Risk of COVID-19 Transmission Aboard Aircraft: An Epidemiological Analysis Based on the National Health Information Platform

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Research Article

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Abstract

Background: Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), the type of coronavirus that causes the Coronavirus Disease 2019 (COVID-19), is mainly spread by respiratory droplets and aerosols. This study aims to investigate the risk of COVID-19 transmission on aircraft. This in turn provides the scientific basis for the return of air travel from pandemic to normal conditions.

Methods: We obtained data on all international flights to Lanzhou, China, from June 1 to August 1, 2020, through the Gansu Province National Health Information Platform and the official website of the Gansu Provincial Center for Disease Control and Prevention. We calculated the period prevalence rate of COVID-19 among the passengers of all flights during the 14-day period following the flight, and stratified the prevalence by the seat positions (aisle, middle, window), and the relationship to other confirmed cases (1-2 rows ahead, same row, 1-2 rows behind).

Results: Three international flights arrived in Lanzhou, China, during the study period, from Riyadh (MU7792), Jeddah (MU7790), and Moscow (CA608) each. The flights had a total of 700 passengers, of whom 405 (57.9%) were male and 80 (11.4%) were children below age fourteen. Twenty-seven (3.9%) passengers were confirmed to have COVID-19. There were no fatalities and all patients were cured. We identified three family clusters of cases. Confirmed patients were primarily male (n=17, 65.4%) with a median age of 27.0 years. The majority of confirmed cases were seated in the middle rows of the economy class, or near public facility areas such as restrooms and galleys. The prevalence of COVID-19 did not differ between passengers sitting on window, aisle or middle seats. Compared with passengers sitting on the same row up to two rows behind a confirmed case, passengers seated in the two rows ahead a confirmed case were at a slightly higher risk of being infected.

Conclusions: COVID-19 may possibly be transmitted during a passenger flight, although there is still no direct evidence.

Background

The routes of transmission of the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), the pathogen of the Coronavirus Disease 2019 (COVID-19), remains still partly unclear [1]. According to the present knowledge [2], the main routes of transmission of COVID-19 are respiratory droplets from close contacts as well as aerosols in confined spaces [3, 4]. But there is no evidence to exclude the possibility of other routes of transmission, such as gastrointestinal tract transmission [5]. In addition, COVID-19 is an emerging infectious disease, and despite the recent vaccination efforts the majority of the world's population is still susceptible to infection. As of 25 July 2021, World Health Organization (WHO) reports over 194 million cases of COVID-19 causing 4.0 million deaths, which demonstrates the magnitude of the burden of this pandemic [6].

The global volume of passenger air traffic has been rapidly increasing over the past years. According to the Statistical Bulletin of Civil Aviation Industry Development, almost 5.0 million passenger flights took off in 2019 in China, an increase of 5.8% compared with 2018 [7]. Although the aviation industry was deeply affected by the COVID-19 in 2020, 4.5 million passenger flights were still carried in 2020 [8]. There have been many outbreaks of airborne diseases, such as tuberculosis, Severe Acute Respiratory Syndrome (SARS), Middle Eastern Respiratory Syndrome (MERS) and Influenza A (H1N1), during flights [9]. Therefore, we intend to explore the risk of transmission of COVID-19 on aircraft based on the Gansu Province National Health Information Platform. This in turn provides the scientific basis for the return of air travel from pandemic to normal conditions.

Methods

Research subjects

We obtained the passenger information data for all international flights to Lanzhou, China from June 1 to August 1, 2020, from the Gansu Province National Health Information Platform. The following variables were extracted for all passengers: age, nationality, gender, native place, flight number, seat number, origin, destination, source city, temperature, place of transshipment, nucleic acid test results, the date of entry, the date of diagnosis, the date to release the management of confirmed cases. All passengers were tested for nucleic acid after disembarkation and transferred directly to the hospital if a positive result was found, or to the quarantine site in Lanzhou New Area if the result was negative. In most cases, each person was accommodated in a separate quarantine room, in cases of passengers who were incapacitated. After arrival, passengers were tested for nucleic acid (once a day) for the first three days, and on the 12th day and the 13th day. Additional tests were taken if required by the person's condition. After completing 14 days of quarantine in Lanzhou New Area, the passengers could return to their place of residence for a further 14 days of home quarantine. Nucleic acid testing would be carried out twice during the home quarantine by the local Centers of Disease Control and Prevention (CDC) staff. During the initial 14-day quarantine period, if symptoms or a positive nucleic acid test result occurred, the person was transferred to a designated hospital [10].

