ORIGINAL ARTICLE

Transmission of the Severe Acute Respiratory Syndrome on Aircraft

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ABSTRACT

BACKGROUND

The severe acute respiratory syndrome (SARS) spread rapidly around the world, largely because persons infected with the SARS-associated coronavirus (SARS-CoV) traveled on aircraft to distant cities. Although many infected persons traveled on commercial aircraft, the risk, if any, of in-flight transmission is unknown.

METHODS

We attempted to interview passengers and crew members at least 10 days after they had taken one of three flights that transported a patient or patients with SARS. All index patients met the criteria of the World Health Organization for a probable case of SARS, and index or secondary cases were confirmed to be positive for SARS-CoV on reverse-transcriptase polymerase chain reaction or serologic testing.

RESULTS

After one flight carrying a symptomatic person and 119 other persons, laboratory-confirmed SARS developed in 16 persons, 2 others were given diagnoses of probable SARS, and 4 were reported to have SARS but could not be interviewed. Among the 22 persons with illness, the mean time from the flight to the onset of symptoms was four days (range, two to eight), and there were no recognized exposures to patients with SARS before or after the flight. Illness in passengers was related to the physical proximity to the index patient, with illness reported in 8 of the 23 persons who were seated in the three rows in front of the index patient, as compared with 10 of the 88 persons who were seated elsewhere (relative risk, 3.1; 95 percent confidence interval, 1.4 to 6.9). In contrast, another flight carrying four symptomatic persons resulted in transmission to at most one other person, and no illness was documented in passengers on the flight that carried a person who had presymptomatic SARS.

CONCLUSIONS

Transmission of SARS may occur on an aircraft when infected persons fly during the symptomatic phase of illness. Measures to reduce the risk of transmission are warranted.

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THE SEVERE ACUTE RESPIRATORY SYNDROME (SARS) is characterized by the acute onset of fever with cough, shortness of breath, difficulty breathing, or some combination of these symptoms; the symptoms begin an average of four days after exposure to an infected person. As of September 26, 2003, 8098 cases of SARS and 774 deaths due to SARS (10 percent mortality) in more than 25 countries had been reported to the World Health Organization (WHO).[1,2]

Although there have been anecdotal reports of transmission on aircraft, the risk, if any, to passengers has not been well documented. WHO and the Centers for Disease Control and Prevention (CDC) issued guidelines for air travel to and from areas affected by SARS, specifying that hand hygiene is important and that it may be appropriate to place a mask on a passenger suspected of having SARS.[3-5] Nevertheless, the public perception of the risk of in-flight transmission resulted in the widespread use of masks by passengers and crew members, as well as the implementation of preflight screening by airlines and a substantial decrease in air travel from and to some Asian countries. We conducted a study involving the evaluation of the passengers and crew members on three flights that had carried one or more persons in whom SARS was later diagnosed, in an attempt to quantify the risk of transmission during various phases of illness.

METHODS

During the early part of the SARS outbreak, 9 of the first 11 patients in Taiwan whose illness met the WHO definition of a probable case of SARS traveled from an area affected by SARS to Taiwan on a commercial aircraft.[6] There were a total of eight flights of concern; flight numbers were identified for seven, and we were able to obtain the manifest (full passenger list) for four. Three of these flights had a clear link to a laboratory-confirmed case of SARS and were investigated intensively. The first (Flight 1) was a flight on which a person with a probable case of SARS flew during the week before the onset of clinical illness (i.e., the incubation phase). The second two (Flights 2 and 3) were flights that carried a person or persons who had symptomatic SARS. Passenger rosters and seat assignments were obtained from the airline; for Flight 2, a list of Taiwanese passengers and their seat assignments was obtained from a nongovernmental organization in mainland China, and information about additional passengers was obtained from the Department of Health of the Hong Kong Special Administrative Region, China, and the Epidemiology and Disease Control Division of the Singapore Ministry of Health. Attempts by Taiwan to obtain the entire manifest directly from the airline were unsuccessful. Hong Kong did obtain names and seat numbers from the airline but were required to take multiple other steps to obtain contact information.

