Mitigation of COVID-19 epidemics will likely fail if the population reduces rates of transmission in response to the saturation of critical care facilities

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The UK is currently planning a mitigation response to the COVID-19 epidemic rather than ongoing containment. This strategy is informed by prior modelling studies and analysis of the severe 1918 influenza pandemic. The primary benefit of mitigation is that the epidemic will be over more quickly than might otherwise be the case, with the population having acquired herd immunity and also having experienced a relatively low peak. Here, we use simple compartmental models and recent infection fatality rate estimates for the UK to explicitly examine the implications of the UK population responding to a severe pathogen more strongly than did populations in 1918. We show that critical care facilities in the UK would be saturated quickly. If populations spontaneously reduce transmission close to threshold values when this occurs, any possible benefits of attempting mitigation are lost. The country would then have to either struggle on to the availability of a vaccine without a functioning health system or attempt the most stringent possible interventions to lower incidence back to containment levels. Over the same period of time, either of these scenarios would likely have far greater economic costs than would result from an immediate switch now to ongoing containment. These results directly support current advice from the World Health Organisation and are consistent with policy decisions made by China, Hong Kong, Singapore, Japan, South Korea and most recently Italy. Even if ongoing containment were to fail, we would have gained time and knowledge with which to decide our next strategy.

At the end of December 2019, cases COVID-19 severe respiratory disease, caused by the SARS-CoV-2 virus were reported to the World Health Organization [1]. Since then, the virus has spread to all global regions and is in the process of taking off in many countries. Many vaccine candidates are under development, but reliable products are not expected to be available in large volumes for 18 months, and there are no guarantees that vaccines will be available then [2].

Government responses to the global spread of COVID-19 fall into two broad categories: either countries are attempting to minimize the number of cases by keeping transmission below the critical threshold (ongoing containment, e.g. China, Hong Kong and Singapore) or intervention plans are in place to dampen transmission such that populations achieve no more than the required herd immunity with as little societal disruption as possible (mitigation, e.g. UK and USA).

Government policy during a pandemic is not determined only by epidemiology. In theory, any epidemic of a directly transmitted pathogen can be stopped if all social contact is stopped, as was the case in China initially. However, without any activity the economy also halts, resulting in societal breakdown and associated adverse health outcomes. Although the complete shutdown of Wuhan in China was sufficient, it may not have been necessary to achieve ongoing control of COVID-19. China's stated aim is to restart the economy and to manage any rebound in cases using rapid testing and advanced, technology-enabled, public health processes.

The current global outbreak of COVID-19 is the most widespread public health challenge posed by a virus since 1918, with many countries relying on influenza preparedness plans that were developed during the early 2000s and then updated after the 2009 H1N1 pandemic. These plans include the concept of mitigation based on historical analysis of the 1918 pandemic [3,4]. There was evidence that social distancing and the banning of mass gathering resulted in slightly lower rates of transmission. The lowered transmission did not achieve ongoing containment for these epidemics, rather, it reduced epidemic peaks and total infections while allowing the build up of herd immunity, allowing life to return to relatively normal conditions within a few months. Influenza preparedness plans are supported by evidence from disease dynamic studies, motivated by those historical analyses e.g. [5]. These studies did not assume any widespread changes in behaviour other than the interventions they considered explicitly.

Over one hundred years have passed since these relatively modest behavioral changes occurred during the circulation of the 1918 H1N1 strain of influenza. The world of 1918 was very different to the world of 2020. For example, while the main source of information was newspapers, only 31% of the global population were literate [6]; television had not yet been invented. Moreover, the average life expectancy in Europe was a mere 37 years [7].

