Update on Transmission of Infectious Diseases and Air Travel

Mark A Gendreau[1] and Anthony D B Evans[2]

The spread of infectious diseases is a significant worldwide health problem. Over the past three decades more than thirty new infectious diseases have emerged or resurged.[1] In all, human kind is subjected to over 1,400 infectious disease threats, and death from an infectious illness remains a common cause of mortality worldwide.[1, 2] As the current novel Influenza A (H1N1) pandemic demonstrates, modern era pandemics and large-scale infectious outbreaks emerge and spread quickly. Air transportation is a major vehicle for the rapid spread and dissemination of infectious diseases. With over 1.4 million persons crossing international borders on air carriers every day, the risk of disease transmission associated with commercial aircraft has increased.[3] Here we discuss the recent key issues.

The Aircraft Cabin Environment and Infectious Disease Risk

The air provided to passengers and crew on commercial jet aircraft is typically a combination of conditioned external (ambient) air that has been diverted to the cabin from the engine compressor stages, and air that is taken from the cabin, filtered and recirculated. The environmental control system is designed to minimize the introduction of harmful contaminants into the cabin and to control cabin pressure, ventilation and temperature. Compared with most terrestrial environments, humidity is low since ambient air at cruising altitude (above 30,000 feet) is very dry.[4] Most commercial aircraft will provide 10–15 air changes per hour of the passenger cabin depending upon the aircraft type, as the original cabin air is progressively diluted with incoming ambient air.[4] Cabin airflow is principally side–to–side and compartmentalized into 4–7 seat rows within the passenger cabin, thereby limiting longitudinal (front–to–back and vice versa) cabin contamination.[4, 5] However, recent evidence employing computational fluid dynamic modeling in a mockup full sized aircraft cabin section suggests airflow patterns are more complex than previously thought and are influenced by many factors including seat and cabin geometry, occupancy density and thermal loads of passengers and equipment.[6, 7] Background microbial contamination of cabin air aboard commercial aircraft has recently gained attention with the development of molecular based detection assays and an increasing interest in the role fomites play in the transmission of infectious diseases in public areas and in the transport sector. Aerobiologic compositions within the aircraft cabin are typically broader in nature than previously appreciated.[8-10] For example, the total microbial burden of the cabin air in 125 samples collected from business-class sections of 16 commercial flights found that bacterial diversity (identified by cultivation) within the cabin air of sampled flights constituted only 1–10% of the total microbial population ultimately detected using more sensitive detection methods, with gram-positive bacteria such as *Staphylococcus* and *Bacillus* being the predominant species. Cloning and sequencing the 16S rRNA gene (gold standard in bacterial identification and classification) directly from the samples without cultivation revealed a broader microbial diversity encompassing over 100 bacterial species. Some evidence suggests potentially harmful microbial contamination of coliform and methicillin– resistant staphylococcus aureus (MRSA) within passenger cabins of commercial aircraft and one unpublished study found sink handles and soap dispensers within aircraft restrooms to be sources of coliform contamination. MRSA was cultured from 60% of seat back trays on three randomly selected commercial flights.[11] However, the clinical significance of this broad microbial contamination within aircraft and its impact on passenger health remains to be

established, the biological diversity is broad in nature, most of the species rarely cause significant health problems to the majority of travellers. Although cabin crew have been recorded as having higher rates of upper respiratory infection (URI) symptoms when compared to the general public[12], one prospective questionnaire study of air travellers and URI symptom rate during the winter months reported a wide variation of reported URI frequency, ranging from 3–20%, depending upon the reporting method.[13] Air travellers are likely to be more aware of any upper respiratory infection they may be suffering, since cabin pressure changes during flight can cause sinus and middle ear symptoms that may not be experienced were the individual to remain on the ground, making comparison between air travelers and ground based control groups difficult. Polymerase Chain Reaction assays to study atypical bacteria and respiratory viruses in 155 air travelers showed that not many travellers had the same viral profile and no association existed between any pathogen and a particular airport, suggesting that travellers acquired their viruses before rather than during the flight.[14] Thus it appears other factors are contributory to reported URI symptoms in air travelers, such as travel-related stress on the immune system, or transient responses to environmental conditions within the cabin such as low humidity.[15, 16] Transmission of infection between individuals within a confined space such as an aircraft passenger cabin also appears to be dependent upon complex interplay between the infectiousness of the contagious person spreading the illness, the rate which the infectious agent is introduced into the environment; the health and susceptibility of the potential hosts; the degree of exposure (seating proximity and duration of exposure); ventilation of the space, and chance. Other factors unique to air travel including the mild hypobaric hypoxia, low humidity, cosmic radiation and ozone exposures also may have an influence, but these exposures have not been rigorously studied in the context of infectious disease spread.[3, 17-19]

