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Air transport and the spread of infectious diseases

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ABSTRACT

Dynamically growing number of airline passengers and flights, especially intercontinental ones, is a key factor conducive to the spread of infectious diseases. The threat to public health may be even more noticeable if it is taken into account, that the developing countries record larger increase in air traffic than most European high developed states with good sanitary conditions. The aim of the study is to make a review of the literature concerning risk assessment and ways to prevent transmission of infectious diseases aboard civil aircrafts. Airline-associated spread of infectious diseases can refer to airborne and vector-borne diseases, as well as these transmitted by fecal-oral route. The particular danger of rapid spread of a disease through airline passengers is caused by influenza virus strains with the potential for causing pandemics or coronaviruses that are infectious agents of MERS and SARS. Passengers suffering from active tuberculosis are also a reason of a serious epidemiological concern. Also other airborne diseases like measles can be easily transmitted by air transport when travelling from endemic countries. On the other hand, flight-related food poisonings are less and less frequent – the most common cause are still bacteria of the *Salmonella* genus. Among vector-borne diseases, particular attention is paid to the problem of possible transfer of mosquitoes infected with West Nile Virus. In the prevention of the spread of communicable diseases via air transport, there are important factors such as: efficient identifying of sick travellers and crew members, use of personal protective equipment (such as masks with HEPA filter) by passengers travelling alongside sick person, efficient ventilation inside the passenger cabin, proper disinfection of aircrafts' interiors, vaccination of cabin crews against influenza and proper preparation and handling of catering provided to aircrafts.

***Keywords*:** air transport, infectious diseases, influenza, pandemic, aircraft, MERS, West Nile Virus, tuberculosis, airport, aviation

1. INTRODUCTION

An aircraft is nowadays more and more popular means of transport. According to preliminary data announced by the ICAO (International Civil Aviation Organization), there were 3.7 billion airlines' passengers worldwide in 2016. More than a half of travellers in the international traffic have chosen air transport [1]. In the past, travel-associated spread of infectious diseases was the domain of the ships, which were incomparably slower than planes are. The fact that flying, previously elite, became egalitarian and is the fastest conveyance, should prompt us to check, how high the risk of spreading infectious diseases via air transport is [2]. Estimating this risk will be helpful in implementation of guidelines for airlines, airports, aviation authorities and, of course, medical services when facing a threat of a new pandemic. It is even more important, when we realize, that the fastest growth in air traffic occurs in the group of developing countries, many of which present low sanitary standards [1]. ICAO, in Article 14 of the Chicago Convention (properly – the Convention on International Civil Aviation, signed in Chicago, 1944 with further changes) indicates, that contracting states should "take effective measures to prevent the spread by means of air navigation" of contagious diseases [3].

The aim of the study is to make a review of the literature on risk factors of spreading infectious diseases onboard, cases of significant outbreaks of contagious diseases during and after flight and prevention methods and guidelines concerning abovementioned problems.

2. RESULTS

Airline-associated transmissions of communicable diseases are not a homogeneous group. These include airborne and vector-borne diseases, as well as these transmitted by fecal-oral route. Airborne diseases carry the greatest risk for the public health and are the most common in aviation, thus we will give them most attention in this study.

2. 1. Airborne diseases of the respiratory tract

To better understand the risk of spreading airborne diseases aboard an aircraft it is vital to analyze the specific conditions in the passenger cabin.

Passengers inside the airliner are exposed to reduced air pressure. This so called cabin altitude is set between 1,500 m and 2,400 m above the sea level on most flights. The situation is acceptable for most healthy passengers, however some of these with cardiac or pulmonary diseases are at risk of exacerbation of their condition due to hypobaric hypoxia. Moreover, because of high cruising altitudes of most passenger jets (about 10,000 m), the air taken from the outside of the plane is dry, resulting in low humidity in cabin (about 10-20%) [4]. Although the air supplied to the aircraft is rather sterile while flying at these high cruising altitudes [5], the air composition (in terms of microorganisms suspended in the air) inside the cabin differs significantly from the composition of the air outside at the ground level.

