BMJ Open

Travel-related control measures to contain the COVID-19 pandemic: an evidence map

Ani Movsisyan ,[1,2] Jacob Burns ,[1,2] Renke Biallas,[1,2] Michaela Coenen,[1,2] Karin Geffert,[1,2] Olaf Horstick,[3] Irma Klerings,[4] Lisa Maria Pfadenhauer ,[1,2] Peter von Philipsborn ,[1,2] Kerstin Sell,[1,2] Brigitte Strahwald,[1,2] Jan M Stratil,[1,2] Stephan Voss,[1,2] Eva Rehfuess[1,2]

To cite: Movsisyan A, Burns J, Biallas R, *et al*. Travel-related control measures to contain the COVID-19 pandemic: an evidence map. *BMJ Open* 2021;**11**:e041619. doi:10.1136/bmjopen-2020-041619

► Prepublication history and additional supplemental material for this paper is available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2020-041619).

AM and JB are joint first authors.

Received 13 June 2020
Revised 09 November 2020
Accepted 03 March 2021

[1]Institute for Medical Information Processing, Biometry and Epidemiology, Ludwig Maximilians University Munich, Munich, Germany
[2]Pettenkofer School of Public Health, Ludwig Maximilians University Munich, Munich, Germany
[3]Heidelberg Institute of Global Health, Heidelberg University, Heidelberg, Germany
[4]Department for Evidence-based Medicine and Evaluation, Danube University Krems, Krems, Austria

Correspondence to
Dr Ani Movsisyan;
ani.movsisyan@ibe.med.uni-muenchen.de

ABSTRACT

Objectives To comprehensively map the existing evidence assessing the impact of travel-related control measures for containment of the SARS-CoV-2/COVID-19 pandemic.

Design Rapid evidence map.

Data sources MEDLINE, Embase and Web of Science, and COVID-19 specific databases offered by the US Centers for Disease Control and Prevention and the WHO.

Eligibility criteria We included studies in human populations susceptible to SARS-CoV-2/COVID-19, SARS-CoV-1/severe acute respiratory syndrome, Middle East respiratory syndrome coronavirus/Middle East respiratory syndrome or influenza. Interventions of interest were travel-related control measures affecting travel across national or subnational borders. Outcomes of interest included infectious disease, screening, other health, economic and social outcomes. We considered all empirical studies that quantitatively evaluate impact available in Armenian, English, French, German, Italian and Russian based on the team's language capacities.

Data extraction and synthesis We extracted data from included studies in a standardised manner and mapped them to a priori and (one) post hoc defined categories.

Results We included 122 studies assessing travel-related control measures. These studies were undertaken across the globe, most in the Western Pacific region (n=71). A large proportion of studies focused on COVID-19 (n=59), but a number of studies also examined SARS, MERS and influenza. We identified studies on border closures (n=3), entry/exit screening (n=31), travel-related quarantine (n=6), travel bans (n=8) and travel restrictions (n=25). Many addressed a bundle of travel-related control measures (n=49). Most studies assessed infectious disease (n=98) and/or screening-related (n=25) outcomes; we found only limited evidence on economic and social outcomes. Studies applied numerous methods, both inferential and descriptive in nature, ranging from simple observational methods to complex modelling techniques.

Conclusions We identified a heterogeneous and complex evidence base on travel-related control measures. While this map is not sufficient to assess the effectiveness of different measures, it outlines aspects regarding interventions and outcomes, as well as study methodology and reporting that could inform future research and evidence synthesis.

Strengths and limitations of this study

- ► We applied systematic and standardised methods at all stages and have produced a comprehensive evidence map of travel-related control measures for containment of the SARS-CoV-2/COVID-19 pandemic.
- ► For title/abstract and full-text screening, we developed guidance documents and conducted piloting exercises to ensure consistency among review authors; we additionally collected and clarified all uncertainties on a rolling basis through daily team calls.
- ► We conducted searches in three major health-related databases and two COVID-specific databases; however, it is likely that most studies assessing economic and social outcomes are found in other databases.
- ► The unspecific and inconsistent reporting of primary studies with regard to interventions, especially when a package of control measures was investigated, meant that determining eligibility, as well as summarising and mapping these studies, was challenging.
- ► We did not include travel warning or travel advice in the evidence map, which limits the scope of this map.

INTRODUCTION

In December 2019, the occurrence of the SARS-CoV-2 was reported in Wuhan, China. Over the next weeks, the virus and the associated respiratory disease referred to as COVID-19 spread further into China and other parts of Asia including Japan, South Korea and Thailand.[1] By mid-March 2020, when the WHO declared COVID-19 a global pandemic, cases had been observed in over 100 countries and territories across the globe.[2]

According to WHO, various travel-related control measures, such as entry/exit screening, travel bans to and/or from specific

areas within or between countries, and quarantine of travellers have since been implemented by most countries around the world to contain and mitigate the spread of SARS-CoV-2 and COVID-19.[3] Following the early-stage responses in Asian countries, strict measures, such as border closures and drastic reductions in airline travel, have been put into place in most countries around the world, starting in February 2020 and continuing into May 2020. While in the context of a rapidly evolving pandemic decisions often need to be made even in the absence of high quality evidence, efforts to identify and synthesise the best available evidence will help inform whether the currently implemented measures should be sustained, adapted or lifted. Where possible, decisions need to be based on evidence regarding the effectiveness of these measures in contributing to the control of the pandemic, as well as regarding the associated economic and social impacts. They will also need to take into account short-term and longer term costs, acceptability and feasibility of such measures.

Travel-related control measures have been assessed through systematic or narrative reviews in the context of previous epidemics and pandemics, such as influenza, severe acute respiratory syndrome (SARS-CoV-1/SARS) and Middle East respiratory syndrome (MERS-CoV/MERS). Regarding the containment of influenza, these reviews have examined the effectiveness of a broad set of measures,[4–6] as well as the effectiveness of specific measures, such as entry/exit screening[6 7]; they have also assessed the economic implications of various pharmaceutical and non-pharmaceutical interventions during influenza pandemics.[8 9] Effectiveness of measures, such as international travel bans and entry/exit screening, have also been examined in reviews of SARS and MERS.[7 10] To date and to the best of our knowledge, the evidence on travel-related control measures for the control of the current pandemic has not been systematically assessed.

In this paper, we aim to systematically identify and map the existing evidence assessing the impact of travel-related control measures (ie, border closures, travel restrictions and bans, entry and exit screening, quarantine/isolation of travellers crossing borders and multiple interventions combined) for containment of the SARS-CoV-2/COVID-19 pandemic, drawing on evidence from the current pandemic, as well as on evidence in relation to SARS, MERS and influenza. This evidence map was commissioned by the WHO to serve as an important resource for researchers and policymakers in providing an overview of the currently available evidence in relation to various travel-related control measures to contain the COVID-19 pandemic. In itself, the evidence map is not sufficient to assess the effectiveness of different measures. Instead, it provides an important basis for decisions regarding the need for and possibility to conduct primary research as well as more specific evidence synthesis (eg, regarding a specific category of control measures or a specific type of studies).

METHODS

Search strategy

We designed the evidence map in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) reporting guideline, and implemented the entire project within ten days (see online supplemental file S1) for the completed PRISMA-ScR checklist). We searched the following databases: (1) Ovid MEDLINE ALL (1946–present); (2) Embase.com (Elsevier); (3) Science Citation Index Expanded (1900–present), Social Sciences Citation Index (1900–present) and Emerging Sources Citation Index (2015–present) (Web of Science); (4) the US Centers for Disease Control and Prevention's COVID-19 Research Articles Downloadable Database (includes published articles, as well as grey literature, such as preprints) and (5) WHO COVID-19 Database (includes published articles only).

The initial search strategy was developed for MEDLINE (see online supplemental file S2) and further adapted for the other databases. All database searches were conducted up to 3 May 2020. The search strategies were designed and conducted by an experienced information specialist. The searches were conducted in English. Where database functionality allowed for it, we limited the search results to Armenian, English, French, German, Italian and Russian, based on the language capacity of the research team and considered studies for inclusion published in all of these languages. We also conducted forward and backward citation searches of all relevant (systematic) reviews identified through the database searches (see online supplemental file S3) up to 6 May 2020 in Scopus (Elsevier).

Eligibility criteria

We determined eligibility of studies based on the investigated population/context, intervention, outcome and study type.

Regarding the population/context, this evidence map draws on direct evidence from human populations susceptible to the current SARS-CoV-2/COVID-19, as well as indirect evidence from a set of other relevant respiratory infectious diseases. To help define a set of diseases that is most similar and relevant to COVID-19, we used the following criteria: (1) diseases of viral origin; (2) mode of transmission primarily airborne via droplets/aerosols (as well as person to person); (3) acute disease with the potential to cause an epidemic/pandemic; (4) similar clinical features (ie, non-specific febrile illness with the potential to develop into pneumonia and acute respiratory distress syndrome; difficult diagnosis based on clinical features during transmission-relevant phase, including the period prior to symptom development and during early-stage symptoms); and (5) unavailability of a vaccine and/or difficulty to contain an outbreak through vaccination. As a result, we considered:

- SARS-CoV-2/COVID-19.
- SARS-CoV-1/SARS.
- MERS-CoV/MERS.

- Influenza.

Studies in all other populations/contexts, including evidence on infectious diseases less relevant to the current SARS-CoV-2/COVID-19 pandemic (eg, avian influenza, Ebola, meningitis, HIV/AIDS, tuberculosis, dengue, plague, cholera, fever, smallpox, measles or Zika virus) were excluded.

Regarding the intervention, we considered travel-related control measures affecting human travel across national or subnational borders, specifically:

- Closure of borders (borders closed to entry and/or exit).
- Travel bans (suspension of flights, ground crossing, ship itineraries, refusal of entry or travel and visa suspension/denial) between countries and between regions and large cities within countries.
- Travel restrictions (ie, varying levels of travel reductions) between countries and between regions and large cities within countries).
- Entry/exit screening (eg, temperature measurement, health questionnaire, thermography, physical examination, laboratory tests, passive observation and/or follow-up quarantine) at airports, ports, land borders and train stations.
- Quarantine/isolation of travellers from affected regions (at borders, at designated institutions or at home).
- Any combination of the above measures and/or with other control measures (eg, combination of border closure and school closure).

All other interventions were excluded. This comprised those not directly related to travel (eg, community-based quarantine, hygiene measures and bans on mass gatherings), those related to the movement of animals or goods, travel warnings or travel advice issued by the WHO or national governments, situations affecting travel but not representing travel-related control measures (eg, school holidays) and those solely concerned with the effectiveness of laboratory tests rather than their implementation as part of an entry/exit screening procedure.

