

Assessment of the potential for international dissemination of Ebola virus via commercial air travel during the 2014 west African outbreak



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Summary

Background The WHO declared the 2014 west African Ebola epidemic a public health emergency of international concern in view of its potential for further international spread. Decision makers worldwide are in need of empirical data to inform and implement emergency response measures. Our aim was to assess the potential for Ebola virus to spread across international borders via commercial air travel and assess the relative efficiency of exit versus entry screening of travellers at commercial airports.

Methods We analysed International Air Transport Association data for worldwide flight schedules between Sept 1, 2014, and Dec 31, 2014, and historic traveller flight itinerary data from 2013 to describe expected global population movements via commercial air travel out of Guinea, Liberia, and Sierra Leone. Coupled with Ebola virus surveillance data, we modelled the expected number of internationally exported Ebola virus infections, the potential effect of air travel restrictions, and the efficiency of airport-based traveller screening at international ports of entry and exit. We deemed individuals initiating travel from any domestic or international airport within these three countries to have possible exposure to Ebola virus. We deemed all other travellers to have no significant risk of exposure to Ebola virus.

Findings Based on epidemic conditions and international flight restrictions to and from Guinea, Liberia, and Sierra Leone as of Sept 1, 2014 (reductions in passenger seats by 51% for Liberia, 66% for Guinea, and 85% for Sierra Leone), our model projects 2·8 travellers infected with Ebola virus departing the above three countries via commercial flights, on average, every month. 91 547 (64%) of all air travellers departing Guinea, Liberia, and Sierra Leone had expected destinations in low-income and lower-middle-income countries. Screening international travellers departing three airports would enable health assessments of all travellers at highest risk of exposure to Ebola virus infection.

Interpretation Decision makers must carefully balance the potential harms from travel restrictions imposed on countries that have Ebola virus activity against any potential reductions in risk from Ebola virus importations. Exit screening of travellers at airports in Guinea, Liberia, and Sierra Leone would be the most efficient frontier at which to assess the health status of travellers at risk of Ebola virus exposure, however, this intervention might require international support to implement effectively.

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Introduction

On Aug 8, 2014, and for only the third time in the agency's history, the WHO declared a public health emergency of international concern (PHEIC) to unite the global community in its efforts to bring the current epidemic of Ebola virus in west Africa under control.¹ Key factors influencing the declaration were the unprecedented scale and geographic range of the epidemic coupled with the constrained public health capacity of affected countries, high fatality ratio, and the observed international spread of Ebola virus into Nigeria—Africa's most populous country, with a population of more than 170 million.² Coordinated international action to control the epidemic at its source is mounting; however, uncoordinated unilateral actions

are also emerging including controversial measures that ban travel and trade to and from affected countries.³

The 2005 International Health Regulations (IHR) describe the guiding principles by which 196 participating countries are bound when responding to a PHEIC, such as the current Ebola epidemic. The purpose and scope of the IHR are to “prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade”.⁴ However, evidence is missing to help decision makers objectively and dispassionately balance the reduction in risk to unaffected countries by restricting international travel from areas affected by Ebola virus, against the possible

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humanitarian and public health consequences to countries currently in the midst of the epidemic. Using empirical data for global population mobility via air travel, Ebola virus surveillance, and health-care system capacity, we aimed to offer perspective on the potential for Ebola virus to spread across international borders via commercial air travel, assess the relative efficiency of exit versus entry screening of travellers at commercial airports, and assess the capacity of receiving areas to effectively detect and respond to potential imported cases.

Methods

Overview and data sources

We studied patterns of commercial air travel out of Guinea, Liberia, and Sierra Leone, the three countries with widespread and intense Ebola virus transmission as of Sept 1, 2014,⁵ which we deemed the most likely sources of exported infections of Ebola virus. For our travel analyses, we used two complementary datasets from the International Air Transport Association, representing the most up-to-date data currently available. The first dataset includes information on future flight schedules (ie, passenger carrying capacity as seats on flights between directly connected airports), which we used to describe all non-stop flights out of Guinea, Liberia, and Sierra Leone between September, 2014, and December, 2014. The second dataset includes monthly, passenger-level flight itinerary data from September, 2013, to December, 2013, which we used to describe the expected final destinations of travellers departing Ebola virus affected countries while accounting for all traveller flight connections.