More recently, we have seen the disease dynamics of SARS, MERS, and Ebola all be influenced greatly by public awareness of the consequences of a severe infection: regardless of specific public health policy, armed with the knowledge of the presence of the pathogen and its severity, people substantially reduced their risky behaviours and also their volume of social contacts. In terms of the infection fatality rate (IFR), at ~1%, SARS-CoV-2 is substantially less severe than any of SARS, MERS or Ebola. However, estimates for SARS-CoV-2 have been made for populations with sufficient capacity for critical care. We would expect the IFR to rise to ~5%, based on rates of mechanical ventilation, in the absence of critical care facilities, with even higher rates in the elderly.

We use a simple compartmental model of SARS-CoV-2 transmission to illustrate the likely epidemic profiles and health impact of different strategies: no intervention; successful mitigation and successful ongoing containment (SC). Crucially, we also look at a plausible mechanism of failure for mitigation. We estimate the total numbers of infections and deaths during the first 18 months of the epidemic for each scenario as well as the degree of herd immunity achieved at the end of that period.

The most recent detailed analysis of linelist data from Wuhan suggests an R_0 of 2.0 in a population undergoing no mitigation and without knowledge of the presence of a severe pathogen (*C. Fraser, personal communication*). Therefore, for a population to be protected by herd immunity, 50% of individuals need to have been infected and no longer susceptible. In a fully mixed population, a mitigated transmissibility of R_0=1.4 would produce a final size of ~50%, leaving the population protected against re-invasion by the same pathogen even at the uncontrolled R_0 of 2.

Results

We use the term '"successful" mitigation' (SM) because we believe it represents close to a desired outcome under current plans, not because we consider it to be a successful outcome. The benefits of SM over an unmitigated epidemic (UE) are substantial in a large well-mixed population of 66 million people, under the assumption that it starts with 5,000 people infectious on day 0, that interventions start on day 14, and that 10 infectious individuals arrive in the country each week from overseas (Scenarios UE and SM, Figure 1 and Table 1). We estimate 53 million infections and 2.7 million deaths for UE. This is reduced to 35 million infections and 1.7 million deaths under SM. The model predicts many people will become severely ill but not have access to critical care. Therefore the mortality rate is substantially higher than 1%. Under SM, the epidemic is over after 7 months and with slightly more infections than is required for herd immunity.

"Successful" mitigation could be a better strategy than attempting SC because: (1) SC could fail, (2) SC will not generate herd immunity and (3) SM has a clear endpoint. Successful ongoing containment would clearly be the optimal outcome if it is possible, as is naively obvious from the orders of magnitude difference in infections and deaths (Table 1). However, it generates no herd immunity and must be in place for the full period, and beyond if a viable vaccine is not available after 18 months. Hence the consideration of SM, despite its enormous health impacts. It may be the case that because there is a clear likely end point for SM, it is a preferred strategy over attempting SC. However, such detailed economic evaluation is beyond the scope of this work.

Mitigation may not succeed. Following recent reports from Italy, the unavoidable consequence of saturated critical care will be geographical quarantine: symptomatic or exposed individuals will not be allowed to leave their home area and consume health care resources in geographical areas that are less affected at that time. Therefore, individuals will be living with a circulating pathogen with an age-averaged IFR of ~5% and will be forcibly prohibited from leaving. Based on studies of SARS, MERS and Ebola; we think it is extremely unlikely that the average number of contacts and the nature of those contacts will not be reduced substantially relative to the period prior to the saturation of critical care. Crucially, we must consider that saturated critical care will lead to levels of transmission at or below 1.0. If the mitigation strategy is working at the point that critical care is saturated, this will only be a reduction of 23% from 1.3 to 1.0.

If mitigation fails in this way when critical care is saturated (UM, Figure 1), it will have no benefits over an all out attempt on SC. UM lasts for the full 18 months yet still does not generate herd immunity. For that period, the health care system will struggle to operate. The economy will likely be just as badly affected by people being inactive because of fears of the virus as it would be affected by stringent interventions in SC. The numbers of infections and deaths under UM is vastly higher than those we would expect under SC.