Regarding outcomes, we considered those assessing the quantitative impacts of the interventions on:

- Infectious disease outcomes (eg, number/proportion of cases, number/proportion of deaths, time to/delay in epidemic arrival or peak, reproduction number, healthcare demand and utilisation).
- Screening outcomes (eg, number/proportion of persons screened and number/proportion of those screened identified as cases).
- Other health outcomes (eg, psychosocial impact).
- Economic outcomes (eg, travel volumes, costs of measures implemented and losses to different economic sectors).
- Social outcomes (eg, stigmatisation/discrimination of foreigners, xenophobia and migration volumes).

All other outcomes, such as those on the human rights and legal implications of interventions, were excluded.

Regarding study types, we considered all types of empirical studies that quantitatively evaluate impact (eg, epidemiological, modelling, simulations and econometric studies). All other study types, including qualitative studies, diagnostic studies focused on test performance and non-empirical studies (eg, commentaries, narrative and systematic reviews) were excluded.

Study selection

After deduplication, all titles and abstracts were screened by one reviewer (shared among several team members), excluding only those studies that were clearly irrelevant. For all studies deemed potentially relevant or unclear at the title/abstract screening stage, one reviewer screened the full text. At this stage, a final decision regarding eligibility was made. We adopted a very inclusive approach: any unclear cases were discussed with a second reviewer, and remaining uncertainties were resolved with involvement of a third reviewer and/or the whole review team. In addition, all studies excluded at the full-text screening stage based on the intervention (ie, not addressing travel-related control measures) were double-checked by a second reviewer to make sure that no relevant studies were excluded.

We used Endnote to manage collection and deduplication of records. For title and abstract screening, we used Rayyan, a web-based application designed for citation screening for systematic reviews.[11] We documented reasons for the exclusion of full texts and reported those using Microsoft Excel.

For both the title/abstract and full-text screening stages, we developed screening guidance forms to ensure that all reviewers screen similarly and consistently. We discussed inconsistencies and challenges encountered within the review team, after having screened approximately 300 titles/abstracts and 50 full texts and subsequently refined the screening guidance. We additionally collected and clarified all uncertainties in screening on a rolling basis. These were discussed in daily online meetings to ensure consistency in screening across multiple reviewers and that any questions and comments were addressed.

Data extraction

One reviewer extracted study characteristics and data into the predefined categories of the data extraction form in Microsoft Excel (see online supplemental file S4). The extraction form was pilot-tested in the review team. The following categories were covered by the extraction form: population, setting and context; characterisation of the respiratory pathogen/disease (ie, SARS-CoV-2/COVID-19, SARS CoV-1/SARS, MERS CoV/MERS and influenza), types of interventions (eg, entry/exit screening, border closure, quarantine of travellers and travel bans), comparisons (where available), outcomes of interest (eg, health, economic and social impact) and study designs (eg, epidemiological study and modelling study).

Mapping

We charted the extracted data based on categories and present findings in a tabular, narrative or graphical manner. Most of these categories were defined a priori, while one category, namely, geographical setting, was adapted post hoc. Specifically, we sought to define, summarise and present clusters of studies based on the pathogen/disease (ie, SARS-CoV-2/COVID-19, SARS-CoV-1/SARS, MERS-CoV/MERS and influenza), type of intervention (border closure, entry/exist screening including follow-up measures, such as isolation of positive cases, travel ban, travel-related quarantine in the absence of entry/exit screening, travel restrictions and multiple travel-related control measures combined), timing of the intervention (ie, early phase, local transmission phase, postpeak phase and unclear phase), outcomes of interest (ie, infectious disease outcomes, screening outcomes, other health outcomes, economic and social outcomes) and study designs (eg, epidemiologic study and modelling study). All data presented in the tables, text and graphics were double-checked by a second reviewer with an emphasis on accuracy in reporting on populations, interventions and outcomes and in relation to consistency of presentation.

Patient and public involvement

Considering the time constraints and the nature of this research (ie, a rapid systematic evidence map), it was conducted without patient and public involvement.

RESULTS

Database searches yielded a total of 4928 unique records. Through snowballing of reviews identified through the database searches, we identified an additional 1700 studies. During the title/abstract screening stage, we excluded 4445 records as clearly irrelevant. We subsequently assessed the full texts of 483 records and excluded another 361 records. Overall, we included 122 studies in this evidence map (see online supplemental file S5 for the full list). Of these, 80 were journal articles, 41 were preprints and 1 was a report. Figure 1 provides an overview of our searching and screening procedures.

Characteristics of included studies

The 122 included studies were characterised by substantial heterogeneity in relation to the countries and populations targeted, the diseases addressed, the types of travel-related control measures examined (sometimes assessed against a range of other interventions to contain an epidemic/pandemic) and the numerous outcomes assessed. They comprise both studies that are inferential in nature and studies that are descriptive in nature, varying greatly in the specific methods applied; notably, many of the studies addressing COVID-19 were preprints. We summarise these aspects below and provide a description of each study in table 1.

Countries and settings

Included studies assessed interventions across the globe, including, according to WHO world regions, from the Western Pacific Region (WPR) (n=71), the Southeast Asia region (n=5), the region of the Americas (n=12), the European region (EUR) (n=8), and the African region (AFR) (n=2). None of the studies included in this evidence map was conducted in a country of the Eastern Mediterranean Region (EMR). The specific countries in which interventions were implemented are listed in table 1 (under

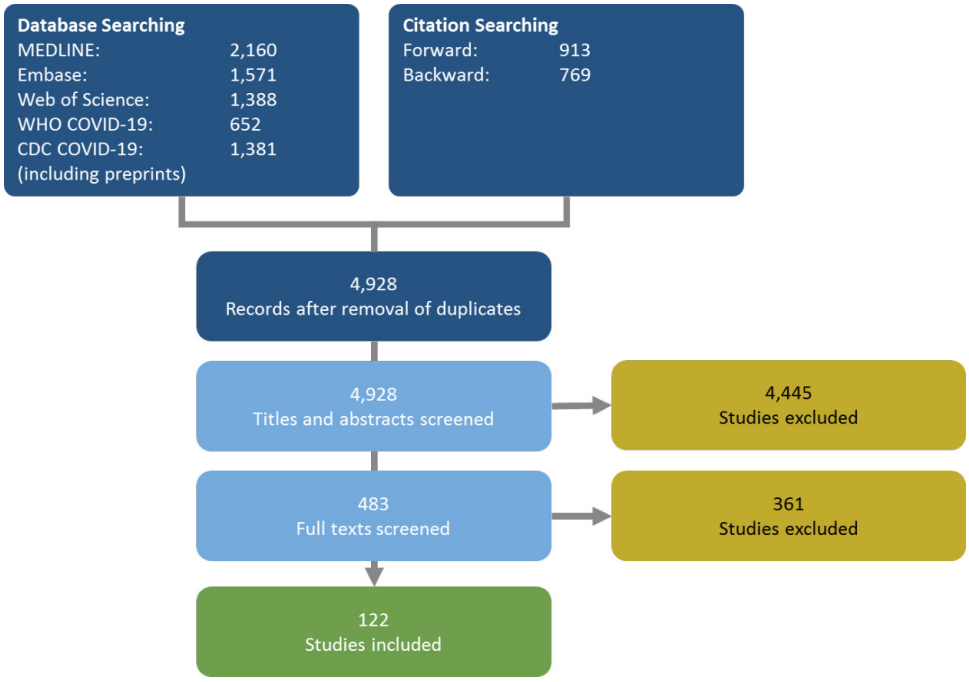

Figure 1 Flow chart of studies identified and included during different stages of searching and screening.

Table 1 Characteristics of included studies

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Adekunle 2020[14] (preprint)	Inferential	WPR	Island state	Australia	China, Iran, South Korea and Italy	COVID-19	Travel ban	Number or proportion of cases
Aleta 2020[15] (preprint)	Inferential	WPR	Non-island state	Regions within China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Anonymous 2003[16]	Descriptive	AMR	Non-island state	Vancouver, Toronto, other parts of Canada	All other countries	SARS	Entry/exit screening	Detection of high risk persons or cases
Anzai 2020[17]	Inferential	WPR	Non-island state	Multiple countries	China	COVID-19	Multiple travel-related control measures	Number or proportion of cases; temporal development of epidemic
Arima 2020[18]	Descriptive	WPR	Island state	Japan	China	COVID-19	Entry/exit screening; travel-related quarantine	Detection of high risk persons or cases
Arino 2007[19]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Hypothetical infectious disease	Travel restriction	Number or proportion of cases
Bajardi 2011[20]	Inferential	All	Non-island state	All countries	Mexico	Influenza (H1N1 2009 pandemic)	Travel ban; travel restriction: land	Temporal development of epidemic
Banholzer 2020[21] (preprint)	Inferential	EUR, WPR and AMR	Non-island state	Austria, Australia, Belgium, Canada Denmark, France, Finland, Italy, Norway, Switzerland, Sweden, Spain and USA	All other countries	COVID-19	Border closure	Number or proportion of cases
Bolton 2012[22]	Inferential	WPR	Non-island state	Mongolia	Neighbouring countries	Influenza (H1N1 2009 pandemic)	Travel restriction	Number or proportion of cases
Boyd 2017[23]	Inferential	WPR	Island state	New Zealand	All other countries	Hypothetical infectious disease	Border closure	Costs
Boyd 2018[24]	Inferential	WPR	Island state	New Zealand	All other countries	Hypothetical infectious disease	Border closure	Costs
Caley 2007[25]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza	Entry/exit screening; travel restriction: air	Detection of high risk persons or cases; temporal development of epidemic

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Chang 2020[26] (preprint)	Inferential	WPR	Island state	Taiwan	Different cities in Taiwan	COVID-19	Travel restriction	Number or proportion of cases; temporal development of epidemic
Cheng 2020[27]	Descriptive	WPR	Island state	Taiwan	China	COVID-19	Exit/entry screening; travel-related quarantine	Number or proportion of cases
Chinazzi 2020[28]	Inferential	WPR	Non-island state	Other regions of China, all other countries	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Chiyomaru 2020[29] (preprint)	Inferential		Non-island state	Multiple countries	Multiple countries	COVID-19	Travel ban	Number or proportion of cases
Chong 2012[30]	Inferential	WPR	Quasi-island state	Hong Kong	All other countries	Influenza (H1N1 2009 pandemic)	Travel restriction: land, air and maritime	Number or proportion of cases; temporal development of epidemic
Chung 2015[31]	Inferential		Non-island state	Multiple countries	Multiple countries	SARS; 2006 Avian influenza; 2009 Swine influenza H1N1	Travel restriction: air	Industry impact
Ciofi 2008[32]	Inferential	EUR	Non-island state	Italy	Italy and all other countries	Influenza	Travel restriction: air	Number or proportion of cases; temporal development of epidemic
Clifford 2020[33] (preprint)	Inferential	n.a.	Hypothetical	Hypothetical	All other countries	COVID-19	Entry/exit screening	Detection of high risk persons or cases; temporal development of epidemic
Colizza 2007[34]	Inferential	All	Non-island state	All countries	All countries	Influenza	Travel restriction: air	Number or proportion of cases; temporal development of epidemic
Cooper 2006[35]	Inferential	All	Non-island state	All countries	All countries	Influenza	Travel restriction: air	Temporal development of epidemic

