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Airplanes and Infectious Disease

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Abstract Air travel is associated with crowded conditions that can facilitate the transmission of airborne infectious diseases. The risk of contracting such diseases depends on the presence of an infected person who is shedding infectious particles and sufficient exposure of a sensitive person to achieve an adequate dose to cause disease. Proximity to the infectious person and the length of time spent near the person are the most important risks for contracting a disease. Ventilation patterns play a lesser role in disease transmission. Well-documented outbreaks of influenza, severe acute respiratory syndrome (SARS), and tuberculosis have occurred. Other common respiratory illnesses have probably also

been spread via aircraft, but outbreaks remain unrecognized. Research on the spread of infectious disease in aircraft has focused on sampling for microorganisms in air (which has little relevance), and on the development of models to predict the risks for specific diseases.

Keywords Aircraft · Infection · Contagious disease · Airborne · Tuberculosis · Influenza · SARS

Abbreviations
TB Tuberculosis
SARS Severe acute respiratory syndrome

1 Introduction

Commercial air transport has provided access to the world for those able to undertake such travel. In fact, 1.7 million passengers travel each year, representing 600 passenger miles of travel [1]. There are risks associated with all forms of travel and many of them are similar across transport types [2]. Thus, stress, accidents, and exposure to disease agents are associated with all forms of transportation. However, because of the distances that can be traversed in a relatively short time, the crowded conditions on most commercial aircraft, and the inability to "escape", concern regarding the risk of contracting infectious disease during air travel has become significant [3, 4].

It is important to remember that there are other infection-associated concerns associated with air travel. Historically, transport of disease vectors has been of particular concern. Many studies could be cited regarding transport of mosquitoes that subsequently led to outbreaks of malaria [5]. Control of these problems has focused on disinsection of aircraft during flight [6].

Food-borne outbreaks of disease have also occurred on aircraft [7–9]. These are uncommon, and control depends on appropriate food handling rather than any change in the aircraft environment. Aircraft sewage also contains human pathogens that could be transported over long distances, but the risk of transmission from this source is probably low [10].

The movement of infectious agents from one part of the world to another via aircraft is another important concern [11]. People traveling in an infectious state may contribute to the spread of epidemics. This phenomenon is of concern for the spread of weaponized organisms that cause contagious disease. On the other hand, modeling studies have indicated that halting air travel in order to interrupt the transmission pathway even for very serious diseases such as smallpox is likely to cause greater disruption than the disease itself [12]. The possibility that long-distance flights

could temporarily damage the immune system has also been raised [13]. Such damage could lead to recurrent infections acquired on the ground after a flight. Further research will be needed to document the validity of these concerns.

The primary concern today appears to be person-to-person spread of contagious disease in the aircraft cabin, and that will be the focus of this chapter.

2 Contagious Disease

Contagious diseases are infections that are spread from an infected person to an uninfected sensitive person. Contagious diseases can be spread by aerosols, by large droplets, by direct contact with materials or surfaces that have been contaminated by an infectious person (fomites) or by direct person-to-person contact [14]. All of these modes of transmission could occur in a crowded aircraft cabin.

Table 1 Examples of common contagious diseases and their modes of transmission

Disease	Agent	Transmission	References
Influenza	Virus	Aerosols	[15, 16]
Tuberculosis	Bacterium	Aerosols	[17]
Chicken pox	Virus	Aerosols	[18]
Measles	Virus	Aerosols	[19, 20]
SARS	Virus	Droplets, aerosols	[21, 22]
Common colds	Viruses	Droplets, aerosols, fomites	[23, 24]

Aerosol-transmitted diseases are generally caused by agents that are resistant to environmental stresses, and diseases that lead to environmental release of agent-containing secretions. Thus, respiratory illnesses are most commonly airborne, although many other diseases could be spread artificially or accidentally via the airborne route. Examples in this latter category include hepatitis, some gastrointestinal viruses and smallpox.

For a contagious disease to be transmitted from one person to another there must be an infectious person in the environment (i.e., a source for the agent). There must be an exposure pathway so that the agent can travel from the infectious person to another person, and there must be a person who is sensitive (i.e., not resistant) to the agent. Thus, the risk of infectious disease transmission is related to the probability that:

1. There is a person infected with the agent in the environment
2. The infected person is actively shedding the disease agent

3. There is an uninterrupted pathway from the infected person to other people
4. There are one or more sensitive persons in the environment
5. These sensitive people are in the aerosol long enough for sufficient exposure to occur.

