An integrative review of the limited evidence on international travel bans as an emerging infectious disease disaster control measure

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ABSTRACT

In our increasingly interconnected world, the potential for emerging infectious diseases (EIDs) to spread globally is of paramount concern. Travel bans—herein defined as the complete restriction of travel from at least one geographic region to at least one other international geographic region—are a potential policy solution to control the global spread of disease. The social, economic, and health-related consequences of travel bans, as well as the available evidence on the effectiveness of travel restrictions in preventing the global spread of influenza, have been previously described. However, the effectiveness of travel bans in reducing the spread of noninfluenza EIDs, characterized by different rates and modes of transmission, is less well understood. This study employs an integrative review approach to summarize the minimal evidence on effectiveness of travel bans to decrease the spread of severe acute respiratory syndrome (SARS), Middle Eastern respiratory syndrome (MERS), Ebola virus disease (EVD), and Zika virus disease (ZVD). We describe and qualify the evidence presented in six modeling studies that assess the effectiveness of travel bans in controlling these noninfluenza EID events. We conclude that there is an urgent need for additional research to inform policy decisions on the use of travel bans and other control measures to control noninfluenza EIDs in advance of the next outbreak.

Key words: emerging infectious diseases, SARS, Zika, Ebola, control measure, policy, travel bans, MERS

INTRODUCTION

In light of increased global travel and trade, a threat anywhere in the world has the potential to be a threat to the entire global community. Emerging infectious diseases (EIDs) are infectious diseases with human incidence that threatens to increase, or has increased, in the past twenty years. Restrictions of travel from certain geographic regions may be used as a policy tool to limit or prohibit people’s movement across geographic boundaries or borders. Travel bans, or the complete restriction of travel from at least one geographic region to at least one other international geographic region, are among the most austere travel restrictions. Travel bans may be implemented through visa bans based on nationality; bans on direct flights from impacted countries; or complete bans on anyone (regardless of nationality) entering a country that spent time in an impacted country based on the time period they were in the country, time since they left that country, intracountry activities, disease status, or other factor.

The International Health Regulations (IHR), an international instrument that binds all 194 World Health Organization (WHO) state parties, aim to protect nations from diseases that have the potential to transcend borders and yield global impacts. The IHR provide nations with autonomy 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.” Thus, as a matter of global health law and policy, the
potential effectiveness of travel bans and the international spread of disease must be considered relative to their travel and trade consequences. Practically, these restrictions should not be put into place without scientific evidence, or in the absence of a WHO recommendation.  

The potential economic, social, and political impacts of travel bans have been well described. These include propagation of stigma associated with an EID, interference with the rights of affected individuals, and impacts on the movement of healthcare supplies necessary to respond to the disease itself. During the 2014 Ebola virus disease (EVD) outbreak, the WHO discouraged the use of travel bans because of their potential: to create a false sense that the disease was being controlled; decrease the number of healthcare workers volunteering in affected countries; and negatively impact the economy and exacerbate humanitarian hardship secondary to reductions in essential trade, including food, fuel, and healthcare equipment. Moreover, travel bans may have adverse impacts on health secondary to the fear of accessing treatment among those who do not comply with the ban. For example, in 1987, individuals with human immunodeficiency virus (HIV) were prohibited from entering the United States. Infected individuals could only apply for a waiver to enter the United States for 30 days upon visiting a US embassy and disclosing their status to employees, who could have been friends or neighbors. It was reported that individuals did not disclose their status in order to enter the United States, and subsequently did not bring their medications. Moreover, immigrants residing in the United States illegally were reported not to seek treatment for fear of deportation, thereby enhancing the potential for increased disease transmission rather than minimizing it.  

Despite these types of potential consequences, travel bans have been discussed as a possible policy tool to restrict the geographic spread of disease and minimize its global impact. Despite WHO recommendations, 42 countries banned entry of, and another 15 applied exclusions or substantial restrictions to, foreigners departing a country with widespread EVD transmission. There have since been calls for better partnerships among politicians, scientists, and the media to facilitate the translation of scientific evidence to inform policy and communication during responses to such crises.  

