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Research Article

A solution scan of societal options to reduce transmission and spread of respiratory viruses: SARS-CoV-2 as a case study

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ABSTRACT

Societal biosecurity – measures built into everyday society to minimize risks from pests and diseases – is an important aspect of managing epidemics and pandemics. We aimed to identify societal options for reducing the transmission and spread of respiratory viruses. We used SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) as a case study to meet the immediate need to manage the COVID-19 pandemic and eventually transition to more normal societal conditions, and to catalog options for managing similar pandemics in the future. We used a 'solution scanning' approach. We read the literature; consulted psychology, public health, medical, and solution scanning experts; crowd-sourced options using social media; and collated comments on a preprint. Here, we present a list of 519 possible measures to reduce SARS-CoV-2 transmission and spread. We provide a long list of options for policymakers and businesses to consider when designing biosecurity plans to combat SARS-CoV-2 and similar pathogens in the future. We also developed an online application to help with this process. We encourage testing of actions, documentation of outcomes, revisions to the current list, and the addition of further options.

1. Introduction

Respiratory viruses are known as a major global threat.[1] They have risen to the forefront of public attention through the ongoing COVID-19 pandemic, which presents an unprecedented global challenge. As of 4 August 2021, there have been over 199 million

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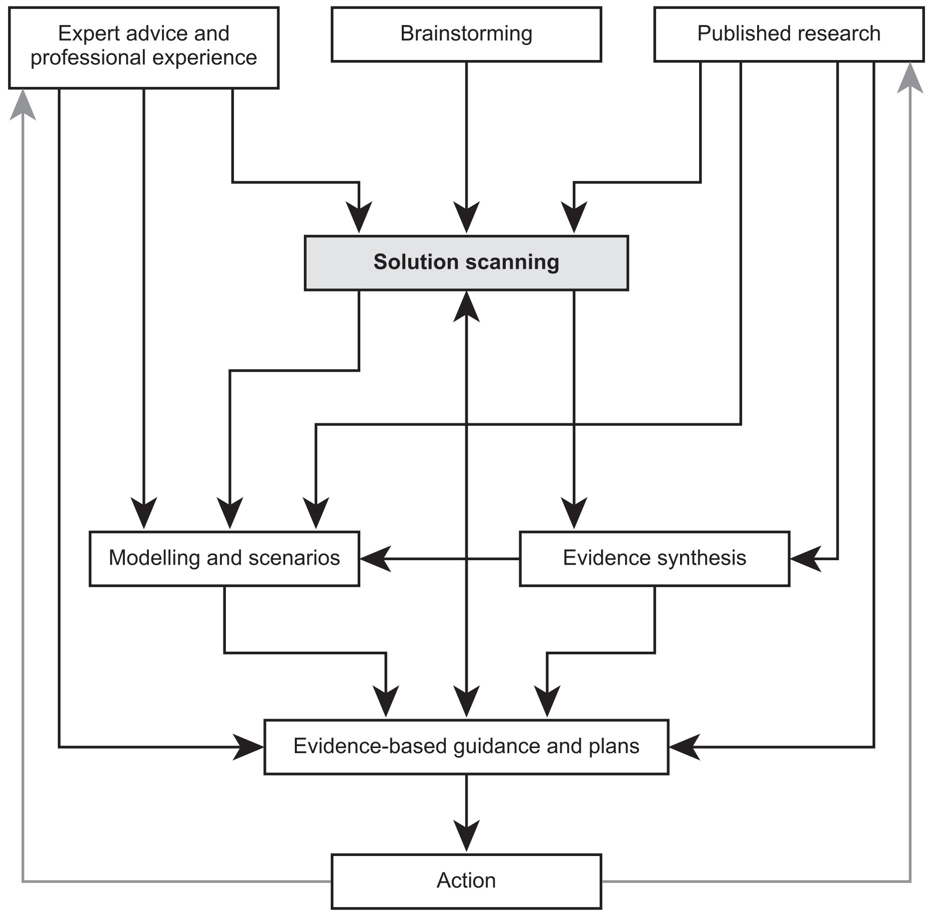

