among household contacts was 10.3% in our study, which was consistent with secondary attack rates of 11.2% in other cities in China (20) and 10.5% in the United States (21). In China, the quarantine of household contacts started immediately in designated places by local CDCs after index cases were diagnosed, which may have resulted in a lower secondary attack rate among household contacts compared with published studies in other countries (21, 22). However, the risk for secondary infection via household contact was still highest compared with other contact settings because people spent more time at home, which led to more frequent and longer unprotected exposure than the other contact settings. Another explanation is that mask wearing to prevent infection was mandatory in public settings but not in households during the study period. Thus, effective measures to reduce household transmission and quarantine of household contacts are extremely important.

In addition, we found that the risk for transmission via public transportation or health care settings was low. Although the risk for infection in any individual who shared public transportation with an infected person is low, the large numbers of people on public transportation and the difficulty in identifying all close contacts may lead to a great number of persons being infected in this setting.

Our results showed that patients with COVID-19 who had more severe symptoms had a higher transmission capacity, whereas transmission capacity from asymptomatic cases was limited. This supports the view of the World Health Organization that asymptomatic cases were not the major drivers of the overall epidemic dynamics (12). This mechanism may be that COVID-19 cases with more severe symptoms might carry a higher viral load of SARS-CoV-2 and thus have greater transmission capacity (22). Consistent with previous studies (23–26), we also found that clinical symptoms at onset were more severe in index cases than in secondary cases. This phenomenon may be explained by selection bias and regression to the mean, reflecting the difference between identifying cases through presenting symptoms versus intensive surveillance of a close contact. The severity of symptoms in secondary cases is probably more reflective of the true severity profile of COVID-19, given the systematic identification of secondary cases.

Our study has limitations. First, some of the estimates had wide CIs, and thus some clinically important point estimates (for example, the OR of 1.37 [CI, 0.95 to 1.98] for the infectiousness of index cases with dry cough) could not be statistically distinguished from a null effect. Second, different countries implemented different measures to control the COVID-19 outbreak. The measures in China mainly included case surveillance and reporting, epidemiologic investigation and close contact management, treatment of COVID-19 cases in designated hospitals, social distancing, and mask wearing in public settings. These measures may influence the secondary attack rate among close contacts and the generalization of our results. Finally, symptoms and severity in index cases were not assessed at the time of exposure to contacts, and recall bias of symptoms at onset among index cases and secondary cases may exist.

In conclusion, we found that the secondary attack rate of COVID-19 was relatively low, and household contacts were at higher risk for infection. Moreover, patients with more clinically severe cases or those with symptoms were more likely to infect their close contacts.

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Appendix Table 1. Index Cases and Cluster Sizes, by Exposure Setting*

| Cluster Size | Household | Public Transportation | Health Care Settings | Entertainment Venues or Workplaces | Multiple Exposure Settings |
|--------------|-----------|-----------------------|----------------------|-----------------------------------|---------------------------|
|              | Index Cases, n (%) | Median Cluster Size (IQR) | Index Cases, n (%) | Median Cluster Size (IQR) | Index Cases, n (%) | Median Cluster Size (IQR) | Index Cases, n (%) | Median Cluster Size (IQR) | Index Cases, n (%) | Median Cluster Size (IQR) |
| 1            | 59 (24.2) | 1                     | 55 (33.1)            | 10 (22.2)                         | 58 (40.3)                    | 1                     | 8 (61.5)                         | 1                     |
| 2            | 49 (20.1) | 2                     | 33 (19.9)            | 9 (20.0)                          | 27 (18.8)                    | 2                     | 3 (23.1)                         | 2                     |
| 3            | 37 (15.1) | 3                     | 17 (10.2)            | 5 (11.1)                          | 14 (9.7)                     | 3                     | –                               | –                     |
| 4            | 36 (14.8) | 4                     | 10 (6.0)             | 2 (4.5)                           | 8 (5.5)                      | 4                     | 1 (7.7)                         | 4                     |
| 5            | 19 (7.8)  | 5                     | 6 (3.6)              | 5 (11.1)                          | 6 (4.2)                      | 5                     | 1 (7.7)                         | 5                     |
| 6-10         | 31 (12.7) | 7 (6-9)               | 26 (15.7)            | 6 (13.3)                          | 15 (10.4)                    | 8 (6-9)               | –                               | –                     |
| 11-20        | 8 (3.3)   | 16 (12-17)            | 14 (8.4)             | 2 (4.5)                           | 6 (4.2)                      | 15 (14-16)            | –                               | –                     |
| >20          | 5 (2.0)   | 27 (22-67)            | 5 (3.1)              | 6 (13.3)                          | 10 (6.9)                     | 65 (29-89)            | –                               | –                     |
| Total        | 244 (100.0) | 6 (3-12) | 166 (100.0) | 10 (4-17) | 45 (100.0) | 66 (29-274) | 144 (100.0) | 22 (6-65) | 13 (100.0) | 2 (1-4) |

IQR = interquartile range.
* Cluster size is the number of close contacts for each index case.