Passengers and crew members were contacted in person or by telephone and were interviewed with a questionnaire that asked about symptoms of illness (fever, cough, shortness of breath, and difficulty breathing) since the flight. Persons suspected of having SARS were seen at a hospital where a chest radiograph was obtained. Reverse-transcriptase polymerase-chain-reaction (RT-PCR) assays were performed with the use of established sets of primers, and antibody testing was performed with the use of indirect fluorescence assays and enzyme-linked immunosorbent assays; these tests were performed at the Hong Kong Department of Health, the Taiwan Center for Disease Control, or the CDC.[7]

To estimate the range of possible attack rates, we calculated two point estimates: the number of persons with documented illness divided by the total number of persons interviewed, and the number of persons believed to be ill divided by the total number of persons on the aircraft. For each of these two point estimates, we calculated exact binomial 95 percent confidence intervals.

RESULTS

A total of 304 of the 681 passengers on the three flights (45 percent) were interviewed directly; 16 had laboratory-confirmed SARS, 2 had illness that met the WHO definition of a probable case of SARS and were interviewed, 4 were reported to have probable cases of SARS but were not interviewed, and 1 had a suspected case of SARS. The infection in these 23 patients was subsequently transmitted to at least 13 others, 2 of whom died of SARS.

FLIGHT 1

On February 21, 2003, a Boeing 777-300 carrying 315 passengers and crew members flew for 90 minutes from Hong Kong to Taipei. A person with presymptomatic SARS was one of the passengers on board; fever developed in this passenger four days after the flight, his illness later met the WHO definition of a probable case of SARS, and he was de-

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termined to be seropositive for the SARS-associated coronavirus (SARS-CoV). This patient was a 54-year-old businessman who had worked in Guangdong Province from February 5 to February 21. His fever began on February 25 and lasted 24 days; he required mechanical ventilation for 13 days.

Interviews of passengers were conducted a median of 27 days (range, 25 to 41) after the flight. A total of 74 of the 315 passengers and crew members (23 percent) were interviewed, and none reported an illness consistent with SARS (Table 1). Routine surveillance did not result in the detection of any additional cases among the remaining 77 percent of the passengers and crew members.

FLIGHT 2

On March 15, 2003, a Boeing 737-300 carrying 120 persons (112 passengers, 6 flight attendants, and 2 pilots) flew for three hours from Hong Kong to Beijing. One of the passengers was a symptomatic 72-year-old man in whom fever had developed on March 11. He was hospitalized on arrival in Beijing, where he was given a diagnosis of atypical pneumonia and died on March 20. This passenger had visited his brother at the Prince of Wales Hospital in Hong Kong several times between March 4 and the brother's death on March 9. During this time, there were other patients with known cases of SARS on the same ward as the brother. The niece of the 72-year-old man, who had also visited her father in the hospital, was later given a diagnosis of SARS.

Of the 112 passengers, 65 were contacted at least eight days after the flight; 18 of these passengers had illness that met the WHO definition of a probable case of SARS, and probable cases of SARS in 4 more were reported to the WHO, although these 4 passengers were not interviewed directly (Table 1). Thirteen of the passengers in whom SARS developed were from Hong Kong, four were from Taiwan, and one was from Singapore; the four who were not interviewed were from China.

In Hong Kong, the Department of Health was notified of a cluster of three SARS cases by a local hospital on March 23. An epidemiologic investigation revealed that the patients in question had joined 33 other persons for a five-day tour of Beijing and had been on the flight described above. Ten passengers from the tour had illness that met the definition of a probable case of SARS, as did three others, two of whom were traveling together. All three were unknown to the tour group and had different itineraries before and after the flight. All 13 persons whose illness met the WHO definition of a probable case had laboratory evidence of SARS-CoV (9 had positive results on RT-PCR and serologic testing, 2 on RT-PCR only, and 2 on serologic testing only).

The four Taiwanese passengers who became ill were part of a business group that had been traveling together. While they were in Beijing, all seven members of this group had stayed at the company guesthouse, each in a single room. They had attended meetings each day and reported engaging in no sightseeing or other activities outside of work. They met with 10 colleagues from Beijing, none of whom were ill during the meeting; illness did not develop in any of the Beijing colleagues within 14 days after

Table 1. Frequency of Transmission on Three Aircraft Carrying One or More Persons Given a Diagnosis of a Probable Case of SARS.*

Flight No.	Model of Aircraft	Date of Flight	Duration of Flight	Phase of Illness (no. of patients)	No. Believed to Have Become Infected/Total No. of People on Aircraft (% [95% CI])	No. Who Became Ill/ No. Interviewed (% [95% CI])†
1	777-300	Feb. 21, 2003	90 min	Incubation (1)‡	0/315 (0 [0–1.2])	0/74 (0 [0–4.9])
2	737-300	Mar. 15, 2003	3 hr	Fever with cough (1)	22/120 (18.3 [11.9–26.4])	18/65 (27.7 [17.3–40.2])
3	777-300	Mar. 21, 2003	90 min	Fever (2); fever with cough (2)	1/246 (0.4 [0–2.2])	1/166 (0.6 [0–3.3])§

* The 95 percent confidence intervals (CIs) given are the exact binomial 95 percent confidence intervals around point estimates. SARS denotes the severe acute respiratory syndrome.