We extracted data on the confirmed COVID-19 cases from the official website of the Gansu Provincial Center for Disease Control and Prevention, including the following variables: age, nationality, gender, clinical classification, symptom. Case definition of COVID-19 followed the diagnostic criteria in the "Diagnosis and treatment plan for COVID-19 (Version 7)" issued by the National Health Commission of the People's Republic of China [11]. A case was confirmed as COVID-19 if it met at least one of the following conditions: (1) positivity for SARS-CoV-2 nucleic acid by real-time fluorescence Reverse Transcription-Polymerase Chain Reaction (RT-PCR); (2) viral gene sequencing results that are highly homologous to the known sequences of SARS-CoV-2; or (3) positivity for serum SARS-CoV-2-specific IgM and IgG antibodies, or 4-fold or more elevation of serum novel coronavirus-specific IgG antibodies from negative to positive or in the recovery phase compared with the acute phase. We excluded cases that did not meet the above criteria. Clinical classification was also based on the "Diagnosis and treatment plan for COVID-19 (Version 7)" [11], with the following four stages: (1) Light: The clinical symptoms were mild, and there was no sign of pneumonia on imaging; (2) Ordinary: The patient had fever, respiratory tract and other symptoms, and imaging signs of pneumonia; (3) Severe: The patient met at least one of the following conditions: □ Shortness of breath with respiratory rate greater than or equal to 30 beats/min; □ At rest, means oxygen saturation ≤ 93%; □ Partial arterial oxygen concentration/inspired oxygen faction (PaO2/FiO2) ≤ 300mmHg (1mmHg = 0.133kPa); and (4) Critical: The patient met at least one of the following conditions: □ Respiratory failure, mechanical ventilation was required; □ Shock; □ Other organ failure needing intensive care unit (ICU) monitoring.

Statistical analysis

We used SPSS 26.0 to conduct statistical analysis. Variables expected to be normally distributed was expressed as means ± standard deviations (SD), and other variables as medians with interquartile ranges (IQR). We used Student's t test for normally distributed variables, and Mann-Whitney U test for other variables. Categories variables (e.g., SARS-CoV-2 prevalence, gender, adults/children) were expressed by rate or composition ratio, and differences between rate or composition ratio were analyzed using Chi-square test or, when not applicable, Fisher's exact probability method. We were unable to distinguish between index cases and secondary cases because the chain of transmission of cases could not be traced. Therefore, the primary outcome indicator was the period prevalence, i.e., the number of confirmed cases on a particular flight during the observation period of 14 days divided by the number of all passengers of the same flight.

The WHO declared that passengers seated in the same row or a maximum of two rows ahead or behind and in the same block (i.e. no aisle in between) of each confirmed patient are considered close contacts [12]. Therefore, in order to explore the possible transmission risk on the aircraft, we performed an analysis where we divided the seats near each confirmed case into three groups: the two rows ahead, the same row, and the two rows behind the case. We considered only seats within the same block i.e. seats not separated by an aisle with the index patient, and calculated the prevalence at each three row groups (excluding the index patient). We performed this analysis for each confirmed case as an index patient separately, and then calculated the overall prevalence of the three row groups for each flight (see *Figure A.1* in the Appendix for an illustration). In addition, in order to explore the period prevalence of passengers in different seating positions, we divided the seats on the aircraft into three categories, namely window seats, middle seats and aisle seats, and calculate the prevalence for each of these categories. In all prevalence calculations, empty seats were excluded from the denominator.