Appendix Table 2. Distribution of Clusters, Close Contacts, and Secondary Cases, by Cluster Size and Exposure Setting*

| Cluster Size | Household | Public Transportation | Health Care Settings | Entertainment Venues or Workplaces | Multiple Exposure Settings |
|--------------|-----------|-----------------------|----------------------|-----------------------------------|---------------------------|
|              | Index Cases, n | Median Cluster Size (IQR) | Index Cases, n | Median Cluster Size (IQR) | Index Cases, n | Median Cluster Size (IQR) | Index Cases, n | Median Cluster Size (IQR) | Index Cases, n | Median Cluster Size (IQR) |
| 1            | 59, 59, 9 | 55, 55, 0             | 10, 10, 0            | 58, 58, 3                          | 8, 8, 1                    |
| 2            | 49, 98, 18 | 33, 66, 1             | 9, 18, 0             | 27, 54, 3                          | 3, 6, 0                    |
| 3            | 37, 111, 16 | 17, 51, 0            | 5, 15, 4             | 14, 42, 0                          | 0, 0, 0                    |
| 4            | 36, 144, 24 | 10, 40, 0            | 2, 8, 0              | 8, 32, 0                           | 1, 4, 2                    |
| 5            | 19, 95, 10 | 6, 30, 0             | 5, 25, 0             | 6, 30, 0                           | 1, 5, 0                    |
| 6-10         | 31, 227, 17 | 26, 200, 0          | 6, 48, 1             | 15, 113, 0                         | 0, 0, 0                    |
| 11-20        | 8, 119, 7 | 14, 209, 0            | 2, 29, 0             | 6, 88, 0                           | 0, 0, 0                    |
| >20          | 5, 162, 4 | 5, 167, 0             | 6, 526, 2            | 10, 458, 5                         | 0, 0, 0                    |
| Total        | 244, 1015, 105 | 166, 818, 1       | 45, 679, 7            | 144, 875, 11                       | 13, 23, 3                  |

* Cluster size is the number of close contacts for each index case.
Appendix Figure 1. Distribution of quarantine duration among 3410 close contacts and 127 secondary cases.

Day 1 is the start of quarantine. The quarantine period was extended for 337 close contacts in whom reverse transcriptase polymerase chain reaction testing was delayed. COVID-19 = coronavirus disease 2019.

Appendix Figure 2. Distribution of days from last contact to symptom onset and quarantine start, and days from symptom onset to RT-PCR diagnosis among secondary cases.

For days from last contact to symptom onset, a total of 31 symptomatic cases with symptoms before the last contact and 8 asymptomatic cases were excluded; for days from symptoms to RT-PCR diagnosis, a total of 55 secondary cases who tested positive on RT-PCR at the first time were further excluded. RT-PCR = reverse transcriptase polymerase chain reaction.
### Appendix Table 3. Secondary Attack Rate of Coronavirus Disease 2019 Among 3410 Close Contacts

| Characteristic                                      | Close Contacts, n | Events, n | Secondary Attack Rate (95% CI), % | P Value |
|-----------------------------------------------------|-------------------|-----------|----------------------------------|---------|
| **Frequency of contact (n = 3410)**                 |                   |           |                                  | <0.001  |
| Occasional                                          | 1531              | 4         | 0.3 (0.0–0.5)                    |         |
| Moderate                                             | 1175              | 7         | 0.6 (0.2–1.0)                    |         |
| Often                                               | 704               | 116       | 16.5 (13.7–19.2)                 |         |
| **Number of index cases contacted (n = 3410)**      |                   |           |                                  | <0.001  |
| 1                                                   | 3206              | 117       | 3.7 (3.0–4.3)                    |         |
| 2                                                   | 128               | 9         | 7.0 (2.6–11.5)                   |         |
| ≥3                                                  | 76                | 1         | 1.3 (0.0–3.9)                    |         |
| **Index cases with Hubei exposure history (n = 1731)** |                   |           |                                  | <0.001  |
| No                                                  | 495               | 14        | 2.8 (1.4–4.3)                    |         |
| Yes                                                 | 1236              | 90        | 7.3 (5.8–8.7)                    |         |
| **Severity of index cases (n = 2610)**               |                   |           |                                  | 0.000   |
| Asymptomatic                                        | 305               | 1         | 0.3 (0.0–1.0)                    |         |
| Mild                                                | 576               | 19        | 3.3 (1.8–4.8)                    |         |
| Moderate                                             | 1469              | 82        | 5.6 (4.4–6.8)                    |         |
| Severe                                              | 155               | 5         | 3.2 (0.4–6.0)                    |         |
| Critical                                             | 105               | 11        | 10.5 (4.6–16.3)                  |         |

* A total of 1679 close contacts could not be categorized by Hubei exposure history.
† A total of 800 close contacts could not be categorized by severity of index cases owing to lack of data.