International air travel out of areas affected by Ebola virus

We first quantified the total volume of international commercial air travellers departing every country in the world in 2013, highlighting Guinea, Liberia, Sierra Leone, the four neighbouring countries that share a land border (Côte d'Ivoire, Guinea-Bissau, Mali, and Senegal), and Nigeria. To estimate how international air traffic flows to and from Guinea, Liberia, and Sierra Leone have changed due to the Ebola epidemic, we calculated the reduction in total aircraft seat capacity based on online media reports of airline flight cancellations and travel restrictions imposed by countries as of Sept 1, 2014.

We then analysed the flight itineraries of all international travellers departing Guinea, Liberia, and Sierra Leone between September, 2013, and December, 2013, and mapped the final destinations of these travellers (ESRI ArcGIS v10), indicating which cities are scheduled to receive non-stop flights between September, 2014, and December, 2014. We deemed individuals initiating travel from any domestic or international airport within these three countries to have possible exposure to Ebola virus. We deemed all other travellers, including those simply transiting through Guinea, Liberia, or Sierra Leone, or originating from Nigeria or Senegal (where at the time of writing no evidence of widespread community-based

transmission was reported), to have no significant risk of exposure to Ebola virus. Although no new cases have been reported in Nigeria since early September, because of the potential for new or undetected cases appearing, we separately assessed global air traffic patterns out of Lagos and Port Harcourt, Nigeria (which collectively include 540 812 travellers, 81% of Nigeria's international air traffic volume in 2013).

We then quantified the number of travellers needed to be screened to capture one traveller potentially exposed to Ebola virus (defined as any individual initiating travel from an airport within Guinea, Liberia, or Sierra Leone) and compared the number of cities in which traveller screening would be required to detect all potentially exposed travellers. This analysis included options for screening at: international points of departure from Guinea, Liberia, or Sierra Leone (exit-screening); international points of arrival on non-stop flights arriving from Guinea, Liberia, or Sierra Leone (entry-screening for direct flights); and international points of arrival via connecting flights (ie, airports receiving travellers via multisegment flights originating from these three countries; entry-screening for indirect flights). To estimate the likelihood of an asymptomatic air traveller infected with Ebola virus (in the incubation period) developing detectable symptomatic illness during the course of an international flight, we calculated the median (IQR) and mean (SD) of travel times for all potential travellers exposed to Ebola virus to reach their final destination. We assumed a 1 h layover for domestic flights and a 2 h layover for international flights.

Projections of international Ebola virus spread

To estimate the potential for international spread of Ebola virus out of Guinea, Liberia, and Sierra Leone via commercial air travel between September, 2014, and December, 2014, we used the number of active cases (defined as confirmed, probable, or suspected cases within the 21 day period before Sept 21, 2014, as reported by WHO), World Bank 2013 country population estimates, and the monthly number of international outbound air travellers between September, 2013, and December, 2013 (ie, pre-outbreak flows) to calculate expected numbers of Ebola virus exportations (ie, [number of active cases/country population] × monthly number of international outbound air travellers).⁵ We then estimated the expected time in months for one air traveller infected with Ebola virus to depart the above three countries (ie, 1/expected number of Ebola virus exportations per month). This method assumed flows of international travellers before the outbreak (ie, 2013), a homogeneous distribution, and constant prevalence of Ebola virus infection in the general population, an equal risk of infection between travellers and non-travellers, and no under-reporting of cases of Ebola virus. In view of existing uncertainties, we did sensitivity analyses to explore scenarios of increasing case burden (2×, 5×, 10×), exponential risk in case burden over time,⁶ and

decreasing international air traffic capacity due to flight cancellations, travel restrictions, or changes in travel behaviours (50%, 75% reduction; appendix).