The air inside the aircraft includes more bacteria associated with human skin, respiratory and gastrointestinal tract, including pathogenic agents [6].

The air that passengers breathe consists of the air recirculated from the cabin's floor level and the air taken from the outside of the aircraft, in a ratio of about 1:1. During flight the fresh air from the outside is provided firstly by engines (this air is referred to as "bleed air"), where it is heated or by auxiliary power units, special ground cart and airport high-pressure hydrants, when on the ground [7]. Afterwards, the air is pressurized and cooled to the temperature acceptable for passengers and mixed with recirculated air by the environmental control system, inherent in every passenger airliner. This mixed air is delivered to the cabin at the ceiling level, falls down and is drained to the luggage compartment. Also a small part of the air bounces off the floor (Figure 1). The air provided to the luggage compartment is partially recirculated, and the rest of it is removed from the fuselage. The recirculated air passes through the HEPA filter (high efficiency particulate air filter), where it is cleared of bacteria and viruses and then it is mixed with bleed air by the environmental control system, which is available at the flight deck (Figure 2). A standard ventilation rate in a passenger aircraft ranges from 15 to 20 times per hour (so the entire air in the cabin is exchanged every 3-4 minutes) [5], however, one of the major European legacy airline declares, that in its fleet of Airbus A340-300 aircrafts the ventilation rate is about 30 times per hour (so the whole air is exchanged every 2 minutes) [8]. It is proven, that more frequent air exchange reduces the risk of infection [5]. According to Figure 1, thanks to the fact, that the air in the cabin flows mainly from top to bottom, a front-to-back flow is limited, therefore the risk of transmission of infected droplets throughout the cabin is reduced.

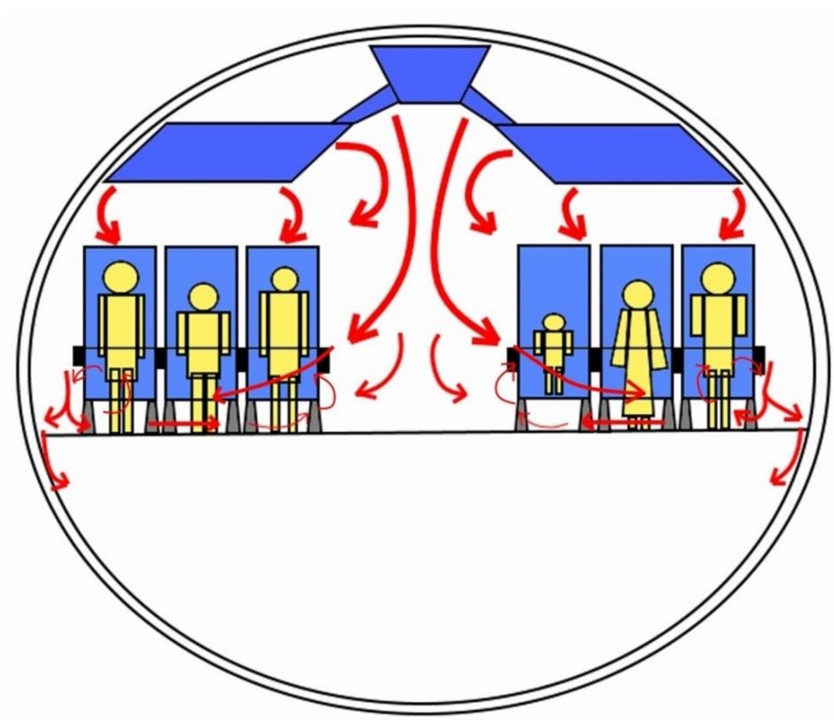

Figure 1. A schematic air flow pattern in a narrow-body passenger aircraft, own work, based on descriptions and illustrations in other publications [5,7].