Fig. 1. A process for creating evidence-based guidance and plans, including biosecurity plans for SARS-CoV-2. Solution scanning is an initial stage for generating a reasonably comprehensive set of options for consideration. Next, research evidence is rigorously reviewed, and models are created based on the available evidence. Guidance and plans combine research with values, knowledge, and experience to provide the information needed for appropriate action. Action should ideally lead to feedback on the adopted options, including their practicality, effectiveness, and off-target effects.

recorded cases and over 4.2 million deaths attributed to COVID-19 worldwide.[2]

Managing a pandemic involves a combination of providing medical care for those suffering from the disease, pharmaceutical and clinical efforts such as testing drugs and developing vaccines, logistics, such as organizing facilities for testing and delivery of protective equipment, and a variety of societal biosecurity measures. Biosecurity risk management focuses on minimizing, as far as possible, the probabilities of emergence, entry, establishment, and spread of pests and diseases, and limiting the magnitude of impacts within their extent of spread.[3] 'Societal biosecurity' refers to measures adopted within everyday society to achieve these goals. Societal biosecurity is critical to compensate for limitations in other approaches, such as shortages of medical equipment, the time needed to develop and administer vaccines, and potential vaccine ineffectiveness due to pathogen mutation and resistance.

Severe and disruptive societal biosecurity measures, such as international travel bans and local or national lockdowns, have been successfully used to manage ongoing COVID-19 epidemics in many countries.[4,5,6] In particular, lockdowns have been widely used to 'flatten the curve' of infected cases to avoid overwhelming healthcare systems. However, such severe measures have also had serious economic and social consequences,[7,8,9] so decision-makers are keen to implement them for the shortest time possible. Thus, a range of softer, less disruptive societal biosecurity measures, such as physical distancing and wearing face masks, have also been adopted. It is likely that some of these measures will remain in place in the short to medium term, as we manage the ongoing pandemic and a safe transition to more normal societal conditions. For example, while the global population is vaccinated against SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2; the causative agent of COVID-19), soft societal biosecurity measures may help to mitigate the spread of novel viral variants and transmission of the virus by vaccinated individuals.[10,11] They may also be used to cope with future seasonal resurgences of COVID-19.[12] Some measures may remain in place permanently or be reinstated, as mitigation measures against future respiratory pathogens.

In any decision-making process (Fig. 1), it seems sensible to be aware of the full range of possible measures. The aim of this study was to catalog the range of practical societal biosecurity measures relating to the transmission and spread of SARS-CoV-2. A comprehensive list of options should inform biosecurity plans that will contribute to the management of the ongoing COVID-19 pandemic and the transition to more normal societal conditions over the coming months and years. In the long term, it will provide a starting point for managing future epidemics and pandemics involving respiratory pathogens.

To explore the options, we performed a 'solution scan'. The process of solution scanning uses published research, existing guidance, the experience of experts and practitioners, and brainstorming (including crowd-sourcing) to identify a range of potential solutions to a problem.[13] This includes options that may be ineffective, inconvenient, controversial, or have negative side effects. Importantly, solution scans can identify options not yet captured in the published literature (for novel or fast-moving topics) or overlooked by the published literature (for established topics). Solution scans have been widely used to identify options to maintain or enhance ecosystem services[13] and interventions to conserve biodiversity[14,15,16], but the process can be applied to problems in any discipline. Walsh et al.[17] demonstrated how solution scans can broaden the range of options considered by decision-makers: 92 conservation practitioners responsible for addressing a problem were aware of only 57% of the possible interventions identified by a solution scan.

2. Methods

2.1. Creating the list of options

The broad societal approaches for limiting transmission (small scale, e.g., between individuals or within an office) and spread (large scale, e.g., between cities or countries) of SARS-CoV-2 are well-accepted. They include physical distancing, use of physical barriers such as screens and masks, improved cleaning and hygiene, and managing large-scale travel. The aim of our solution scan was to explore more specific options for implementing such approaches in practice.