Traveller destinations and Health System Capacity

As a crude surrogate marker for health-care capacity, we examined the World Bank income group (ie, low-income, lower-middle-income, upper-middle-income, or high-income country) of the final destinations of travellers departing Guinea, Liberia, and Sierra Leone.⁷ Destination cities of travellers were aggregated to the country level and also compared with selected national indicators of health-care system capacity from the World Bank (eg, health-care expenditures per head, physicians per 1000 people, hospital beds per 1000 people) to identify countries with high levels of connectivity to Ebola virus affected areas but with constrained health-care resources.⁷

Role of the funding source:

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

In 2013, 0·02% (183 485 travellers) of the world's total commercial international air traffic volume (1 105 005 867 individuals) were air travellers departing Guinea, 0·02% (163 274 individuals) were air travellers departing Sierra Leone, and 0·01% (148 101 individuals) were air travellers departing Liberia (figure 1). Countries sharing a land border with Guinea, Liberia, and Sierra Leone also had low volumes of international air traffic, whereas Nigeria accounted for about four times the volume of international air travel from the above three countries combined. Reported flight cancellations and restrictions as of Sept 1, 2014, reduced scheduled commercial air traffic capacity (between Sept 1, 2014, and Dec 31, 2014) to and from Liberia by 51%, Guinea by 66%, and Sierra Leone by 85%.

We found that health screening of travellers at risk of exposure would be most efficient if done at international points of departure from countries with community-based transmission of Ebola virus (table 1). Exit screening travellers at airports in three cities (ie, Conakry, Monrovia, and Freetown) would allow for health assessments of all travellers departing Guinea, Liberia, and Sierra Leone. By comparison, entry screening the very same travellers as they arrive in other countries via non-stop international flights (ie, entry screening of direct flights) would require intervention in 15 cities across 15 countries. Of the commercial airports in 1238 cities worldwide that do not receive direct flights from Guinea, Liberia, or Sierra Leone, an average of 2512 travellers would have to be screened (or their trip itineraries examined) to identify one traveller originating from one of the above three countries. We also

found the median travel times on non-stop flights out of Guinea, Liberia, and Sierra Leone to be 2·7 h (IQR 2·0–6·1), making it unlikely that an infected individual who was asymptomatic at exit screening would develop symptoms during their flight; hence the expected

See Online for appendix

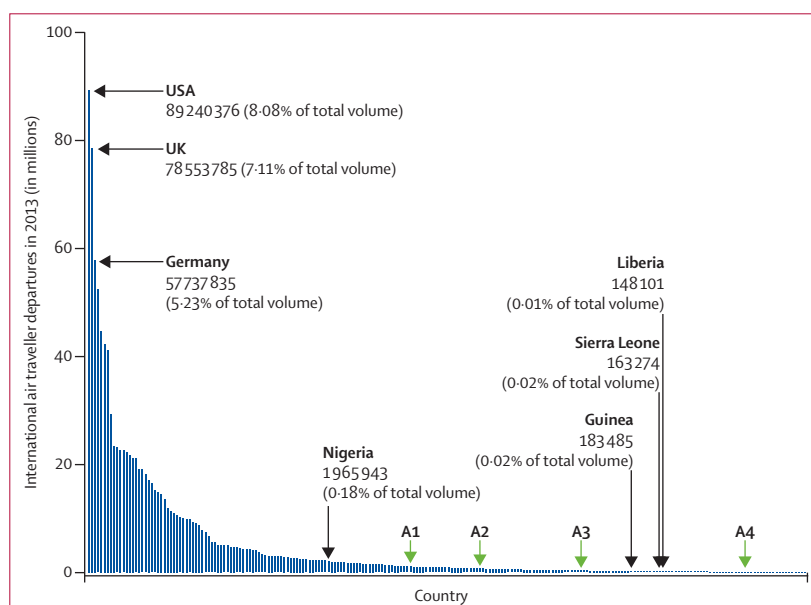


Figure 1: Global volume of international air traveller departures by country, 2013