† Illness was defined as fever with cough, shortness of breath, or difficulty breathing. The number of patients who became ill excludes the index patient or patients.

‡ The incubation phase is defined as the 10 days before the onset of fever.

§ Illness in the one passenger who became ill met the WHO criteria for a suspected case of SARS; no chest radiograph was obtained.

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the meeting. Three of the four Taiwanese patients with SARS were seropositive for SARS-CoV, and one of these patients also had a throat swab that tested positive on RT-PCR.

Interviews with contacts of the patient in Singapore identified no other exposure to persons with SARS. She did not go to any hospital or visit ill persons during the last few days before she left Singapore. While she was in Beijing, she spent time with two colleagues from Singapore who were subsequently screened and found not to be ill.

Four additional cases that were potentially associated with this flight were identified by Chinese health authorities and newspaper reporters and were reported to the WHO. Two of the patients were Chinese officials who stayed a short time in Beijing and then flew to Thailand on March 17, becoming ill on March 19 and 20, four and five days, respectively, after the flight. One of these two patients was briefly hospitalized in Bangkok and flew back to Beijing, where he was rehospitalized and died on March 28. According to newspaper reports, the other two patients were Chinese flight attendants, one in the economy-class section and one in the first-class section, who became ill on March 18 and 19, respectively.[8,9]

Among the 22 patients with SARS, the date of onset of illness ranged from March 17 to March 23, a mean of four days after the flight (range, two to eight) (Fig. 1). A total of five persons died as a result of their illness (three persons from Hong Kong, one from China, and one from Singapore).

Seating in the economy-class section of the aircraft was six seats abreast (seats A, B, and C on one side of the aisle, and seats D, E, and F on the other). The flight was 88 percent full, and the index patient sat in seat 14E (Fig. 2). The seat assignments of the two Chinese businessmen are unknown. The risk of illness was related to the proximity to the index patient, with illness reported in 8 of the 23 passengers who were seated in the same row as the patient or in the three rows in front of him, as compared with 10 of the 88 passengers who were seated elsewhere (relative risk, 3.1; 95 percent confidence interval, 1.4 to 6.9). It is notable that 56 percent of the passengers who became infected were not seated in the same row as the index patient or in the three rows in front of him.

The WHO working definition of a contact on a flight is any passenger seated in the same row of seats or within two rows in front of or behind the index patient, or any flight attendant.[10] On Flight 2, 31 percent of persons who fit this definition became ill, as compared with 11 percent of persons who were seated elsewhere on the plane (11 of 35 vs. 9 of 84; relative risk, 2.9; 95 percent confidence interval, 1.3 to 6.5). The WHO definition would have missed 45 percent of the patients with SARS. The risk was greater in the same row or in the three rows in front of the index patient than in the three rows behind him, although the difference was not statistically significant (8 of 23 [35 percent] vs. 3 of 18 [17 percent]; relative risk, 2.1; 95 percent confidence interval, 0.6 to 6.8). There was no significant difference in risk between persons seated in an aisle seat and those seated in a middle or window seat (6 of 39 [15 percent] vs. 12 of 72 [17 percent]; relative risk, 0.9; 95 percent confidence interval, 0.4 to 2.3). Two of the 20 passengers who became infected (and whose seating assignments are known) were seated within 0.9 m (36 in.) of the index patient.

