Clinical Infectious Diseases

MAJOR ARTICLE

Characteristics of Household Transmission of COVID-19

Wei Li,[1] Bo Zhang,[2] Jianhua Lu,[3] Shihua Liu,[4] Zhiqiang Chang,[4] Cao Peng,[5] Xinghua Liu,[1] Peng Zhang,[1] Yan Ling,[6] Kaixiong Tao,[1] and Jianying Chen[1]

[1]Department of Gastrointestinal Surgery, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China, [2]Department of Thyroid and Breast Surgery, Union Hospital Affiliated With Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China, [3]Department of General Surgery, Chibi People's Hospital, Chibi, China, [4]Department of Infectious Diseases, Zaoyang First People's Hospital, Zaoyang, China, [5]Department of Emergency Medicine, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China, and [6]Department of Physical Examination, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, China

Background. Since December 2019, SARS-CoV-2 has extended to most parts of China with >80 000 cases and to at least 100 countries with >60 000 international cases as of 15 March 2020. Here we used a household cohort study to determine the features of household transmission of COVID-19.

Methods. A total of 105 index patients and 392 household contacts were enrolled. Both index patients and household members were tested by SARS-CoV-2 RT-PCR. Information on all recruited individuals was extracted from medical records and confirmed or supplemented by telephone interviews. The baseline characteristics of index cases and contact patients were described. Secondary attack rates of SARS-CoV-2 to contact members were computed and the risk factors for transmission within the household were estimated.

Results. Secondary transmission of SARS-CoV-2 developed in 64 of 392 household contacts (16.3%). The secondary attack rate to children was 4% compared with 17.1% for adults. The secondary attack rate to the contacts within the households with index patients quarantined by themselves since onset of symptoms was 0% compared with 16.9% for contacts without quarantined index patients. The secondary attack rate to contacts who were spouses of index cases was 27.8% compared with 17.3% for other adult members in the households.

Conclusions. The secondary attack rate of SARS-CoV-2 in household is 16.3%. Age of household contacts and spousal relationship to the index case are risk factors for transmission of SARS-CoV-2 within a household. Quarantine of index patients at home since onset of symptoms is useful to prevent the transmission of SARS-Co-2 within a household.

Keywords. household transmission; COVID-19; novel coronavirus pneumonia; SARS-CoV-2.

In December 2019, an increasing number of cases of patients with pneumonia of unknown etiology emerged in Wuhan, a large city of 11 million people in central China [1–3]. The pathogen was soon identified as a novel coronavirus similar to the severe acute respiratory syndrome coronavirus (SARS-CoV) and shares more than 79% of genetic sequence [4]. Consequently, the novel virus was named SARS-CoV-2 and its infectious disease was named coronavirus disease 2019 (COVID-19) by the World Health Organization (WHO) [5]. With its rapid spread, the virus has extended to most parts of China with more than 80 000 cases and also to at least 100 countries with more than 60 000 international cases as of 15 March 2020 [6]. Despite the increasing number of reports on COVID-19, the research on epidemic features of this disease is limited and little is known about the transmission probability and infectivity of SARS-CoV-2 in the household. Here, the retrospective data on household transmission of COVID-19 were systemically analyzed and demonstrated certain epidemiological characteristics of COVID-19 between persons living in the same household.

METHODS

Data Sources

Data were collected from 2 local hospitals, Zaoyang First People's Hospital, 250 kilometers from Wuhan, and Chibi People's Hospital, 150 kilometers from Wuhan, between 1 January and 20 February 2020. Eligible household was defined as a family with only 1 member, known as the index patient, who had a clear history of exposure to Wuhan (departed from or traveled to Wuhan), to persons from Wuhan or to high-risk sites such as hospitals, supermarkets, or railway stations within 14 days before illness onset and with other family members who had no history of exposure to these, and all of the family members resided in 1 house before the index cases were hospitalized. Index patients and infected contacts were confirmed by positive results of their nasopharyngeal swab samples on SARS-CoV-2 reverse transcriptase–polymerase chain reaction (RT-PCR) [7], and uninfected household contacts were those who had no symptoms and at least twice tested negative on SARS-CoV-2

Received 15 March 2020; editorial decision 13 April 2020; accepted 16 April 2020; published online April 17, 2020.