Countries are shown in decreasing order of air traffic volume. Countries sharing a land border with Guinea, Liberia, and Sierra Leone are shown by green arrows. A1=Senegal (1 022 058; 0.09% of total volume). A2=Côte d'Ivoire (663 438; 0.06% of total volume). A3=Mali (325 983; 0.03% of total volume). A4=Guinea-Bissau (45 702; <0.01% of total volume).

	Exit screening	Entry screening of direct flights	Entry screening of indirect flights
Number of cities where screening would be required	3*	15†	1238
Estimated number of travellers who would be screened	144 798	144 798	362 855 926
Estimated number of low-risk‡ travellers who would be screened (%)	376 (0.1%)	376 (0.1%)	362 711 504 (99.9%)
Number of travellers needed to screen to assess one traveller with potential exposure to Ebola virus§	1	1	2512
Travel time until screening, h			
Median (IQR)	0	2.7 (2.0–6.1)	4.0 (2.0–7.6)¶
Mean (SD)	0	3.9 (2.6)	5.8 (4.9)

Data include travellers departing Guinea, Liberia, and Sierra Leone and travellers on connecting flights departing these countries. Data are based on air traveller flows reported from Sept 1, 2013, to Dec 31, 2013. *Four international airports in three cities across three countries (since these countries do not have any solely domestic airport this number represents all airports in the three countries); one airport in Monrovia has since been closed. †16 airports in 15 cities across 15 countries. ‡We defined low-risk travellers as any traveller with an origin outside Guinea, Liberia, or Sierra Leone, including those simply transiting through these countries. §We defined travellers with possible exposure to Ebola virus as individuals initiating travel from any domestic or international airport within Guinea, Liberia, and Sierra Leone. Travellers transiting through airports within Guinea, Liberia, and Sierra Leone or initiating travel from Senegal or Nigeria were not deemed to have such an exposure risk. ¶We assumed a 1 h layover for domestic flights and a 2 h layover for international flights.

Table 1: Efficiency of airport-based interventions to screen international travellers departing Guinea, Liberia, and Sierra Leone by frontier

	Population estimates*	Number of active cases†	Estimated prevalence (per 100 000)	Number of monthly international travellers (outbound, unrestricted air travel)‡	Projected number of infected travellers per month (outbound, unrestricted air travel)§	Projected time to one internationally exported case (unrestricted air travel)	Projected time to one internationally exported case (restricted air travel)¶
Guinea	11 745 189	292	2·49	14 732	0·37	2·7 months	8·0 months
Liberia	4 294 077	1707	39·75	12 781	5·08	0·2 months	0·4 months
Sierra Leone	6 092 075	737	12·10	14 237	1·72	0·6 months	3·9 months
Total	22 131 341	2736	18·11 (19·3)**	41 750	7·17	0·14 months	0·35 months

*Source: World Bank, 2013. †Sum of the number of confirmed, probable, and suspected cases in the past 21 days to estimate active cases as of Sept 21, 2014. ‡Based on average traveller volumes recorded between Sept 1, 2013, to Dec 31, 2013; includes international travel between Guinea, Liberia, and Sierra Leone. §Model assumptions include: Ebola virus disease activity is constant and equally distributed across the population; an individual's risk of Ebola virus infection is independent of the probability of international air travel; we calculated projected numbers of internationally outbound travellers infected with Ebola virus using the following formula: [number of active cases/country population] × monthly number of international outbound air travellers; we calculated the time to one internationally exported case as the inverse of the projected number of Ebola virus exportations per month (using case counts as of Sept 21, 2014). ¶We assumed a reduction in international air travel volume of 51% for Liberia, 66% for Guinea, and 85% for Sierra Leone. **Represent mean value (SD) for the three countries.