FLIGHT 3

On March 21, 2003, a Boeing 777-300 carrying 246 passengers and crew members flew for 90 minutes from Hong Kong to Taipei. Four symptomatic passengers (all of whom had also taken Flight 2) were on board. Fever had developed three days before the flight in one of the passengers, two days before the flight in two of them, and on the day of the flight in the fourth. Later, two of the four patients with SARS reported that they had been coughing during the

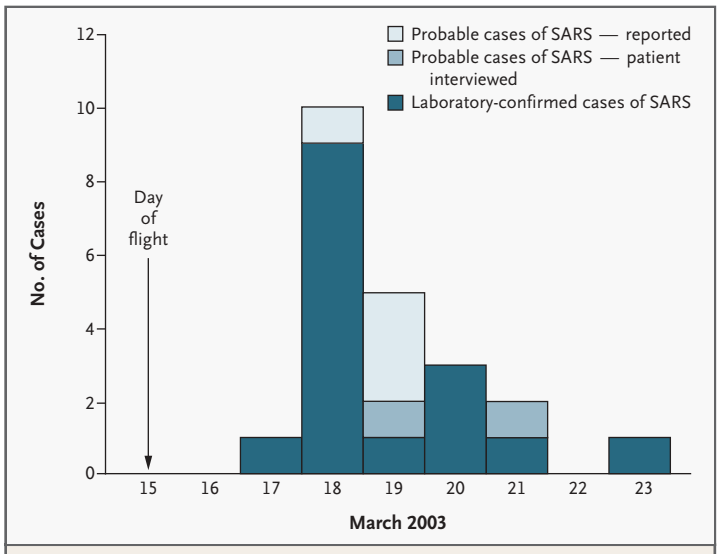

Figure 1. Time of Onset of Illness Relative to Flight 2 among 22 Persons Whose Illness Met the WHO Definition of a Probable Case of SARS.

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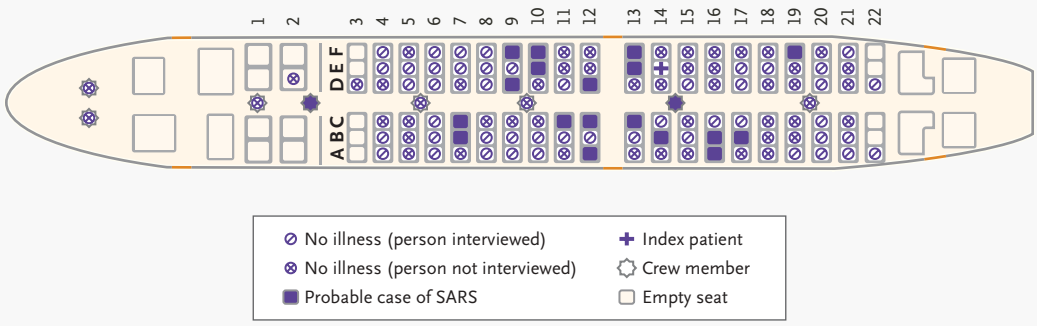

Figure 2. Schematic Diagram of the Boeing 737-300 Aircraft on Flight 2 from Hong Kong to Beijing.
Two flight attendants and two Chinese officials also reportedly had illness that met the WHO criteria for a probable case of SARS. The flight attendants are shown here as members of the crew. The seat locations of the two Chinese officials are unknown, and they are not included in the diagram.

flight; three were confirmed to be seropositive, and one of the three was also positive on RT-PCR.

Interviews of passengers were conducted a median of 11 days (range, 6 to 11) after the flight. Of the 166 persons interviewed (67 percent), 1 reported fever and respiratory symptoms but never had a chest radiograph obtained and was not reported as having a probable case of SARS (Table 1). He has since fully recovered without hospitalization. Routine surveillance did not result in the detection of any additional cases among the remaining 33 percent of the passengers and crew members.

DISCUSSION

We believe that the most plausible explanation for the development of SARS in the passengers and crew members on Flight 2 is that they were infected while on board the aircraft, although other explanations are possible. As might be expected of a flight carrying patients with SARS, Flight 2 was traveling from a SARS-affected area (Hong Kong) to a destination that would later be identified as a SARS-affected area (Beijing). Therefore, it is possible that the passengers in whom SARS developed were infected before or after the flight. However, the clustering of the dates of onset of illness around four days after the flight is in keeping with the expected incubation period for SARS[11,12] and points to the day of the flight as a likely time of transmission. Furthermore, we identified no alternative exposures before or after the flight through our interviews with the ill passengers. One ill person, who was part of a tour that traveled together, had an onset of illness eight days after the flight, an interval that might have been attributable to secondary spread from another member of the tour group.

The observation that the passengers who became infected were clustered in the few rows directly in front of or behind the ill passenger, rather than being randomly distributed throughout the aircraft, is consistent with the pattern described in other cases in which a respiratory pathogen was transmitted on board an aircraft[13] and lends further plausibility to the theory that transmission occurred during the flight. The risk to passengers was greatest if they were seated in the same row as the index patient or within three rows in front of him. The greater concentration of persons who became infected in front of the index patient than behind him may point to the role of coughing in transmission, causing a combination of aerosol and small-droplet spread.