For policy makers to make more informed decisions about implementing travel bans in the face of their tremendous potential costs, it is imperative to understand the existing evidence on their effectiveness to minimize the spread of noninfluenza EIDs to unaffected geographic areas. A systematic review of the literature of travel restrictions in influenza control found that the available evidence does not support their use for the rapid containment of influenza. Yet, the evidence on the effectiveness of travel bans on preventing the global spread of noninfluenza EIDs, with different modes, rates, and impacts of transmission, has yet to be systematically compiled or synthesized. In response, this review of the literature aims to assemble, synthesize, and critically analyze the quality of available evidence on the use of travel bans to reduce geographic spread of EIDs other than influenza. Specifically, we explore the literature around travel bans for four twenty first century EIDs of international concern for which the United States Centers for Disease Control and Prevention issued travel guidance, information, or restrictions: severe acute respiratory syndrome (SARS), Middle Eastern Respiratory Syndrome (MERS), EVD, and Zika virus disease (ZVD).  

METHODS  

An integrative literature review was conducted to identify and summarize prior research on the use of travel bans to reduce the geographic impact of MERS, SARS, EVD, and ZVD and assess the type and quality of evidence.  

Based on the research objective, the investigators generated a series of search terms to systematically identify relevant literature in the PubMed database. These search terms were refined based on the results of preliminary searches and discussion with an institutional librarian familiar with the study topic. Final search terms were placed in three categories (Table 1), and all combinations incorporating one search term from each category were used to identify articles for review. The investigators purposively employed a broad search strategy since limited literature on this topic was anticipated.
Inclusion and exclusion criteria

Articles were included if they were written in English and explored the use of travel bans to control the international spread of SARS, MERS, EVD, or ZVD through empirical research or modeling. Travel bans were defined as the complete restriction of travel from at least one geographic region to at least one other international geographic region. Articles were excluded if they: addressed the use of travel restrictions other than travel bans (eg, entry screening, isolation/quarantine or restricted movement of only individuals presumed to be exposed or infected); addressed the use of travel bans in controlling the international spread of diseases other than SARS, MERS, EVD, or ZVD; addressed the domestic/intranational use of travel bans; or did not present findings from empirical research or modeling.

Two investigators (NAE and LR) independently reviewed article titles relative to the inclusion and exclusion criteria. Results were compared, and discrepancies were adjudicated through consensus building discussion. Two investigators, including one from the title review team (NAE and LMS), then independently reviewed the abstracts of the remaining articles relative to the inclusion criteria. Results were compared, and discrepancies were again adjudicated through consensus building discussion.

One investigator, who participated in both the title and abstract reviews, reviewed the remaining articles in their entirety (NAE). The reference list of each included article was also reviewed to identify additional sources of relevant information.

The following elements were abstracted from the included articles (NAE):

- Methods
- Data source
- Findings
- Limitations
- Additional relevance to practice (if applicable)

Abstracted data were synthesized to identify commonalities, differences, and gaps in approach, methods, findings, and practical relevance. Synthesized data were reviewed for accuracy (LMS).

RESULTS

In total, 2,006 unique articles were initially identified (Table 2) through searches conducted in June 2017 and March 2018. Through title review, 1,799 articles were excluded. Of the 206 articles that underwent abstract review, 121 were excluded. Of the 86 articles that underwent full text review, six articles were determined to meet inclusion criteria. All included studies employed models or simulations,

Table 1. Search terms by category

<table>
<thead>
<tr>
<th>Category 1: Disease</th>
<th>Category 2: Travel</th>
<th>Category 3: Control strategy</th>
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<tbody>
<tr>
<td>EVD</td>
<td>Travel</td>
<td>Restriction</td>
</tr>
<tr>
<td>Ebola</td>
<td>Transport</td>
<td>Advisory</td>
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<tr>
<td>MERS</td>
<td>International</td>
<td>Ban</td>
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<tr>
<td>Middle East Respiratory Syndrome</td>
<td>Border</td>
<td>Control</td>
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<tr>
<td>SARS</td>
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<td>Risk</td>
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<tr>
<td>Severe Acute Respiratory Syndrome</td>
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<tr>
<td>Zika</td>
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Note: Searches used all combinations incorporating one search term from each category.
and disease-specific evidence identified was limited to EVD\textsuperscript{21-25} and SARS\textsuperscript{26} (Table 3).