Table 2: Modelled estimates of Ebola virus exportation from Guinea, Liberia, and Sierra Leone via commercial air travel

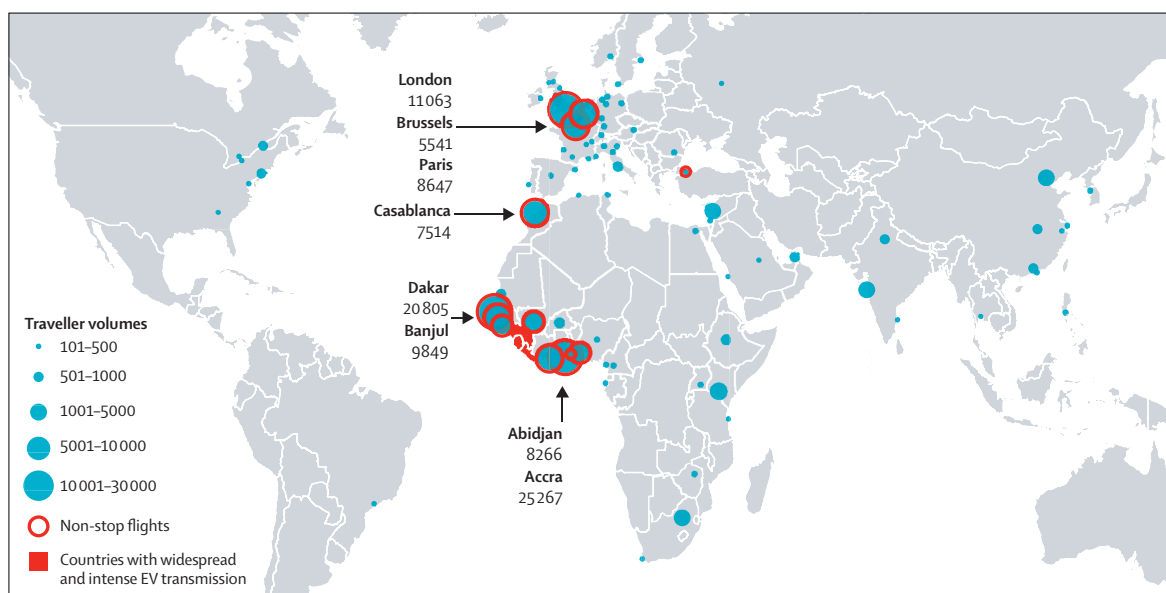


Figure 2: Final traveller destinations, passenger volumes* and scheduled non-stop flights† departing Guinea, Liberia, and Sierra Leone

*From Sept 1, 2013, to Dec 31, 2013. †From Sept 1, 2014, to Dec 31, 2014.

incremental usefulness of entry screening in addition to effective exit screening would be very low.

Assuming pre-outbreak and unrestricted travel conditions and no health screening of travellers (and the model assumptions described in the methods' section), we estimated one infected international air traveller would leave Guinea every 2·7 months, Liberia every 0·2 months, and Sierra Leone every 0·6 months (table 2). The appendix shows different scenarios of increasing Ebola virus case burden in the source countries and decreasing air traffic volumes.

When analysed by World Bank income category, 42 825 (29%) travellers coming from these three countries had final destinations in high-income countries, 10 041 (7%) in upper-middle income countries, 70 182 (49%) in lower-middle income countries, and 21 365 (15%) in low-income countries. Figure 2 and the appendix show

the final destinations of air travellers departing Guinea, Liberia, and Sierra Leone at the city level, with Accra, Dakar, and London at the top 3. Table 3 shows the most common final destination countries of individuals initiating air travel from within Guinea, Liberia, and Sierra Leone, with potential national indicators of health-care capacity. Separately, the appendix shows anticipated final destinations of air travellers departing Lagos and Port Harcourt, Nigeria, with London, Dubai, and Accra at the top 3.