Large-droplet spread is often believed to occur within 36 in. of a patient,[14] and this cutoff has been used to define exposure to SARS in other investigations.[15] However, the distance covered by three economy-class rows on a Boeing 737-300 is 2.3 m (90 in.). On this aircraft, 90 percent of the persons who became ill were seated more than 36 in. away from the index patient, so airborne, small-particle, or other remote transmission may be more straightforward explanations for the observed distribution

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of cases. Although many respiratory pathogens are primarily transmitted through direct contact and large-droplet spread, a few — such as *Mycobacterium tuberculosis*, influenzavirus, and measles virus — may also be transmitted through airborne routes.[16] Other potential modes of transmission include contact with contaminated fomites, contact resulting from the movement of the passengers closer together during the flight, and contact occurring in waiting areas or lines immediately before boarding or after disembarkation. Hand contact might have been expected to increase the risk among passengers who sat in aisle seats, but we did not find such a pattern.

As was expected on the basis of the known patterns of transmission of SARS,[12,15] the fact that the virus appeared to be transmitted by passengers who were in the symptomatic phase of illness but not by those who were in the presymptomatic phase suggests that the risk of transmission varies according to the phase of illness. It is likely that persons who fly during the incubation period (within 10 days before the onset of illness) pose very little or no risk to other passengers. However, we might have missed some cases because of the low percentage of passengers from Flight 1 who were contacted and because of the limitations in routine surveillance.

There have been well-documented instances of transmission of other respiratory agents on aircraft.[13,17] As in our findings with regard to Flights 2 and 3, the risk of transmission can vary widely. The variation in risk might be influenced by the duration of the flight, the stage of illness, the type of air-ventilation system in use, the size of the aircraft, and the number of infected persons on board.[13,17,18] In addition, some investigators have proposed that poorly characterized host factors in certain patients predispose them to transmit the virus to large numbers of persons (making them so-called "superspreaders"), a hypothesis that has been used to explain epidemiologic clustering in Hong Kong and Singapore and that might be applicable to the index patient on Flight 2.[2,19]

It is important to emphasize that the true attack rate on Flight 2 may be different from the rate we calculated. Sixteen of the 22 cases that resulted from this flight had laboratory confirmation of SARS-CoV. No specimens were available for testing from five patients, and one patient had a negative test; some patients who were deemed to have probable cases of SARS may not have been infected with SARS-CoV. On the other hand, five of the cases resulted in death, and the other patients had illness compatible with a diagnosis of SARS whose onset occurred within the expected incubation period. Forty-six of the passengers who were considered not to have been infected were not interviewed, including the two who sat next to the index patient, and it is possible that routine surveillance missed some additional infections.

There have been some anecdotal reports of the transmission of SARS during airline flights, but the extent of risk, if any, has not been clearly documented. It seems likely that the overall risk to airline passengers is quite low. As of May 12, 2003, the WHO reported that 35 flights were under investigation because a patient with symptomatic SARS had been on board, but only 4 of these flights were deemed to be associated with possible transmission.[20,21] Aircraft ventilation systems are believed to be highly efficient at keeping the air free of pathogens, which they do by exchanging the air in passenger cabins every three to four minutes and passing the circulated air through high-efficiency particulate-arresting (HEPA) filters designed to filter out all particles larger than 0.3 μm by 1 μm.[22,23] The fact that only 45 percent of the passengers were interviewed despite intensive investigation by three health departments over the course of two months highlights the difficulties faced by such investigations and raises the possibility that more transmission occurred than was recognized.

Furthermore, the risk of transmission may have been reduced after April 2003, thanks to the implementation of safety measures.[3-5] Additional studies are needed to evaluate the effect of these measures on the transmission of SARS. The WHO reports that no transmission was identified after March 23.[24] Nevertheless, the episodes described above indicate that in certain circumstances, the risk of transmission from a patient with SARS during an airplane flight may be significant, and further attention to measures that can reduce the likelihood of transmission is warranted.

We are indebted to the members of county health departments throughout Taiwan and the branches of the Taiwan Center for Disease Control for their assistance in interviewing persons, to the Taiwan Field Epidemiology Training Program trainees for assistance in obtaining flight manifests, and to the WHO Global Alert and Response in Geneva and their colleagues in the WHO regions.

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