The following information resources have been selected by the National Health Library and Knowledge Service Evidence Virtual Team in response to your question. The resources are listed in our estimated order of relevance to practicing healthcare professionals confronted with this scenario in an Irish context. In respect of the evolving global situation and rapidly changing evidence base, it is advised to use hyperlinked sources in this document to ensure that the information you are disseminating to the public or applying in clinical practice is the most current, valid and accurate.

YOUR QUESTION

What are the approaches to modelling the COVID-19 pandemic within and across countries with a specific focus on health service implications? How are countries using modelling to inform the response of health services to the pandemic?

Key Themes

Modelling does not predict the future; it is a tool to explore scenarios and the potential impact of actions we might take.

The lack of real data on COVID-19 makes it difficult to build accurate models but this will improve as access to data specific to a particular country becomes more available.

Models seem to focus on two strategies – suppression vs mitigation – with the aim of guiding governments as to how they can ensure that health services are able to respond so that sufficient capacity is available: ie buying time or delaying.

A second peak may follow the lifting of containment measures.

What does the European Centre for Disease Prevention and Control say?

European Centre for Disease Control and Prevention. Rapid risk assessment: Coronavirus disease 2019 (COVID-19) pandemic [Eighth Update][1]

Over the past few weeks, EU/EEA countries and the UK have implemented a range of measures to reduce further transmission of the virus, focussing in particular on physical distancing to decrease the burden on healthcare services, protect populations at risk of severe disease and reduce excess mortality. There is evidence from countries in Asia that were affected early in the pandemic, which is supported by modelling studies, and preliminary signs from Italy and Austria, that a combination of stringent measures can achieve meaningful reductions in transmission.

INFORMATION ON MODELLING COVID-19

Chapman (09/04/2020). [Cochrane] Quarantine for controlling COVID-19 (coronavirus). New Cochrane evidence[2]

The COVID-19 modelling studies in the review consistently report a benefit of quarantine in reducing the number of people who get infected and who die from COVID-19. The studies on SARS and MERS have similar results.

Adam (2020). Special report: The simulations driving the world's response to COVID-19: How epidemiologists rushed to model the coronavirus pandemic[3]

Many of the models simulating how diseases spread are unique to individual academic groups that have been developing them for years, but the mathematical principles are similar. They are based around trying to understand how people move between three main states, and how quickly: individuals are either susceptible (S) to the virus; have become infected (I); and then either recover (R) or die. The R group is presumed to be immune to the virus, so can no longer pass on the infection. People with natural immunity would also belong to this group.

The simplest SIR models make basic assumptions, such as that everyone has the same chance of catching the virus from an infected person because the population is perfectly and evenly mixed, and that people with the disease are all equally infectious until they die or recover. More-advanced models, which make the quantitative predictions policymakers need during an emerging pandemic, subdivide people into smaller groups — by age, sex, health status, employment, number of contacts, and so on — to set who meets whom, when and in which places.

Jefferson, Heneghan [Oxford University Centre for Evidence Based Medicine] (2020). Modelling the models[4]

Those that have a mathematical basis are usually referred to as models. According to Wikipedia "a model may help to explain a system and to study the effects of different components, and to make predictions about behaviour". If applied to biomedicine and specifically to infectious diseases, models may help to understand the interactions of the different variables such as characteristics of the agent, target population, evolution of the spread and possible future scenarios. All models, be they prospective or retrospective, if they are based on scientific principles, have substantial uncertainty as to their starting point and are incompatible with oracle-like statements of certainty.