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Costantino 2020[36] (preprint)	Inferential	WPR	Island state	Australia	All other countries	COVID-19	Travel ban	Number or proportion of cases; number or proportion of deaths; temporal development of epidemic
Cowling 2020[37]	Inferential	WPR	Quasi-island state	Hong Kong	China, South Korea, Iran, Italy and affected regions in France, Germany, Japan, and Spain, Schengen Area, Macau and Taiwan.	COVID-19	Travel restriction: air and land; travel ban; travel-related quarantine; border closure	Reproduction number; number or proportion of cases; acceptability
Dandekar 2020[38] (preprint)	Inferential	WPR, EUR and AMR	Island state; quasi-island state	China, Italy, South Korea and USA	All other countries	COVID-19	Multiple travel-related control measures	Reproduction number
de Vlas 2009[39]	Descriptive	WPR	Non-island state	Regions of China	Regions of China	SARS	Travel-related quarantine	Reproduction number
Ediriweera 2020[40] (preprint)	Inferential	SEAR	Island state	Sri Lanka	All other countries	COVID-19	Multiple travel-related control measures; travel-related quarantine	Number or proportion of cases; healthcare resources
Eichner 2009[41]	Inferential	WPR	Hypothetical	Hypothetical	All other countries	Influenza (pandemic)	Travel restriction: air	Probability of epidemic
Epstein 2007[42]	Inferential	All	Non-island state	All countries (focus on USA)	All countries	Influenza	Travel restriction: air	Number or proportion of cases; temporal development of epidemic
Fang 2020[43] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Ferguson 2006[44]	Inferential	AMR	Island state; quasi-island state	USA and UK	Countries connected by air traffic	Influenza (pandemic)	Border controls; travel restrictios	Number or proportion of cases; temporal development of epidemic

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Flahault 2006[45]	Inferential	n.a.	Quasi-island state	52 international cities and surrounding regions	Cities connected via air traffic	Influenza (pandemic)	Travel restriction: air	Number or proportion of cases
Fujita 2011[46]	Inferential	WPR	Island state	Regions in Japan	USA, Canada and Mexico	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Detection of high risk persons or cases
Germann 2006[47]	Inferential	AMR	Non-island state	USA		Influenza (pandemic)	Travel restriction: air	Number or proportion of cases
Glass 2006[48]	Inferential	n.a.	Non-island state	Non-infected region	Non-infected region	SARS	Entry/exit screening	Probability of epidemic
Gostic 2020[49]	Inferential	All	Island state	All countries	All countries	COVID-19	Entry/exit screening	Detection of high risk persons or cases
Gostic 2015[50]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	SARS; MERS; influenza (H1N1 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases
Goubar 2009[51]	Inferential	EUR	Island state; quasi-island state	Germany and UK	China and Hong Kong	SARS	Entry/exit screening	Number or proportion of cases
Gunaratnam 2014[52]	Descriptive	WPR	Island state	Australia	All other countries	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases
Hale 2012[53]	Descriptive	WPR	Island state	New Zealand	Initially USA, Canada, Mexico, then all other countries	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases
Hamidouche 2020[54] (preprint)	Inferential	AFR	Non-island state	Algeria	All neighbouring and connected (via air) countries	COVID-19	Border closure; travel ban; travel-related quarantine	Number or proportion of cases; reproduction number
He 2020[55] (preprint)	Inferential	WPR	Island state; quasi-island state	China, South Korea, Italy and Iran	Italy (Lombardy, Veneto, Emilia-Romagna, Piedmont and Marche) and China (Zhejiang).	COVID-19	Multiple travel-related control measures	Number or proportion of cases; temporal development of epidemic
Hien 2010[56]	Inferential	WPR	Non-island state	Vietnam	Countries with confirmed cases of 2009 H1N1	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Hollingsworth 2006[57]	Inferential	n.a.	Hypothetical	Hypothetical	Countries connected via air traffic	SARS and influenza	Travel restriction: air	Number or proportion of cases; temporal development of epidemic
Hossain 2020[58] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Temporal development of epidemic
Hou 2020[59] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases; reproduction number
Hsieh 2007[60]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza (endemic)	Travel ban	Reproduction number
Hsieh 2006[61]	Inferential	WPR	Island state	Taiwan	Countries with SARS cases	SARS	Travel-related quarantine	Number or proportion of cases
Jia 2020[62]	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases; other
Jiang 2020[63] (preprint)	Inferential	WPR	Non-island state	Regions of China	Regions of China	COVID-19	Multiple travel-related control measures	Other
Kerneis 2008[64]	Inferential	n.a.	Non-island state	52 international cities and surrounding regions	52 international cities and surrounding regions	Influenza (pandemic)	Travel restriction: air	Number or proportion of cases; temporal development of epidemic
Khan 2013[65]	Inferential	AMR	Non-island state	Other countries	Mexico	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases; other
Kim 2017[66]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Hypothetical infectious disease	Entry/exit screening	Reproduction number
Kong 2020[67] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19 and influenza	Multiple travel-related control measures	Number or proportion of cases
Kraemer 2020[68]	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Kuo 2009[69]	Descriptive	WPR	Island state	Taiwan	All affected countries (eg, Mexico, USA and Canada)	Influenza (H1N2 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases
Lai 2020[70] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Lam 2011[71]	Inferential	WPR	Quasi-island state	Hong Kong	All other countries	Influenza (H1N1 2009 pandemic)	Travel restriction	Probability of epidemic; temporal development of epidemic
Lau 2020[72] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases; temporal development of epidemic
Lee 2012[73]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza (H1N1 2009 pandemic)	Travel restriction	Temporal development of epidemic
Li 2020[74] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Lin 2020[75] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Reproduction number; other
Linka 2020[76] (preprint)	Inferential	EUR	Non-island state	All European countries	All European countries	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Liu 2006[77]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Hypothetical infectious disease	Entry/exit screening	Reproduction number
Liu 2020[78]	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Liu 2020a[79] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Cities outside of Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Malmberg 2020[80] (preprint)	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Hypothetical infectious disease	Travel restriction; travel-related quarantine	Probability of epidemic
Malone 2009[81]	Inferential	AMR	Non-island state	USA	Asia	Influenza (pandemic)	Entry/exit screening	Detection of high-risk persons or cases; number or proportion of cases; number of deaths
Mandal 2020[82]	Inferential	SEAR	Non-island state	India	China, Hong Kong, Singapore, Thailand, Japan, South Korea, Iran and Italy	COVID-19	Entry/exit screening	Temporal development of epidemic; number or proportion of cases

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Marcelino 2012[83]	Inferential	All	Non-island state	All countries	Mexico city	Influenza (pandemic)	Travel restriction: air	Number or proportion of cases
Mbuvha 2020[84] (preprint)	Inferential	AFR	Non-island state	South Africa	South Africa and the all other countries	COVID-19	Travel ban	Number or proportion of cases; temporal development of epidemic
Mondal 2020[85] (preprint)	Inferential	SEAR	Non-island state	India	India	COVID-19	Travel ban	Number or proportion of cases
Moriarty 2020[86]	Inferential	WPR and AMR	Non-island state	Japan, USA, home countries of cruise ship passengers	Home countries of cruise ships	COVID-19	Travel-related quarantine	Detection of high risk persons or cases
Mummert 2013[87]	Inferential	AMR	Non-island state	USA	Mexico	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Number or proportion of cases
Muraduzzaman 2018[88]	Descriptive	SEAR	Non-island state	Bangladesh	Saudi Arabia	MERS	Entry/exit screening	Detection of high-risk persons or cases
Nakata 2015[89]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Hypothetical infectious disease	Travel restriction	Reproduction number
Nigmatulina 2009[90]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza	Travel restriction	Number or proportion of cases
Nishiura 2009[91]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza (pandemic)	Travel-related quarantine	Detection of high-risk persons or cases
Odendaal 2020[92] (preprint)	Inferential	AMR	Non-island state	USA	China and other affected countries	COVID-19	Travel restriction	Number or proportion of cases
Pan 2020[93] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Pan 2020a[94]	Inferential	WPR	Non-island state	China	China	COVID-19	Multiple travel-related control measures	Number or proportion of cases; reproduction number
Pang 2003[95]	Descriptive	WPR	Non-island state	Beijing	All other countries	SARS	Entry/exit screening	Number or proportion of cases

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Pinkas 2003[96]	Descriptive	EUR	Non-island state	Poland	All other countries	COVID-19	Entry/exit screening; border closure; travel ban; travel-related quarantine	Number or proportion of cases
Pitman 2005[97]	Descriptive	EUR	Quasi-island state	UK	Any of the top 100 sources of international airline passengers	SARS and influenza	Entry/exit screening	Detection of high-risk persons or cases
Priest 2013[98]	Descriptive	WPR	Island state	New Zealand	Australia	Influenza (type A and B)	Entry/exit screening	Detection of high-risk persons or cases
Pullano 2020[99]	Inferential	WPR	Non-island state	Other regions of China and European countries	Wuhan	COVID-19	Travel ban	Probability of epidemic
Qiu 2020[100] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Quilty 2020[101] (preprint)	Inferential	WPR	Non-island state	Beijing, Chongqing, Hangzhou and Shenzhen	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases; probability of epidemic
Ray 2020[102]	Inferential	SEAR	Non-island state	India	All other countries	COVID-19	Travel ban	Number or proportion of cases
Sakaguchi 2012[103]	Descriptive	WPR	Island state	Japan	Mexico, USA and Canada	Influenza (A H1N1 2009 pandemic)	Entry/exit screening	Detection of high-risk persons or cases
Samaan 2004[104]	Descriptive	WPR	Island state	Australia	All countries affected by SARS	SARS	Entry/exit screening	Detection of high-risk persons or cases
Sang 2012[105]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	SARS	Entry/exit screening	Reproduction number; temporal development of epidemic; number or proportion of cases; number or proportion of deaths
Scala 2020[106] (preprint)	Inferential	EUR	Non-island state	Individual regions of Italy	Individual regions of Italy	COVID-19	Travel restriction	Temporal development of epidemic
Scalia Tomba 2008[107]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza (pandemic)	Travel restriction/ border control	Temporal development of epidemic