The proximity of passengers, especially in the economic class, contributes to easier transmission of infectious agents. However, movement behaviour of the sick patient, as well as other passengers and crew members, are important factors that should be taken into account when assessing the risk of flight-related transmissions. Walking inside the cabin during a flight significantly increases the risk of infection in yet healthy passengers and flight attendants, if there is a sick person onboard [9], notwithstanding remaining seated may be not a sufficient protection too, when a crew member is sick, and this kind of situation is very common [10]. In a research conducted earlier this year, it turned out, that even half of commercial pilots fly with symptoms of upper respiratory tract infections [11]. It is obvious, however, that pilots meet with passengers only briefly, so that a presence of upper respiratory tract infections' symptoms in flight attendants is more important. Still, fleeting interactions must not be underestimated as infection can occur after passengers and crew members contact with each other in gates, during embarking and deplaning [12]. According to a survey conducted in 2010, every fourth respondent, who was an airline passenger, reported symptoms such as fever, sore throat, diarrhoea, myalgia and rash in two weeks prior to departure [13]. It seems that the greatest threat exist not so much in the possible transmission between passengers on board, but in the fact, that a sick passenger in a dozen of hours may come to the other side of the globe and become a source of epidemics there [2].

Considering the factors contributing to the spread of infectious diseases on board, it is important to analyze the role of the duration of the flight and the distance from the sick person (further in this study referred to as the "index case") in which seated passengers are most likely to be infected.

The general rule referring to the distance from the index case is a "2-row rule", which states that the greatest risk of getting infected concerns passengers, who sit not further than 2 rows apart from the index case [12], while sitting as far as 15 rows apart from the index case minimizes this risk to almost zero. The most effective exposure takes place during long-haul flights which last at least 8 hours (including ground delays when passengers are seated) [5]. However, these rules are simplifications (Table 1). They are in general true for tuberculosis, for instance [14], but transmission of SARS-CoV (severe acute respiratory syndrome coronavirus) escaped these standard rules during 2002-2003 outbreak [5]. Also in the case of influenza, despite the studies showing that long-haul flights are especially important in the spread of the disease via air transport [15], ECDC RAGIDA (European Centre for Disease Prevention and Control, "Risk assessment guidelines for infectious diseases transmitted on aircraft") expound that influenza transmission occurs both during short-haul and long-haul flights and it is not certain whether the flight duration has an influence on the spread of the disease. Certainly, though, ground delays, when passengers remain seated, increase the risk of transmission [16]. This is an extremely important factor, when the delay is caused by a failure of engines or the auxiliary power unit, which is responsible for ventilation, when the aircraft is parked at the terminal. In that case the United States Department of Transportation recommends, that "if the ventilation system is not operating, passengers should not stay aboard the plane for long time" [17].

Influenza is one of the most vulnerable diseases to be transmitted via air transport. Civil aviation played a major role during 2009 pandemic of A/H1N1 influenza [18]. The risk of being infected aboard an aircraft, according to studies, is noticeable when sitting not further than 2 rows apart from the index case [19]. That is why it is so important to vaccinate all of the crew members, who can get into a close contact with large number of passengers.

Unfortunately, only about 25% of flight attendants of European and North American airlines admit to undergoing influenza vaccination regularly [10]. If sensitive passengers (for example with impaired immunity) are forced to travel next to the index case, a good solution for them may be using a NIOSH-approved N95 mask (National Institute of the Occupational Safety and Health, the United States; N95 means, that the filter blocks 95% of particles of 0.3 µm and larger diameter) [20]. The introduction of these masks as a mandatory aircraft equipment seems to be an idea worth consideration. American CDC (Centers for Disease Control and Prevention) recommends the use of N95 respirators for coughing and sneezing passengers, as well as for those who sit next to them and for the flight attendants, who are designated to help the index case [21].

Figure 2. Environmental control system panel in a Boeing 737-800. By Wsombeck, released into the Public Domain, Wikimedia Commons.

While referring to the risk of tuberculosis transmission aboard an aircraft, it is necessary to stress out, that there are no cases of in-flight transmission of active tuberculosis described in the literature. Nevertheless, it is possible for TST (tuberculosis skin test) to convert to positive results, when sitting not further than 2 rows apart from the index case on the long-haul flight (in general longer than 8 hours) [14]. However, the risk of transmission of tuberculosis (in terms of positive TST results) during a flight is difficult to assess [22].