Correspondence: J. Chen, Department of Gastrointestinal Surgery, Union Hospital, Tongji Medical College, Huazhong University of Science and Technology, Wuhan, 430022 China (bobytail@sina.com).

Clinical Infectious Diseases® 2020;71(8):1943–6

DOI: 10.1093/cid/ciaa450

RT-PCR. All of the family contacts were quarantined immediately after the index cases were confirmed for 14 days in places designated by the local governments and were monitored every day by health service personnel. The nasopharyngeal swab samples were collected at the beginning and at the middle of the quarantine duration. The quarantined contacts who had symptoms were inspected at least 4 times by SARS-CoV-2 RT-PCR until their tests were positive. The information on all recruited persons was extracted from medical records and confirmed or supplemented by telephone interviews. The last enrolled index case in this study was hospitalized 13 February 2020 and the final date of followed-up was 1 March 2020. Household members were excluded if they lived less than 24 hours in the residence of the index cases. A total of 105 households with 392 family contacts were enrolled.

Statistical Analysis

The secondary attack rate is defined as the proportion of infected household contacts (or household members except for the index patient) in the total number of household contacts. For categorical variables, the percentages of patients in each category were calculated. A logistic generalized estimating equation model was applied to identify risk factors associated with the secondary attack rate while accounting for correlation of members within a household [8].

RESULTS

Baseline Characteristics of Index Patients With COVID-19

The study included 105 index patients. The median age of the index patients was 47 years (25th to 75th percentile, 40–56 years) and 60 (57.1%) were male. Of the 105 patients, 65 (61.9%) patients had a direct history of exposure to Wuhan, 13 (12.4%) patients had close contact with persons from Wuhan, and another 27 (25.7%) patients had visited high-risk sites within 14 days before onset of illness. Of the 105 patients, 56 (53.3%) patients had fever at onset of illness, 31 (29.5%) had cough, 20 (19%) had fatigue, 12 (11.4%) had chills, 6 (5.7%) had dyspnea or anorexia, 5 (4.8%) had dizziness or myalgia, 3 (2.9%) experienced vomiting or nausea, 2 (1.9%) had diarrhea or nasal congestion, and 1 patient had headache or palpitations. The period between onset of symptoms and hospitalization was 0 to 11 days. Of the 105 patients, 12 (11.4%) waited 0 to 1 day for hospitalization after onset of illness, 34 (32.4%) waited 2–5 days, and 59 (56.2%) waited 7–11 days. There were 14 (13.3%) index patients who quarantined themselves at home, with a mask, dining separately, and residing alone immediately after the onset of symptoms (Table 1).

Table 1. Baseline Characteristics of Index Patients With COVID-19

	n (%)
Age, median (25th–75th), years	47 (40–56)
Gender	
Male	60 (57.1)
Female	45 (43.9)
Exposure history within 14 days	
Physically in Wuhan before	65 (61.9)
Contact with people from Wuhan	13 (12.4)
Previously in local high-risk sites	27 (25.7)
Symptoms at onset of illness	
Fever	56 (53.3)
Cough	31 (29.5)
Fatigue	20 (19)
Chill	12 (11.4)
Dyspnea or anorexia	6 (5.7)
Dizziness or myalgia	5 (4.8)
Vomit or nausea	3 (2.9)
Diarrhea or nasal congestion	2 (1.9)
Headache or palpitations	1 (0.95)
Time from onset of illness to hospitalization	
0–1 days	12 (11.4)
2–5 days	34 (32.4)
>5 days	59 (56.2)
Quarantine at home immediately after onset of symptoms	
Yes	14 (13.3)
No	91 (86.7)

Abbreviation: COVID-19, coronavirus disease 2019.