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Shi 2020[108] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Song 2020[109]Wang 2020[110]	Inferential	WPR	Non-island state	Other regions of China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases; reproduction number
St. John 2005[111]	Descriptive	AMR	Non-island state	Canada	All other countries	SARS	Entry/exit screening	Detection of high-risk persons or cases
Su 2020[112] (preprint)	Inferential	WPR	Non-island state	Beijng, Shanghai, Guangzhou and Shenzhen	Beijng, Shanghai, Guangzhou and Shenzhen	COVID-19	Multiple travel-related control measures	Number or proportion of cases; temporal development of epidemic
Tang 2020[113]T	Inferential	WPR	Non-island state	Beijing	Wuhan and other cities in China	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Tian 2020[114] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in China	COVID-19	Multiple travel-related control measures	Number or proportion of cases; temporal development of epidemic
Tsuboi 2020[115]	Descriptive	WPR	Island state	Japan	Diamond Princess	COVID-19	Travel-related quarantine	Number or proportion of quarantined diagnosed
Wang 2015[116]	Inferential	n.a.	Hypothetical	Hypothetical (low-risk patches)	Hypothetical (high-risk patch)	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Reproduction number
Wang 2020[110]	Inferential	WPR	Non-island state	China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases; number or proportion of deaths
Wang 2007[117]	Descriptive	WPR	Island state	Taiwan	All SARS-affected regions	SARS	Travel-related quarantine	Detection of high-risk persons or cases diagnosed
Wang 2012[118]	Inferential	WPR	Non-island state	Different regions in China	Different regions in China	Influenza (pandemic)	Travel restriction	Temporal development of epidemic
Wells 2020[119]	Inferential	WPR	Non-island state	All other countries	China	COVID-19	Multiple travel-related control measures	Number or proportion of cases; probability of epidemic
Weng 2015[120]	Inferential	WPR	Hypothetical	Hypothetical	Hypothetical	Influenza (H1N1 2009 pandemic)	Travel restriction	Number or proportion of cases

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Wilder-Smith 2003[121]	Descriptive	WPR	Non-island state	Singapore	All SARS-affected regions	SARS	Entry/exit screening	Detection of high-risk persons or cases
Wood 2007[122]	Inferential	WPR	Non-island state	Melbourne and Sydney	Sydney and Darwin	Influenza	Travel restriction: air	Temporal development of epidemic
Yang 2020[123]	Inferential	WPR	Non-island state	Other regions of China, particularly Guangdong and Zhjiang provinces	Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases; temporal development of epidemic
Ying 2020[124] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Yu 2012[125]	Inferential	WPR	Non-island state	China	All other countries	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Number or proportion of cases
Yuan 2020[126] (preprint)	Inferential	WPR	Non-island state	Other regions of China and countries	Wuhan	COVID-19	Multiple travel-related control measures	Temporal development of epidemic
Yuan 2020a[127] (preprint)	Inferential	WPR	Non-island state	China	Wuhan	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Zhang 2012[128]	Descriptive	WPR	Non-island state	Beijing	All other countries	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Number or proportion of screened identified as cases
Zhang 2014[129]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza (pandemic)	Entry/exit screening	Number or proportion of cases; temporal development of epidemic
Zhang 2019[130]	Inferential	n.a.	Hypothetical	Hypothetical	Hypothetical	Influenza (H1N1 2009 pandemic)	Entry/exit screening; reductions in human mobility	Temporal development of epidemic
Zhang 2020[131]	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases
Zhang 2020a[132] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases; reproduction number

Continued

Table 1 Continued

Study	Study type	WHO region	Geographical setting	Region protected by travel-related measure	Region restricted by travel-related measure	Disease	Intervention category	Outcome type
Zhao 2020[133]	Inferential	WPR	Non-island state	Regions of China	Regions of China	COVID-19	Multiple travel-related control measures	Number or proportion of cases; reproduction number; temporal development of epidemic
Zhou 2020[134] (preprint)	Inferential	WPR	Non-island state	Other regions of China	Wuhan and other cities in Hubei	COVID-19	Multiple travel-related control measures	Number or proportion of cases; number or proportion of deaths
Zlojutro 2019[135]	Inferential	AMR	Non-island state	USA	All other countries	Influenza (H1N1 2009 pandemic)	Entry/exit screening	Number or proportion of cases; cost; other

AFR, African region; AMR, region of the Americas; EUR, European region; MERS, Middle East respiratory syndrome; SARS, severe acute respiratory syndrome; SEAR, Southeast Asia region; WPR, Western Pacific Region.

'regions protected by travel related measure'). Several modelling studies looked at hypothetical regions (n=16).

Of the identified interventions, some were implemented in island states (n=24) or in what we define quasi-island states (n=9), such as the UK or Hong Kong, which have limited land borders connected through, for example, a tunnel. Most interventions were implemented in non-island states (n=74). The remaining interventions assessed hypothetical regions, some of which were framed as comparable to island states, while others were more general in their framing and assumptions.

COVID-19 and other relevant respiratory infectious diseases

Included studies assessed the impact of interventions aiming to prevent or slow the transmission of COVID-19 and other infectious respiratory diseases. We identified a large number of studies focusing on COVID-19 (n=59); we also found studies focusing on SARS (n=11), MERS (n=1) and various strains of influenza (n=39). Other studies looked at multiple infectious respiratory diseases (n=5) or a hypothetical infectious disease with COVID-19 relevant properties (n=7).

Figure 2 illustrates how the number of publications concerned with each disease has developed over time and explores where interventions have been implemented. As expected, there has been a rapid burst of research related to COVID-19 travel restrictions in 2020 (panel A), currently consisting mostly of non-peer-reviewed preprints. Research on SARS, MERS and influenza travel restrictions is more spread over time and also clusters around specific outbreaks (eg, SARS 2003; H1N1 influenza 2009) (panel B).

Intervention categories and interventions

The 122 included studies assessed the impact of a wide range of travel-related control measures. We classified these according to broad intervention categories, including border closures (n=3), entry/exit screening (n=31), travel-related quarantine (n=6), travel bans, such as suspension of international flights (n=8), and travel restrictions (n=25).

For travel restrictions, a few studies described imposing restrictions in relation to the mode of travel (eg, restricting air, land or maritime travel); most used the term 'travel restrictions' without providing any specification. However, most of the studies in this category were modelling studies, which commonly simulated 'travel restrictions' as different percentage reductions in the travel volume (eg, 50% and 90%).

We identified a relatively large number of studies assessing the impact of a bundle of different travel-related control measures (eg, entry/exit screening and quarantining all arriving passengers) (n=49). More than half of these (n=29) assessed the impact of the lockdown of Wuhan (n=29), combining several travel-related measures. We classified all of these studies as assessing *multiple travel-related control measures* (see online supplemental file S6), as

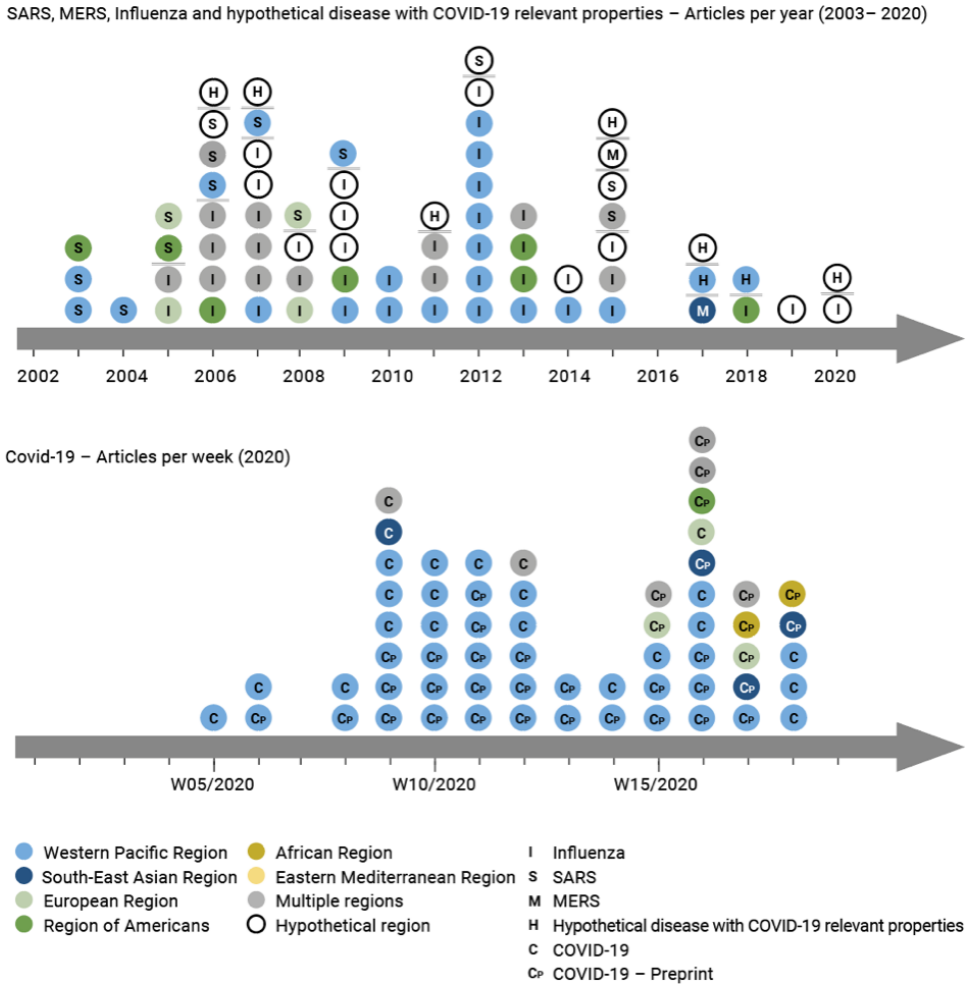

Figure 2 Illustration of the number of studies published over time; the top panel (2002–2020) shows studies focused on SARS, MERS, influenza and hypothetical disease with COVID-19 relevant properties, while the bottom panel (2020) shows studies focused on COVID-19. The specific disease is indicated by the single letter within the circle. Additionally, the colour represents the WHO world region. MERS, Middle East respiratory syndrome; SARS, severe acute respiratory syndrome.

it was impossible to identify the specific measures assessed due to lack of reporting.

Figure 3 visualises the body of evidence according to the respective disease, intervention implemented, as well as region in which an intervention was implemented. It becomes clear that the majority of the evidence assesses multiple travel-related control measures to delay or limit the progression of COVID-19. The second largest block of evidence emerges from studies focusing on various influenza strains and the impact of travel restrictions and entry/exit screening.