Discussion

In accordance with the central tenets of the IHR (2005)—a global treaty ratified by the World Health Assembly—the international community has agreed to respond to global infectious disease threats in ways that carefully balance the potential benefits and possible harms from

public health interventions that interfere with international traffic and trade.⁴ In this study, we aimed to support policy makers in making informed decisions about travel-related interventions that could decrease risks to currently unaffected countries but which could concurrently have adverse economic, health, social and humanitarian consequences to affected countries (panel).

We determined that the volume of international air traffic departing the three countries facing widespread community-based transmission of Ebola virus disease, namely Guinea, Liberia, and Sierra Leone, was low relative to other countries. To study the potential for Ebola virus exportation, however, these numbers must be considered in the context of potential travel restrictions, the intensity of Ebola virus activity in affected countries, and the underlying assumptions of our model. As shown in our analysis and witnessed by the imported case of Ebola virus into Nigeria and the USA, the potential for further international spread via air travel remains present. Of additional concern is that the anticipated destinations of more than 60% of travellers departing Guinea, Liberia, and Sierra Leone are to low-income or lower-middle income countries, where inadequately resourced medical and public health systems might be unable to detect and adequately manage an imported case of Ebola virus disease, including possible subsequent community spread.⁸

One intervention, which could help maintain crucial supply chains into affected countries but mitigate the risk of international spread of disease, is the use of non-commercial flights to transport essential personnel and materials. For commercial flights, airport-based traveller screening, which can be done at the point of exit (departure) from or entry (arrival) to an airport can be considered. Exit screening would help identify travellers with symptoms consistent with Ebola virus disease at an earlier stage than entry screening,⁹ whereas both would miss latent infections during the 8–10 day average (range 2–21 day) incubation period.

Our analyses show that exit screening at international points of departure would offer greater efficiency, and might be simpler to operationalise, than entry screening all flights arriving directly from affected countries. By comparison, entry screening at international airports to which no direct flights are arriving from affected countries would be highly inefficient if border authorities are unable to easily identify which travellers originated from countries currently experiencing community-based Ebola virus transmission.

Furthermore, in view of the non-specific symptoms of early Ebola virus infection, the predictive value of a positive health screening test would be extremely low, regardless of its sensitivity or specificity (ie, likelihood that a positive screening test would represent Ebola virus disease). Hence, screening travellers on multisegment flights to their final destination would probably have minimum benefits to unaffected countries but could

	Traveller volume*	Proportion of total volume (%)	Health-system capacity measures (global rank out of 191 countries)			
			Health-care expenditure per head, US\$†	Physicians per 1000 people†	Nurses and midwives per 1000 people†	Hospital beds per 1000 people†
Ghana	25 272	17.5%	83 (149)	0.1 (135)	0.9 (116)	0.9 (142)
Senegal	20 818	14.4%	51 (158)	0.1 (135)	0.4 (140)	0.3 (165)
UK	12 493	8.7%	3647 (20)	2.8 (42)	8.8 (23)	2.9 (69)
France	10 292	7.1%	4690 (14)	3.2 (31)	9.3 (19)	6.4 (15)
Gambia	9849	6.8%	26 (177)	0 (152)	0.6 (130)	1.1 (134)
Côte d'Ivoire	8266	5.7%	88 (147)	0.1 (135)	0.5 (136)	NA
Morocco	7574	5.2%	190 (119)	0.6 (104)	0.9 (116)	0.9 (142)
Belgium	5541	3.8%	4711 (13)	3 (34)	15.8 (4)	6.5 (13)
Nigeria	4182	2.9%	94 (144)	0.4 (110)	1.6 (100)	NA
China	4090	2.8%	322 (100)	1.9 (67)	1.9 (92)	3.8 (49)
Mali	3680	2.5%	42 (164)	0.1 (135)	0.4 (140)	0.1 (168)
USA	2927	2.0%	8895 (3)	2.5 (52)	9.8 (18)	2.9 (69)
India	2466	1.7%	61 (153)	0.7 (102)	1.7 (96)	0.7 (149)
Kenya	2392	1.7%	45 (162)	0.2 (122)	0.8 (121)	1.4 (123)
Germany	1825	1.3%	4683 (15)	3.8 (14)	11.5 (12)	8.2 (6)
Lebanon	1706	1.2%	675 (62)	3.2 (31)	2.7 (81)	3.5 (55)
South Africa	1558	1.1%	645 (64)	0.8 (99)	4.9 (55)	NA
Guinea-Bissau	1340	0.9%	30 (175)	0 (152)	0.6 (130)	1 (139)
Canada	1299	0.9%	5741 (8)	2.1 (61)	9.3 (19)	2.7 (75)
Italy	1293	0.9%	3032 (23)	4.1 (9)	0.3 (145)	3.4 (60)