Table 1. On-board transmissions of airborne diseases of the respiratory tract analyzed in the European guidelines [23].

Disease	No. of studies with evidenced on-board transmissions	Range of flights' durations including ground delays (hours)	Range of distances of contacts (seat rows)	Analyzed period of time	Comments
tuberculosis	6	2-14	same row – 29 rows	1992-1997	No active tuberculosis transmission, only TST conversion.
influenza	4	3-4	same row – 10 rows	1977-1999	Data includes the period before 2009 A/H1N1 pandemic.
SARS	4	3-8	same row – 7 rows	2003	SARS outbreak.
meningococcal disease	1	15	12 rows	2003	The only described case in the literature.
measles	5	8-10	3-8 rows	1981-2005	-

Another problem is the possible transmission of acute respiratory diseases caused by coronaviruses: SARS and MERS (Middle East Respiratory Syndrome). All significant in-flight transmissions of SARS were reported during 2002-2003 outbreak, when the epidemic began in China and was quickly spread out by means of air transport to such distant countries as Canada, France, the USA and Germany [23]. No cases of onboard transmissions have been reported since then. In turn, MERS can be emerging problem in not so distant future. The virus, discovered in 2012, began an epidemic in Saudi Arabia that year. All cases of the disease described outside the Middle East in 26 countries were linked to the air transport, with the biggest outbreak in South Korea. The risk of spreading MERS worldwide is considered high, because of annual pilgrimages to Saudi Arabia such as Hajj with millions of participants from all Muslim countries [24]. In cases of suspected highly infectious diseases caused by coronaviruses on board, CDC and ECDC recommend to isolate the index case from other passengers if it is possible, designate only one flight attendant to contact with the index case, and only one toilet exclusively for the suspected person [21,23].

Another disease that can be easily transmitted on board is measles. In countries of high rates of measles immunization, imported cases of the disease from countries with rate of vaccine immunization lower than 90% is a serious source of measles outbreaks [25]. In the literature, there are descriptions of cases of in-flight transmissions in passengers sitting as far as 8 rows from the index case during at least 8-hour-long flights [23]. Because measles has high transmissibility, the transmission can occur also during brief contacts at airports. A study from 2016 describes a measles outbreak in the United Kingdom and the Netherlands involving a virus strain with genotype typical for the epidemics in the Philippines. The cases were mainly airports' workers and passengers from transit zones (not necessarily of the same flights) [26].

Meningococcal disease's transmission is unlikely. There is only one case of flight-related infection in the literature [27]. Despite this fact, a chemoprophylaxis is recommended for passengers sitting close to the index case [5].

There are no evidenced cases of in-flight transmission of rubella, nor diphtheria [23], although sometimes contact tracing is performed [28].

A summary of the cases analyzed by ECDC in the RAGIDA guidelines concerning in-flight transmissions of airborne diseases is collected in Table 1.

2. 2. Food-borne, water-borne and other gastrointestinal diseases

Diseases of the gastrointestinal tract are usually associated with an in-flight catering, when they are food-borne or water-borne or with an ill passenger, if they are airborne.

The most common food-borne disease aboard commercial flights is salmonellosis. Until 2005 there were 15 reported outbreaks of flight-related salmonellosis [5]. One of the most recent cases from 2014 concerned a group of 25 tourists returning from Tanzania, who developed symptoms of the disease after consuming milk and egg products from an in-flight catering [29].

Shigellosis and staphylococcal food poisoning are less frequent [5] with no new outbreaks described in the last decade. These kinds of infections are also related exclusively with in-flight catering.

There are only few cases of flight-related cholera outbreaks in the literature. The most significant and the last one occurred in 1992. A plane belonging to one of the South American carriers departed from Buenos Aires and was en route to Los Angeles with a scheduled stopover in Peru's capital, Lima with 336 passengers and 20 crew members onboard in February 1992, just after cholera epidemic in Peru. A seafood salad eaten by passengers after departure from Lima turned out to be the vehicle of the disease. 75 people developed diarrhoeal illness, one died [30]. Since then, no new cases of flight-related cholera outbreaks have occurred.

