

## REVIEW

# Respiratory infections during air travel

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### Abstract

An increasing number of individuals undertake air travel annually. Issues regarding cabin air quality and the potential risks of transmission of respiratory infections during flight have been investigated and debated previously, but, with the advent of severe acute respiratory syndrome and influenza outbreaks, these issues have recently taken on heightened importance. Anecdotally, many people complain of respiratory symptoms following air travel. However, studies of ventilation systems

and patient outcomes indicate the spread of pathogens during flight occurs rarely. In the present review, aspects of the aircraft cabin environment that affect the likelihood of transmission of respiratory pathogens on airplanes are outlined briefly and evidence for the occurrence of outbreaks of respiratory illness among airline passengers are reviewed. (Intern Med J 2005; 35: 50–55)

**Key words:** respiratory infections, travel, aircraft.

## INTRODUCTION

Approximately  $1.5 \times 10^9$  people undertake air travel annually. Up to half the travelling population experience a health problem related to overseas travel, and approximately 5% require medical attention.<sup>1</sup> A recent review of admissions to an Australian tertiary care hospital following travel showed respiratory tract infections to be the second commonest cause of illness after gastrointestinal infections and the second most common cause of fever behind malaria.<sup>2</sup>

Travel on commercial aircraft might be a high-risk environment for transmission of infectious diseases. Confined space, limited ventilation, prolonged exposure times and recirculating air, all common to air travel, are demonstrated risk factors for the transmission of upper respiratory tract infections in other settings and create the potential for the spread of respiratory pathogens during flight.<sup>3</sup> The debate regarding infectious disease transmission and air travel has centred on whether cabin ventilation systems, particularly those that involve the now-standard 50% recirculated air, contribute to the transmission of airborne diseases.

The two main transmission routes for respiratory infections are by droplet spread and by the airborne route. Droplet spread involves relatively large droplets containing organisms that settle out of the air quickly. It requires direct contact of droplets produced by

coughing, sneezing or talking onto the mucous membranes of recipients for transmission, necessitating contact at close range (usually within 1 m). The common cold is an example of an infection spread predominantly by this route. Airborne transmission involves dissemination of tiny suspensions of microbial particles (droplet nuclei) that can remain suspended in the air for prolonged periods. Droplet nuclei are usually 1–10 µm in size, can disperse widely and rapidly in closed environments with a recirculation ventilation system and can easily be drawn into the bronchioles of recipients' respiratory tracts. Transmission by this route can lead to infections in a large number of people. Tuberculosis (TB) and smallpox can spread in this way. Some infections, such as influenza and measles, can be spread by both routes, but are predominantly spread by the indirect airborne route. Severe acute respiratory syndrome (SARS) is predominantly spread by droplets, but airborne transmission and transmission by contact with contaminated fomites can also occur.<sup>4</sup>

Anecdotally, many people complain of respiratory symptoms following air travel that could be from acquisition of infection, but could alternatively be associated with other factors inherent in flight, such as lowered barometric pressure, hypoxia and low humidity.<sup>5,6</sup> Breathing low-humidity air for prolonged periods, for example, can result in dry mucous membranes of the nose and throat, which can lead to respiratory tract irritation.<sup>7</sup>

The recent advent of SARS brought the issue of potential transmission of infections on board aircraft back into the limelight. Thus, it is timely to review the potential role of air travel in the spread of respiratory infections. Aspects of the aircraft cabin environment that influence the potential transmission of respiratory pathogens on airplanes will be outlined here and then the

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## AIRCRAFT CABIN ENVIRONMENT

Most passenger-carrying aircraft have pressurized cabins that allow the cabin to be ventilated and maintained at a desired cabin air pressure, as well as enabling control of the temperature, relative humidity and air flow volume. Cabin air is derived largely from cabin pressurization systems, which generally result in a cabin altitude of 4000–8000 feet at an aircraft altitude of 30 000–40 000 feet. Air at this altitude contains very few microbiological agents. It enters the engine of the aircraft and is compressed to very high pressures (approximately 2750 kPa) and heated to very high temperatures (more than 800°C). Any residual microbiological agents in the ambient air will be destroyed at such high temperatures.