Baseline Characteristics of Household Contact Patients With COVID-19

A total of 392 eligible household contacts from the 105 family clusters were enrolled in this investigation. The median household size was 4 (25th to 75th percentile, 3–6) members. The median adult age was 46 (25th to 75th percentile, 32–58) years and the median child age was 6.5 (25th to 75th percentile, 4–11) years. There were 64 contacts infected with SARS-CoV-2. The median age of the secondary cases was 45 years (25th to 75th percentile, 30–57 years). Of the 64 contact patients, 33 (51.6%) were male, 36 (56.3%) contact cases had fever at onset of illness, 11 (17.2%) had cough, 4 (6.3%) had chills or fatigue, 3 (4.7%) had diarrhea, and 1 contact case had dizziness or myalgia or sneeze or anorexia. There were 9 (14.1%) asymptomatic patients in the total SARS-CoV-2–positive contacts and 3 nucleic acid–negative contacts with symptoms: 1 adults with cough and fatigue, 1 adult with fatigue, and 1 child with cough.

Of the 64 contact patients, 4 (6.3%) cases were aged below 18 years and all were male, 12 (18.8%) cases were aged 18–30 years, 14 (21.9%) cases were aged 31–40 years, 9 (14.1%) cases were 41–50 years, 18 (28.1%) cases were 51–60 years, and 7 (10.9%) cases were older than 60 years (Table 2). The median time interval, from symptom onset of index cases to symptom onset of household contacts, was 6 days (25th to 75th percentile, 4–10 days).

Characteristics of Secondary Transmission of COVID-19 in Households

The secondary attack rates to household contacts were evaluated in different conditions. The secondary attack rate of the total 392 household contacts was 16.3%. When the data were stratified for analysis by age of contacts, the secondary attack rate to children (aged <18 years) was 4% compared with 20.5%

Table 2. Baseline Characteristics of Household Contact Patients With COVID-19

	Values
Household size, median (25th–75th), n	4 (3–6)
Age of total contacts, median (25th–75th), years	35 (16–55)
Adults	46 (32–58)
Children	6.5 (4–11)
Age of infected contacts, median (25th–75th), years	45 (30–57)
Gender, n (%)	
Male	33 (51.6)
Female	31 (48.4)
Ages of the contact patients, n (%)	
<18 years	4 (6.3)
18–30 years	12 (18.8)
31–40 years	14 (21.9)
41–50 years	9 (14.1)
51–60 years	18 (28.1)
>60 years	7 (10.9)
Symptoms of the contact patients, n (%)	
Fever	36 (56.3)
Cough	11 (17.2)
Chill	4 (6.3)
Fatigue	4 (6.3)
Diarrhea	3 (4.7
Dizziness or anorexia	1 (1.6)
Headache or myalgia	1 (1.6)
Symptom-free, n (%)	9 (14.1)
Time interval,[a] median (25th–75th), days	6 (4–10)

Abbreviation: COVID-19, coronavirus disease 2019.
[a]Time interval: the time from symptom onset of index cases to symptom onset of household contacts.

Table 3. Characteristics of Secondary Transmission of COVID-19 in Households

	Infected Cases, n	Total Contacts, n	Secondary Attack Rates, %	OR (95% CI)	*P*
General transmission rate	64	392	16.3	…	
Symptomatic transmission rate	55	392	14	…	
Gender of contacts					
Female	31	181	17.1	0.92 (.51–1.64)	.78
Male	33	211	15.6	…	
Ages of contacts					
<18 years	4	100	4	0.18 (.06–.54)[a]	.002
0–5 years	1	44	2.3	…	
6–17 years	3	56	5.4	…	
≥18 years	60	292	20.5	…	
18–30 years	12	55	21.8	…	
31–40 years	14	76	18.4	…	
41–50 years	9	35	25.7	…	
51–60 years	18	71	25.3	…	
>60 years	7	55	12.7	…	
Quarantine of index case at initiation of symptom					
Yes	0	43	0	0 (.00–.00)	.00
No	64	349	18.3	…	
Relationships with index cases					
Spouse	25	90	27.8	2.27 (1.22–4.22)	.010
Not spouse (excluded children)	35	202	17.3	…	
Gender of index cases					
Female	29	183	15.8	.79 (.42–1.47)	.45
Male	35	209	16.7	…	
Symptoms of index cases					
No fever	26	194	13.4	.61 (.30–1.24)	.169
Fever	38	198	19.2	…	
No cough	45	271	16.6	.88 (.47–1.64)	.68
Cough	19	121	15.7	…	
Exposure-period[b] categories					
0–1 day	10	46	21.7	.90 (.61–1.33)	.58
2–5 days	14	91	15.4	…	
>5 days	40	253	15.8	…	