**Ebola virus disease.** Mathematical modeling and simulation results provide limited evidence to support conclusions about the impact of travel bans on the reduction or delay of international EVD spread. Using historic epidemic parameters and implemented international flight restrictions, Bogoch et al. developed a model to estimate EVD case exportation from West Africa during September 2014’s EVD outbreak.\textsuperscript{21} They concluded that an average of 2.8 infected travelers would still exit the affected countries of Guinea, Liberia, and Sierra Leone per month, mostly with destinations in low and lower middle income countries. The results demonstrate that travel bans in place during a real-world event would not completely stop the exit of infected individuals. The authors recommended exit screening from affected countries as the most efficient way of screening travelers during an outbreak or epidemic. The article did not discuss the number of infected travelers who would have left Guinea, Liberia, and Sierra Leone per month if travel bans were not in place.\textsuperscript{21}

Gomes et al. used a stochastic epidemiologic model known as the Global Epidemic and Mobility Model to simulate the global spread of EVD.\textsuperscript{22} The study included an analysis of the impact of an 80 percent reduction of airline traffic. The authors found that this reduction would significantly reduce the probability of EVD case importation for a short period of time; as the probability of case importation increased with time, the travel reductions resulted in a three to four week delay of case importations. Moreover, the study found that the size of an EVD outbreak cluster linked to an imported case would be very small (less than six), and large outbreaks from an imported case— involving more than ten individuals—were considered to be possible but unlikely. The study uses data from the 2014 EVD outbreak, assumes a single disease dynamic across all three affected countries, and a constant rate of transmission. In addition, while the study used detailed data on air traffic flow, it acknowledged limited data were available on the demographics of travelers, which would introduce heterogeneity into the model that could improve accuracy.\textsuperscript{22}

Poletto et al. also used the Global Epidemic and Mobility Model to test the effect of travel reductions resulting from airline cancellations and country-level bans as of August 31, 2014 to quantify the effect of travel bans on the importation of EVD cases outside of West Africa.\textsuperscript{23} They conclude that a 60 percent reduction in air traffic would delay the importation of EVD cases from a few days to a few weeks, with 56 percent of countries receiving less than a one-month delay. The authors acknowledge that fear, not accounted for in the model, may have further decreased travel. Additional limitations include the possibility of incomplete information on air traffic restrictions and inability to access primary sources of information. In response to uncertainty, the authors assumed the largest traffic reduction possible to achieve the “best case” scenario in delay time.\textsuperscript{23}

Otsuki et al. used EVD case importation and air network data to retrospectively model the effectiveness of travel restrictions on disease importation based on effective distance between countries.\textsuperscript{24} A 75 percent travel reduction resulted in a <20 percent relative risk reduction (effectiveness) of case importation. Risk reductions were geographically specific, and the model was developed based on a total of six case importations, four of which were medical evacuations for treatment. The study was further limited by the lack of individualized data, lack of consideration of land and sea crossings, and the assumption than an exporting individual is randomly selected from a source country. The authors note that capacity building at the local level is more critical for effective containment.\textsuperscript{24}

### Table 3. Included articles

<table>
<thead>
<tr>
<th>Citation</th>
<th>Methods</th>
<th>Included EID</th>
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<tbody>
<tr>
<td>Bogoch et al.\textsuperscript{21}</td>
<td>Model simulation</td>
<td>EVD</td>
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<tr>
<td>Gomes et al.\textsuperscript{22}</td>
<td>Model simulation</td>
<td>EVD</td>
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<tr>
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<tr>
<td>Otsuki et al.\textsuperscript{24}</td>
<td>Model simulation</td>
<td>EVD</td>
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<tr>
<td>Cope et al.\textsuperscript{25}</td>
<td>Model simulation</td>
<td>EVD</td>
</tr>
<tr>
<td>Hufnagel et al.\textsuperscript{26}</td>
<td>Model simulation</td>
<td>SARS</td>
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Cope et al. employed two models to assess the risk of EVD importation into Australia in light of the country’s October 27, 2014 announcement that it would refuse or cancel visas from affected countries using international flight data and WHO outbreak data as of October 17, 2014 and December 3, 2014. The first, a discrete-time stochastic susceptible-exposed-infectious-removed model, assumes EVD remained confined to Guinea, Liberia, and Sierra Leone. The model predicted the cumulative risk of importation to Australia as of July 1, 2015 to be 0.34 if travel remains unchanged; 0.19 when transport levels from West Africa are reduced by 50 percent; 0.16 when visas from West Africa are no longer granted and reentry from West African countries is restricted to only Australian residents; and 0 when the EVD contact rate within West Africa is reduced by 20 percent. Under historic traffic levels from West Africa to Australia, and epidemic parameters and initial conditions as reported on October 17, 2014, the probability of a case entering Australia by April 1, 2015 was 0.97. However, results were significantly different using parameters based on conditions reported on December 3, 2014 (probability = 0.09). Similarly, the probability of a case entering within 200 days of October 17, 2014 was 1.00, compared to a probability of 0.30 within 200 days of December 3, 2014. The authors attribute these strong differences to control measures employed in West Africa and more accurate data (eg, by including only confirmed cases in counts).