Flight-related viral enteritis is not very often reported in the literature. However, the spread of the disease can be very quick amid passengers. In a study from 2010 an outbreak of Norovirus infection in 2008 was described. 36 sick members of a tour group experienced vomiting and diarrhoea during flight from Boston to Los Angeles. The situation was serious enough that the pilots decided to perform an emergency diversion after 3 hours from take-off. Despite short time of the flight, during next few days another 7 passengers, who were not members of the tour group, developed the illness [31]. Another viral enteritis was described in 2009, when during long-haul trans-Pacific flight the index case was vomiting in the cabin and in the toilet. 41 fellow passengers out of 122 in adjacent zones developed gastrointestinal illness within 60 hours of arrival. The authors claimed, that not only surface contamination, but also airborne route and cross-contamination in the toilet contributed to the transmission of the virus to a big number of passengers [32].

Proper disinfection of toilets in aircraft may reduce the risk of transmitting abovementioned viral enteritis between two different flights, when the next flight takes place right after a flight with a sick passenger aboard. A meta-genomic analysis from 2015 showed, that in toilet waste from long-haul flights, genes of some pathogenic agents can be found, including *Salmonella enterica* and Noroviruses from flights with origins in South Asia and *Clostridium difficile* from flights with origins in North America [33].

Possible sources of gastrointestinal infections and basic solutions for passengers, crew members and airlines to reduce the risk of transmission are depicted on the Figure 3.