Commercial aircraft serving as vehicles of world–wide infection spread

A growing body of evidence from modeling studies suggests that discontinuing or restricting commercial flights would have little effect on the spread of novel infectious agent epidemics or pandemics.[20-22] Limiting or cancelling nonessential internal travel, including the limitation or closing of mass transit systems and motorways remains impractical, impossible, and understudied. Modeling suggests that limiting internal travel would have little benefit in limiting the spread of infection.[23] The United Kingdom (U.K.) Pandemic Plan points out that even a 60% reduction in all travel, including commuting to work, would only result in small reductions in the order of 5–10% in the national peak incidence within the U.K. One study shows that imposing a 90% restriction on all air travel would delay the peak of a pandemic wave by no more than 1 to 2 weeks, whereas rapidly halting almost all air travel (99.9%) out of an affected area would delay the pandemic wave up to 2 months.[20] Many national pandemic preparedness plans do not address the issue of commercial air travel. 24 Passenger screening in airports during the 2002–2003 SARS epidemic, such as questionnaires, visual inspection and thermal scanning were relatively ineffective in identifying infectious individuals. [22, 25, 26] Recently, several countries have expanded their quarantine station programs and the U.S. Centers for Disease Control and Prevention has established a centralized electronic passenger database capability (e-manifest) to be used during infectious outbreaks for prompt passenger notification, but contact tracing remains resource intense and challenging.[27] The International Civil Aviation Organization in partnership with the WHO, International Air Transport Association and Airports Council International, as well as other stakeholders, recently established guidelines for the aviation industry for operations during outbreaks of communicable disease, such as pandemic influenza, in order to minimize spread by commercial air travel. These include risk communication to the travelling public, command and control systems, consideration of airport screening and increasing airport and airline preparedness e.g. regarding in–flight illness, aircraft cleaning and disinfection. Close collaboration between many different stakeholders is clearly necessary for effective preparedness planning in the aviation sector.[24, 28-31]

Emerging Vector–borne diseases and Air Travel

The risk of the introduction of emerging and reemerging vector-borne infections into the northern hemisphere continues to grow, as evidenced by a narrowly avoided epidemic of chikungunya fever, an arboviral infection, in Europe in 2007.[32] Cases of imported malaria and other arboviral infections continue to pose a problem to western countries. Factors responsible for this emerging threat include the rapid growth in global trade and air travel, climate change, and the growing introduction of the Asian tiger mosquito *Aedes albopictus* into the northern hemisphere. This mosquito species continues to establish itself in temperate climates throughout the world including the Caribbean, Europe and North and South America. [33, 38] Studies demonstrate that it is a competent vector for 22 infectious diseases including west nile virus (WNV) fever, dengue, and chikungunya fever.[38, 40] Although no UK-acquired case of WNV has been identified since the start of surveillance in 2002, five imported cases have been confirmed in individuals who had traveled to Portugal, Canada and the U.S.[41] While malaria is no longer endemic in western countries, imported cases of malaria continue to pose a problem. A total of 1,370 cases of imported malaria were reported in the UK in 2008 with the majority due to travellers returning from visiting friends and relatives in their country of origin.[42] These travelers frequently have the perception that they are not at risk of malaria, since the destination abroad is familiar to them – and as a consequence they may not seek medical advice on malaria (or other infectious disease) prevention prior to their travels.[43] Better understanding of the behaviours of this traveling population, improved entomologic surveillance and mosquito control, in addition to early recognition of local transmission, [44] remain areas of high priority in the control of vector–borne diseases.

Whilst infectious diseases have affected human kind for thousands of years, the advent of air travel that has changed the implications of such diseases for the global community. Billions of air travellers each year cover longer distances, more rapidly, than ever before. This remarkable increase over recent decades seems set to continue. The role of aviation in disseminating infectious disease is being increasingly recognized and studied, yet at present, the options to minimize such spread appear limited. What seems clear is that, the science on which to base decisions concerning interventions such as airport screening and reduction of risk of transmission of disease at airports and on aircraft, needs to be further developed – and improved – before action can be taken by the global community to reliably reduce such risk. The U.S. Transportation Research Board of the National Academies of Science recently held a two day symposium in Washington D.C. on the transmission of disease in airports and on aircraft, to explore current research concerning the spread of infectious diseases by aircraft, as well as to identify gaps in knowledge and to inform future research projects.[45] A formal publication summarizing the conclusions of the symposium are anticipated to be published in 2010.