Jia at al. (01/04/2020). Modelling COVID-19 transmission: from data to intervention[5]

Mathematical models have been used to simulate scenarios and predict evolution of infectious diseases since the early 20th century. Models are usually driven by a disease's intrinsic mechanism or fitted through sufficient data, but they are frequently expected to provide quick insights of and predictive power on a new pathogen in the early stages of an outbreak, which are seemingly contradictory expectations. Indeed, it is not clear whether early cases of COVID-19 were from infection by animal or human, and data are limited and unreliable. In this case, models fitted by early data probably produce results divorced from reality. Early modelling studies have proved overly optimistic about the situation in Wuhan. The closer to reality, the more resources a model requires. Modellers must compromise with reality most of the time. As data are shared and computing performance improves [including artificial intelligence], we believe that the above contradictions will be alleviated. Mathematical modelling will have a greater role in supporting clinical diagnosis and optimising a combination of strategies. In view of substantial data accumulated for COVID-19, an essential next step is to estimate whether a second wave of COVID-19 will appear in China.

Wynants at al. (24/03/2020). Prediction models for diagnosis and prognosis of covid-19 infection: systematic review and critical appraisal[6]
COVID-19 related prediction models are quickly entering the academic literature, to support medical decision making at a time where this is urgently needed. Our review indicates proposed models are poorly reported and at high risk of bias. Thus, their reported performance is likely optimistic and using them to support medical decision making is not advised. We call for immediate sharing of the individual participant data from COVID-19 studies to support collaborative efforts in building more rigorously developed prediction models and validating [evaluating] existing models. The aforementioned predictors identified in multiple included studies could be considered as candidate predictors for new models. We also stress the need to follow methodological guidance when developing and validating prediction models, as unreliable predictions may cause more harm than benefit when used to guide clinical decisions.

INTERNATIONAL APPROACHES

Ireland

[RTE News] More time needed for reliable surge projection: NPHET[7]
The chair of the NPHET Irish Epidemiological Modelling Advisory Group has said it was not possible to make a prediction on the surge in COVID-19 cases at this time, as more time was needed for a more reliable picture. Speaking at this evening's COVID-19 briefing at the Department of Health, Professor Philip Nolan said that to make projections now on what things will be like in a few weeks or months would be inappropriate and based on assumptions that would be too broad. Ms O'Connor added that they are not working to a traditional model and are examining how to have ventilated beds in areas they would not have been previously. Under the worst-case scenario, the peak number of patients requiring intensive care a day would be 546 by 13 April. Some experts believe this scale of cases is unlikely to be seen because of the stay at home and other major measures announced by Government and recommended last Friday by the National Public Health Emergency Team and because the number of contacts per confirmed case is now down to under five.

[Journal.ie] [reaction to IHME report] 'It simply isn't true': Health officials dismiss US report which says Ireland is past COVID-19 peak[8]

Northern Ireland

'Minister Highlights Key Findings of NI COVID-19 Modelling'[9]
Health Minister Robin Swann has set out key findings of an expert NI modelling study which will inform intensive hospital planning for the forthcoming surge in COVID-19 cases.

UK

Imperial College [London]. Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand[10]
Researchers from Imperial College, London have analysed the likely impact of multiple public health measures on slowing and suppressing the spread of coronavirus. The latest analysis comes from a team modelling the spread and impact COVID-19 and whose data are informing current UK government policy on the pandemic. The findings are published in the ninth report from the WHO Collaborating Centre for Infectious Disease Modelling within the Imperial College London.
They have also published further reports including: Report 13: Estimating the number of infections and the impact of non-pharmaceutical interventions on COVID-19 in 11 European countries[11]

London School of Hygiene and Tropical Medicine (2020). Estimates for the relative impact of different COVID-19 control measures in the UK[12]
The London School of Hygiene and Tropical Medicine's Centre for the Mathematical Modelling of Infectious Diseases (CMMID) is conducting crucial work on the COVID-19 pandemic. Since February, CMMID has been asked by governmental advisory bodies to project the possible trajectory of the COVID-19 epidemic in the UK under a range of different scenarios, including introduction of non-pharmaceutical interventions such as school closures, social distancing shielding of the elderly and adults in high-risk groups. These large-scale interventions, including home isolation, aim to reduce coronavirus transmission. Estimates [not peer-reviewed] in a new pre-print combine some of the work CMMID has been conducting for the

government in February and March with more current data which has become available as this fast-moving epidemic evolves.