2.1 Presence of Infected Individuals

In order for contagious disease transmission to occur, one or more infected individuals must be present, or have been present recently in the case of fomite transmission (fomites are inanimate objects that act as reservoirs for disease agents). The risk of disease transmission is related to the probability that one or more individuals infected with the agent will be present in the environment. The exception to this is, of course, bioterrorism, for which an inanimate reservoir may have been prepared.

The probability that an infected person will be in the environment is related to the incidence of the disease in the population likely to be in the environment. Thus, agents of the common cold are probably in most aircraft. During the influenza season, there is a reasonably high probability that one or more persons harboring the influenza virus will be on board. On the other hand, there is only a small probability that a person with tuberculosis will be on board any individual aircraft. In the USA, tuberculosis is not uncommon, but is present primarily in populations that do not routinely fly (e.g., prison and homeless populations) [25, 26]. In other parts of the world, TB is very common, but, again, most of those with the disease do not fly. For diseases that are rare in the general population (e.g., SARS, hemorrhagic fevers, plague), it is extremely unlikely that an infectious individual will be aboard any individual aircraft.

2.2 Stage of the Disease

Not only must the infected individual be present, but the disease must be in a stage where agents are being shed into the environment in sufficient quantity that transmission could occur. For some diseases, this stage occurs before symptoms appear. For most, however, active disease must be present resulting in symptoms that lead to agent release. In the case of TB, for example, the majority of people with the disease do not shed large quantities of organisms, further reducing the probability of disease transmission.

2.3 Pathways for Agent Transfer

2.3.1 Aerosols

Bacterial and viral aerosol particles are essentially droplet nuclei. The organisms are shed from the infected host in wet droplets containing one or more agents embedded in wet mucous secretions. Once in the air, the droplets dry rapidly, shrinking to the size of the contained agents surrounded by dried secretions. These dried secretions tend to protect the organisms from environmental damage.

Bacteria and viruses in aerosols act as small particles, settling and/or traveling on air currents and in response to electrical charges in the same way as other small particles [27]. True aerosol-transmitted disease agents can remain airborne, travel relatively long distances and remain infective [28, 29].

Distribution of the aerosols depends on air movement patterns within the space. Although theoretically air movement in aircraft is in a circular motion within rows, actually there is some general transfer of air backward within the aircraft (see Sect. 2.1). Aerosols generally decay (become less concentrated) logarithmically with distance both physically and biologically. Needless to say, the closer one is to the source, the greater the risk of sufficient exposure to cause illness. For diseases such as measles, where inhalation and deposition of very few virions can cause illness, the risk of contracting the disease decreases less with distance than, for example, for anthrax, where a significant number of organisms must reach an appropriate site before illness is likely.

2.3.2 Droplets and Fomites

Droplet-borne diseases are thought to spread up to one meter from the source patient, and hospital infection control practices reflect this belief. The droplets may impact directly in the respiratory tract, or on the hands or other skin surfaces, or even on nearby inanimate surfaces. Touching contaminated surfaces could transfer organisms to the host's hands, and infection could occur with hand transfer to the respiratory tract. A study of rhinovirus colds transfer by this method, however, indicated that secretions would have to be transferred while still damp, which in the aircraft environment would be a very short time [30].

2.3.3 Direct Contact

Direct contact means just what it says: touching an infected person in some way. Some diseases can be transmitted with minimal contact (many common colds). Others require intimate contact of a sort unlikely to occur accidentally.

2.3.4 Role of Ventilation

Ventilation can only interrupt airborne infectious diseases, and then only for individuals relatively distant from the source. Increasing clean air ventilation rates has been shown to reduce the incidence of upper respiratory infections in large office buildings [31, 32]. High ventilation rates combined with good filtration will reduce exposure over time. In aircraft where recirculation is used, the filtration systems are probably adequate to remove the vast majority of droplet nuclei. Even with good filtration and very high air exchange rates, however, ventilation cannot significantly reduce the risk of exposure for those very close to the source (e.g., sitting in the same row in an aircraft).