A critical aspect in relation to the likely impact of travel-related control measures is the timing of implementation. Figure 4 (panel A) visualises during which phase of an epidemic or pandemic different types of interventions addressed by included studies were implemented. With respect to the timing of implementation we distinguish the following:

- Early phase: interventions are implemented at a time when there are either no or only singular detected/notified cases (ie, all cases are detected and quarantined). During this phase, imported cases represent the main source of infections.
- Local transmission phase: interventions are implemented during more or less widespread human-to-human transmission of the disease. During this phase, local transmission and imported cases represent sources of infections.
- Postpeak phase: interventions are implemented during/after successful containment of an initial outbreak/epidemic/pandemic with the possibility of recurrence. During this phase, imported cases may again represent a major source of infections.
- Unclear phase: the phase of the outbreak/epidemic/pandemic is not reported or is not directly relevant for implementation of the intervention.

Figure 4 (panel A) shows, for example, that many interventions, especially those comprising multiple measures, are implemented when local transmission of the disease has already been established. Travel restrictions are often employed in the early phase of an epidemic or pandemic while entry/exit screening measures tend

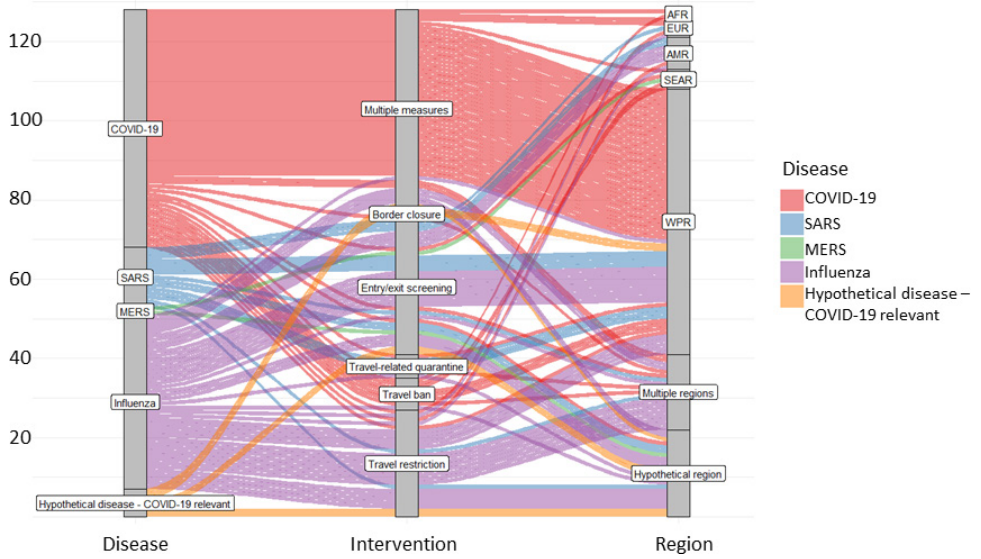

Figure 3 Overview of the body of evidence showing the frequency of studies investigating the specific diseases (left column), interventions (middle column) and the WHO world regions (right column). MERS, Middle East respiratory syndrome; SARS, severe acute respiratory syndrome.

to be implemented both in the early stages, as well as throughout the phases of an epidemic or pandemic. Further details on the specific travel-related control measures reported in each included study and their phase of implementation is presented in the online supplemental file S6.

Outcome categories and outcomes

We considered studies assessing five broad categories of outcomes: infectious disease outcomes, screening outcomes, other health outcomes, economic outcomes and social outcomes. Identified studies, however, largely assessed infectious disease (n=98) and/or screening outcomes (n=25). We identified no studies concerned with other health outcomes and very few studies assessing economic (n=5) or social outcomes (n=1).

Infectious disease outcomes included several types of outcomes related to disease timing and transmission, including the number or proportion of cases, the number or proportion of deaths, the reproduction number, the probability of an epidemic, demand for healthcare resources and the temporal development of the epidemic. Studies assessed various specific outcomes under these broader types, for example, 'time to epidemic peak' and 'delay of epidemic' both belong to the outcome type 'temporal development of the epidemic'. Screening outcomes all comprised some form of measuring the number and/or proportion of high-risk persons and/or cases detected. Economic outcomes covered costs and industry impact, and social outcomes examined the acceptability of travel-related control measures. These outcome types as assessed in each study are listed in table 1. A comprehensive list of the specific outcomes reported for each category and type of outcome and how often these were used across the evidence map can be found in online supplemental file S7.

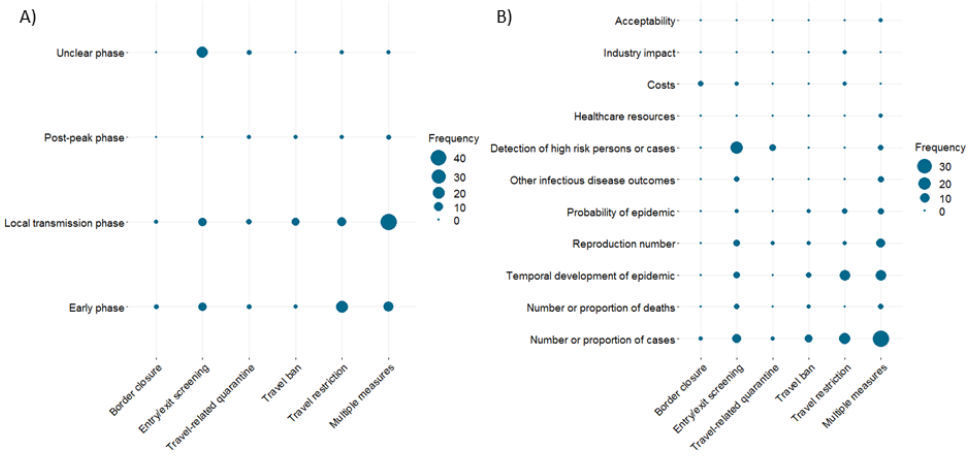

Figure 4 Bubble plots illustrating in included studies (A) during which phase of an epidemic or pandemic different types of interventions were implemented and (B) which intervention categories were assessed against different types of outcomes.

Figure 4 (panel B) illustrates which intervention categories were assessed by different outcome categories. Infectious disease outcomes such as the number or proportion of cases, the temporal development of an epidemic and the reproduction number were well represented across all intervention types. Conversely, screening outcomes were assessed primarily with respect to entry/exit screening. The lack of studies assessing economic and social outcomes is also clearly visible.

Study types

We included all studies assessing the quantitative impact of travel-related control measures on infectious disease, screening, economic and social outcomes. As a consequence of this broad scope, included studies employed a range of vastly different approaches drawing from the fields of infectious disease research, epidemiology, economics, biology and mathematics, among others. We categorised each study as being either inferential or descriptive. Most of the studies we found were inferential in nature (n=103), aiming to retrospectively calculate or prospectively forecast the impact of one or multiple travel-related control measures on outcomes. The remaining studies were descriptive in nature (n=19), aiming to describe the impact of control measures through summary statistics and/or graphics.

Within these broad categories, however, included studies varied greatly with regard to the specific approach taken. Inferential studies applied numerous modelling and epidemiological techniques; compartmental models, such as SIR models (S: susceptible, I: infectious, R: recovered) or SIR model derivatives, were common. Several studies also applied spatial models to explore how disease transmission moves geographically. Epidemiological time series models, as well as other epidemiological modelling and testing strategies, were also common. Descriptive studies comprised primarily observational studies and graphical summary studies, both of which measured and reported descriptive summary statistics related to intervention impact. The types of studies illustrated here are not exhaustive, and the methodological boundaries between the approaches employed are sometimes blurry. In fact, several studies apply multiple techniques, combining, for example, compartmental and spatial models or compartmental and time series models. online supplemental file S8 provides a more detailed overview of the study types included, along with examples from the included studies.

DISCUSSION

Summary of findings

This evidence map provides a comprehensive overview of travel-related control measures available for the control of SARS-CoV-2/COVID-19.

Most of the included studies used infectious disease or epidemiological modelling methods to examine the impact of travel-related control measures on the current COVID-19 pandemic. We also identified studies on SARS-CoV-1/SARS and influenza, mostly undertaken in the context of previous epidemics/pandemics. We found very few studies addressing MERS-CoV/MERS. The identified studies assessing travel-related control measures in the context of SARS-CoV-2/COVID-19, were mostly preprint publications that have not yet undergone peer review and are often characterised by poor reporting and conduct.[12]

Studies were undertaken across the globe. The geographical region most represented was WPR, driven in part by a number of studies focusing on the Hubei region of China and in part by studies across the region during the previous SARS-CoV-1/SARS outbreak. AFR and EUR were the least represented; we did not identify any studies from EMR. Most studies operated at the level of countries and reported little about specific settings of interest (eg, a named airport and a specific country border) or the broader implementation context (eg, usual border arrangements when control measures are not in place).

Travel-related control measures can be classified as (1) border closure, (2) travel bans, (3) travel restrictions, (4) entry/exit screening, (5) travel-related quarantine and (6) multiple travel-related control measures. Studies were identified and mapped for all of these categories. We identified a relatively large body of evidence on entry/exit screening, as well as on travel restrictions. The latter also included subnational measures, for example, city-to-city travel restrictions across broader regions, making a clear distinction from general social distancing measures challenging. We also found many studies examining the impact of bundles of travel-related control measures. Interventions are often poorly described, both in relation to the measure itself (eg, border closure) and in relation to how the measure is implemented or enforced (eg, border patrols, fines and exceptions). Moreover, travel-related control measures rarely happen in a vacuum: the closer to real-life the intervention (and the study), the more cointerventions tend to be involved. This makes it very difficult to assess the unique impact of a specific measure.

The impact of travel-related control measures in controlling geographical spread and overall disease transmission likely varies between early, local transmission and postpeak phases of an outbreak/epidemic/pandemic, yet reporting of the timing of implementation tends to be poor. Most studies focused on the early and local transmission phases; few studies were concerned with the postpeak phase.

The identified studies almost exclusively examined infectious disease and screening outcomes. Surprisingly, we did not identify any study reporting on other health outcomes, such as implications for the physical and psychosocial health of stranded travellers, of those unable to visit family members, of regular commuters unable to reach their workplace, of individuals quarantined, of people unable to obtain medical treatment and other collateral damage (eg, suspended immunisation programmes and impacts on food supply due to

limited air, maritime and land travel of either people or goods). Only three included studies were concerned with economic and social outcomes.

The bulk of the evidence derives from modelling studies. In an acute outbreak situation, the time and resources that can be dedicated to conducting timely, empirical research are limited. Modelling studies vary greatly in type (eg, SIR-like models vs time series models) and in the underlying assumptions regarding the disease, interventions or regions/settings. Additionally, many studies do not fall into clean categories, and a single study may combine compartmental infectious disease models with epidemiological spatial models. They also vary with respect to whether and how they have been validated through real-life applications.