Our scan began by soliciting input from the authors of this paper, based on their knowledge and personal experience. The work was initiated by those affiliated with BioRISC (Biosecurity Research Initiative at St Catharine's College, Cambridge), Conservation Evidence based in the Department of Zoology, University of Cambridge, and the Center for the Study of Existential Risk. The authorship group was selected to include expertise in behavioral interventions, biosecurity, business, disease transmission, the environment, epidemiology, existential risks, medicine, pandemics, public health, public policy, and solution scanning. Our scan was global in scope, but we accept that there is some bias in the geographical coverage of the authors (mostly from the Global North) and that measures other than those listed may be more appropriate in other contexts.

The authors' knowledge and experience were supplemented by ad hoc searches of the literature, crowdsourcing of ideas through social media, and informal personal communications. The literature included peer-reviewed articles, preprints, guidance, government policies and briefs, newspapers, and other popular media, in a variety of languages (including Chinese, English, French, German, Italian, Romanian and Spanish). A particular effort was made to acquire information that complemented the authors' experience, for example, by examining publications from countries or regions with which we were less familiar.

The scanning process was initiated in March 2020. An initial list of 275 options was published as a preprint[18] and gathered considerable media attention, leading to further suggestions of options from policy-makers and the public. The list was refined and expanded up to August 2021. We anticipate further updates to the list of options on the website https://covid-19.biorisc.com.

2.2. Scope

In considering societal measures that may reduce the transmission and spread of SARS-CoV-2, we specifically do not consider pharmaceutical measures (e.g., drugs and vaccines) or measures to reduce transmission in a clinical setting (e.g., patient management and disinfection of medical equipment). We focus on reducing human–human transmission of an existing pathogen, rather than preventing zoonotic spillover from wild animals into humans. A parallel paper has been written to identify the means of reducing the risk of new human pathogens emerging from wild and domestic animals.[19]

Our audience is primarily governments, policy-makers, businesses, and other organizations considering how to reduce viral transmission and spread during ongoing infection waves and transitions to more normal but pandemic-resilient societal conditions. Researchers can use our list to stimulate primary research and evidence synthesis.

We stress that we have generated a list of options to consider, not recommendations, as we did not assess the effectiveness of these options. Some measures might be ineffective at reducing transmission risk or could even increase it, depending on the context. For example, will limiting the number of items that can be purchased at one time result in people shopping more frequently? Does shutting pubs earlier in the evening reduce transmission or increase it as people leave simultaneously and crowd together? Nevertheless, we avoided listing options lacking any kind of credible evidence base,[20] such as the idea of removing/destroying 5G phone masts that circulated in the UK.[21] Additionally, we did not consider the consequences of these measures on anything other than disease transmission or spread, or any means of mitigating these consequences. Many of these measures interact with environmental, economic, and social issues such as civil rights, inclusivity, justice, and the availability of medical resources (see Section 4.2).

3. Results

The full, current list of 519 societal options to reduce SARS-CoV-2 transmission or spread is included as an appendix to this paper.

4. Discussion

Our solution scan can inform the selection of appropriate societal biosecurity measures against the transmission and spread of SARS-CoV-2 (Fig. 1). The measures can be incorporated into biosecurity guidance and plans for immediate crisis management (e.g., surges of infected cases), long-term management of ongoing epidemics, and the design of a future pandemic-resilient society. Although we used SARS-CoV-2 as a case study, we expect that many of the measures are transferable to future epidemics or pandemics caused by pathogens transmitted or spread through similar pathways.[22] We discuss below how our list of options fits into the biosecurity planning process.