2.4 Role of Host Sensitivity

In order to develop an infectious disease, the host must be sensitive [33]. Infections can only occur in people who do not have either natural or specific acquired immunity to the agent. There is a range of natural immunity in the population, with some people being highly resistant while others are highly sensitive, and it is not a given that any individual without specific immunity to a disease agent will become infected. The risk of illness following exposure along this immunity distribution ranges from near zero for the most resistant to very high for the most sensitive. In addition to this natural sensitivity range, acquired immunodeficiency is becoming more and more common in the population, and some of these individuals are exquisitely sensitive even to agents of relatively low virulence.

For many of the common contagious childhood diseases, a large majority of the US population has naturally or artificially acquired immunity. For tuberculosis, many countries other than the US immunize for this very common disease. TB is sufficiently uncommon in the US that immunization is relatively rare.

2.5
Time Spent in the Environment

The time spent in an aerosol is another critical factor in calculating risk of a disease-causing exposure. The longer one is in the presence of an infectious aerosol, the higher the risk that a potentially infectious dose will be inhaled. The lower the aerosol concentration (or the number of agents on a surface or in each respiratory droplet) the longer one must remain in contact with the aerosol. Clearly, time spent in contact with TB patients is critical in determining the risk of contracting the disease [34]. Although less well studied for other diseases, this is probably a universal phenomenon.

3
Reports of Outbreaks

Theoretically, any contagious disease that is airborne could cause an outbreak on an aircraft, and those that are droplet borne could spread to those in adjacent seats. Obviously, diseases that fit these categories and are common world wide are the most likely candidates for such spread. Thus, common colds, influenza, tuberculosis, and measles have been spread on aircraft, and many cases have probably occurred that have gone unreported because of follow up failures. The rare or newly emergent diseases are much less likely to be present on aircraft. On the other hand, follow up is likely to be intensive, so that these are over-reported in relation to the more common illnesses. In addition, there is the problem of separating infections acquired in flight from those acquired at other points in travel [3]. Thus it is impossible to say whether or not a specific case of the common cold was contracted while staying away from home, on the airplane going to or from home, or, in fact, at home before travel began. Given these cautions, the following is a brief discussion of some of the outbreaks that have been documented on commercial aircraft.

3.1
Upper Respiratory Infections

Zitter et al. evaluated the development of upper respiratory symptoms in passengers on jets with 50% recirculation versus 100% fresh air. There was no difference between the two populations. It should be noted, however, that the trips were relatively short (San Francisco to Denver) [35]. Given that some very common upper respiratory infections are airborne, and others produce copious droplets that could easily infect adjacent passengers, it is likely that such disease transmission does occur routinely on aircraft as it does in any other crowded environment. Given the frequency of these dis-

eases, it would be nearly impossible to trace an outbreak to the aircraft environment.

3.2 Influenza

Moser et al. reported an outbreak of influenza on board a commercial aircraft grounded for three hours with no ventilation. The index case remained aboard, and the other passengers who remained on board were the most likely to develop the illness [36]. This is a rare case where the passengers all disembarked in a relatively small city and many were seen by the same physician. If the plane had landed in New York or Washington (for example) the passengers would have dispersed, and the outbreak would have gone unrecognized. Given the infectiousness of the influenza virus and its airborne transmission ability, the incidence of outbreaks of this disease linked to commercial airliners has probably been underestimated.

3.3 Tuberculosis

Outbreaks of tuberculosis (TB) have occurred following transport of the organisms through ventilation systems in settings other than aircraft [37]. One of the best documented cases of TB transmission aboard a commercial airliner involved a crew member with active TB. Time spent with this crew member was the principal risk factor, and at least two other crew members acquired positive skin tests. Frequent flying passengers may also have been affected [38].

Another well-documented case involved a multiply drug-resistant strain of *Mycobacterium tuberculosis*, and indicated that the presence of a highly infectious person, a long flight, and close proximity to the infectious person are the primary risk factors for transmission [39]. A study using retrospective TB testing following transport of an infected patient indicated (but did not prove) transmission to several other passengers [40]. On the other hand, a pilot with active TB failed to infect any other of the pilots with whom he flew [41]. Although this may confirm the low risk for transmission, it may also represent a case with little shedding of infectious bacteria, or the very high ventilation rate in the cockpit compared to the passenger cabin.

