Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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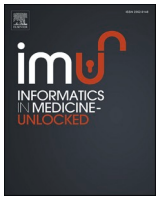

Sources of SARS-CoV-2 transmission in Jordan: Self-reported approach

Hassan M. Kofahi *, Omar F. Khabour, Samer F. Swedan, Refat M. Nimer

Department of Medical Laboratory Sciences, Jordan University of Science and Technology, P.O. Box 3030, Irbid, 22110, Jordan

A R T I C L E I N F O

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A B S T R A C T

Background: Understanding the dynamics of virus transmission is essential for controlling the COVID-19 pandemic. Demographic factors could influence transmission of the virus in different communities. Herein, the sources of COVID-19 infection in Jordan were explored. In addition, the effects of demographic factors and the adherence to preventive measures on household transmission were investigated.

Methods: The study recruited Jordanian adults who recovered from COVID-19 from March to July 2021. Using a questionnaire, information about participants' demographics, level of adherence to personal protective measures, and their perceived source of COVID-19 infection were collected. Crosstabs were used to test for differences in household transmission ratios between different demographic variables. Logistic regression analysis was used to predict risk factors for household transmission.

Results: The study recruited a total of 2313 participants. Household transmission was the most frequently reported source of infection (44.9%). Other sources of transmission were work/education related (16.0%), friends (8.6%), healthcare facilities (4.8%), social/event gathering (3.1%), shopping activities (2.2%), and public transport (1.6%). Significantly higher ratios of household transmission were reported by older adults (>60 years), college/university students, and female participants. No significant difference in household transmission was found between low-income and medium-high income groups. A significant increase in household transmission ratios was found with increased adherence to mask-wearing and social distancing. This could be a reflection of the reduced risk of community transmission with increased adherence to these preventive measures, coupled with the difficulty in adhering to these measures within the household setting. In multivariate logistic regression, females, young adults (18–30 years), older adults (>60 years), and those who adhere to mask-wearing most of the time were associated with an increased risk of infection in the household setting.

Conclusion: The results reported in the current study provided an insight into the transmission dynamics of the virus in Jordan, as an example of the MENA region. These findings could be invaluable for the future design of public health policies to control COVID-19 and possibly future pandemics.

1. Introduction

More than two years after the first case was identified, COVID-19 continues to burden the healthcare systems and economies of many countries. As of August 2022, more than 590 million confirmed cases of COVID-19 and approximately 6.4 million deaths related to COVID-19 have been recorded globally [1]. COVID-19 is caused by an infection with the coronavirus family member SARS-CoV-2. This virus is transmitted primarily by inhalation of virus-containing respiratory droplets generated by an infected person [2]. However, other routes such as airborne transmission and contact (fomite) transmission have been suggested to participate in virus spread among communities [3,4].

To avoid overwhelming health care systems, many countries have imposed measures to control virus spread. These measures range from mask-wearing and social (physical) distancing to complete lockdown. For example, wearing masks and social distancing have been shown to reduce transmission significantly and could slow down virus spread in the community [4]. However, these measures might be less effective in preventing the transmission in certain settings, such as between members in the same household.

Several daily activities have been associated with an increased risk of infection. For example, an association between infection and dining in restaurants has been reported by one group [5]. Religious and social gatherings were claimed to be responsible for COVID-19 outbreaks

* Corresponding author.
E-mail addresses: hmkofahi@just.edu.jo (H.M. Kofahi), khabour@just.edu.jo (O.F. Khabour), sfswedan4@just.edu.jo (S.F. Swedan), rmnimer@just.edu.jo (R.M. Nimer).

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[6–8]. Certain occupations, including healthcare and certain food industries, were associated with an increased risk of transmission [9,10].

Jordan is located in the Middle East and North Africa (MENA) region. The population of Jordan has many characteristics in common with other MENA region countries that may have an impact on the transmission dynamics of COVID-19. For example, it is estimated that 60% of the Jordanian population is under 30 years of age, which makes Jordanians among the youngest in the world [11]. On average, Jordanian households contain 4.7 members [12]. Approximately, a third of young Jordanian adults study at educational institutions [12]. Moreover, the tribal nature of the Jordanian population generates strong social ties with the extended family and other tribal members [13].