P < .05 was considered statistically significant.
Abbreviations: CI, confidence interval; COVID-19, coronavirus disease 2019; OR, odds ratio.
[a]Comparing children with adults.
[b]The time between onset of illness and hospitalization of index patient.

for adult members (odds ratio [OR], .18; 95% confidence interval [CI], .06–.54; *P* = .002). The secondary attack rate to the contacts in the household with index patients quarantined at home immediately since onset of symptoms was 0% compared with 18.3% for the contacts in the households without index patients quarantined during the period between initiation of symptoms and hospitalization (OR, 0; 95% CI, .00–.00; *P* = .000). Spousal relationship was another risk factor for the infection of SARS-CoV-2 to household contacts; the secondary transmission rate for individuals who were spouses of index cases was 27.8% compared with 17.3% for other members in the households (OR, 2.27; 95% CI, 1.22–4.22; *P* = .010). Gender, symptoms, and the time between onset of illness of the index patients and hospitalization were not related to the secondary attack rates of SARS-CoV-2 to household contacts (Table 3).

DISCUSSION

The household model provides a clear and fixed exposure of infection sources, which makes it a feasible model to estimate the transmissibility and infectivity of prevalent virus [8, 9]. Here, we found that the general secondary attack rate of SARS-CoV-2 to contact members in households was 16.3%, which is higher than that of 2 other coronavirus-related respiratory diseases, severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS) [10, 11], and is also higher than that of the pandemic influenza A in 2009, at 13% [8]. This might contribute to the dramatically higher number of infected cases compared with the 2 other coronavirus-related diseases. As the time and chance of infection exposure to susceptible people

within the household model were more than that in the community and at the population level, the probability of transmission in households may be greater than that in the community and at the population level in most cases [8, 10, 11]. Although the household differs from the community and the larger population, our results suggest the probability of transmission of SARS-CoV-2 in one aspect.

Although 1 center in China reported 9 infants under 1 year who were infected with SARS-CoV-2 [12] and the population distribution of COVID-19 by age groups was described by several other groups [12, 13], there was no denominator number of persons exposed to a clear source of infection and the relative susceptibilities to SARS-CoV-2 for children and adults remain to be studied. In this report, the results showed that the secondary attack rate of SARS-CoV-2 to adults was dramatically higher than that to children, which might reflect the different susceptibility to SARS-CoV-2 between children and adults and indicate that adults were more susceptible to SARS-CoV-2 than children aged below 18 years when they exposed themselves to the same sources of infection. This is similar to the SARS virus, which primarily infected persons aged above 18 years. However, the real causes leading to the different secondary attack rates between adults and children need to be further explored and many factors could influence the secondary transmission of epidemic diseases in a household, such as behavior of contacts and occupations of household members [10].

Asymptomatic carriers exist in many infectious diseases [14]. In our data, we also found 9 cases in contact cases (14.1%). This is more than 10 times the rate reported by another group in a large population-level study [6]. In our household model, all of the negative contacts were tested by SARS-CoV-2 RT-PCR at least twice. However, in that large population-level study, the whole close-contact population could not be screened by the laboratory test, which may have led to missing many symptom-free cases that were not statistically counted, and which may contribute to inconsistencies compared with our study. In this case, there might be more asymptomatic carriers than we expected based on previous report. We know that asymptomatic carriers of SARS-CoV-2 can transmit virus to other people [14, 15], so more strategies may be needed to detect asymptomatic cases in the population.