3.4 SARS

Although generally considered droplet-borne, airborne precautions are also recommended in the clinical setting, and one building-related outbreak was determined to be airborne [21, 22]. In fact, it seems clear that airborne trans-

mission can occur. The first 10 patients in the Taiwan SARS epidemic were closely associated with an infected person on an airplane [42]. Likewise, SARS may have been introduced to France by a patient who contracted the disease in Hanoi and infected others on the Hanoi–Paris flight [43]. In an interview survey, Olsen et al. [44]. documented transmission of SARS to airline passengers seated within the three rows in front of the index case. Other studies have estimated a low risk of SARS transmission on aircraft, possibly related to the stage of the illness in the SARS patient, or the number of agent units being released [45].

3.5
Measles, Chicken Pox

Measles is another disease for which transmission through a ventilation system has been documented [46]. On the other hand, one study revealed no new measles cases following a seven-hour flight with an index patient [47]. Although measles is a common disease, most people have some level of immunity, and children traveling with active infectious measles are probably rare. Chicken pox transmission has not been reported related to airliner cabins, probably for the same reason that measles outbreaks are rare in this environment. For shingles, also caused by the chicken pox virus, the long delay between infection and symptoms makes tracing exposure sources nearly impossible.

3.6
Bacterial Meningitis

The Centers for Disease Control have reported one case of bacterial meningitis acquired during travel on a commercial airliner [48]. While this disease agent, *Neisseria meningitidis*, is the most common cause of bacterial meningitis in the USA, it, nevertheless is a relatively rare disease, and is likely to present only a small risk for air travelers.

3.7
Hemorrhagic Fevers

The filoviruses Ebola and Marburg are able to transmit disease via the airborne route in the laboratory, but to date have not been documented to do so in the natural environment. Thus, the risks are probably low for the aircraft environment. However, the possibility of their use as biological weapons remains of potential concern.

4
Research Designed to Address Concerns

4.1
Microbial Investigations

Several studies have evaluated bacterial levels in commercial airliners during flight. Bacterial levels have either been lower than ground-based interiors or higher [49, 50]. It is important to remember, however, that the organisms found in airliner cabin air are rarely (if ever) those likely to cause disease. The chance of actually collecting a disease agent on any individual flight is the product of the probabilities of an infectious person being on board, this person releasing infectious organisms, the samples being collected in close proximity to this person, and the organisms being identifiable using the sampling and analytical method chosen. These factors apply to other environments as well, making air sampling not the most logical approach for documenting (or monitoring) airborne infectious disease.

4.2
Models and Risks

4.2.1
General Infectious Disease Models

Rudnick et al. [51] developed equations that could be used to model infection risk on aircraft. Their models depend on knowing the air supply rate and having it more or less constant, both of which are achievable in aircraft. They use carbon dioxide measurements, assuming that the CO_2 is exhaled from the occupants. Beggs et al. [52] evaluated several different models and determined that Gammiatoni and Nucci's [53] generalized formulation is most appropriate for ventilated spaces.

4.2.2
Models Applied to Aircraft

Ko et al. used single and sequential box models to estimate the risk of TB transmission. These authors concluded that the risk is small except for those in close contact with the infective patient [34]. Rydock et al. used tracer gas measurements and came to the same conclusion. This study also documented the minimal effect of ventilation rate on the potential for disease transmission [54].

5 Conclusions

While contagious disease could be acquired during travel on commercial airliners, the risk of contracting anything more serious than the common cold is low. Excluding persons from aircraft who are obviously suffering upper and lower respiratory symptoms (sneezing, coughing continuously) would help to prevent transmission of some diseases. However, the risks of this approach would have to be balanced with the actual risks of transmission and of the diseases' outcomes. Increasing quality of filtration and/or ventilation rates is unlikely to significantly lower the risk of disease transmission in the aircraft environment where each passenger spends such a relatively short time. The risk for crew members would have to be calculated, but probably remains quite low.

Further research that applies some of the good infectious disease transmission models to the aircraft environment would elucidate actual risks for specific diseases [34]. The use of molecular epidemiological techniques in tracking outbreaks would also contribute [55]. Until further studies can document a significant risk for infectious disease transmission in the aircraft environment, cost-increasing measures to reduce already minimal risks seem unwarranted.

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