In this study, the sources of COVID-19 infection in Jordan were explored. In addition, the effects of demographic factors and the adherence to preventive measures on household transmission were investigated. The results of this study, for the first time in the MENA region, will provide insights on the dynamics of the spread of the COVID-19 virus. Such information could be valuable for estimating the efficacy of current preventive measures and in identifying areas for improvements. The study findings could be useful for controlling future epidemics in Jordan and other countries with similar socioeconomic characteristics.

2. Methods

2.1. Study design

This study is part of the Jordan COVID-19 Project (JCP) which is a survey-based project that aims to investigate multiple COVID-19 related topics in the Jordanian population. Inclusion criteria were Jordanian adults who recovered from COVID-19. The study was conducted from March to July of 2021. The approval of the institutional review board (IRB) of Jordan University of Science and Technology was granted before the recruitment of participants (Ref. 3/139/2021, dated March 30, 2021). Each participant provided consent before participating in the study. The participants responded to a questionnaire with the help of trained research assistants.

2.2. Study sample

The study sample was recruited using a convenient sampling technique. The required sample size was calculated using the Raosoft® Online Sample Size Calculator (Raosoft Inc., Seattle, WA, USA). Confidence interval, margin of error, and response distribution were set to 95%, 3%, and 50%, respectively. As the target population was Jordanians who recovered from COVID-19, the population size was set to 770,712, which is the cumulative number of confirmed COVID-19 cases in Jordan as of the end of July 2021 [1]. The results of the calculations showed that the recommended sample size was 1066. However, we were able to recruit a total of 2313 subjects into the study, which is more than twice the sample size required.

The study participants were recruited from all over Jordan by a total of 10 trained research assistants. Any adult Jordanian resident who recovered from COVID-19 before the recruitment date was eligible to participate. Children (<18 years) were excluded from the study. The study participants were approached in-person or over the phone by research assistants. To reduce selection bias, the study population was stratified according to age and gender. Then, research assistants recruited a predetermined number of subjects within each stratum.

2.3. Study instrument

The study questionnaire was written in Arabic language and was constructed using Google forms. The questionnaire was first face validated and piloted by a group of experts in the field of the project and then revised based on experts' comments. Pilot study responses were not included in the final analyses. The questionnaire collected demographic and socioeconomic information from each participant including age, gender, household income, and education. Participants were requested to report their levels of adherence to mask-wearing and social distancing measures. To achieve this, the participants were asked to report if they adhere to each measure "most of the times", "sometimes" or "never". The participants were also requested to report their perception on the source of their COVID-19 infection. The participants were given the choice to select "no clue" if they did not have any idea regarding the source of infection. The following sources were provided to the participants in the questionnaire to select from: household member, work/education related, friends, healthcare facilities, social gathering, public transport, travel, restaurants and coffee shops, fitness clubs/gyms, houses of worship, and no clue.

2.4. Statistical analysis

The participants were stratified into groups according to their age, gender, family income, education, and level of adherence to mask-wearing or social distancing measures. The size of each group, as well as the frequency of each source of infection, were presented as counts and percentages. Some participants reported having no clue about the source of infection and were excluded from subsequent analyses. Next, the ratios of household transmission were compared between the different demographic, socioeconomic or adherence groups. Chi square was used to test the significance of differences in ratios between groups. Univariate and multivariate logistic regression analyses were performed to predict risk factors for household transmission. The results of the univariate logistic regression analysis were presented as odds ratios (OR) and 95% confidence intervals (CI). Results of the multivariate logistic regression analysis were presented as adjusted odds ratios (aOR) and 95% CI. Each aOR was calculated by including all other independent variables (age, gender, income, and adherence to mask-wearing) in equation. P values less than 0.05 were considered statistically significant. Statistical analysis was performed using the Statistical Package for Social Sciences version 26 (IBM Inc., Armonk, New York, United States).

3. Results

In total, 2313 participants were recruited into the study, 58.3% of whom were females. Participants were stratified into 5 groups based on their age. About a third of the participants (32.7%) were young adults (18–30 years). More than half of the participants (53.5%) reported a total household income of less than 650 JD (approximately 900 USD). A detailed description of the demographic characteristics of the study

Table 1
Demographic characteristics of the study sample.