A proportion of this hot compressed air is used for cabin pressurization purposes. It is sent to the conditioning system and is passed through a series of heat exchangers and refrigeration systems. The air released is dry (relative humidity of approximately 5%), sterile and free of dust. It is also much cooler and at a lower pressure.

The conditioned air then enters a mixing manifold, where it is combined with an equal quantity of filtered recirculated air. The typical mix of conditioned air and recirculated air in a modern jet transport aircraft is 50:50. Older commercial aircraft were generally ventilated with 100% fresh air. However, the introduction of air recirculation systems arose from the requirement during the 1980s to reduce aircraft operating costs.

Use of a recirculation system means filtration of the air is required. The recirculation system draws air from the aircraft cabin by a series of fans, and this air is passed through high-efficiency particulate air (HEPA)-type filters. These filters are similar to those used in hospital operating theatres and sterile wards, and are several orders of magnitude more efficient at removing particulate material than filters used in buildings.

HEPA-type filters are rated using 0.3- $\mu\text{m}$  sized particles. Most bacteria have diameters of approximately 1  $\mu\text{m}$ , so will be removed. Viruses are usually 0.01–0.10  $\mu\text{m}$  in size, but generally form clumps or attach to larger dust particles so are also usually trapped in the filters.<sup>7</sup> Thus, the use of HEPA-type filters in aircraft cabin pressurization systems means that 99.9% of bacteria and viruses produced by aircraft passengers are removed from cabin air.<sup>8,9</sup>

Because both air from outside the aircraft and recirculated air are free of microbial agents, the cabin air is essentially sterile. It has a relative humidity of 10–20% and a temperature of 18–30°C. Relative humidity can influence microorganism numbers: a low relative humidity will generally be beneficial for viral growth, as relative humidity and survival are inversely related for viruses, but bacteria will not thrive in a low relative humidity environment.<sup>9</sup>

Air then enters the distribution pipework for delivery to the cabin. Cabin air is taken from below the floor of

the aircraft to the overhead cabin ventilation system, which runs the length of the cabin. The ventilation system is usually designed so that air entering the cabin at a given seat row is exhausted at the same seat row. This limits the amount of air flowing in the fore and aft directions (i.e. towards the front and back of the aircraft, respectively), which also helps minimize infection risk.

With modern cabin pressurization systems, the cabin air is completely exchanged at least 20 times per hour, compared with 12 air exchanges per hour in a typical office building and 5 exchanges per hour in most homes.<sup>10</sup> This high air exchange rate further reduces the likelihood of transmission of infections.

### Microbial air quality on aircraft

Flights can last 10 h or more, during which people sit in close proximity to each other. Even if the supplied cabin air is sterile, microbial contaminants can be introduced by passengers. It has been demonstrated that passengers' respiratory tract flora can be isolated from cabin surfaces and air, indicating a potential for transmission of diseases spread by respiratory droplets.<sup>11</sup> However, there is a common misconception among the travelling public that if one person on board an aircraft has an infection, then all other passengers are at risk. Because air flow is generally from top to bottom, with little if any front to back flow, and because respiratory pathogens are diluted by frequent air exchanges, passengers at most risk are those in close proximity to the infected passenger, with minimal risk for others. The relative infectiousness of the ill passenger will thus be an important factor in the risk of transmission.

Only one study has assessed the role of air recirculation as a predictor of postflight upper respiratory tract infections.<sup>3</sup> In this study, the rate of respiratory symptoms after air travel was assessed among passengers on airplanes that did and did not recirculate air. The study found the reported rates of a cold and/or runny nose were similar, suggesting that aircraft cabin air recirculation does not increase the risk for upper respiratory symptoms.<sup>3</sup>

A few studies have examined microbial contaminants in cabin air and have found no evidence for increased disease transmission on board commercial aircraft than if equivalent time had been spent on any other form of public transport or in other public places.<sup>12,13</sup> One study assessing the health risks of air pollutants, including bacteria and fungi, found that levels of organisms measured in the airline cabin were lower than that required to pose a risk of illness.<sup>14</sup> A recent study found bacterial and fungal counts in aircraft to be a log concentration below that found on city buses, in shopping malls and in the outside air.<sup>10</sup> Another study found only very low levels of viable organisms during regular checks of cultures from cabin air.<sup>8</sup> Thus, the risk of disease transmission as a result of microbial concentrations in cabin air is considered to be low. However, there are no requirements for airlines to monitor cabin air quality, and whether the few studies that have been performed can be generalized to the thousands of flights undertaken by world airlines every year is unknown.<sup>5</sup>