The effect of self-quarantine at home was also assessed in the household model. Of 105 index patients, 14 cases were quarantined by themselves at home immediately at the onset of symptoms—with masks, dining separately, and residing alone. The results showed no infected contacts in the households with index cases who implemented quarantine immediately after the appearance of symptoms, and so the secondary attack rate was zero. This indicated that home quarantine by itself since the onset of symptoms might make sense in preventing the transmission of SARS-CoV-2 in the household. However, the power to make this conclusion is low since the number of cases was limited and a large-scale investigation remains to be made.

Interestingly, the analysis of data stratified by spouses who were the husbands or wives of index cases demonstrates that the secondary attack rate of SARS-CoV-2 to spouses was significantly higher than that to other family members. This might be because of the longer time of exposure to the infection source, and the greater chance of illness for contacts and spouses who might spend more time with each other than with any other members within the household.

Notes

Author contributions. K. T. and J. C. had full access to all of the data in the study, take responsibility for the integrity of the data and the accuracy of the data analysis, revised the manuscript for important intellectual content, and are the guarantors. W. L., K. T., and J. C. conceptualized and designed the study. X. L., P. Z., J. L., S. L., Z. C., P. C., and Y. L. acquired, analyzed, and interpreted the data. W. L. drafted the manuscript. J. C. attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted.

Acknowledgments. The authors thank the 2 local hospitals, Zaoyang First People's Hospital and Chibi People's Hospital, for supporting the data, and they also thank the enrolled patients with COVID-19 and their contact family members.

Financial support. This work was supported by the National Natural Science Foundation of China (grant number 81902703; to W. L.).

Potential conflicts of interest. The authors: No reported conflicts of interest. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest.

References

1. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. N Engl J Med **2020**; 382:727–33.
2. Chen N, Zhou M, Dong X, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. Lancet **2020**; 395:507–13.
3. Du Toit A. Outbreak of a novel coronavirus. Nat Rev Microbiol **2020**; 18:123.
4. Zhou P, Yang XL, Wang XG, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. Nature **2020**; 579:270–3.
5. World Health Organization. Naming the coronavirus disease (COVID-19) and the virus that causes it. **2020**; Available at: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it
6. Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72314 cases from the Chinese center for disease control and prevention. JAMA **2020**; 323:1239–42.
7. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med **2020**; 382:1199–207.
8. Cauchemez S, Donnelly CA, Reed C, et al. Household transmission of 2009 pandemic influenza A (H1N1) virus in the United States. N Engl J Med **2009**; 361:2619–27.
9. Lipsitch M, Swerdlow DL, Finelli L. Defining the epidemiology of Covid-19 - studies needed. N Engl J Med **2020**; 382:1194–6.
10. Wilson-Clark SD, Deeks SL, Gournis E, et al. Household transmission of SARS, 2003. CMAJ **2006**; 175:1219–23.
11. Hui DS, Azhar EI, Kim YJ, Memish ZA, Oh MD, Zumla A. Middle East respiratory syndrome coronavirus: risk factors and determinants of primary, household, and nosocomial transmission. Lancet Infect Dis **2018**; 18:e217–27.
12. Wei M, Yuan J, Liu Y, Fu T, Yu X, Zhang ZJ. Novel coronavirus infection in hospitalized infants under 1 year of age in China. JAMA **2020**; 323:1313–4
13. Xu X, Wu X, Jiang X, et al. Clinical findings in a group of patients infected with the 2019 novel coronavirus (SARS-Cov-2) outside of Wuhan, China: retrospective case series. BMJ **2020**; 368:m792.
14. Chisholm RH, Campbell PT, Wu Y, Tong SYC, McVernon J, Geard N. Implications of asymptomatic carriers for infectious disease transmission and control. R Soc Open Sci **2018**; 5:172341.
15. Bai Y, Yao L, Wei T, et al. Presumed asymptomatic carrier transmission of COVID-19. JAMA **2020**; 323:1406–7.