4.1. Designing biosecurity plans: identifying risks

Before considering possible measures to mitigate risks, decision-makers should identify high-risk areas and pathways. For respiratory viruses, such as SARS-CoV-2, transmission through direct or close contact with infected individuals appears critical.[23] Therefore, it is sensible to prioritize the application of measures to mitigate the risk posed by close interactions, especially in enclosed spaces. Transmission through contaminated items is also possible,[24] so decision-makers should identify specific items or interfaces that pose the highest risk in the situation being analyzed, perhaps because they are widely shared[25] or composed of a certain material.[26] At a larger scale, genomic analyses can be used to map out viral spread and key transmission routes.[27] Key areas and pathways will be somewhat context-dependent, varying over time and between settings (e.g., office building vs. nightclub, or countries with different cultural practices). A precautionary approach may be prudent when there is uncertainty in the importance of pathways in facilitating transmission, especially in the early stages of dealing with a disease.

4.2. Designing biosecurity plans: identifying options

Once the key risks have been identified, decision-makers should select relevant and practical measures to tackle them. Our list of options provides a starting point for this study. For any particular problem, the long list of options will quickly be whittled down to a much shorter list of candidate options based purely on relevance and practicality alone (Box 1). The online application at https://alecchristie888.shinyapps.io/Covid_19_options/ was designed to help with this. The shortlisted options should be further assessed (Fig. 1) taking into account factors such as likely effectiveness, off-target consequences, cost, legality, fairness, social acceptability, likely compliance, and coherence with other measures within guidance or plans. We reiterate that the list of options does not include information on these factors: many will be very context-dependent, and at the time of writing, many lack a published evidence base.

Ideally, effectiveness should be assessed using robust evidence, not simply intuition. Behavioral measures that seem intuitively sensible may not actually work: providing financial incentives for adults to attend literacy classes, for example, can actually *reduce* attendance.[28,29] Systematic reviews of evidence, such as those provided by the Oxford COVID-19 Evidence Service (https://www.cebm.net/oxford-covid-19/) or listed in the Cochrane Library (https://www.cochranelibrary.com/covid-19), often provide the most reliable and comprehensive assessment of effectiveness. Rapid reviews, synopses, or other evidence-based guidance (e.g., reducing risks during food shopping at www.flattenthecurve.com) can also be useful, especially when there are temporal or financial limitations. Expert opinion can be a useful supplement to existing published evidence.[30]

Box 1 Creating a context-specific shortlist from the master list of options As a hypothetical example, consider the possible measures for reopening a museum that was shut because of severe crowding. How can the museum be safely reopened, minimizing the risk of transmission due to close interactions? The solution scan provides a range of options that may reduce the frequency or duration of close interactions, from which a shortlist can be made (10 here) largely based on relevance and practicality. The shortlist should then be subjected to further consideration on likely effectiveness, compliance, costs, and any negative consequences (e.g., regarding public relations or social equity). At this stage, the latest guidance, such as that from the Centers for Disease Control and Prevention (CDC) or the World Health Organization (WHO), should be consulted.

1. Remove, block off or close facilities that encourage groups to form (e.g., benches).
2. Limit time inside shared space.
3. Require pre-booking of time slots to use or enter facilities.
4. Provide access to alternative spaces (e.g., free access to museums that normally charge admission).
5. Provide virtual reality alternatives to visits outside the home (e.g., virtual museums).
6. Encourage people to observe physical distancing, with effective messaging.
7. Provide wearable items that mark out safe distances between individuals.
8. Encourage or require walking in one direction (e.g., clockwise) around shared spaces.
8. Clearly separate entrances and exits.
10. At congested entry points give directions for users to alternate who goes next from a physically-distanced queue on each side.

In the absence of a collated body of evidence testing practical measures, pragmatic decisions need to be made. For example, during the COVID-19 pandemic, supermarkets were faced with clear evidence-based advice to increase the physical distance between individuals, and there was evidence of increased risk to vulnerable groups. They applied a series of measures including one-way systems, markings on the floor to encourage spacing, prioritizing home delivery to vulnerable groups, and restricting the first hour of opening each day to vulnerable groups and caregivers. There was little evidence on the effectiveness *of these specific measures*, but since there was a need to act urgently, we consider this approach to be highly appropriate. Where there is a limited evidence base, implementing and testing alternative strategies can be highly valuable, especially when the results are shared with other decision-makers.