1 Lahey Clinic, Burlington, MA USA and 2 International Civil Aviation Organization, Montreal, Canada
Correspondence: Mark Gendreau, MD Department of Emergency Medicine, Lahey Clinic, 41 Mall Rd. Burlington, MA 01805, USA email: mark.a.gendreau@lahey.org

References

1 Morens DM, Folkers GK, Fauci AS. The challenge of emerging and re-emerging infectious diseases. *Nature* 2004;430(6996):242-9.
2 Armstrong GL, Conn LA, Pinner RW. Trends in infectious disease mortality in the United States during the 20th century. *JAMA* 1999;281(1):61-6.
3 Mangili A, Gendreau MA. Transmission of infectious diseases during commercial air travel. *Lancet* 2005;365(9463):989-96.
4 National Research Council. The airline cabin environment and the health of passengers (2002). Washington, DC: *National Academic Press*, 2002.
5 Rydock JP. Tracer study of proximity and recirculation effects on exposure risk in an airliner cabin. Aviation, space, and environmental medicine 2004;75(2):168-71.
6 Zhang Z, Chen X, Mazumdar S, Zhang T, Chen Q. Experimental and numerical investigation of airflow and contaminant transport in an airline cabin mock up. Building and Environment 2009;44(1):85-94.

7 Schnorpfeil P, Noll A, Schulze R, Ehlert U, Frey K, Fischer JE. Allostatic load and work conditions. Soc Sci Med 2003;57(4):647-56.
8 Osman S, La Duc MT, Dekas A, Newcombe D, Venkateswaran K. Microbial burden and diversity of commercial airline cabin air during short and long durations of travel. *Isme J* 2008;2(5):482-97.
9 McKernan LT, Wallingford KM, Hein MJ, Burge H, Rogers CA, Herrick R. Monitoring microbial populations on wide-body commercial passenger aircraft. *Ann Occup Hyg* 2008;52(2):139- 49.
10 La Duc MT, Stuecker T, Venkateswaran K. Molecular bacterial diversity and bioburden of commercial airliner cabin air. *Can J Microbiol* 2007;53(11):1259-71.
11 Sexton J, Maxwell SL, Gerba CP. Occurrence of MRSA on fomites in public facilities. #Q-402. Presented at: The 107th General Meeting of the American Society for Microbiology;
May 21-25, 2007; Toronto.
12 Whelan EA, Lawson CC, Grajewski B, et al. Prevalence of respiratory symptoms among female flight attendants and teachers. Occup Environ Med 2003;60(12):929-34.
13 Zitter JN, Mazonson PD, Miller DP, Hulley SB, Balmes JR. Aircraft cabin air recirculation and symptoms of the common cold. *JAMA* 2002;288(4):483-6.
14 Luna LK, Panning M, Grywna K, Pfefferle S, Drosten C. Spectrum of viruses and atypical bacteria in intercontinental air travellers with symptoms of acute respiratory infection. *J Infect Dis* 2007;195(5):675-9.
15 Silverman D, Gendreau M. Medical issues associated with commercial flights. *Lancet* 2009;373(9680):2067-77.
16 Nagda NL, Hodgson M. Low relative humidity and aircraft cabin air quality. Indoor air 2001;11(3):200-14.
17 Ko G, Thompson KM, Nardell EA. Estimation of tuberculosis risk on a commercial airliner. Risk Anal 2004;24(2):379-88. 18 Liao CM, Chang CF, Liang HM. A probabilistic transmission dynamic model to assess indoor airborne infection risks. Risk Anal 2005;25(5):1097-107.
19 Wells W. On airborne infection study II: droplet nuclei. *Am J Hygiene* 1934;20:611-8.
20 Ferguson NM, Cummings DA, Fraser C, Cajka JC, Cooley PC, Burke DS. Strategies for mitigating an influenza pandemic. Nature 2006;442(7101):448-52.
21 Germann TC, Kadau K, Longini IM, Jr., Macken CA. Mitigation strategies for pandemic influenza in the United States. Proceedings of the National Academy of Sciences of the United States of America 2006;103(15):5935-40.
22 Cooper BS, Pitman RJ, Edmunds WJ, Gay NJ. Delaying the international spread of pandemic influenza. PLoS Med 2006;3(6):e212.
23 Wood JG, Zamani N, MacIntyre CR, Beckert NG. Effects of internal border control on spread of pandemic influenza. Emerging infectious diseases 2007;13(7):1038-45.
24 Evans A, Finkelstein S, Singh J, Thibeault C. Pandemic influenza: a note on international planning to reduce the risk from air transport. Aviat Space Environ Med 2006;77(9):974-6.
25 Hays GC, Houghton JD, Doyle T, Davenport J. Aircraft give a new view of jellyfish behaviour. *Nature* 2003;426(6965):383.
26 Pitman RJ, Cooper BS, Trotter CL, Gay NJ, Edmunds WJ. Entry screening for severe acute respiratory syndrome (SARS) or influenza: policy evaluation. *BMJ* (Clinical research ed) 2005;331(7527):1242-3.
the Singapore experience. *Trop Med Int Health* 2003;8(11):1035-7.
27 Wilder-Smith A, Paton NI, Goh KT. Low risk of transmission of severe acute respiratory syndrome on airplanes: 28 International Civil Aviation Organization. Guidelines for states concerning the management of communicable disease posing a serious public health risk. 5 July 2007 ICAO, Montreal Canada.(Accessed 3 November, 2009 at :http://www.icao.int/icao/en/med/guidelines.htm).
29 World Health Organization. WHO technical advice for case management of Influenza A(H1N1) in air transport. 13 May, 2009, Geneva, Switerland. (Accessed 2 November, 2009 at:
http://www.who.int/ihr/trav el/A(H1N1)_air_transport_ guidance.pdf).
30 Airports Council International. Airport preparedness guidelines for outbreaks of communicable disease. December, 2006., Geneva, Switzerland. (Accessed 3 November, 2009 at:http://www.airports.org/aci/aci/file/Free%20docs/ CommunicableDisease_airport_preparedness.pdf).
31 International Air Transport Association: Influenza A(H1N1) Guidelines for airlines. Montreal, Canada. (Accessed 3 November, 2009 at:
http://www.iata.org/whatwedo/safety_security/safety/health_safety/h1n1).
32 Setbon M, Raude J. Popultion response to the risk of vector-borne diseases:lessons learned from socio-behavioral research during large-scale outbreaks. *Emerging Threats Journal* 2009;2:e6:doi:10.3134/ehtj.09.006.
33 Patz JA, Epstein PR, Burke TA, Balbus JM. Global climate change and emerging infectious diseases. *JAMA* 1996;275(3):217-23.
34 Jones K, Patel N, Levy M, et al. Global trends in emerging infectious diseases. *Nature* 2008;451(7181):990-3.
35 Morgan D. Control of arbovirus infections by a coordinated response: West Nile Virus in England and Wales. FEMS Immunol Med Microbiol 2006;48(3):305-12.