NA=No data available. *From Sept 1, 2013, to Dec 31, 2013. †2007–12 estimates from World Bank.

Table 3: Top 20 final destination countries of individuals initiating air travel from within Guinea, Liberia, and Sierra Leone and corresponding indicators of health system capacity

incur important opportunity costs. Moreover, the short flight durations out of affected countries, compared with the much longer incubation period of Ebola virus, indicates that if exit screening from affected countries were implemented effectively, the incremental gains from additional entry screening would be negligible. On Aug 8, 2014, the WHO proposed the use of exit screening.¹⁰ However, since exit screening is likely to further draw on valuable health and human resources from resource-poor countries in the midst of an emergency,^{11,12} support from the international community will be necessary to effectively implement these recommendations. For maximum efficacy, any screening programme should be coupled with strategies for the early detection of imported cases.

Although not directly assessed in this study, educational and communication strategies could be used to further reduce the risk of international spread of Ebola virus or to rapidly identify new imported cases. These strategies could include advice for individuals before travelling, with emphasis on international aid workers and foreign-born diaspora populations returning home to visit friends and relatives in affected areas. In some cases, international aid workers have agreed to a self-imposed 21-day monitoring period post-return from affected countries.^{13,14} Travellers

Panel: Research in context

Systematic Review

We searched Medline for relevant published articles on the current Ebola epidemic, the role of commercial air travel in the international spread of infectious diseases, and the 2005 International Health Regulations in relation to global epidemic threats. We used the terms "Hemorrhagic Fever, Ebola" OR "Air Travel" OR "International Health Regulations" OR "World Health" using the Medline database from January, 1996, to September, 2014. We also searched for online media related to the current Ebola epidemic using Google News, focusing on articles describing flight cancellations by commercial airlines and travel restrictions implemented by countries not experiencing Ebola activity. Finally, we searched the WHO website for Ebola Situation Updates and Ebola Response Roadmap documents) as well as the US Centers for Disease Control and Prevention website for guidance documents and updates.

Interpretation

Responding to the 2014 west African Ebola epidemic, this Article adds to the current body of knowledge by estimating the potential for, and most likely international pathways of Ebola virus spread, using global empirical data for commercial air traffic flows at the level of flight routes and individual traveller flight itineraries. These data, along with indicators of health-care capacity can help countries and the international community to better assess the potential effect of Ebola virus outside of Guinea, Liberia, and Sierra Leone, the three countries with current intense and widespread transmission. The Article also compares the relative efficiency of screening airline travellers as they depart these countries versus screening travellers as they arrive in airports worldwide. These analyses could assist countries in making decisions that balance their risks from importations of Ebola virus against the potential harms to Ebola-affected countries that could occur by disrupting international travel and trade, as required under the 2005 International Health Regulations.