Characteristic	Frequency Count (%)
Total number of participants	2313
Gender	
Females	1349 (58.3)
Males	964 (41.7)
Age (years)	
18–30	756 (32.7)
31–40	533 (23.0)
41–50	417 (18.0)
51–60	323 (14.0)
>60	284 (12.3)
Income	
Low (<650 JD)	1238 (53.5)
Medium-high (≥650 JD)	1075 (46.5)
Highest education	
High school or below	539 (23.3)
Current undergraduate student	227 (9.8)
Undergraduate degree	1210 (52.3)
Graduate degree	337 (14.6)

sample is presented in Table 1.

First, the sources of SARS-CoV-2 infection in the study population were explored. To achieve this, the participants reported their perceived source of infection. Household transmission was the most frequently reported source and was reported by 44.9% of the participants. Other sources of infection were reported as well, including work/education (16.0%), a friend (8.6%), healthcare facilities (4.8%), and others (Table 2). On the other hand, 410 participants (17.7%) reported having no clue regarding the source of their infection, and hence were excluded from the subsequent analyses.

Since household transmission was the most common source of infection in the study population, the demographic factors influencing this source of transmission were examined. First, a significant difference in household transmission ratios between the age groups was seen ($P < 0.001$) (Table 3). The highest ratio of household transmission (68.7%) was reported by the older than 60 years age group, followed by the young adults (18–30 years) (Table 3). As the young adults group contained most of the college/university students, a second analysis was carried out within this group to investigate the effect of being a student on household transmission (Table 4). University/college students had a significantly higher ratio of household transmission than non-student young adults ($P < 0.001$).

Gender and income could have an influence on individuals' behavior and daily activities, which might affect the risk of community transmission of COVID-19. Hence, the association between these two factors and the risk of household transmission were investigated. Female participants reported a significantly higher ratio of household transmission than male participants ($P < 0.001$, Table 3). On the other hand, the medium-high income group (more than 650 JD) had a slightly higher ratio of household transmission than the low-income group. However, the difference was not statistically significant ($P = 0.117$, Table 3).

The associations between the levels of adherence to the preventive measures and household transmission were investigated by dividing the study population into groups based on the adherence level and comparing the ratios of household transmission between the groups. The results of this analysis showed a significant increase in the ratios of household transmission with increased adherence to mask-wearing ($P = 0.011$) and social distancing ($P = 0.015$, Table 3).

To predict risk factors for household transmission, a multivariate logistic regression analysis was performed to control for potential confounding factors. The results of this analysis showed that, after adjusting for other factors, being female, being a young adult (18–31 years), being an old adult (>60 years), and adhering to the practice of mask-wearing most of the times, were associated with an increased risk of SARS-CoV-2 infection in the household setting (Table 5).

4. Discussion

In the current study, the sources of COVID-19 infection in Jordan were explored. In addition, the effects of demographic factors and the adherence to preventive measures on the transmission of the virus were investigated. The results showed that household transmission was the most frequently reported source of infection and accounted for approximately half of the cases. Other sources that showed notable fractions of transmission were work/education related (16.0%), friends (8.6%), and healthcare facilities (4.8%). Household transmission was

Table 2
Distribution of the perceived sources of SARS-CoV-2 infections in the study population.

Assumed source	Frequency	Percentage
Household member	1038	44.9
Work/education-related	369	16.0
Friend	198	8.6
Healthcare facilities	110	4.8
Social gathering	71	3.1
Shopping-related	51	2.2
Public transport	37	1.6
Travel	10	0.4
Restaurants and coffee shops	9	0.4
Fitness clubs/gyms	7	0.3
Houses of worship	3	0.1
No clue	410	17.7
Total	2313	100.0

Table 3
Household transmission and possible influencing socioeconomic and adherence factors.

Characteristic	Assumed household member as the source of infection Number (%)	P value
Age (years)		<0.001
18-30	382 (58.5%)	
31-40	236 (51.4%)	
41-50	152 (44.7%)	
51-60	123 (51.2%)	
Older than 60	145 (68.7%)	
Gender		<0.001
Females	692 (60.9%)	
Males	346 (45.2%)	
Income		0.117
Low	517 (52.8%)	
Moderate-high	521 (56.4%)	
Adherence to mask-wearing before infection		0.011
Never	22 (37.9%)	
Sometimes	203 (51.7%)	
Most of the times	809 (56.0%)	
Adherence to social distancing		0.015
Never	37 (42.0%)	
Sometimes	301 (52.4%)	
Most of the times	696 (56.4%)	

Table 4
Household transmission rates in the young adults (18–30 years) age group: comparing students with non-students.