36 Andreadis TG. Failure of Aedes albopictus to overwinter following introduction and seasonal establishment at a tire recycling plant in the northeastern USA. *J Am Mosq Control Assoc* 2009;25(1):25-31.
37 Takumi K, Scholte EJ, Braks M, Reusken C, Avenell D, Medlock JM. Introduction, scenarios for establishment and seasonal activity of Aedes albopictus in The Netherlands. Vector Borne Zoonotic Dis 2009;9(2):191-6.
38 Gratz NG. Critical review of the vector status of Aedes albopictus. Med Vet Entomol 2004;18(3):215-27.
39 Simon F, Savini H, Parola P. Chikungunya: a paradigm of emergence and globalization of vector-borne diseases. *Med Clin North Am* 2008;92(6):1323-43, ix.
40 Staples JE, Breiman RF, Powers AM. Chikungunya fever: an epidemiological review of a re-emerging infectious disease. Clin Infect Dis 2009;49(6):942-8.
41 Health Protection Agency. Surveillance for human west Nile virus in the UK. (Accessed 3 November, 2009 : http://www.hpa.org.uk/web/HPAweb&HPAwebStandard/HPAweb_C/1218180261207).
42 Health Protection Agency. Malaria imported into the United Kingdom in 2008: implications for those advising travelers. Health Protection Report Vol 3 No. 16 - 24 April 2009 (Accessed 3 November, 2009 at :http://www.hpa.org.uk/hpr/archives/2009/hpr1609.pdf.)
43 Health Protection Agency. Emerging Infections Update: July -December 2007. Health Protection Protection Report. 2008; Volume 2(6) .(Accessed 3 November, 2009 at http://www.hpa.org.uk/hpr/archives/2008/hpr0608.pdf.
44 Charrel RN, de Lamballerie X, Raoult D. Chikungunya outbreaks--the globalization of vectorborne diseases. *N Engl J Med* 2007;356(8):769-71.
45 Transportation Research Board of the National Academies of Science. Symposium on Research on the Transmission of Disease in Airports and on Aircraft. 18 September, 2009, Washington, DC (see: http://www.trb.org/SpreadofDisease2009/Public/ SpreadofDisease2009.aspx).