Australia

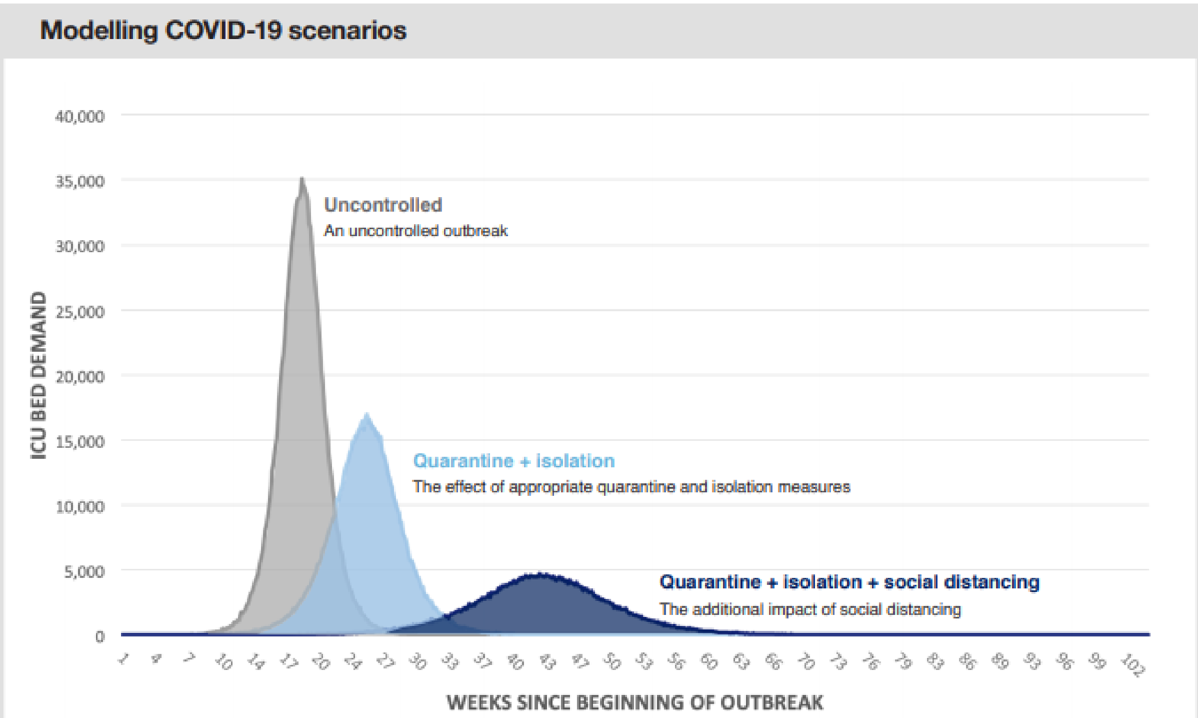
Australian Government (2020). Impact of COVID-19: theoretical modelling of how the health system can respond[13]

Modelling for COVID-19 involves making assumptions about how the virus behaves. Under the pandemic plan the Australian Government immediately started to develop possible scenarios. We used early data from China and other countries and our understanding of how other coronaviruses behave. The model also considers the impact of different levels of isolation and distancing.

The baseline for the modelling is not a realistic scenario. It is a theoretical, uncontrolled pandemic. It assumes the virus moves through the community with each infected person spreading it to 2.5 other people. It assumes no health system or community action to slow the spread.

The modelling finds our ICUs will cope if we continue to:

- have effective social distancing,
- increase our health system capacity
- isolate people with the virus and their close contacts



Moss at al.. [Preprint not yet submitted for peer-review]. Modelling the impact of COVID-19 in Australia to inform transmission reducing measures and health system preparedness[14]

The ability of global health systems to cope with increasing numbers of COVID-19 cases is of major concern. In readiness for this challenge, Australia has drawn on clinical pathway models developed over many years in preparation for influenza pandemics. These models have been used to estimate health care requirements for COVID-19 patients in the context of broader public health measures.