	Household transmission	Other sources	P value
Students	141 (74.2%)	49 (25.8%)	<0.001
Others (non-students)	241 (52.1%)	222 (47.9%)	
Total	382	271	

Table 5
Univariate and multivariate logistic regression results predicting risk factors of household transmission of SARS-CoV-2.

Variable	Category	Univariate		Multivariate	
		P value	OR (95% CI)	P value	aOR[a] (95% CI)
Gender	Male		Reference		Reference
	Female	**<0.001**	1.888 (1.568–2.273)	**<0.001**	1.960 (1.613–2.382)
Age (years)	18–30	**<0.001**	1.456 (1.195–1.775)	**0.016**	1.283 (1.047–1.573)
	31–60		Reference		Reference
	>60	**<0.001**	2.270 (1.656–3.112)	**<0.001**	2.748 (1.983–3.808)
Income (JD)	<650		Reference		Reference
	≥650	0.117	1.155 (0.964–1.384)	0.126	1.157 (0.960–1.394)
Adherence to mask-wearing before infection	Never		Reference		Reference
	Sometimes	0.053	1.748 (0.993–3.079)	0.057	1.774 (0.984–3.199)
	Most of the times	**0.008**	2.085 (1.214–3.579)	**0.012**	2.060 (1.172–3.621)

[a] aOR were calculated using a multivariate logistic regression analysis that included all independent variables (gender, age, income, and adherence to mask wearing) in the analysis.

found to be influenced by age, gender, and levels of adherence to mask-wearing and social distancing measures.

The MENA region includes 20 middle eastern and north African countries [14]. Like other parts of the world, the MENA region has been hit hard by the COVID-19 pandemic. The MENA region countries, including Jordan, share many demographics, social, and economic characteristics. Some demographic factors, such as age, gender, occupation, population density at the place of residence, and ethnicity, were reported to influence the risk of COVID-19 infection [15–17].

Household transmission was the most frequently reported source of COVID-19 (44.9% of the cases) by the study population. Typically, a household member becomes infected from the community, then, secondary transmission occurs within the household setting [18]. The transmission of the virus between household members is facilitated by several factors including close contact between family members, use of sharded bathrooms, sharing of furniture and house tools, poor ventilation of indoor spaces, and the difficulty of implementing preventive measures, such as mask-wearing and social distancing, among family members [19]. For example, a study conducted on the households of COVID-19 patients showed that personal items were most often contaminated by the virus, followed by patients' bedrooms, kitchens, and bathrooms [20]. Similarly, sharing bedrooms, bathrooms, and dining facilities has been shown to facilitate the spread of the virus among Colombian military personnel [21]. Food containers, door handles, bathrooms, and shared sanitation facilities have also been reported as important sources in COVID-19 transmission [22–24]. Poor ventilation has been shown to account for an outbreak early during the pandemic in an apartment in South Korea [25]. The rate of household secondary attack was estimated to be high, ranging from 16% to 49% (summarized in Table 6) [26–29]. Early in the pandemic, household transmission was reported to play a major role in increasing in the numbers of COVID-19 infected cases in China [30,31]. Similarly, the current results show that household transmission is a major source of COVID-19 infections in Jordan. The results are also consistent with a meta-analysis that showed that infection risk of household contacts is 10 times higher than other contacts [32]. Thus, the results of the current study provide further evidence for the assumption that household transmission is a major source of virus transmission during the COVID-19 pandemic.

The highest risk of household transmission was found in the oldest age group (more than 60 years old) of the study population. This result can be explained in-part by the increased adherence to preventive measures, such as mask-wearing in public, with increased age [34]. Furthermore, a large proportion of older adults is retired, which limits their contact with other individuals in the community. These two factors reduce the risk of contracting the infection from the community, making household transmission the major source of COVID-19 infection in this age group. In agreement with our results, Fung et al. reported in a review that household secondary attack rates (SAR) were higher among the older adults than the younger age groups [26]. In a study from China, the age of household contacts was a risk factor for transmission of the virus within a household [29]. Age was also a factor in SARS-CoV-2 transmission among children [35].