For Ebola updates from WHO
see <http://www.who.int/csr/disease/ebola/en/>

For Ebola updates from the CDC
see <http://www.cdc.gov/vhf/ebola/>

visiting friends and relatives might also be at increased risk of exposure to Ebola virus, for example if they are visiting ill relatives or attending funerals.¹⁵

In addition to the use of air traffic patterns to identify global geographies at increased risk of Ebola virus importation, public health officials could make use of national demographic data to proactively engage foreign-born diaspora populations from countries currently affected by Ebola virus. Targeted programmes to inform and educate populations on how to detect symptoms and avoid infection could be explored. For example, the Liberian man with Ebola virus disease who travelled to Nigeria was planning to return home to Minneapolis, home to the largest Liberian population in the USA.¹⁶ Such demographic data, however, must be used responsibly and preventatively to target educational efforts and not to stigmatise foreign-born populations.

Our study is limited by the absence of demographic data for air travellers or their intended purpose for travel, which is related to the risk of disease acquisition. For example, most business travellers or airline personnel travelling to or from the region would be unlikely to have direct contact with blood or body fluids from infected people, whereas this contact might be more likely for foreign health-care workers involved in epidemic response, particularly if breaches in infection control occur. Because of the absence

of such data, we assumed that the risk of exposure to Ebola virus was uniform across the entire population and similar for travellers and non-travellers. This assumption might inflate our risk estimates since air travel is generally confined to higher socioeconomic groups who might be at lower risk of exposure than people in low socioeconomic groups. Conversely, our risk estimates could be underestimated, since we did not account for under-reporting of cases. Finally, our estimates of traveller flows were based on historical data and might not portray the most current patterns of travel, which are continuously evolving because of changes in airline flight cancellations, imposed border closings, and global travel behaviours. Results from an analysis⁷ of global travel behaviours during the H1N1 influenza pandemic showed that the volume of air traffic into Mexico decreased by about 40% at the height of the pandemic. Although our model of Ebola virus exportations is simple, readers can use the data provided (table 2) to build their own scenarios as Ebola virus epidemic conditions progress by updating or projecting active case counts or traveller volumes, or both. Finally, our analysis does not take into consideration ground travel, which is an important source of population mobility within this region, and is likely to be associated with local transmission, as seen with the recent imported case into Senegal.¹⁸ Although this limitation restricts our ability to model risks of spread within currently affected countries, and to some extent those sharing a contiguous land border, our analysis is more oriented to a worldwide perspective.

The extremely high virulence of Ebola virus, the absence of antiviral drugs or vaccines that have been proven to be safe and effective, and the recorded instances of international spread of Ebola virus infection via air travel to Lagos, Nigeria, and Dallas, USA, have led some countries to try and mitigate their risks of disease importation by restricting air travel.^{19,20} Since the most proactive and preventive approach to minimise risks to the global community involves control of the epidemic at its source, excessive constraints in connectivity could have severe economic consequences that could destabilise the region (several countries have only recently recovered from long civil wars),²¹ and possibly disrupt crucial supply chains of food and other essential services.²² Our analysis aims to help countries balance these competing risks in the context of their capacity to effectively detect and manage Ebola virus importations.

Countries have been screening travellers arriving at their borders for centuries to protect their own health, security, and economic interests. However, in a world where the benefits of interconnectedness and the risks of interdependence are deeply intertwined, public health interventions to global threats made by individual countries must use the best available evidence to be "commensurate with and restricted to public health risks and avoid unnecessary interference with international traffic and trade."⁴

Contributors

IIB, MIC, JM, and TT contributed to the design and analysis of the study, along with preparation of and edits to the final version of the report. MSC made significant content contributions to the initial draft of the manuscript and edits to the final draft of the report. JSB, SH, AA, and AT contributed epidemiological data pertaining to Ebola and made significant content contributions and edits to the final report. NP, SA, JWY, DMcF, and MG made significant content contributions and edits to the final report. WH, AN, and IIB did all statistical analyses of air traffic data and helped prepare the final version of the report. KK led the study from its initial design to the preparation of the first and last drafts of the report.

Declaration of interests

KK is the founder of BioDiaspora Inc, a social benefit corporation that models global infectious disease threats. IIB is a consultant to BioDiaspora and MIC is currently on secondment to BioDiaspora.

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