USA

Institute of Health Metrics and Evaluation (IHME) at the University of Washington. COVID-19 Projections[15]

A modelling tool that predicts peak of virus and death rate by August, as well as bed capacity for all countries. [NB: the predictions for Ireland have been challenged[8]].

CANADA

Scarabel at al.. (30/03/2020) [Pre-proof to appear in Infectious Disease Modelling] Canada needs to rapidly escalate public health interventions for its COVID-19 mitigation strategies[16]

The present paper aims to predict the trend of the COVID-19 outbreak in Canada by means of comparative modelling, using Italy as comparison.
In conclusion, Canada will not become the next Italy, but will fail to achieve better results in controlling the outbreak if a comprehensive package of public health interventions is not quickly enforced. Considering the delayed effect of intervention measures and the hospital bed shortage, it is imperative to take prompt actions to reduce the epidemic growth rate and to avoid overwhelming the capacity of the Canadian health system.

INTERNATIONAL LITERATURE

Leung at al. (08/04/2020) First-wave COVID-19 transmissibility and severity in China outside Hubei after control measures, and second-wave scenario planning: a modelling impact assessment[17]

The interventions China implemented in response to the COVID-19 outbreak had a real and dramatic effect on interrupting transmission in all areas outside of Hubei. As economic activity continues to resume in the coming weeks, real-time assessment by monitoring the instantaneous effective reproduction number could allow policy makers to tune relaxation decisions to maintain transmissibility to below the self-sustaining threshold of 1. CFRs vary between provinces, which might be determined by health-care availability, quality, and surge capacity. Therefore, health services planning should be optimised to minimise mortality related to COVID-19.

Steinberg at al. (06/04/2020). Calculated decisions: COVID-19 calculators during extreme resource-limited situations[18]

In the near future, clinicians may face scenarios in which there are not have enough resources – ventilators, ECMO machines, etc. – available for the number of critically sick COVID-19 patients. There may not be enough healthcare workers, as those who are positive for COVID-19 or those who have been exposed to the virus and need to be quarantined. During these worst-case scenarios, new crisis standards of care and thresholds for intensive care unit (ICU) admissions will be needed. Clinical decision scores may support the clinician's decision-making, especially if properly adapted for this unique pandemic and for the patient being treated. This review discusses the use of clinical prediction scores for pneumonia severity at 3 main decision points to examine which scores may provide value in this unique situation. Initial data from a cohort of over 44,000 COVID-19 patients in China, including risk factors for mortality, were compared with data from cohorts used to study the clinical scores, in order to estimate the potential appropriateness of each score and determine how to best adjust results at the bedside.

Kim at al. (06/04/2020). School Opening Delay Effect on Transmission Dynamics of Coronavirus Disease 2019 in Korea: Based on Mathematical Modeling and Simulation Study[19]

Nonpharmaceutical intervention strategy is significantly important to mitigate the coronavirus disease 2019 (COVID-19) spread. One of the interventions implemented by the government is a school closure. The Ministry of Education decided to postpone the school opening from March 2 to April 6 to minimize epidemic size. We aimed to quantify the school closure effect on the COVID-19 epidemic.

Hou at al. (03/04/2020). The effectiveness of the quarantine of Wuhan city against the Corona Virus Disease 2019 (COVID-19): well-mixed SEIR model analysis[20]

The present study shows that by reducing the contact rate of latent individuals interventions such as quarantine and isolation can effectively reduce the potential peak number of COVID-19 infections and delay the time of peak infection.