Gaps in the current evidence base

The evidence map identified several gaps in the evidence base related to travel-related control measures that could inform future research as well as evidence synthesis. First, some regions were under-represented, specifically studies conducted or simulated for the countries in the AFR, EMR and EUR were lacking. Second, the most commonly reported travel-related control measures were entry/exit screening and restrictions, which in the context of modelling studies were simulated as different levels of travel reductions. Thus, the evidence base regarding more stringent measures, such as travel bans and complete border closures, remains sparse. Third, our evidence map identified lack of consideration of the impact of these measures on broader health outcomes, such as physical and mental health, as well as social and economic outcomes, such as cost and burden on communities and socioeconomic inequalities. Finally, the key gap relates to the lack of empirical studies assessing the impact of travel-related control measures, including experimental and quasiexperimental approaches.

Methodological limitations of this study

This evidence map was put together over 10 days, and the process is thus characterised by several limitations.

While we conducted searches in three major databases and two COVID-specific databases, these were mostly health centric. We only searched Web of Science—comprising Science Citation Index Expanded (1900–present), Social Sciences Citation Index (1900–present) and Emerging Sources Citation Index (2015–present)—to identify social and economic studies. As we identified very few economic and social outcomes, it is likely that there is another body of evidence to be located with more focused searches in specific economic and social science databases. In addition, we did not search for grey literature sources. Furthermore, since COVID-19 initially started in Wuhan, China, many studies are published on the topic in Chinese journals and databases. Because of the language barrier, we did not consider these sources.

The unspecific and inconsistent reporting of primary studies with regard to interventions, especially when a package of control measures was investigated, sometimes made inclusion/exclusion decisions difficult. While we developed and calibrated screening guidance to ensure consistency among reviewers, it is nevertheless possible that we excluded some travel-related control measures that were not explicitly described as such. Also, we did not undertake double-screening of all studies but only reassessed a subset of studies excluded at the full-text screening stage. In general, however, we applied a very conservative approach to title/abstract, as well as full-text screening, where any uncertainties associated with a study were marked for further checking by a second reviewer and/or for discussion among the whole review team.

We developed and calibrated data extraction guidance to be used consistently by reviewers. Nevertheless, we had to refine some categories post hoc. We also had a large number of reviewers extracting data, which created heterogeneity in the dataset. To address this, a second reviewer double-checked all extracted information for each of the main domains, that is, all information regarding interventions, outcomes and study design. Overall, high-quality data extraction was limited by poor reporting of the travel-related control measures and the specific contexts in which they are implemented in primary studies.[13]

Finally, we did not include travel warning or travel advice in the evidence map, which limits the scope of this map. While these may be classified as travel-related control measures,[13] their inclusion would have likely broadened our search strategy and prolonged the timeline of its development. In general, lack of intervention specification in the included studies makes it challenging to draw clear categories of interventions without potential overlap (eg, drawing clear distinction between a travel ban vs a travel restriction and when these are used only as descriptors in the studies without further specification).

Implications for moving forward

An evidence map is not designed to assess the effectiveness of interventions, in this case the effectiveness of travel-related control measures in controlling infectious disease spread. The present evidence map sheds light on the variety of evidence available with regards to the quantifiable impacts of travel-related control measures, the outcomes used, as well as the study types employed. It thus represents a stepping stone towards a systematic review on the effectiveness of all or a subset of travel-related control measures.

Given our health-centric searches, we feel confident that we have identified most of the available body of evidence regarding the quantifiable impacts of travel-related control measures on health. In terms of conducting a systematic review of effectiveness, it would, however, be advisable to undertake additional forward-backward citation searches and/or similar studies searches with included studies. We identified a number of challenges related to the full analysis of this evidence base. These include: (1) classifying interventions in an appropriate and consistent manner;

(2) capturing the details of interventions (eg, components, timing and implementation characteristics) and cointerventions through an analysis of linked sources of evidence; (3) assessing the quality and usefulness of different types of studies ranging from simple observational studies to complex modelling studies; (4) quantitatively synthesising this extremely heterogeneous evidence base; and (5) dealing with the large number of preprint studies and their varying quality. Moving forward with a full analysis, we suggest reviewers plan ahead and develop strategies on how these challenges can be adequately managed. For example, this might entail consideration of external sources of evidence beyond scientific databases, such as governmental websites on the implementation of different travel-related control measures (eg, their timing and duration) and other measures in local contexts. To contain the COVID-19 pandemic, governments have employed a range of public health measures often in a bundle, which challenges assessment of the effectiveness of any single measure, such as a travel ban. It would therefore be important to explicitly document and, where possible, assess various combinations of measures implemented—including those related to travel–in future research.

Importantly, decisions to maintain or stop travel-related control measures are determined by a range of factors beyond effectiveness, including legal and human rights aspects, as well as considerations of broader health, economic and social implications, as well as sociocultural and political acceptability. Gathering evidence about these broader factors in a systematic manner was beyond the scope of the current evidence map; however, such aspects might be important to inform decision making. Future evidence synthesis would therefore require a different scope and a broader search strategy, notably encompassing searches in economics and social science databases, as well as multidisciplinary databases (eg, EconLit, PsycINFO and Scopus).

Twitter Brigitte Strahwald @strahwald

Acknowledgements We are grateful to Susan L Norris and Carmen Dolea for their guidance in scoping this evidence map.

Contributors JB, AM, ER and OH defined the study scope and developed the study protocol with significant intellectual input from all review authors. JB and AM coordinated the entire study process. IK designed the search strategy and conducted all the searches. JB, AM, RB, MC, KG, LMP, PvP, KS, BS, JMS, SV and ER conducted data screening and extraction. JB, AM, JMS, LMP and PvP did data mapping. JB, AM and ER prepared the first draft of the manuscript, which was further critically examined by all the authors and revised based on their feedback. All review authors reviewed and approved the final draft.

Funding The conduct of this evidence map was funded by the World Health Organization (WHO; grand/award number: N/A).

Disclaimer This study was commissioned and paid for by the World Health Organization (WHO). Copyright of the original work, a report submitted to WHO, belongs to WHO. This article was developed based on the WHO report and the authors have been given permission to publish. The authors alone are responsible for the views expressed in this publication and they do not necessarily represent the views, decisions or policies of WHO.

Competing interests None declared.

Patient consent for publication Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. No original data were generated for this study. All studies included in the evidence map are presented in the supplementary file.

ORCID iDs
Ani Movsisyan http://orcid.org/0000-0003-0258-8912
Jacob Burns http://orcid.org/0000-0003-4015-6862
Lisa Maria Pfadenhauer http://orcid.org/0000-0001-5038-8072
Peter von Philipsborn http://orcid.org/0000-0001-7059-6944

REFERENCES

1 WHO. *Novel Coronavirus (2019-nCoV) situation report - 1*. Geneva: World Health Organization, 2020.
2 WHO. *Novel coronavirus (2019-nCoV) situation report - 51*. Geneva: World Health Organization, 2020.
3 WHO. *Weekly update on COVID-19, April 8–15, 2020. health emergencies programme*. Geneva: World Health Organization, 2020.
4 Mateus ALP, Otete HE, Beck CR, *et al*. Effectiveness of travel restrictions in the rapid containment of human influenza: a systematic review. *Bull World Health Organ* 2014;92:868–80.
5 Ryu S, Gao H, Wong JY, *et al*. Nonpharmaceutical measures for pandemic influenza in Nonhealthcare Settings-International Travel-Related measures. *Emerg Infect Dis* 2020;26:961–6.
6 WHO. Non-pharmaceutical public health measures for mitigating the risk and impact of epidemic and pandemic influenza. Licence: CC BY-NC-SA 3.0 IGO.: Licence: CC BY-NC-SA 3.0 IGO, 2019. Available: https://creativecommons.org/
7 Mouchtouri VA, Christoforidou EP, An der Heiden M, *et al*. Exit and entry screening practices for infectious diseases among travelers at points of entry: looking for evidence on public health impact. *Int J Environ Res Public Health* 2019;16:4638.
8 Pasquini-Descomps H, Brender N, Maradan D. Value for money in H1N1 influenza: a systematic review of the cost-effectiveness of pandemic interventions. *Value Health* 2017;20:819–27.
9 Pérez Velasco R, Praditsitthikorn N, Wichmann K, *et al*. Systematic review of economic evaluations of preparedness strategies and interventions against influenza pandemics. *PLoS One* 2012;7:e30333.
10 Errett NA, Sauer LM, Rutkow L. An integrative review of the limited evidence on international travel bans as an emerging infectious disease disaster control measure. *J Emerg Manag* 2020;18:7–14.
11 Ouzzani M, Hammady H, Fedorowicz Z, *et al*. Rayyan-a web and mobile app for systematic reviews. *Syst Rev* 2016;5:210.
12 Glasziou PP, Sanders S, Hoffmann T. Waste in covid-19 research. *BMJ* 2020;369:m1847.
13 Lee K, Worsnop CZ, Grépin KA, *et al*. Global coordination on Cross-border travel and trade measures crucial to COVID-19 response. *Lancet* 2020;395:1593–5.
14 Adekunle AI, Adekunle AI, Meehan M, *et al*. Delaying the COVID-19 epidemic in Australia: evaluating the effectiveness of international travel bans.. *medRxiv*. 2020.
15 Aleta A, Aleta A, Hu Q, *et al*. A data-driven assessment of early travel restrictions related to the spreading of the novel COVID-19 within mainland China.. *medRxiv*. 2020.
16 Anonymous. Thermal image scanners to detect fever in airline passengers, Vancouver and Toronto, 2003. *Can Commun Dis Rep* 2004;30:165–7.