Interestingly, young adults (18–30 years old) were predicted to have a higher risk of household transmission compared to the 31–60 years age group. Although surprising at first, this result could be attributed to the fact that this age group contains most of the college/university students. Since early in the pandemic, Jordanian colleges/universities moved to distant virtual learning. This measure limited the mobility of this age group and reduced their risk of community infections, making household transmission their major source of infection. To test this assumption, the frequencies of household transmission were compared between students and non-students within this age group (Table 4). As expected, students reported significantly higher ratios of household transmission than non-students.

Female participants were predicted to have a higher risk of household transmission than their male counterparts. This result can be explained by the fact that the unemployment rates of females are significantly higher than the unemployment rates of males in Jordan and MENA countries [36,37]. Thus, females are more likely to stay-at-home which reduces their risk of COVID-19 community transmission. Furthermore, an association between female gender and an increased risk of household COVID-19 transmission was reported previously [33].

The preventive measures, such as mask-wearing and social distancing, are known to reduce the transmission of COVID-19, including secondary transmission between household members [4,38]. However, proper adherence to these measures within the place of residence is difficult to achieve. Herein, we report higher ratios of household transmission among participants with higher levels of adherence to the preventive measures. This result could be a reflection of the reduced risk of community transmission, which consequently would increase the ratio of household transmission among these participants.

Among the other sources of the COVID-19 infection reported in the current study are work/education related (16.0%), friends (8.6%), and healthcare facilities (4.8%). A previous study showed the presence of SARS-CoV-2 genome on inanimate surfaces of emergency/intensive care units [39]. In a Canadian study, healthcare workers were more likely to have been infected with SARS-CoV-2 [40]. Additionally, SARS-CoV-2 transmission among other countries has been reported to be significantly high in work and education environments [41–43]. Thus, the present study confirmed findings of previous reports from other countries on the sources of SARS-CoV-2 transmission.

Table 6
Selected studies reporting on household transmission of COVID-19.

No.	Authors	Country	Study design	Main findings/ conclusion
1	Fung, H.F. et al. [26]	10 countries	Systematic review of 22 studies	Overall estimate of household SAR was 17%. SAR was higher in older adults and in contacts with symptomatic cases
2	Lopez Bernal, J. et al. [27]	United Kingdom	Prospective case-ascertained study	Overall estimate of household SAR was 37%. SAR inversely correlated with the household size.
3	Bhatt, M. et al. [28]	Canada	Prospective case-ascertained antibody-surveillance study	Overall estimate of household SAR was 49% Adults had a higher likelihood to transmit SARS-CoV-2 than children.
4	Li, W. et al. [29]	China	Retrospective study	Household SAR was estimated to be 16.3%. SAR to children was lower than SAR to adults.
5	Xin, H. et al. [33]	China	Prospective study	Household SAR was 17.9%. Female index patients were associated with higher risk of household transmission
6	Lei, H. et al. [32]	China, South Korea, USA and Germany	Systematic review and meta-analysis	The risk of infection was 10 times higher for household contacts than other contacts. Adults were at higher risk of household transmission than children.

SAR: secondary attack rate.

By using a relatively large sample size, this study is the first to report on the sources of COVID-19 infections and the demographic factors associated with household transmission in the understudied MENA region. The results of the current study provide insights on the dynamics of COVID-19 transmission in the region. Such insights could be useful for identifying shortcomings in the currently implemented public health policies. This information would be invaluable to improve these policies to control COVID-19, as well as, any future pandemics, in Jordan and the MENA region. However, this study has some caveats that need to be acknowledged. First, the data was self-reported by the study participants. This fact makes the results susceptible to some limitations including recall bias. Second, the study population did not include children. Although children are not believed to be a major driver of virus spread among communities, including infected children in the study population would provide a more comprehensive view of the transmission dynamics [44]. Consequently, future studies are recommended to confirm the present findings.

5. Conclusion

The results of the current study showed that household transmission was the most frequently reported source of infection and accounted for approximately half of the cases. Other sources that showed notable fractions of transmission were work/education-related (16.0%), friends (8.6%), and healthcare facilities (4.8%). Household transmission was found to be influenced by age, gender, and levels of adherence to mask-wearing and social distancing. These results could help in understanding the dynamics of COVID-19 transmission and in the design of public health policies for controlling COVID-19 and future pandemics.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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