Results

Three international flights arrived in Lanzhou City, Gansu Province, China from June to August 2020: flight MU7792 from Riyadh, flight MU7790 from Jeddah, and flight CA608 from Moscow, including a total 700 passengers, of whom 27 were confirmed to have COVID-19. We were able to extract the details of all except one confirmed case. After treatment, all 27 confirmed cases with the information available were eventually cured and discharged without a single death. Details are shown in *Table 1*.

Table 1

Summary of basic characteristics of three flights

Flight No.	Date of Flight	Origin	Destination	Total passengers		Male [N (%)]	Confirmed cases [N (%)]	Children [a]	
				N	M(IQR)			N (%)	M(IQR)
1	Jun.15,2020	Riyadh	Lanzhou	253	31(24.0-37.0)	152(60.1%)	20(7.9%)	41(16.2%)	4(2.0-6.0)
2	Jun.23,2020	Jeddah	Lanzhou	254	28(22.0-37.0)	169(66.5%)	4(1.6%)	37(14.6%)	4(3.0-7.0)
3	Jul.4,2020	Moscow	Lanzhou	193	23(21.0-25.0)	84(43.5%)	3(1.6%)	2(1.0%)	6(5.5-6.5)

[a] The age of a child is defined as being under 14 years of age.

Flight 1

On June 15, 2020, 253 Chinese passengers entered from Riyadh, Saudi Arabia to Lanzhou, China. Of the passengers, 152 (60.1%) were male; 41 (16.2%) were children below the age 14; the median age was 31 years old (IQR, 24.0-37.0). A total of 20 passengers on the flight were intermittently diagnosed to be infected with SARS-CoV-2, but for one of the cases, detailed information could not be obtained. The seating positions of all passengers are shown in *Figure 1*. There were three family clusters of infection, meaning confirmed cases from the same household who were seated close together. Besides, most of the confirmed patients were located in the middle: there were three confirmed cases in rows 35 and 36, and four cases in rows 61 and 62. The remaining confirmed patients were scattered in rows 26, 27, 32, 33, 34, 38, 39, 64 , and 70. The prevalence rates were 4.8% [95% CI (0.7%, 10.3%)] among passengers seated on the window seats (seats with suffixes A and L), 15.5% [95% CI (5.9%, 25.1%)] on the middle seats (seats with suffixes F and G), and 5.6% [95% CI (1.5%, 9.8%)] on the aisle seats (seats with suffixes C, D, H and J) (P=0.054). The prevalence rates were 16.7% [95% CI (9.5%, 27.2%)] in the two rows ahead each confirmed case; 14.0% [95% CI (5.8%, 28.6%)] in the same row with a confirmed case; and 10.7% [95% CI (6.0%, 17.9%)] in the two rows behind each confirmed case (P=0.465).

Flight 2

On June 23, 2020, a plane with 254 passengers flew from Jeddah, Saudi Arabia, to Lanzhou China. The median age of passengers was 28 years old (IQR, 22.0-37.0), the majority (n=169, 66.5%) were male, and 37 (14.6%) passengers were children below age 14. There were four confirmed cases, all from different households. The prevalence on the window seats (A, L) was 0, on the middle seats (F, G) 3.4% [95%CI (1.4%, 8.1%)], and the on the aisle seats (C, D, H and J) 1.6% [95%CI (0.6%, 3.8%)] (P=0.268). In the two rows ahead each confirmed case, the prevalence was 4.5% [95%CI (0.2%, 24.9%)], in the same row 0, and in the two rows behind 4.2% [95%CI (0.2%, 23.1%)] (P=1.000).

Flight 3

On July 4, 2020, 193 passengers arrived on the flight from Moscow, Russia, to Lanzhou, China. Eighty-four (43.5%) passengers were male, and the median age was 23 years old (IQR, 21.0-25.0). Two (1.0%) were children below age 14. There were three confirmed cases, all from separate households. The prevalence rates were 2.3% [95% CI (2.3%, 6.9%)] in the window seats (seats with suffixes A and L), 1.6% [95% CI (1.6%, 4.8%)] in the middle group (seats with suffixes B, E and K), and 1.1% [95% CI (1.1%, 3.4%)] in the aisle group (seats with suffixes C, D, H and J) (P=1.000). There were no other confirmed cases around the seats of the three confirmed patients.