The potential for the failure of mitigation is robust to some straightforward sensitivity analysis. If the population behaviour change trigger is at twice the ICU capacity, rather than at actual capacity, the outcome is even worse (UMs1, Figure 2, Table 1). Herd immunity is still not achieved, the outbreak lasts the full 18 months and far more deaths would occur. The impact of the same trigger but less of a behavioural change has very similar outcomes (UMs2,

Figure 2, Table 1). A behaviour change smaller than a drop in R_0 1.3 to 1.1 from a period of effective mitigation with critical care to a period without critical care seems unlikely.

Discussion

If the local human population responds to saturation of critical care with COVID-19 patients by reducing contacts such that transmission is close to R=1, there will be no benefit to attempting mitigation over attempting ongoing control. Rather, the epidemic will still last through to the time at which a vaccine may be available, far more people will be infected than would be the case with ongoing containment, and far more will die. The health care service will never have an opportunity to recover and it seems likely there would be substantial additional health costs from the knock-on effects of the prolonged period of high COVID-19 incidence.

Our study has a number of limitations. The model is not spatial nor age structured. Rather it is as simple as possible to make the key points. The scale of difference between the health benefits is so large that we do not think this is an issue. However, we have not directly strong age specific social distancing with the other policies. Because the fatality rate is so much higher in older age groups, it is possible that a very stringent social distancing of older adults could dramatically reduce the crude numbers of deaths presented here based on age-averaged values. That said, IFR values are close to 1% even in the 50-59 age group, so it is not immediately clear how such a strategy could be implemented in an even approximately equitable way.

Essentially, our choice is whether to live with relatively high levels of infections and to let the virus decide our social structure for the next 18 months, or for us to find a way to live such that we keep levels of infection low and our social structures as close to normal as possible.

These results could be disheartening to those planning a response to COVID-19 epidemics. However, we suggest that they may also be a powerful positive motivation for action. The model results here do no more than reinforce the findings of the WHO China Mission and validate the strategy adopted by Chinese health authorities in or around the 23rd of January 2020; and then subsequently by Hong Kong, Singapore, Japan, and South Korea. We suggest that they are strong evidence with which to abandon mitigation strategies, justified in any way by the possibility of a short epidemic. Governments need to devote the entirety of their attention and resources to creating viable ongoing solutions to the presence of this virus. We suggest that the first step is to adopt stringent fixed-term social distancing so as to give time for detailed planning the rapid development of any accompanying technology.

Table 1. Key epidemiological outcomes for the first 18 months of a COVID-19 epidemic under different response policies for a well mixed population of 66 million people.

Scenario	Description	Infections	Deaths[1]	Herd immunity[2]
UE	Completely unmitigated epidemic	53,200,000	2,650,000	161%
SM	"Successful" mitigation	34,900,000	1,740,000	106%
SC	Successful ongoing control	274,000	2,670	1%
UM	Baseline unsuccessful mitigation	9,170,000	446,000	28%
UMs1	Sensitivity 1 unsuccessful mitigation[3]	16,700,000	807,000	51%
UMs2	Sensitivity 2 unsuccessful mitigation[4]	16,900,000	834,000	51%

[1]Assumes 1% IFR when critical care available and 5% otherwise.
[2]Assuming uncontrolled R_0 of 2.0 requires 33 million immune people for herd immunity, therefore can be greater than 100%..
[3]Trigger for behaviour change at 2x critical care capacity, R with critical care full 0.99.
[4]Trigger for behaviour change at 1x critical care capacity, R with critical care full 1.1.