The second, global model was used to assess risk of importation to Australia, including from places that did not currently have an outbreak, through the global flight network. Spread within each individual country was modeled using the susceptible-exposed-infectious-removed model and contact rates were estimated based on country income level to account for ability to mitigate spread. They found cumulative risk of importation to Australia as of July 1, 2015 to be 0.12. However, zero EVD cases were predicted to enter Australia when the rate of air traffic leaving infected countries was decreased by 50 percent for each country that experienced at least 100 cases.

The authors conclude that efforts to control disease in host countries, as well as any countries that have secondary impacts, are the best way to reduce risk of importation to Australia. The authors also suggest that entry may be less susceptible to control measures over time. Both of Cope’s models use a conservative mortality rate of 50 percent and make decisions about other constructs (eg, latency period), despite discrepancy in the literature. The models also assume that disease and transportation dynamics would be consistent, use WHO outbreak numbers which have been criticized as underreporting cases, and do not account for land/sea entry. The generalizability of the implications may be limited as Australia’s remote island geography allows for unique detection of entry/exit.

Severe acute respiratory syndrome. A single modeling study describing the impacts of travel bans on the spread of SARS was identified. Hufnagel et al. introduced a probabilistic model combining local disease dynamics and worldwide transport, using national and international civil aviation traffic with flight data among the 500 largest airports by passenger capacity. The model simulates two travel ban strategies on the 2003 SARS outbreak (using WHO data on SARS cases). The authors find that isolation of 2 percent of the largest cities is shown to reduce the proportion of individuals who need to be vaccinated to prevent the epidemic from spreading from 74.58 percent to 37.50 percent but the model exclusively uses air transport data and does not account for land or sea routes. Moreover, it does not account for behavior change in response to city isolation or airport closure, including individuals seeking alternative routes of transportation or points of departure if their home airport is closed. This approach does not account for the possibility that an infected or exposed person may depart from an alternative domestic air, land, or sea port. The authors suggest that this be used as “a reference point for the development and simulation of control strategies for future epidemics,” likely because of the small amount of travelers studied.

DISCUSSION

The results of this review indicate that there is limited evidence about the effectiveness of travel bans to minimize global EID spread, with disease-specific
evidence limited to EVD and SARS. This body of evidence is limited by conflation of travel bans, airline cancellations, and/or airport closures into travel restrictions or reductions across studies, and lack of comprehensive accounting for land and sea crossings or changes in traveler behavior in response to such closures, for example, by seeking an alternate transportation route or departure point.21-26

The models described herein use parameters based on prior outbreaks of disease, and these parameters may not be applicable in new contexts. Differences in disease contagiousness, individual variation, as well as severity of morbidity and mortality, may yield differences in the effectiveness of control measures such as travel bans.27,28 For example, disease transmissibility (commonly measured by the epidemiologic metric known as the basic reproduction number, R0) can be impacted by the onset and duration of contagiousness after a person becomes infected, the likelihood of contact between an infectious person or vector, and the contact rate.29,30 Thus, transmission rates are readily influenced by individual, social, behavioral, biologic, and environmental factors—including those related to the policy environment, built environment, and public health infrastructure.28,30 As such, transmission rates and associated impacts of travel bans may not be the same across outbreaks of the same pathogen, highlighting the need for rapid response research to create outbreak-specific models that can inform contentious and politically charged decisions with global impact.

Notably, all studies identified used models or simulations, and are not based on empirical research. Development of research questions, partnerships, and protocols in advance of the next noninfluenza EID event could facilitate rapid commencement of research and translation of research findings to inform travel ban-related decisions when the next disaster strikes.31 For instance, our study focused on four twenty-first century EIDs of international concern for which the United States Centers for Disease Control and Prevention issued travel guidance, information, or restrictions at the time of our literature review (June 2017). Yet, spikes in measles cases across the United States in 2018 and 201922 resulted in discussion of the use of the Centers for Disease Control and Prevention (CDC) and United States Department of Homeland Security's Do Not Board List (DNB),33 which allows public health officials to prevent travelers from boarding commercial airplanes departing for or from the United States,34 as a potential control measure to minimize spread in the popular media. This highlights the ability of EIDs to rapidly emerge, and the associated requirement for science preparedness to be able to learn about the impact of travel restrictions and other control measures during an outbreak to inform current and future response.