Characteristics of confirmed cases

The 26 confirmed cases with full data available had a median age of 27.0 years, and most (n=17, 65.4%) were male (*Table 2*). The symptoms of patients were mild, and the main symptoms were throat discomfort (n=12, 46.2%), followed by fatigue (n=6, 23.1%), low fever (n=5, 19.2%) and cough (n=5, 19.2%). Some uncommon symptoms, such as high fever, nasal congestion, runny nose and headache, were also observed. Twelve patients (46.2%) had no fever, and five patients (19.2%) were asymptomatic. Fourteen cases were classified as light and 12 cases as ordinary.

Table 2

Summary of the details of individual cases in a flight-associated outbreak of COVID-19

Number	Flight	Gender	Age (year)	Clinical Classification	Symptom	Family Cluster	Seat Number	Source City	Time from the Date of Entry to the Date of Diagnosis (day)
1	1	Male	4	Light	a	A	25C	Riyadh, Saudi Arabia	1
2		Female	5	Light	b	C	61G	Riyadh, Saudi Arabia	7
3		Female	8	Light	d	B	36G	Riyadh, Saudi Arabia	2
4		Female	9	Light	a	A	25D	Riyadh, Saudi Arabia	1
5		Male	24	Ordinary	a e f	/	64G	Riyadh, Saudi Arabia	7
6		Male	24	Ordinary	b f	/	70C	Riyadh, Saudi Arabia	1
7		Male	25	Ordinary	a g h	/	34F	Riyadh, Saudi Arabia	1
8		Male	27	Light	b e	/	27L	Riyadh, Saudi Arabia	1
9		Male	27	Ordinary	b f	/	35G	Riyadh, Saudi Arabia	7
10		Male	28	Ordinary	i	/	62G	Riyadh, Saudi Arabia	1
11		Male	29	Light	b	/	33F	Riyadh, Saudi Arabia	7
12		Male	29	Ordinary	a	/	38F	Riyadh, Saudi Arabia	7
13		Female	31	Light	d	C	61H	Riyadh, Saudi Arabia	7
14		Male	32	Ordinary	c e	/	39C	Riyadh, Saudi Arabia	13
15		Female	36	Ordinary	a e	A	25A	Riyadh, Saudi Arabia	1
16		Female	37	Ordinary	a	B	36D	Riyadh, Saudi Arabia	1
17		Female	39	Ordinary	a	/	26G	Riyadh, Saudi Arabia	1
18		Male	51	Ordinary	a e	/	61J	Riyadh, Saudi Arabia	1
19		Female	52	Ordinary	c	/	32L	Riyadh, Saudi Arabia	7

20	2	Male	23	Light	d e	/	33G	Jeddah, Saudi Arabia	3
21		Male	26	Light	e	/	35F	Jeddah, Saudi Arabia	3
22		Male	34	Light	d e	/	32J	Jeddah, Saudi Arabia	3
23		Male	49	Light	d e	/	35C	Jeddah, Saudi Arabia	3
24	3	Male	18	Light	a e f	/	51E	Moscow, Russia	0
25		Female	19	Light	a d e	/	39J	Moscow, Russia	0
26		Male	22	Light	a e f	/	43L	Moscow, Russia	0

Notes: a. Body temperature is less than 37.3°C; b. Body temperature is between 37.3°C and 37.9°C; c. Body temperature is greater than or equal to 38°C; d. Fatigue; e. Throat discomfort; f. Cough; g. Stuffed nose; h. Runny nose; i. Headache; /: No report.