Bayham at al. (03/04/2020). Impact of school closures for COVID-19 on the US health-care workforce and net mortality: a modelling study[21]

The coronavirus disease 2019 (COVID-19) pandemic is leading to social physical distancing policies worldwide, including in the USA. Some of the first actions taken by governments are the closing of schools. The evidence that mandatory school closures reduce the number of cases and, ultimately, mortality comes from experience with influenza or from models that do not include the effect of school closure on the health-care labour force. The potential benefits from school closures need to be weighed against costs of health-care worker absenteeism associated with additional child-care obligations. Our model estimates that if the infection mortality rate of COVID-19 increases from 2·00% to 2·35% when the health-care workforce declines by 15·0%, school closures could lead to a greater number of deaths than they prevent. School closures come with many trade-offs and can create unintended child-care obligations. Our results suggest that the potential contagion prevention from school closures needs to be carefully weighted with the potential loss of health-care workers from the standpoint of reducing cumulative mortality due to COVID-19 in the absence of mitigating measures.

Moghadas SM at al. (03/04/2020). Projecting hospital utilization during the COVID-19 outbreaks in the United States[22]

In the wake of community coronavirus disease 2019 (COVID-19) transmission in the United States, there is a growing public health concern regarding the adequacy of resources to treat infected cases. Hospital beds, intensive care units and ventilators are vital for the treatment of patients with severe illness. Our estimates underscore the inadequacy of critical care capacity to handle the burgeoning outbreak. Policies that encourage self-isolation, such as paid sick leave, may delay the epidemic peak, giving a window of time that could facilitate emergency mobilization to expand hospital capacity

Sun Y at al. (25/03/2020). Epidemiological and Clinical Predictors of COVID-19[23]

Rapid identification of COVID-19 cases, which is crucial to outbreak containment efforts, is challenging due to the lack of pathognomonic symptoms and in settings with limited capacity for specialized nucleic acid-based reverse transcription polymerase chain reaction (PCR) testing. Rapidly ascertainable clinical and laboratory data could identify individuals at high risk of COVID-19 and enable prioritization of PCR-testing and containment efforts. Basic laboratory test results were crucial to prediction models.

Mandal S at al. (23/03/2020). Prudent public health intervention strategies to control the coronavirus disease 2019 transmission in India: A mathematical model-based approach[24]

Coronavirus disease 2019 (COVID-19) has raised urgent questions about containment and mitigation, particularly in countries where the virus has not yet established human-to-human transmission. The objectives of this study were to find out if it was possible to prevent or delay the local outbreaks of COVID-19 through restrictions on travel from abroad and if the virus has already established in-country transmission, to what extent would its impact be mitigated through quarantine of symptomatic patients? These questions were addressed in the context of India, using simple mathematical models of infectious disease transmission. While there remained important uncertainties in the natural history of COVID-19, using hypothetical epidemic curves, some key findings were illustrated that appeared insensitive to model assumptions, as well as highlighting critical data gaps.
Port-of-entry-based entry screening of travellers with suggestive clinical features and from COVID-19-affected countries would achieve modest delays in the introduction of the virus into the community. Acting alone,

however, such measures would be insufficient to delay the outbreak by weeks or longer. Once the virus establishes transmission within the community, quarantine of symptomatics may have a meaningful impact on disease burden. Model projections are subject to substantial uncertainty and can be further refined as more is understood about the natural history of infection of this novel virus. As a public health measure, health system and community preparedness would be critical to control any impending spread of COVID-19 in the country.

Koo at al. (23/03/2020). Interventions to mitigate early spread of SARS-CoV-2 in Singapore: a modelling study[25]

Since the coronavirus disease 2019 outbreak began in the Chinese city of Wuhan on Dec 31, 2019, 68 imported cases and 175 locally acquired infections have been reported in Singapore. We aimed to investigate options for early intervention in Singapore should local containment [eg preventing disease spread through contact tracing efforts] be unsuccessful.
We adapted an influenza epidemic simulation model to estimate the likelihood of human-to-human transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in a simulated Singaporean population. Implementing the combined intervention of quarantining infected individuals and their family members, workplace distancing and school closure once community transmission has been detected could substantially reduce the number of SARS-CoV-2 infections. We therefore recommend immediate deployment of this strategy if local secondary transmission is confirmed within Singapore. However, quarantine and workplace distancing should be prioritised over school closure because at this early stage, symptomatic children have higher withdrawal rates from school than do symptomatic adults from work. At higher asymptomatic proportions, intervention effectiveness might be substantially reduced requiring the need for effective case management and treatments, and preventive measures such as vaccines.