17 Anzai A, Kobayashi T, Linton NM, *et al*. Assessing the impact of reduced travel on exportation dynamics of novel coronavirus infection (COVID-19). *J Clin Med* 2020;9:601.
18 Arima Y, Kutsuna S, Shimada T. Severe acute respiratory syndrome coronavirus 2 infection among Returnees to Japan from Wuhan, China, 2020. *Emerg Infect Dis* 2020;26:1596–600.
19 Arino J, Jordan R, van den Driessche P. Quarantine in a multi-species epidemic model with spatial dynamics. *Math Biosci* 2007;206:46–60.
20 Bajardi P, Poletto C, Ramasco JJ, *et al*. Human mobility networks, travel restrictions, and the global spread of 2009 H1N1 pandemic. *PLoS One* 2011;6:e16591.
21 Banholzer N, van Weenen E, Kratzwald B, *et al*. Estimating the impact of non-pharmaceutical interventions on documented infections with COVID-19: a cross-country analysis.. *medRxiv.* 2020.
22 Bolton KJ, McCaw JM, Moss R, *et al*. Likely effectiveness of pharmaceutical and non-pharmaceutical interventions for mitigating influenza virus transmission in Mongolia. *Bull World Health Organ* 2012;90:264–71.
23 Boyd M, Baker MG, Mansoor OD, *et al*. Protecting an island nation from extreme pandemic threats: proof-of-concept around border closure as an intervention. *PLoS One* 2017;12:e0178732.
24 Boyd M, Mansoor OD, Baker MG, *et al*. Economic evaluation of border closure for a generic severe pandemic threat using new Zealand Treasury methods. *Aust N Z J Public Health* 2018;42:444–6.
25 Caley P, Becker NG, Philp DJ. The waiting time for inter-country spread of pandemic influenza. *PLoS One* 2007;2:e143.
26 Chang M-C, Kahn R, Li Y-A LC-S, *et al*. Modeling the impact of human mobility and travel restrictions on the potential spread of SARS-CoV-2 in Taiwan.. *medRxiv.* 2020.
27 Cheng H-Y, Li S-Y, Yang C-H. Initial rapid and proactive response for the COVID-19 outbreak - Taiwan's experience. *J Formos Med Assoc* 2020;119:771–3.
28 Chinazzi M, Davis JT, Ajelli M, *et al*. The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. *Science* 2020;368:395–400.
29 Chiyomaru K, Takemoto K. Global COVID-19 transmission rate is influenced by precipitation seasonality and the speed of climate temperature warming.. *medRxiv.* 2020.
30 Chong KC, Ying Zee BC. Modeling the impact of air, sea, and land travel restrictions supplemented by other interventions on the emergence of a new influenza pandemic virus. *BMC Infect Dis* 2012;12.
31 Chung LH. Impact of pandemic control over Airport economics: reconciling public health with Airport business through a streamlined approach in pandemic control. *J Air Transp Manag* 2015;44:42–53.
32 Ciofi degli Atti ML, Merler S, Rizzo C, *et al*. Mitigation measures for pandemic influenza in Italy: an individual based model considering different scenarios. *PLoS One* 2008;3:e1790.
33 Klepac P, voort SJ, Quilty SJ. Interventions targeting air travellers early in the pandemic may delay local outbreaks of SARS-CoV-2. *medRxiv* 2020.
34 Colizza V, Barrat A, Barthelemy M, *et al*. Modeling the worldwide spread of pandemic influenza: baseline case and containment interventions. *PLoS Med* 2007;4:e13–110.
35 Cooper BS, Pitman RJ, Edmunds WJ, *et al*. Delaying the International spread of pandemic influenza. *PLoS Med* 2006;3:e212–55.
36 Costantino V, Heslop DJ, MacIntyre C, *et al*. The effectiveness of full and partial travel bans against COVID-19 spread in Australia for travellers from China. *medRxiv* 2020.
37 Cowling BJ, Ali ST, Ng TWY, *et al*. Impact assessment of non-pharmaceutical interventions against coronavirus disease 2019 and influenza in Hong Kong: an observational study. *The Lancet Public Health* 2020;5:279–88.
38 Dandekar R, Barbastathis G. Quantifying the effect of quarantine control in Covid-19 infectious spread using machine learning. *medRxiv*2020.
39 de Vlas SJ, Feng D, Cooper BS, *et al*. The impact of public health control measures during the SARS epidemic in mainland China. *Trop Med Int Health* 2009;14 Suppl 1:101–4.
40 Ediriweera DS, de Silva NR, Malavige GN, *et al*. An epidemiological model to aid decision-making for COVID-19 control in Sri Lanka. *PLoS One* 2020;15:e0238340.
41 Eichner M, Schwehm M, Wilson N, *et al*. Small islands and pandemic influenza: potential benefits and limitations of travel volume reduction as a border control measure. *BMC Infect Dis* 2009;9:160.
42 Epstein JM, Goedecke DM, Yu F, *et al*. Controlling pandemic flu: the value of international air travel restrictions. *PLoS One* 2007;2:e401.
43 Fang H, Wang L, Yang Y. Human mobility restrictions and the spread of the novel coronavirus (2019-nCoV) in China. *medRxiv* 2020.
44 Ferguson NM, Cummings DAT, Fraser C, *et al*. Strategies for mitigating an influenza pandemic. *Nature* 2006;442:448–52.
45 Flahault A, Vergu E, Coudeville L, *et al*. Strategies for containing a global influenza pandemic. *Vaccine* 2006;24:6751–5.
46 Fujita M, Sato H, Kaku K, *et al*. Airport quarantine inspection, follow-up observation, and the prevention of pandemic influenza. *Aviat Space Environ Med* 2011;82:782–9.
47 Germann TC, Kadau K, Longini IM, *et al*. Mitigation strategies for pandemic influenza in the United States. *Proc Natl Acad Sci U S A* 2006;103:5935–40.
48 Glass K, Becker NG. Evaluation of measures to reduce international spread of SARS. *Epidemiol Infect* 2006;134:1092–101.
49 Gostic K, Gomez AC, Mummah RO, *et al*. Estimated effectiveness of symptom and risk screening to prevent the spread of COVID-19. *Elife* 2020;9. doi:10.7554/eLife.55570. [Epub ahead of print: 24 02 2020].
50 Gostic KM, Kucharski AJ, Lloyd-Smith JO. Effectiveness of traveller screening for emerging pathogens is shaped by epidemiology and natural history of infection. eLife. 2015 2015;4.
51 Goubar A, Bitar D, Cao WC, *et al*. An approach to estimate the number of SARS cases imported by international air travel. *Epidemiol Infect* 2009;137:1019–31.
52 Gunaratnam PJ, Tobin S, Seale H, *et al*. Airport arrivals screening during pandemic (H1N1) 2009 influenza in New South Wales, Australia. *Med J Aust* 2014;200:290–2.
53 Hale MJ, Hoskins RS, Baker MG. Screening for influenza A(H1N1) pdm09, Auckland International Airport, New Zealand. *Emerg Infect Dis* 2012;18:866–8.
54 Hamidouche M. COVID-19 epidemic in Algeria: assessment of the implemented preventive strategy. *medRxiv* 2020.
55 He J, Chen G, Jiang Y, *et al*. Comparative Analysis of COVID-19 Transmission Patterns in Three Chinese Regions vs. South Korea,Italy and Iran. *medRxiv* 2020.
56 Hien TT, Boni MF, Bryant JE, *et al*. Early pandemic influenza (2009 H1N1) in Ho Chi Minh City, Vietnam: a clinical virological and epidemiological analysis.. *PLoS Medicine / Public Library of Science* 2009;7:e1000277.
57 Hollingsworth TD, Ferguson NM, Anderson RM. Will travel restrictions control the International spread of pandemic influenza? *Nat Med* 2006;12:497–9.
58 Hossain MP, Junus A, *et al*, et al. The effects of border control and quarantine measures on global spread of COVID-19. *medRxiv* 2020.
59 Hou J, Hong J, *et al*. Changing transmission dynamics of COVID-19 in China: a nationwide population-based piecewise mathematical modeling study. *medRxiv* 2020.
60 Hsieh Y-H, van den Driessche P, Wang L. Impact of travel between patches for spatial spread of disease. *Bull Math Biol* 2007;69:1355–75.
61 Hsieh Y-H, King C-C, Chen CWS, *et al*. Impact of quarantine on the 2003 SARS outbreak: a retrospective modeling study. *J Theor Biol* 2007;244:729–36.
62 Jia JS, Lu X, Yuan Y, *et al*. Population flow drives spatio-temporal distribution of COVID-19 in China. *Nature* 2020;582:389–94.
63 Jiang X, Chang L, Shi Y. How does the outbreak of 2019-nCoV spread in mainland China? A retrospective analysis of the dynamic transmission routes. *medRxiv* 2020;92.
64 Kernéis S, Grais RF, Boëlle P-Y, *et al*. Does the effectiveness of control measures depend on the influenza pandemic profile? *PLoS One* 2008;3:e1478.
65 Khan K, Eckhardt R, Brownstein JS, *et al*. Entry and exit screening of airline travellers during the A(H1N1) 2009 pandemic: a retrospective evaluation. *Bull World Health Organ* 2013;91:368–76.
66 Kim S, Chang DE, eds. *Border screening vs. community level disease control for infectious diseases: Timing and effectivenes*. American Institute of Physics Inc, 2017.
67 Kong XS, Liu F, Wang HB, *et al*. Epidemic prevention and control measures in China significantly curbed the epidemic of COVID-19 and influenza. *medRxiv* 2020.
68 Kraemer MUG, Yang C-H, Gutierrez B, *et al*. The effect of human mobility and control measures on the COVID-19 epidemic in China. *Science* 2020;368:493–7.
69 Kuo JS, Lee YH, Heish JW, *et al*. Initial evaluation on screening of novel influenza A (H1N1) at international ports in Taiwan. *Taiwan Epidemiol Bull* 2009;25:254–67.