Beyond effectiveness in reducing disease transmission, it is important to consider the local socio-ecological context when selecting appropriate measures. For example, current medical care capacity may define the appropriate severity of intervention: the initial public health response to SARS-CoV-2 in Lebanon was more stringent than that in South Korea, because medical resources were more limited in Lebanon.[31] Moreover, many of our listed measures involve trade-offs between effects on disease transmission and other biological, social, economic, and environmental issues. Isolation can have severe mental and physical implications.[7] Limiting the number of staff that can work simultaneously may affect household income. Encouraging the use of single-use materials may lead to environmental pollution.[32] These trade-offs must be weighed when selecting measures, and there must be some centralization to ensure that specific biosecurity plans do not unintentionally undermine broader policies. Measures that are likely to cause significant distress or are unlikely to generate sufficient compliance may not be justifiable. This may be the case when the social costs of restrictions are not borne equally by all members of society. For example, closing places of worship will be highly distressing for some people, while for others, it will have no impact. Shifts to online activities may present a disadvantage to those without access to technology or with less confidence in using it.

The measures within biosecurity plans and how those measures are implemented will also vary over time as priorities shift between controlling transmission and allowing activities to resume. However, measures introduced during a pandemic may be maintained during the transition to a more normal society. For example, temperature screening has continued within China and has facilitated the identification of new infections before substantial spread in a number of cities. Physical distancing and wearing face masks in public have become a routine part of daily life around the world.[33,34] In many countries, the transition in and out of severe measures has been phased, for example, by region, age group, or socioeconomic activity.

4.3. Reporting back on implemented options

Once measures have been implemented, it is desirable to report on their effects on disease transmission and spread, off-target or side effects, and practicality (Fig. 1). Reporting will improve future assessments and the targeted selection of options.

For some options, the appropriate outcome for judging effectiveness is the level of disease transmission or spread itself. For example, some evidence suggests that closing public spaces (especially schools and universities), banning gatherings, and international travel restrictions are all associated with a large and significant reduction in SARS-CoV-2 transmission.[35,36] Similarly, a study in China found that regularly cleaning surfaces with chlorine- or ethanol-based disinfectants significantly reduced SARS-CoV-2 transmission within households.[37]

However, the high resolution of many of the options in our list means that intermediate outcomes, such as human behavior, the contact rate, or the presence of viable virus in the environment, might be more realistic outcomes by which to monitor effects. Further evidence or theory links these outcomes to viral transmission and spread. For example, there is strong evidence from laboratory[38,39] and epidemiological[40,41] studies that wearing face masks reduces the risk of contracting COVID-19. The appropriate outcome for judging the effectiveness of many options to increase the effective use of face masks (Appendix Section 2.3) is whether they increase the number of people wearing face masks in the correct manner. To this end, an observational study in Guatemala found that the proportion of people correctly wearing face masks increased after the introduction of a mandatory mask mandate.[42] Options that appear to be less effective based on behavioral outcomes (at least in some specific cases) include providing hand sanitizer stations and installing one-way systems, which have been infrequently used or ignored in bars in Scotland,[43] and encouraging self-isolation of close contacts, which may have pushed people to delete contact tracing apps in the UK.[44]

Many of the specific options in our list remain insufficiently tested, or untested, in the context of the COVID-19 pandemic. Evidence could be co-opted from other similar pathogens or diseases or from the wider behavioral science literature. When carrying out new studies, it is desirable to evaluate the individual effects of interventions. Simultaneous implementation of multiple interventions during the COVID-19 pandemic makes this challenging in post hoc analyses.[35] Studies should also consider evaluating both the overall measure (e.g., encouraging hand washing) and different ways of implementing it (e.g., different poster designs to encourage hand washing[45]). The effectiveness of public health messages can depend strongly on the way in which they are framed, for example, whether they appeal to fear or empathy, and the cultural relevance of the delivery.[46,47]

During the COVID-19 pandemic, clinical practitioners have been sharing their implementation experience and inventing means of improving procedures,[48] and we encourage those involved in public health to do the same. Returning to our supermarket example, open questions surrounding the implementation of measures include: Does trust work when specifying shopping hours for vulnerable groups or is identification needed? Are markings sufficient for a one-way system or are barriers also essential? Are boxes or spots more effective at encouraging physical distancing in queues? Do people in queues now distance themselves automatically without marking? How can the usual one-way system design be improved?