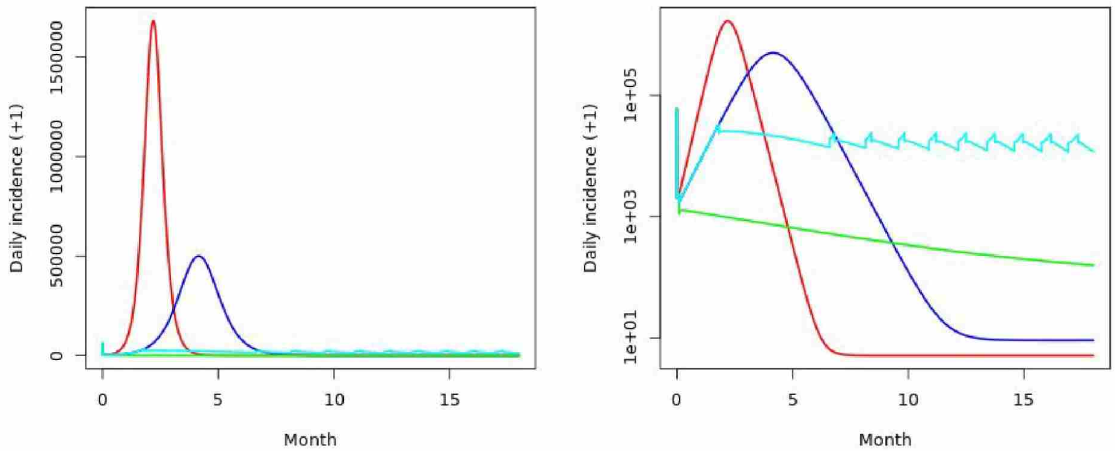

Figure 1. Epidemic trajectories on a linear (**A**) and log (**B**) scale for alternate response strategies. Red is an unmitigated epidemic (UE) with R_0=2.0. Blue is a “successfully” mitigated (SM) epidemic with a later lower peak that still achieves herd immunity for the unmitigated R_0 (however, the negative population health implications of SM are still enormous). Green is the ideal solution of successful sustained ongoing containment (SC). Cyan represents “unsuccessful” mitigation, which has far less negative impact on the population than SC, but lasts for the full 18 months and does not generate herd immunity. See Supporting Information R script and www.github.com/c97sr/idd.

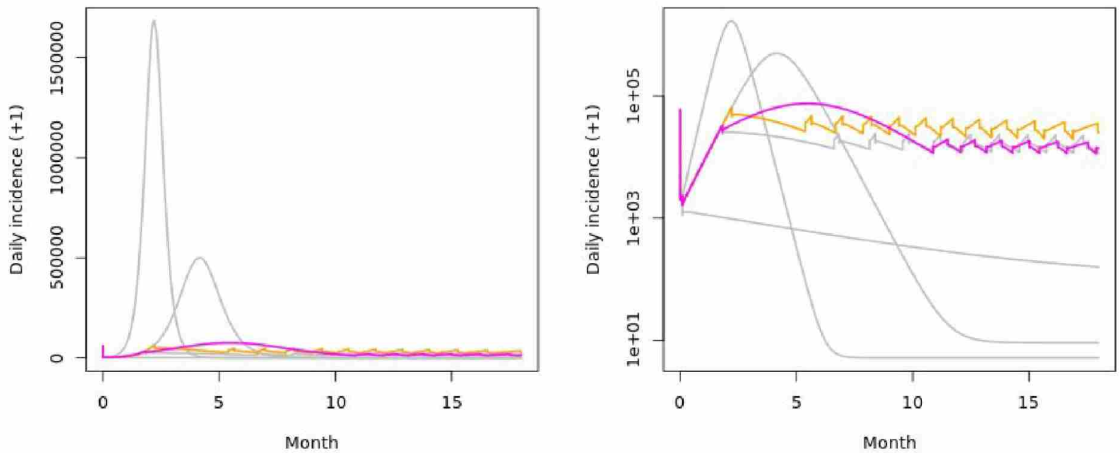

Figure 2. Sensitivity analyses for unsuccessful mitigation scenarios presented in Figure 1. Epidemic trajectories on a linear (**A**) and log (**B**) scale. Orange has a trigger for behaviour change at 2x critical care capacity with R after saturated critical care at 0.99. Magenta has a trigger for behaviour change at 1x critical care capacity, R with after saturated critical care at 1.1. Grey lines are the same as Figure 1 and are shown for reference only.

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