Most of the confirmed cases were seated in the middle of the economy class, and they were in the wing position (rows 32-35). Enclosed public facilities areas were the focus areas of infection, such as rows 61 and 62 of Flight 1 (which were close to the bathroom). Furthermore, there were three family clusters. The median interval time between the date of arrival in Lanzhou, China and the date of diagnosis was 1.5 days (IQR, 1.0-7.0). The median interval between the beginning date of physical release management (ending hospital isolation management) and the date of diagnosis was 12.5 days (IQR, 6.5-15.0), and the median interval time from the formal deisolation management (ending home isolation management) to the date of diagnosis was 26.5 days (IQR, 20.5-29.0). The distribution of the time to release the management of confirmed cases is shown in *Figure 2*. The information about the management of six patients was missing.

Discussion

As far as we know, this is the first comprehensive analysis of aircraft seats during the outbreak of COVID-19. We found that most of the confirmed cases were in the middle of the economy class, around the wing position of the aircraft. Infections were clustered also around bathrooms, galleys and other public facilities, such as 61 and 62 rows of Flight 1. The prevalence did not seem to differ between window, middle and aisle seats. The prevalence was higher for passengers seated in the two rows ahead the confirmed case compared to those seated in the same row or two rows behind.

Aircraft and transmission

Most of the studies so far have shown that the main routes of transmission of COVID-19 are through respiratory droplets, aerosols ere and close contact transmission [13,14,15]. The risk of respiratory transmission is heightened when people move around each other, especially in cases when they are in frequent contact with other people, such as in public transport. However, some studies have claimed that on aero planes the air quality of the cabin is good [16], and the risk of transmitting respiratory virus on the aircraft is extremely low [14,17]. Studies show that SARS [18], H1N1 [19,20], MERS [21,22] and other respiratory viruses have been spread during flights. The basic reproduction number (R_0) of SARS-CoV-2 has been estimated to be between 1.8 and 3.6, which is higher than that of SARS, MERS and influenza viruses. This indicates that COVID-19 seemed to be more likely to cause transmission [23].

In the three flights of our study, 7.5%, 1.6%, and 1.5% of the patients were found to be infected, respectively. In other studies, Chen et al [24] found the prevalence of COVID-19 4.8% among passengers of a flight from Singapore to Hangzhou, China, and Fan et al [25] found a prevalence of 11.9% among 311 overseas Chinese evacuated from Iran to Gansu Province, China. Khanh et al [26] found a 7.4% prevalence of COVID-19 on a direct flight from London, UK to Hanoi, Vietnam. In our study, the prevalence of COVID-19 was lower. There may be several reasons: (1) The incidence of COVID-19 in the origin location (Saudi Arabia, Russia) at the time of the flight was not high. In Saudi Arabia, the number of new confirmed cases was 121.5 per 100,000 over 14 days on 15 June and 160.1 per 100,000 over 14 days on 23 June. In the Russian Federation, the number of new confirmed cases was 66.7 per 100,000 over 14 days on 4 July; (2) In the flights included in our study, passengers were required to wear masks during the flight [27]; (3) The destination of the flight was Lanzhou, China. Since 18 February, there have been no new confirmed cases of indigenous COVID-19 in Gansu Province, which is located in the northwestern part of China and managed to control the outbreak extremely well; (4) The strictness of the quarantine could have an impact. The passengers of all three flights were Chinese nationals who were repatriated by flights chartered by the Chinese government and were not screened for symptoms or nucleic acid prior to boarding. However, the higher prevalence in Flight 1 may be the high number of family clusters in Flight 1.

Seating and transmission

The present study found no evidence for an association between the prevalence of infection and being seated on window, aisle or middle seats. This is in line with the results of Foxwell et al [28]. However, both Flight 1 and Flight 2 showed that the period prevalence rate of passengers in the middle was relatively high, while Foxwell et al found that the risk of infection in the aisle location was higher through the investigation of the spread of H1N1 on international flights in May 2009 [28]. There are several possible reasons for the different results. In the flights of our study, most of the family clusters appear in the middle position (such as family B and family C in Flight 1); the middle seats are densely distributed, which may increase the risk of infection (the middle seats of Flights 1 and 2 had 4 were in all the middle block with 4 seats abreast); and the location close to the aisle has more chances of contact with passengers, so the risk of infection may be higher. In addition, it may also be related to the infectivity of different viruses, aircraft types, and protective measures for passengers.