## OUTBREAKS OF RESPIRATORY ILLNESSES

Considering the large number of flights undertaken, the following reports of outbreaks of illness, which were compiled after an extensive review of published reports, highlight how relatively infrequently epidemics occur. Nevertheless, the actual rate of transmission of respiratory infections during air travel is very difficult to measure. Accurate epidemiological studies and public health surveys of disease transmission on aircraft are almost impossible to perform, as they involve collecting data from millions of passengers worldwide. As well as problems with the follow up of those potentially exposed, there are difficulties with the detection of infectious cases, proving the source of infection and generalizing results of one outbreak to other circumstances. The speed of air travel is such that infected passengers might arrive at their destination before the end of the incubation period and might therefore spread disease before symptoms develop. Even differentiating the risk associated with the cabin environment from contact in the terminal prior to boarding can be difficult. In addition, many infections are associated with a low attack rate and some have long incubation periods, thereby further reducing the reliability of study results.<sup>15</sup> Thus, it is not possible to calculate the exact incidence of passenger illness in-flight or postflight.

### Influenza

The survival and transmission of influenza virus in infectious droplets is facilitated by the low humidity of cabin air. Aircrew have been found to have a high rate of influenza-like illnesses; one study showed a 33% attack rate over a 7-month period in unvaccinated individuals.<sup>16</sup> In addition, outbreaks of influenza transmission during travel have been described.

A well-known example of the possible adverse health effects of air travel is a report documenting influenza transmission on board an aircraft.<sup>17</sup> In 1979, an Alaskan passenger jet suffered engine failure during take-off. The aborted departure resulted in a 3-h ground delay. All 54 passengers remained on board the aircraft during this delay, throughout which time the cabin ventilation system was turned off. The apparent index case developed symptoms while on board. Within 72 h, 72% of the passengers and 40% of the crew had contracted influenza. Largely as a result of this outbreak, it is now recommended that, in the case of ground delays of more than 30 min, adequate aircraft ventilation must be supplied.

An outbreak of an influenza-like illness in 60 military personnel has also been described.<sup>18</sup> The symptoms were those of a respiratory illness characterized by fever, cough, sore throat and myalgia, and influenza virus was recovered from some symptomatic patients. The majority of patients (68%) had recently completed a series of commercial aircraft flights, and the authors concluded that air travel played a role in the transmission of disease among the 60 infected persons.

A recent report described another possible influenza outbreak related to air travel.<sup>19</sup> A person with an influenza-like illness boarded a 75-seat passenger jet aircraft for a flight lasting just under 3.5 h. Over the next 3–4 days, 20 other passengers developed similar illnesses. Most of those affected were sitting close to him, the exceptions being someone who had walked up and down the aisles collecting money for a raffle, and the index case's supervisor who assessed him prior to boarding the flight. Air had been circulated and filtered on the aircraft in a routine manner. It was suspected that transmission occurred via droplets to those sitting near him, as he coughed and sneezed throughout the flight.

### Tuberculosis

TB transmission has been documented on commercial aircraft from both crew and passengers, and a high level of attention has been given to the potential spread of TB during air travel. However, documented cases of travel on aircraft by individuals with active TB have occurred infrequently. Transmission of TB has also been reported during train, bus and ship travel.<sup>20</sup>

Between 1993 and 1995, the Centers for Disease Control and Prevention (CDC; Atlanta, GA, USA) conducted six investigations into cases of active TB in a crewmember and five passengers in separate events.<sup>21</sup> These investigations focused on the potential exposure of more than 2600 passengers and crew on 191 flights involving nine different aircraft types.<sup>22</sup> Each of these investigations involved a highly infectious index case. Of the six investigations, only two produced evidence of possible TB transmission.<sup>23,24</sup>

One report involved the transmission of infectious multidrug-resistant TB from an infected passenger to six other passengers travelling on the same two commercial aircraft flights within the USA.<sup>23</sup> Several factors were identified as being contributory to transmission of disease. These were proximity of the subsequently infected passengers to the index case (mainly within two rows), the level of infectiveness of the index case and the relatively long duration of exposure. Neither the cabin air in general nor the cabin ventilation system in particular was considered to have contributed to transmission. This suggests that air travel itself does not carry a greater risk of transmission than activities in other confined spaces. None of the individuals thought to be infected during flight subsequently developed active TB.