Martín-Calvo at al. (22/03/2020). Effectiveness of social distancing strategies for protecting a community from a pandemic with a data driven contact network based on census and real-world mobility data[26]

The current situation of emergency is global. As of today, March 22nd 2020, there are more than 23 countries with more than 1.000 infected cases by COVID-19, in the exponential growth phase of the disease. Furthermore, there are different mitigation and suppression strategies in place worldwide, but many of them are based on enforcing to a more or less extent the so-called social distancing. The impact and outcomes of the adopted measures are yet to be contrasted and quantified. Our report contains preliminary results that aim at answering the following questions in relation to the spread and control of the COVID-19 pandemic:

- What is the expected impact of current social distancing strategies?
- How long should such measures need to be in place?
- How many people will be infected and at which social level?
- How do R(t) and the epidemic dynamic change based on the adopted strategies?
- What is the probability of having a second outbreak: ie a re-emergence?
- If there is a re-emergence, how much time do we have to get ready?
- What is the best strategy to minimize the current epidemic and get ready for a second wave?

National Academies of Sciences, Engineering, and Medicine (21/3/2020). Rapid Expert Consultation on Data Elements and Systems Design for Modeling and Decision Making for the COVID-19 Pandemic[27]

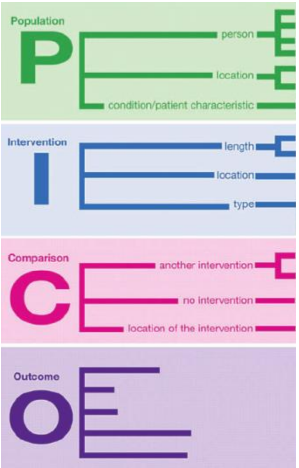
Whether for a known infectious pathogen or a novel one, the ability to model the pathogenesis, transmission, effective control strategies and spread of a disease can provide crucial information to those needing to make decisions about the distribution of limited resources. An example of a successful collaborative effort is the Models of Infectious Disease Agent Study (MIDAS). This effort, funded by the National Institute of General Medical Sciences at the NIH, is a global network of research scientists and practitioners who develop and use computational, statistical and mathematical models to understand infectious disease dynamics. MIDAS has an online portal to share data and information regarding the COVID-19 pandemic and could be used as a resource for decision-makers. To assist with forecasting disease progression and identifying important clinical markers before we obtain more data on COVID-19 in the US, data from other countries, such as the daily number of hospitalizations, intensive care admissions, ventilator use and deaths, can be used in forecasting expected epidemic progression and assist with clinical care decisions. Assessing the capacity of medical facilities to provide intensive care to those in need will facilitate the allocation of ICU beds and ventilators. Programs at local and regional levels currently monitor the availability of hospital beds and other resources, and expanding these programs would provide a national view of areas most in need. Tracking mortality from disease in relation to resources can aid in the interpretation of fatality rates and inform future pandemic preparedness.

Lin at al. (04/03/2020). A conceptual model for the coronavirus disease 2019 (COVID-19) outbreak in Wuhan, China with individual reaction and governmental action[28]

The ongoing coronavirus disease 2019 (COVID-19) outbreak, emerged in Wuhan, China in the end of 2019, has claimed more than 2600 lives as of 24 February 2020 and posed a huge threat to global public health. The Chinese government has implemented control measures including setting up special hospitals and travel restriction to mitigate the spread. We propose conceptual models for the COVID-19 outbreak in Wuhan with the consideration of individual behavioural reaction and governmental actions: eg holiday extension, travel restriction, hospitalisation and quarantine. We employed the estimates of these two key components from the 1918 influenza pandemic in London, incorporated zoonotic introductions and the emigration, and then compute future trends and the reporting ratio. The model is concise in structure, and it successfully captures the course of the COVID-19 outbreak, and thus sheds light on understanding the trends of the outbreak.