We also found that public facility areas such as restrooms and galleys were focal areas of infection. For example, rows 61 and 62 near restrooms in Flight 1 showed a relatively high number of cases, which was consistent with the findings of Chen et al [24]. In addition, infected individuals were also common in the seats around the position of the wings, such as rows 32 to 35 in Flight 1, which may be related to the operation of the aircraft engine, air filtration system or conditioning system, but there is no evidence for this so far. We further explored the differences prevalence of infection of sitting in the two rows ahead, the same row, and the two rows behind of a confirmed case. The results showed that the prevalence of infection was higher for passengers seated ahead two-rows. This can be probably be explained that cabin air enters from the top and exits the cabin down near the floor. And air enters and leaves the cabin mainly in or near the same-row of seats, with a low probability of flow in the front and rear rows [14]. However, when people move around in the cabin, the airflow changes accordingly. The air flow in the cabin can also have different effects on the navigation route of the aircraft, especially in non-smooth conditions such as take-off, landing, and turbulence. Therefore, we suggest recording the flight process in detail in order to provide a basis for research on transmission dynamics.

Symptoms

Most studies showed that fever, cough, and fatigue were the main symptoms of COVID-19 [29,30]. The main symptom of SARS were fever, cough, and shortness of breath in flight [31], while for H1N1 they are cough, fever, headache, runny nose, and diarrhea [28,32]. It is known that asymptomatic SARS-CoV-2 infected individuals can transmit the virus, and nucleic acid detection of patients is essential. Our study showed the symptoms were mild, with only 19.2% of COVID-19 patients presenting a low fever. However, 46.2% patients had a body temperature below 37.7°C, and a few patients had no symptoms despite having positive nucleic acid test results. For COVID-19 transmission in asymptomatic infected individuals in flight, Bae et al [33] suggested that temperature testing and symptom screening alone before air travel will not completely block the possibility of coronavirus transmission. We recommended that passengers should be tested for nucleic acid before flight. Testing could be offered before take-off to reduce the likelihood of cross infection by passengers.

Limitations and Strengths

Our study has several advantages. First, the data was obtained from the National Health Information Platform of Gansu Province, and we conducted a comprehensive analysis of the seating arrangements during the flight, which is to our knowledge the first study for this purpose. Second, we analyzed some potential factors related transmission risk and conditions of COVID-19 in flight, to provide a scientific basis for mitigating the risk of infectious disease transmission during transportation. However, our study also has some limitations. First, we were unable to obtain information on passengers' activities before and during the flight, including whether they had contact with suspected or confirmed patients, whether they drank or ate during the flight, whether they used the restroom, or whether they wore masks all times during the flight. Second, no surface swab sampling or air sampling was performed in the aircraft cabins, so there is no direct evidence that transmission occurred during the flight. Third, we were unable to distinguish between index cases and secondary cases because the chain of transmission of cases could not be traced. The main indicator we used, the period prevalence, can only give insights about the risk of transmission, but not confirm whether onward transmission actually happened during the flight.

Suggestions

According to the results of this study, we make the following suggestions for flights during a pandemic: (1) Before taking flight, passengers must provide a certificate of negative nucleic acid test result or a vaccination or a recovery certificate and do not have symptoms, to further avoid the risk of the spread of infectious diseases on the plane; (2) Airlines shall try best not to arrange seats near public facilities, and at least one empty seat should be left between groups if possible; (3) Passengers should minimize their activities before and during the flight, and always take protective measures such as wearing masks (especially those near to public facilities or in the middle positions). In addition, it is recommended to adopt this scheme for epidemic prevention and control in other confined spaces such as movie theaters and restaurants. and public vehicles such as buses, trains and metros.