The second report involved a retrospective cohort study after a crew member was found to be infected with TB.<sup>24</sup> Positive tuberculin skin test rates were found to be greater in crew members who flew with the infected individual during their highly infectious period, compared with crew members who were exposed during less infective periods (30.0 and 5.8%, respectively) and with unexposed crew (1.6%). The risk of infection also correlated to hours of exposure to the index case. The authors concluded that crew-to-crew transmission of TB had probably occurred. Transmission to passengers could not be excluded: 7% of frequent flyer passengers returned a positive tuberculin skin test and flew during the index case's highly infectious period.

Since these six CDC investigations, another two instances of possible TB transmission have been reported. Wang investigated the risk of TB transmission from a person with highly infectious pulmonary TB to fellow passengers and crew members on a 14-h commercial flight.<sup>25</sup> Nine contacts developed a tuberculin skin test conversion, three of whom reported no other risk factors for positive reactions. Although none of the three contacts had sat in the same section of the plane as the index patient, the authors concluded that the clustering of tuberculin skin test conversions among passengers demonstrated the possible risk of TB transmission during air travel. A second contact investigation of passengers who travelled on flights with an individual with pulmonary TB showed that five of 120 contacts (4%) had a tuberculin skin test conversion.<sup>26</sup> This indicated possible recent contact with TB, but only two of the five passengers had no other identified risk factors for infection.

Other aircraft-related contact investigations for TB have produced inconclusive findings. Moore *et al.* examined the likelihood of transmission from a highly infectious passenger with pulmonary and pharyngeal TB on two commercial aircraft flights, each approximately 1.25 h in duration.<sup>27</sup> All five passengers who subsequently tested positive for TB had identifiable risk factors and were seated throughout the aircraft (at least five rows away from the index case). The authors acknowledged that TB transmission could not be excluded but felt that the likelihood was low. In a second investigation of crew and passengers who had travelled with a person with highly infectious TB on two long flights, four people had a skin test conversion, but again all had at least one other risk factor for a positive result, thus casting doubt that TB transmission during the flights had occurred.<sup>28</sup>

Several other investigations have found no evidence of TB transmission to passengers or crew members after passengers with active disease travelled on flights ranging in duration from 30 min to 9 h.<sup>21,29,30</sup> Interpretation of these investigations is limited, however, because of low response rates and because screening of passengers from countries with a high prevalence of TB and/or where Bacillus Calmette-Guerin vaccination is common makes interpretation of skin testing and the significance of in-flight contact very difficult.

Thus, the overall risk of TB transmission during flight is low, but it increases with proximity and duration of exposure to the source patient. No definitive statistics linking active TB to airline travel exist, but the overall public health importance is minor. The World Health Organization (WHO) has recently published guidelines for the prevention and control of TB during air travel.<sup>22</sup> These guidelines recommend tracing and informing passengers and crew members if they have been on a flight lasting more than 8 h with a highly infectious person, if they have been sitting close to the infected individual and if less than 3 months has elapsed between the flight and case notification to health authorities. They also recommend maximum efficiency air filters, keeping ground delays to a minimum and denying boarding to individuals with active TB.

## Severe acute respiratory syndrome

SARS and travel are intricately linked, as it was an American businessman travelling from China via Hong Kong who exported the disease to Vietnam.<sup>31</sup> The SARS virus is spread predominantly by contact with respiratory droplets from an index case or by direct contact with contaminated hands or objects, although airborne transmission also occurs. The speed with which SARS spread around the world was no doubt facilitated by air travel, but this does not imply that transmission occurred on board aircraft. However, presumed in-flight transmission of SARS has been reported.<sup>4,32,33</sup>

A doctor who had had contact with a SARS patient in Singapore flew from New York to Germany while feeling unwell. His wife and mother-in-law, who were incubating SARS, were also on the flight. The airline was alerted to the possibility of SARS and the doctor and his family were isolated at the back of the plane. A previously well flight attendant had brief contact with them while serving and picking up their food trays. Four days later, the flight attendant developed a fever and was subsequently diagnosed with probable SARS. No other crew members or unrelated passengers contracted SARS.