4.4. Outlook

Our solution scan has already contributed to biosecurity decision-making around the world. It can continue to inform biosecurity planning for SARS-CoV-2, as vaccines are rolled out globally and in response to future resurgence of the virus. In the long term, we anticipate that our catalog of options will be a useful starting point when considering biosecurity management of novel respiratory viruses. Indeed, measures meant to manage SARS-CoV-2 transmission have reduced the incidence of respiratory diseases such as seasonal influenza.[49] We encourage research into the effectiveness, off-target effects, and practicality of the listed options to generate the evidence that is a key part of the biosecurity planning process (Fig. 1). We also encourage the identification of further options to reduce the transmission and spread of SARS-CoV-2, including modifications to existing options and addition of completely novel ideas, and provide a framework for collating these (contact: biorisc@caths.cam.ac.uk). Similar solution-scanning exercises could be carried out in other fields, such as minimizing the economic, mental, and physical health and social consequences of responses to the COVID-19 pandemic, including the challenges faced during societal recovery.[50]

CRediT authorship contribution statement

William J. Sutherland: Conceptualization, Methodology, Investigation, Data curation, Writing - original draft, Writing - review & editing, Project administration, Supervision, Funding acquisition. **Nigel G. Taylor:** Investigation, Data curation, Writing - original draft, Writing - review & editing, Project administration. **David C. Aldridge:** Investigation, Writing - review & editing. **Philip Martin:** Investigation, Writing - review & editing. **Catherine Rhodes:** Investigation, Writing - review & editing. **Gorm Shackelford:** Investigation, Writing - review & editing, Visualization. **Simon Beard:** Investigation, Writing - review & editing. **Haydn Belfield:** Investigation, Writing - review & editing. **Andrew J. Bladon:** Investigation, Writing - review & editing. **Cameron Brick:** Investigation, Writing - review & editing. **Alec P. Christie:** Investigation, Writing - review & editing. **Andrew P. Dobson:** Investigation, Writing - review & editing. **Harriet Downey:** Investigation, Writing - review & editing. **Amelia S.C. Hood:** Investigation, Writing - review & editing. **Fangyuan Hua:** Investigation, Writing - review & editing. **Alice C. Hughes:** Investigation, Writing - review & editing. **Rebecca M. Jarvis:** Investigation, Writing - review & editing. **Douglas MacFarlane:** Investigation, Writing - review & editing. **William H. Morgan:** Investigation, Writing - review & editing. **Anne-Christine Mupepele:** Investigation, Writing - review & editing. **Stefan J. Marciniak:** Investigation, Writing - review & editing. **Cassidy Nelson:** Investigation, Writing - review & editing. **Seán Ó. hÉigeartaigh:** Investigation, Writing - review & editing. **Clarissa Rios Rojas:** Investigation, Writing - review & editing. **Katherine A. Sainsbury:** Investigation, Writing - review & editing. **Rebecca K. Smith:** Investigation, Writing - review & editing. **Lalitha S. Sundaram:** Investigation, Writing - review & editing. **Ann Thornton:** Investigation, Writing - review & editing. **John Watkins:** Investigation, Writing - review & editing. **Thomas B. White:** Investigation, Writing - review & editing. **Kate Willott:** Investigation, Writing - review & editing. **Silviu O. Petrovan:** Investigation, Data curation, Writing - original draft, Writing - review & editing, Project administration.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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