Conclusion

In conclusion, this study is one of the few studies to demonstrate the possibility of SARS-CoV-2 transmission occurring during a flight, exploring the relationship between passengers' seats and prevalence in detail. There are on few evidence-based guidelines for COVID-19 air travel, so it is recommended to carry out more relevant studies and develop reasonable and feasible health policies or guidelines to reduce the risk of the spread of COVID-19 and other airborne infectious diseases on airplanes in the pandemic to respond to the future ones. And this in turn provides the scientific basis for the return of air travel from pandemic to normal conditions.

Abbreviations

SARS-CoV-2, Severe Acute Respiratory Syndrome Coronavirus 2

COVID-19, the Coronavirus Disease 2019

WHO, World Health Organization

SARS, Severe Acute Respiratory Syndrome

MERS, Middle Eastern Respiratory Syndrome

H1N1, Influenza A

CDC, Centers of Disease Control and Prevention

IQR, interquartile ranges

Declarations

Ethics approval and consent to participate

In the National Health Information Platform, all operations are strictly done in accordance with the outline of Action Plan for Big Data Development of the State Council of the People's Republic of China, and strictly comply with the personal information protection law and ethical standards. Our data were obtained with a consent of the Health Commission of Gansu Province. To protect privacy, no personal information of the passengers involved were disclosed to the researchers.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are not publicly available due it is from a private network of Gansu Province National Health Information Platform, but are available from the corresponding author on reasonable request.

Competing interests

There are no conflicts of interest to declare.

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Authors’ contributions

QG and JW contributed equally to this work. QG, JW, XY, YC designed the study. XY and JY collected the data. QG, HL, JZ and SW analyzed the data. QG and JW contributed to writing and editing. QG, JW, JE and YC contributed to modifying and reviewing. All authors have read and approved the manuscript.