Passenger-to-passenger transmission of SARS has also been indicated. In a recent study, passengers and crew members were interviewed at least 10 days after travel if they had been on one of three flights lasting 1.5–3.0 h that had transported a patient or patients with SARS.<sup>4</sup> One of the flights carrying one symptomatic patient with SARS and 119 others was associated with potential transmission of SARS to 22 people. Illness was related to the physical proximity to the index case, with eight of 23 people seated in the three rows in front of the index patient developing illness compared with 10 of 88 people seated elsewhere (relative risk: 3.1). In contrast, another flight carrying four symptomatic patients with SARS and 242 others resulted in transmission to at most one other person, and a third flight carrying a person with presymptomatic SARS resulted in no documented spread of infection to the 314 others on the flight. This suggests that the stage of the illness and size of aircraft might influence transmission. In addition, poorly characterized host factors might predispose certain patients to transmitting the virus to large numbers of people, making them so-called 'super-spreaders' of infection.

Another recent review examined data from flights to Singapore with patients with SARS on board in order to assess the risk of in-flight transmission. Transmission occurred in only one of the three flights with symptomatic patients with SARS on board, and the incidence was estimated to be one in 156 passengers. Thus, the authors concluded that the risk of transmission of SARS appears to be very low, although they also noted that it might be increased with super-spreaders on board.<sup>34</sup>

Subsequent analysis of approximately 35 flights in which a symptomatic probable SARS case was among the passengers or crew found that cases on four of these flights were associated with possible transmission on board. WHO acknowledged that air travellers 'within two rows of an infected person could be in danger',

although the above study<sup>4</sup> suggests the risk extends to (at least) three rows in front of the index case. The greater concentration of illness in people sitting in front of the index case than behind suggests a role of coughing in transmission, possibly with a combination of airborne and droplet spread.

The initiation of screening procedures to detect people with fever prior to boarding during the SARS outbreak was appropriate and presumably further reduced the risk of in-flight transmission.<sup>35</sup> Additional precautions recommended by WHO for patients who became febrile during flight included isolation of the case (as best as possible) from other passengers, initiation of protective masks to be worn by crew and strict adherence to personal hygiene and infection control measures for those caring for the case.

Systematic studies to determine the exact risk of in-flight transmission are almost impossible to perform. Although the media dramatized cases of SARS transmission on airplanes, the fact that SARS is associated predominantly with droplet spread makes the risk of mass infection on aircraft unlikely.<sup>32</sup> Nevertheless, the potential for airborne transmission and super-spreaders means the risk cannot be altogether discounted.

### Other respiratory pathogens

Other pathogens with the potential for respiratory transmission during air travel are the common cold, measles, smallpox and meningococcal infection.

Two published reports have suggested that measles has been transmitted on board international and domestic flights.<sup>36,37</sup> Only passengers seated within a few rows from the ill individuals were infected. Smallpox has now been eradicated, but transmission of smallpox on aircraft has been described.<sup>38</sup> Transmission of meningococcal infection (spread by direct contact with respiratory secretions) has been studied during air travel, but no cases of secondary disease among contacts have been reported.<sup>39</sup> Nevertheless, because of the perceived potential risk, passengers seated next to a patient with meningococcal infection for flights lasting 8 h or more are considered to be at high risk and antimicrobial prophylaxis is recommended.

### CONCLUSIONS

Although concern has been raised about air quality and spread of respiratory pathogens on aircraft, studies of ventilation systems and patient outcomes have suggested the dissemination of pathogens occurs rarely. This is because outside air entering the cabin at altitude is essentially sterile, heating/cooling further reduces microbial risks, HEPA filters remove microorganisms from recirculated air and the low humidity, high airflow rates, laminar airflow pattern and frequent air exchanges incorporated into the cabin ventilation and pressurization systems further minimize microbial contamination on board aircraft. When transmission does occur, it is more likely with pathogens spread predominantly by the airborne route, but it requires close exposure to an infected individual, in which case transmission would be

likely to occur regardless of the mode of transportation. Individuals with significant communicable illness, particularly respiratory infections, should postpone commercial air travel to prevent transmission to others, although the overall risk is very low. Screening procedures to detect febrile persons boarding flights during known outbreaks further reduce risks.

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