70 Lai S, Ruktanonchai NW, Zhou L, *et al*. Effect of non-pharmaceutical interventions for containing the COVID-19 outbreak in China. *medRxiv* 2020.
71 Lam EHY, Cowling BJ, Cook AR, *et al*. The feasibility of age-specific travel restrictions during influenza pandemics. *Theor Biol Med Model* 2011;8:44.
72 Lau H, Khosrawipour V, Kocbach P, *et al*. The positive impact of lockdown in Wuhan on containing the COVID-19 outbreak in China. *J Travel Med* 2020;27. doi:10.1093/jtm/taaa037. [Epub ahead of print: 18 05 2020].
73 Lee JM, Choi D, Cho G, *et al*. The effect of public health interventions on the spread of influenza among cities. *J Theor Biol* 2012;293:131–42.
74 Li D, Liu Z, Liu Q, *et al*. Estimating the efficacy of traffic blockage and quarantine for the epidemic caused by 2019-nCoV (COVID-19). *medRxiv* 2020.
75 Lin H, Liu W, Gao H, *et al*. Trends in transmissibility of 2019 novel coronavirus-infected pneumonia in Wuhan and 29 provinces in China. *medRxiv* 2020.
76 Linka K, Peirlinck M, Sahli Costabal F, *et al*. Outbreak dynamics of COVID-19 in Europe and the effect of travel restrictions. *Comput Methods Biomech Biomed Engin* 2020;23:710–7.
77 Liu X, Takeuchi Y. Spread of disease with transport-related infection and entry screening. *J Theor Biol* 2006;242:517–28.
78 Liu K, Ai S, Song S, *et al*. Population movement, City closure in Wuhan and geographical expansion of the 2019-nCoV pneumonia infection in China in January. *Clinical infectious diseases* 2020.
79 Liu H, Bai X, Shen H, *et al*. Synchronized travel restrictions across cities can be effective in COVID-19 control. *medRxiv* 2020a.
80 Malmberg H, Britton T. Inflow restrictions can prevent epidemics when contact tracing efforts are effective but have limited capacity. *medRxiv* 2020.
81 Malone JD, Brigantic R, Muller GA, *et al*. U.S. Airport entry screening in response to pandemic influenza: modeling and analysis. *Travel Med Infect Dis* 2009;7:181–91.
82 Mandal S, Bhatnagar T, Arinaminpathy N, *et al*. Prudent public health intervention strategies to control the coronavirus disease 2019 transmission in India: a mathematical model-based approach. *Indian J Med Res* 2020;151:23.
83 Marcelino J, Kaiser M. Critical paths in a metapopulation model of H1N1: efficiently delaying influenza spreading through flight cancellation. *PLoS Curr* 2012;4:e4f8c9a2e1fca8.
84 Mbuvha R, Marwala T. Bayesian inference of COVID-19 spreading rates in South Africa. *PLoS One* 2020;15:e0237126.
85 Mondal S, Ghosh S. Searching the Sigmoid-type trend in lock down period covid19 data of India and its different states. *medRxiv* 2020.
86 Moriarty LF, Plucinski MM, Marston BJ, *et al*. Public Health Responses to COVID-19 Outbreaks on Cruise Ships - Worldwide, February-March 2020. *MMWR Morb Mortal Wkly Rep* 2020;69:347–52.
87 Mummert A, Weiss H, Long L-P, *et al*. A perspective on multiple waves of influenza pandemics. *PLoS One* 2013;8:e60343.
88 Muraduzzaman AKM, Khan MH, Parveen R, *et al*. Event based surveillance of middle East respiratory syndrome coronavirus (MERS- CoV) in Bangladesh among pilgrims and travelers from the middle East: an update for the period 2013–2016. *PLoS One* 2018;13:e0189914.
89 Nakata Y, Röst G. Global analysis for spread of infectious diseases via transportation networks. *J Math Biol* 2015;70:1411–56.
90 Nigmatulina KR, Larson RC. Living with influenza: impacts of government imposed and voluntarily selected interventions. *Eur J Oper Res* 2009;195:613–27.
91 Nishiura H, Wilson N, Baker MG. Quarantine for pandemic influenza control at the borders of small island nations. *BMC Infect Dis* 2009;9.
92 Odendaal WG. A method to model outbreaks of new infectious diseases with pandemic potential such as COVID-19. *medRxiv* 2020.
93 Pan J, Yao Y, Liu Z, *et al*. Effectiveness of control strategies for coronavirus disease 2019: a SEIR dynamic modeling study. *medRxiv* 2020. doi:10.1101/2020.02.19.20025387
94 Pan X, Ojcius DM, Gao T, *et al*. Lessons learned from the 2019-nCoV epidemic on prevention of future infectious diseases. *Microbes Infect* 2020a;22:86–91.
95 Pang X, Zhu Z. Evaluation of control measures implemented in the severe acute respiratory syndrome outbreak in Beijing, 2003. *JAMA* 2003;290:3215–21.
96 Pinkas J, Jankowski M, Szumowski Łukasz, *et al*. Public health interventions to mitigate early spread of SARS-CoV-2 in Poland. *Med Sci Monit* 2020;26:e924730.
97 Pitman RJ, Cooper BS, Trotter CL, *et al*. Entry screening for severe acute respiratory syndrome (SARS) or influenza: policy evaluation. *BMJ* 2005;331:1242.2–3.
98 Priest PC, Jennings LC, Duncan AR, *et al*. Effectiveness of border screening for detecting influenza in arriving airline travelers. *Am J Public Health* 2013;103:1412–8.
99 Pullano G, Pinotti F, Valdano E, *et al*. Novel coronavirus (2019-nCoV) early-stage importation risk to Europe, January 2020. *Eurosurveillance* 2020;25.
100 Qiu Y, Chen X, Shi W. Impacts of social and economic factors on the transmission of coronavirus disease (COVID-19) in China. *medRxiv.* 2020.
101 Quilty BJ, Diamond C, Liu Y, *et al*. The effect of inter-city travel restrictions on geographical spread of COVID-19: evidence from Wuhan, China. *medRxiv* 2020.
102 Ray D, Salvatore M, Bhattacharyya R, *et al*. Predictions, role of interventions and effects of a historic national lockdown in India's response to the COVID-19 pandemic: data science call to arms. *Harv Data Sci Rev* 2020;2020. doi:10.1162/99608f92.60e08ed5. [Epub ahead of print: 09 06 2020].
103 Sakaguchi H, Tsunoda M, Wada K, *et al*. Assessment of border control measures and community containment measures used in Japan during the early stages of pandemic (H1N1) 2009. *PLoS One* 2012;7:e31289.
104 Samaan G, Patel M, Spencer J, *et al*. Border screening for SARS in Australia: what has been learnt? *Med J Aust* 2004;180:220–3.
105 Sang Z, Qiu Z, Yan X, *et al*. Assessing the effect of non-pharmaceutical interventions on containing an emerging disease. *Math Biosci Eng* 2012;9:147–64.
106 Scala A, Flori A, Spelta A, *et al*. Between geography and demography: key interdependencies and exit mechanisms for Covid-19. *medRxiv* 2020.
107 Scalia Tomba G, Wallinga J. A simple explanation for the low impact of border control as a countermeasure to the spread of an infectious disease. *Math Biosci* 2008;214:70–2.
108 Shi Z, Fang Y. Temporal relationship between outbound traffic from Wuhan and the 2019 coronavirus disease (COVID-19) incidence in China. *medRxiv* 2020. doi:10.1101/2020.03.15.20034199
109 Song PX, Wang L, Zhou Y, *et al*. An epidemiological forecast model and software assessing interventions on COVID-19 epidemic in China. *medRxiv* 2020.
110 Wang F, Li Y, Tang D, *et al*. Trend of the coronavirus Disease-2019 epidemic in China after the Lockdown of Wuhan City on January 23. *SSRN* 2020.
111 St John RK, King A, de Jong D, *et al*. Border screening for SARS. *Emerg Infect Dis* 2005;11:6–10.
112 Su L, Hong N, Zhou X, *et al*. Evaluation of the secondary transmission pattern and epidemic prediction of COVID-19 in the four metropolitan areas of China. *Front Med* 2020;7:171.
113 Tang B, *et al*, et al, et al. Estimation of the transmission risk of the 2019-nCoV and its implication for public health interventions. *Journal of Clinical Medicine* 2020;9:07.
114 Tian H, Liu Y, Li Y, *et al*. The impact of transmission control measures during the first 50 days of the COVID-19 epidemic in China. *medRxiv* 2020.
115 Tsuboi M, Hachiya M, Noda S, *et al*. Epidemiology and quarantine measures during COVID-19 outbreak on the cruise SHIP diamond Princess docked at Yokohama, Japan in 2020: a descriptive analysis. *Glob Health Med* 2020;2:102–6.
116 Wang X, Liu S, Wang L, *et al*. An epidemic patchy model with Entry-Exit screening. *Bull Math Biol* 2015;77:1237–55.
117 Wang T-H, Wei K-C, Hsiung CA, *et al*. Optimizing severe acute respiratory syndrome response strategies: lessons learned from quarantine. *Am J Public Health* 2007;97 Suppl 1:S98–100.
118 Wang L, Zhang Y, Huang T, *et al*. Estimating the value of containment strategies in delaying the arrival time of an influenza pandemic: a case study of travel restriction and patient isolation. *Phys Rev E Stat Nonlin Soft Matter Phys* 2012;86:032901.
119 Wells CR, Sah P, Moghadas SM, *et al*. Impact of international travel and border control measures on the global spread of the novel 2019 coronavirus outbreak. *Proc Natl Acad Sci U S A* 2020;117:7504–9.
120 Weng W, Ni S. Evaluation of containment and mitigation strategies for an influenza A pandemic in China. *Simulation* 2015;91:407–16.
121 Wilder-Smith A, Paton NI, Goh KT. Experience of severe acute respiratory syndrome in Singapore: importation of cases, and defense strategies at the Airport. *J Travel Med* 2003;10:259–62.
122 Wood JG, Zamani N, MacIntyre CR, Raina MacIntyre C, *et al*. Effects of internal border control on spread of pandemic influenza. *Emerg Infect Dis* 2007;13:1038–45.

123 Yang Z, Zeng Z, Wang K, *et al*. Modified SEIR and AI prediction of the epidemics trend of COVID-19 in China under public health interventions. *J Thorac Dis* 2020;12:165–74.
124 Ying S, Li F, *et al*, et al. Spread and control of COVID-19 in China and their associations with population movement, public health emergency measures, and medical resources. *medRxiv* 2020.
125 Yu H, Cauchemez S, Donnelly CA, *et al*. Transmission dynamics, border entry screening, and school holidays during the 2009 influenza A (H1N1) pandemic, China. *Emerg Infect Dis* 2012;18:758–66.
126 Yuan H-Y, Hossain MP, *et al*, et al. Estimating the risk on outbreak spreading of 2019-nCoV in China using transportation data. *medRxiv* 2020.
127 Yuan Z, Xiao Y, Dai Z, *et al*. A simple model to assess Wuhan lock-down effect and region efforts during COVID-19 epidemic in China mainland. *medRxiv* 2020a.
128 Zhang Y, Yang P, Liyanage S, *et al*. The characteristics of imported cases and the effectiveness of outbreak control strategies of pandemic influenza A (H1N1) in China. *Asia Pac J Public Health* 2012;24:932–9.
129 Zhang W-D, Zu Z-H, Xu Q, *et al*. Optimized strategy for the control and prevention of newly emerging influenza revealed by the spread dynamics model. *PLoS One* 2014;9:11.
130 Zhang N, Zhao P, Li Y. Increased infection severity in downstream cities in infectious disease transmission and tourists surveillance analysis. *J Theor Biol* 2019;470:20–9.
131 Zhang C, Chen C, Shen W, *et al*. Impact of population movement on the spread of 2019-nCoV in China. *Emerg Microbes Infect* 2020;9:988-990.
132 Zhang B, Zhou H, Zhou F. Study on SARS-COV-2 transmission and the effects of control measures in China. *medRxiv* 2020a.
133 Zhao S, Chen H. Modeling the epidemic dynamics and control of COVID-19 outbreak in China. *Quant Biol* 2020:11–19.
134 Zhou X, Wu Z, Yu R, *et al*. Modeling-Based evaluation of the effect of quarantine control by the Chinese government in the coronavirus disease 2019 outbreak. *medRxiv* 2020.
135 Zlojutro A, Rey D, Gardner L. A decision-support framework to optimize border control for global outbreak mitigation. *Sci Rep* 2019;9:2216.