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Figures

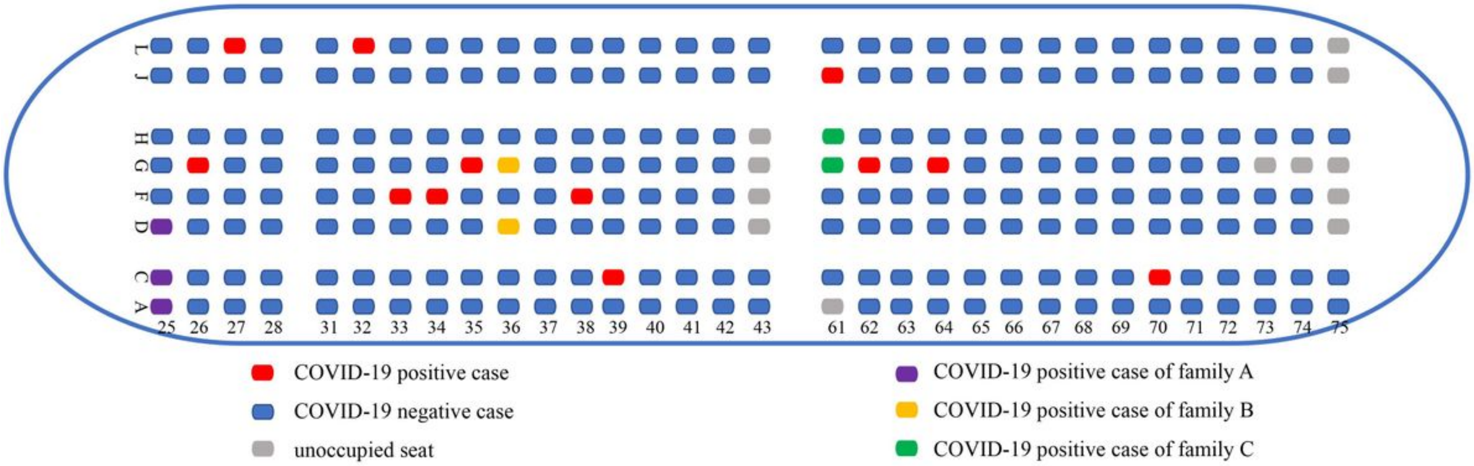

Figure 1

Passenger seating diagram on Flight 1

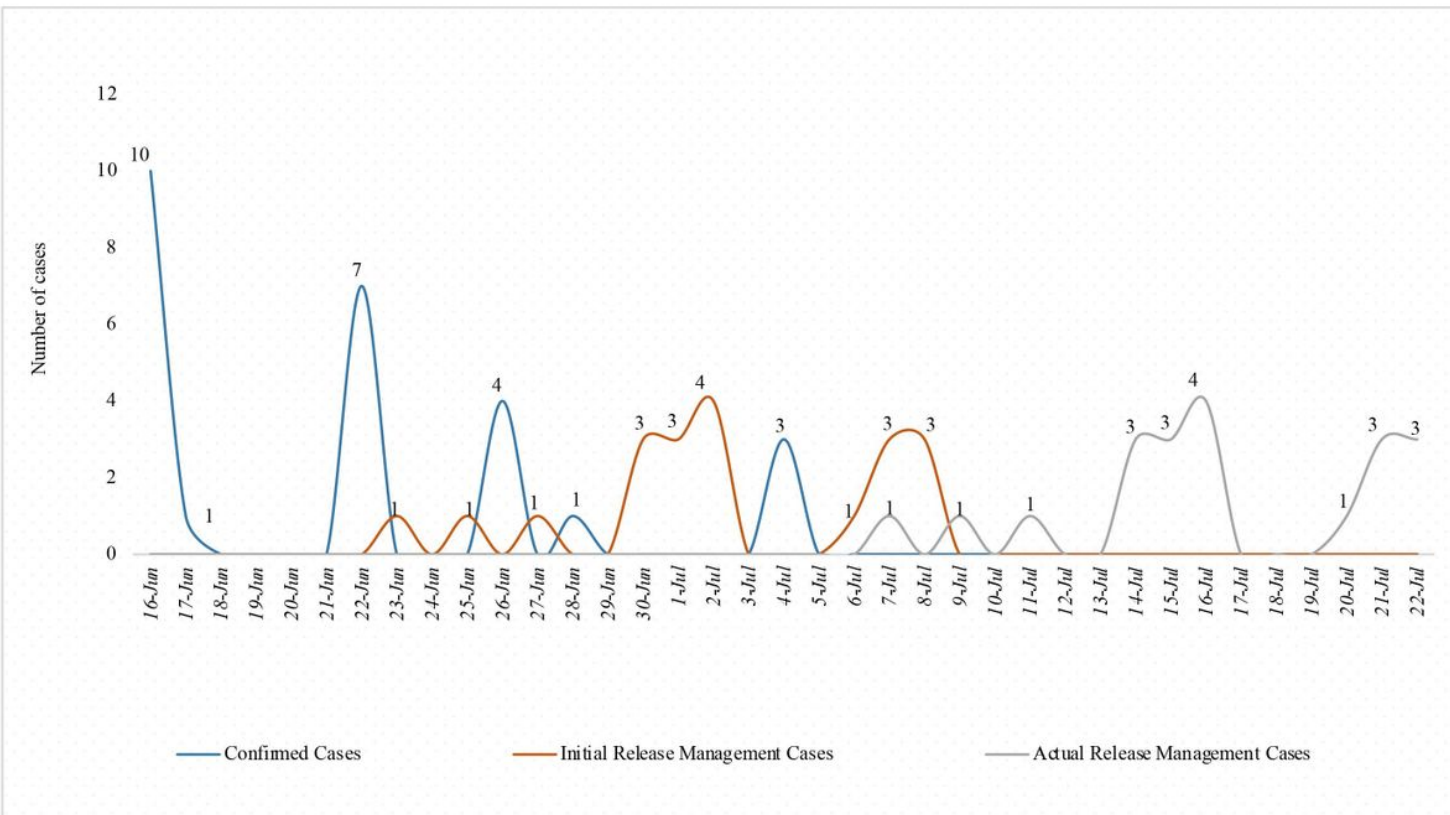

Figure 2

Numbers of COVID-19 cases over time

Supplementary Files

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- AppendixFigureA.1Passengerseatingdiagramonflight.docx