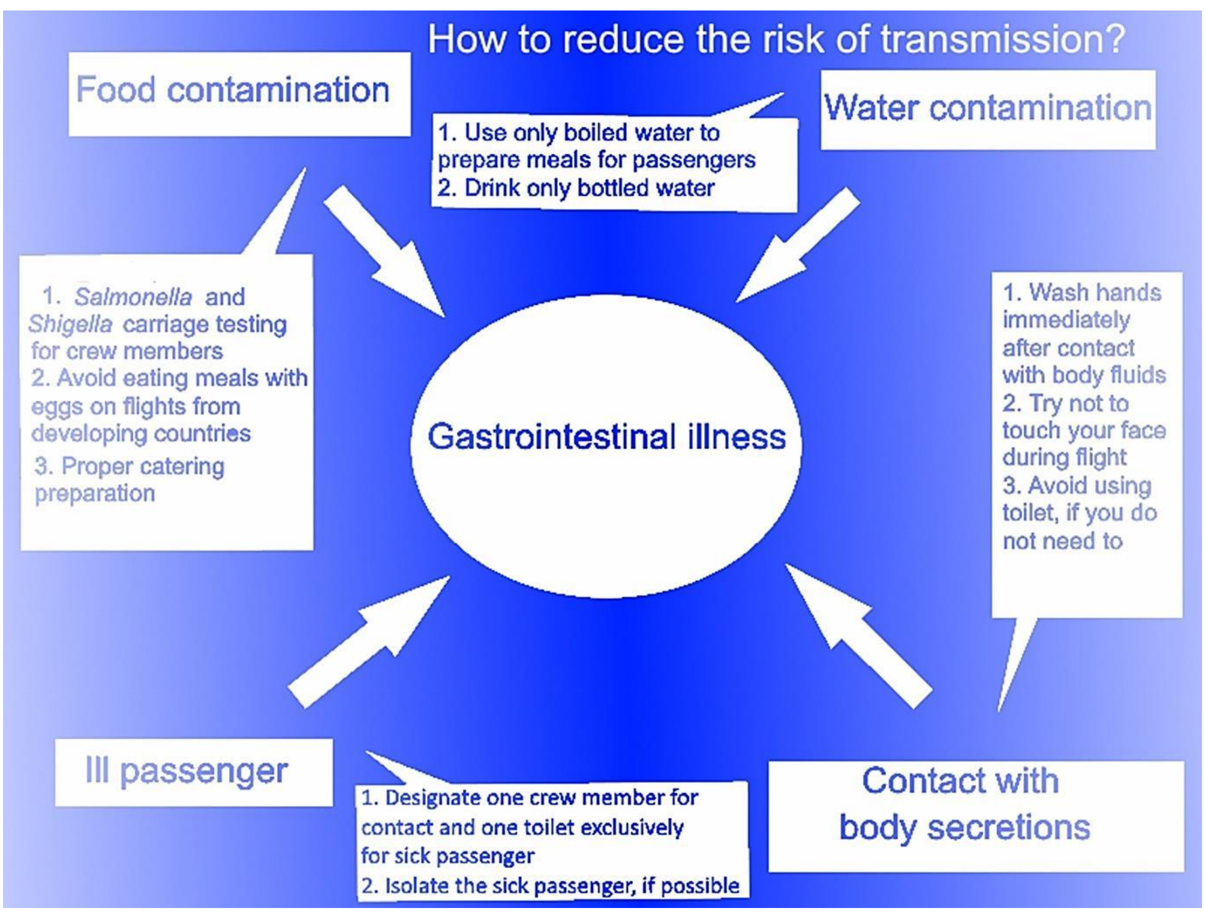

Figure 3. Possible sources of gastrointestinal infections and basic solutions to reduce the risk of in-flight transmission, own work.

2. 3. Vector-borne and other zoonotic diseases

Table 2. European guidelines on contact tracing in case of passenger with confirmed haemorrhagic fever onboard [23].

Haemorrhagic fever	When to initiate contact tracing	For whom contact tracing should be considered
Ebola	When the laboratory-confirmed index case was symptomatic during flight or on board: 1. within the last 26 days; 2. within 4 days before the onset of symptoms.	Obligatory for all passengers and crew members.
Marburg	When the laboratory-confirmed index case was symptomatic during flight or on board: 1. within the last 19 days; 2. within 3 days before the onset of symptoms.	Obligatory for passengers sitting within 2 rows from the index case and other contact persons. Can be considered in all passengers and crew members.
Lassa	When the laboratory-confirmed index case was symptomatic during flight or on board: 1. within the last 19 days; 2. within 3 days before the onset of symptoms.	Obligatory for persons with "special exposure" (i.e. family members, persons having contact with urine or with exposure of skin and mucous membranes to body fluids). Can be considered in passengers sitting within 2 rows from the index case.

Vector-borne and zoonotic diseases that may pose a particular threat to public health include viral haemorrhagic fevers, West Nile fever and malaria.

West Nile fever, caused by WNV (West Nile Virus) and malaria, caused by protozoa from the *Plasmodium* genus, are the diseases transmitted by mosquitoes. It is estimated, that probably each year during the summer season a few mosquitoes infected with WNV are transported from endemic countries to big international hubs like London Heathrow. Therefore, the nearest neighbourhood of high-capacity airports serving intercontinental traffic should be considered as the zone of the increased risk of occurrence of WNV infections in humans and animals [34].

Also malaria-carrying mosquitoes can be transported by aircrafts. In one of the most recent cases of airport malaria, 4 people without a history of travel to malarious countries or other risk factors, were diagnosed with the disease. All of the cases were living close to the Tunis International Airport in Tunisia [35]. Cases of airport malaria are not frequent, therefore airlines do not perform routine disinsection after returning from endemic countries [5]. However, the occurrence of the illness should be considered if a patient living close to the international airport presents suspicious symptoms including fever of unknown origin.

Viruses of haemorrhagic fevers that are issues of special international concern are Ebola Virus, Marburg Virus and Lassa Virus. Until now, there are no known cases of the in-flight transmission of these haemorrhagic fevers in the literature. However, passengers and crew members who may be exposed to body fluids of the passenger suspected of suffering from one of these infections, should be the subject of contact tracing due to high pathogenicity and mortality of haemorrhagic fevers [23]. Rules of contact tracing in case of haemorrhagic fevers on board are shown in the Table 2.

2. 4. Potential use of pathogenic agents of smallpox and anthrax in bioterrorism.

So far there have been no cases of using highly pathogenic agents such as Variola Virus responsible for smallpox and *Bacillus anthracis*, causative agent of anthrax, onboard commercial aircrafts. Smallpox is declared eradicated and available only in a few carefully guarded laboratories in the World, therefore using the virus by terrorists seems unlikely. At all events, contact tracing should be performed for every passenger and cabin crew member onboard if there is a suspicion, that the plane could have been targeted by terrorists possessing the Variola Virus [5,23].