While our review is limited to international travel bans, additional lessons may be learned from research on intranational (ie, within country) travel bans. For example, using a stochastic model fit based on data from the first ten weeks of the 2003 SARS outbreak, a complete ban on travel across Hong Kong districts was estimated to have the potential to reduce further transmission by 76 percent, suggesting that intranational travel restrictions might be a useful control strategy.35 Camitz et al. also provided support for the efficacy of travel bans as a means of decreasing domestic, interlocal disease spread through a stochastic simulation model using survey data of travel patterns between municipalities in Sweden.36 The authors found that a travel ban of trips >50 km would significantly reduce the speed and geographic spread of EIDs when implemented with compliance levels of 70 percent or higher. The authors purport that their results may be applicable to other Western countries with similar motor vehicle use, although they do not apply the model internationally.36 However, these modeling studies do not fully account for changes in human behavior during a real world event.

Evaluation of the impact of ongoing travel restriction programs can also provide useful information about the efficacy of travel bans. For example, CDC's evaluations of the Do Not Board List have been limited to program performance evaluation and description of the individual trajectories of those subject to restriction, rather than the potential for broader impact of the program on disease control.33,37 Additional studies on the impact of this program on EID control, as well as legal analysis, could inform the potential for its expansion in the event of a future EID event of global significance.
As recently as the 2014 EVD pandemic, there was public support for travel bans and travel bans will likely continue to be considered as a policy tool to minimize the global spread of future EIDs other than influenza. Yet, given the significant potential social, economic, health, and political consequences of travel bans, any policy decision must be made with a consideration of tradeoffs and unintended consequences. As such, research is urgently needed to provide practitioners and scholars with an understanding of policy and legal considerations related to the use of travel bans in future emergencies, including commonalities among various laws related to the use of travel bans. Moreover, interpretation of the IHR’s granting of autonomy to member states to implement control measures that avoid unnecessary impacts to international travel and trade requires understanding the effectiveness of travel bans to facilitate interpretation of what is “unnecessary.”

Limitations. An integrative literature review allows for the incorporation of studies using diverse approaches and methodologies, providing for a comprehensive review of the available evidence on a subject. Well-designed integrative literature reviews can enhance evidence-based practice, which is a major goal of this translational research endeavor. Yet, some limitations remain. Given the health-specific nature of the topic, it was believed that indexed studies available through the PubMed database would serve as a comprehensive source for empirical and theoretical literature. However, it is possible that studies on this topic were published as part of multidisciplinary work in nonhealth related journals and were missed by our initial search strategy. In order to counter this potential limitation, the reference lists of included articles were reviewed to identify alternative sources of information. Moreover, work (eg, Brockmann et al.), published in the gray literature, and studies without explicit focus on travel bans (eg, models that may have tested the effects of travel bans as part of a sensitivity analysis) were not included in this review.

In addition, because the integrative review approach allows for the incorporation of studies using a variety of methods, it does not facilitate aggregation of study data to reach a conclusion about a particular question or topic. The small number of studies available on this topic further inhibits such aggregation. As such, this review does not provide any conclusions on the available evidence, but rather describes its relevance and limitations as they relate to the topic of the effectiveness of travel bans on EID spread.

Finally, this review specifically focused on studies that explicitly addressed travel bans, intentionally defined as the complete restriction of travel from at least one geographic region to at least one other geographic region. As such, this review does not incorporate evidence on the impact of travel volume on disease spread, or on the relative effectiveness of alternative travel restrictions (eg, entry screening, isolation/quarantine, or restricted movement of only individuals presumed to be exposed or infected).

CONCLUSIONS

There is limited research to support the use of travel bans to minimize the spread of four EIDs that have arisen during the twenty first century: MERS, SARS, EVD, and ZVD. Additional research is urgently needed to inform policy decisions on control measures that minimize the global spread of EIDs other than influenza, especially in light of the tremendous social, economic, and political impacts of their implementation.

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REFERENCES