The only possible way of infecting large number of people with *B. anthracis* is by releasing anthrax spores. These kinds of attacks were carried out in 2001 using mail handling [36], so there is a limited possibility of repeating them onboard commercial aircraft. Contact tracing should be provided every time, when a flight-related anthrax is confirmed in a passenger [23].

3. CONCLUSIONS

On the basis of the analyzed literature, it seems that there is no particular risk of transmission of infectious diseases during commercial flights. The risk seems to be typical for enclosed spaces with high density of people such as offices, shopping malls, churches or other means of transport. Moreover, it can be assumed, that in comparison to other enclosed spaces, what needs further investigation, this risk may be even lower thanks to the effective ventilation, high air exchange rate and the presence of HEPA filters aboard commercial airliners.

There are many solutions which can prevent or reduce the risk of the spread of infectious diseases onboard civil aircrafts and in general, the spread of epidemics and pandemics in the World via air transport. One of the most important issues is effective, properly frequent ventilation rate inside the passenger cabin. It is important to keep ventilating the cabin also when on the ground, and if the ground delay is caused by engine or auxiliary power unit failure with inoperative ventilation, passengers should leave the aircraft until the fault is repaired.

Since flight attendants come in contact with large number of passengers, prepare and give meals to them, from the epidemiological point of view it is vital that sick crew members should stay home instead of flying. It would be also beneficial if airlines consider mandatory vaccinations against influenza for cabin crew members.

Properly prepared in-flight catering and *Salmonella* and *Shigella* carriage testing for crew members can help reducing the risk of occurrence of flight-related infectious food poisoning, especially if the airline operates in or from developing countries with low sanitary standards.

One of the most important issues is an efficient identification of sick passengers aboard an aircraft. When a highly infectious disease is suspected in the symptomatic index case with symptoms like coughing and sneezing, vomiting, impaired breathing, rash, diarrhoea etc., the index case should be isolated from other passengers if it is possible, even if it will mean transferring the passenger to the business or even first class. These kinds of solutions, however, need to be implemented in internal airline guidelines. The index case should be advised to remain seated for the rest of the flight, as well as other passengers on board. Flight attendants should inform the captain or the first officer about the situation, so that they can switch on the "fasten seat belts" signs in the passenger cabin. Only one flight attendant should be designated to contact with the index case and only one toilet should be chosen exclusively for the sick passenger. The index case, as well as passengers sitting close to him and the crew member contacting him should be provided with N95 masks, which should be introduced as a mandatory equipment of the commercial aircrafts. After the flight with an index case suspected of a highly infectious disease on board, the plane should be disinfected including passenger cabin, the cockpit, toilets and all interior elements. Unfortunately, there are no WHO or aircraft manufacturers' guidelines for aircraft disinfection in case of such diseases like Ebola and Lassa haemorrhagic fevers or SARS and MERS. It is recommended to standardise the procedure on the basis of international aviation law [37].

Although the risk of in-flight transmission of infectious diseases does not seem to be a burning problem of the public health, the fact that the air transport definitely helps to spread communicable diseases around the globe is undisputed. 2002-2003 SARS outbreak, 2009 influenza A/H1N1 pandemic and finally 2012 MERS outbreak showed that the worldwide airline network can play a major role in spreading new, highly infectious diseases and can contribute to a pandemic outbreak in the future. Therefore, it is important to keep international guidelines up-to-date, including IATA (International Air Transport Association) emergency response plans and action checklist for carriers [38] and ICAO Standards and Recommended Practices of relevance to the article 14 of the Chicago Convention in alignment with WHO International Health Regulations [39].

Reducing the risk of the possible spread of infectious diseases via air transport should be a matter of concern and cooperation of airlines, aircraft manufacturers, national and international aviation authorities, medical services, aircraft crew members and finally also passengers who should be made aware of possible routes of transmission of the most common infectious diseases and how to avoid them.

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