Produced by the members of the National Health Library and Knowledge Service Evidence Team[†]. Current as at 09 April 2020.This evidence summary collates the best available evidence at the time of writing and **does not replace clinical judgement or guidance**. Emerging literature or subsequent developments in respect of COVID-19 may require amendment to the information or sources listed in the document. Although all reasonable care has been taken in the compilation of content, the National Health Library and Knowledge Service Evidence Team makes no representations or warranties expressed or implied as to the accuracy or suitability of the information or sources listed in the document. This evidence summary is the property of the National Health Library and Knowledge Service and subsequent re-use or distribution in whole or in part should include acknowledgement of the service.

The following PICO(T) was used as a basis for the evidence summary:



Population	COVID-19
Intervention	MODELLING
Comparison	
Outcome	HEALTH SERVICE PREPAREDNESS AND RESPONSE

The following search strategy was used:

1 exp Coronavirinae/
2 covid-19.ab,ti.
3 coronavirus.ab,ti.
4 "corona virus".ab,ti.
5 (wuhan adj3 virus).ab,ti.
6 ("2019-nCoV" or "2019 ncov").ab,ti.
7 "severe acute respiratory syndrome coronavirus 2".ab,ti.
8 ("2019" and (new or novel) and coronavirus).ab,ti.
9 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8
10 limit 9 to yr="2019 -Current"
11 (mathematical adj3 model*)
12 (theoretical adj3 model*)
13 11 or 12
14 10 and 13

[†] Helen Clark, Librarian, Sligo University Hospital [Author]; Brendan Leen, Regional Librarian, HSE South, St. Luke's General Hospital, Kilkenny [Editor]

---

[1] European Centre for Disease Control and Prevention (2020). Rapid risk assessment: Coronavirus disease 2019 (COVID-19) pandemic [Eighth Update] https://www.ecdc.europa.eu/en/rapid-risk-assessment-coronavirus-disease-2019-covid-19-pandemic-eighth-update. [Accessed 09 April 2020].
[2] Chapman (09/04/2020). [Cochrane] Quarantine for controlling COVID-19 (coronavirus). New Cochrane evidence. https://www.evidentlycochrane.net/quarantine-covid-19/.[Accessed 09 April 2020].
[3] Adam D. Special report: The simulations driving the world's response to COVID-19. *Nature*. 2020;580(7803):316–318. doi:10.1038/d41586-020-01003-6.
[4] Jeferson, T, Heneghan, C. Modelling the models. https://www.cebm.net/2020/04/modelling-the-models/ [Accessed 09 April 2020].
[5] Jia Z, Lu Z. Modelling COVID-19 transmission: from data to intervention [published online ahead of print, 2020 Apr 1]. *Lancet Infect Dis*. 2020;S1473-3099(20)30258-9. doi:10.1016/S1473-3099(20)30258-9
[6] Wynants L, Van Calster B, Bonten MMJ, at al.. Prediction models for diagnosis and prognosis of covid-19 infection: systematic review and critical appraisal. *BMJ*. 2020;369:m1328. Published 2020 Apr 7. doi:10.1136/bmj.m1328.
[7] RTE. https://www.rte.ie/news/coronavirus/2020/0330/1127224-coronavirus-health-covid19/. [Accessed 09 April 2020].
[8] Journal.ie. https://www.thejournal.ie/coronavirus-us-model-ireland-peak-passed-5069341-Apr2020/.[Accessed 09 April 2020].
[9] Department of Health (UK). https://www.health-ni.gov.uk/news/minister-highlights-key-findings-ni-covid-19-modelling. [Accessed 09 April 2020].
[10] Imperial College [London]. https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-9-impact-of-npis-on-covid-19/ [Accessed 09 April 2020].
[11] Imperial College [London]. https://www.imperial.ac.uk/mrc-global-infectious-disease-analysis/covid-19/report-13-europe-npi-impact [Accessed 09 April 2020].
[12] London School of Hygiene and Tropical Medicine. https://www.lshtm.ac.uk/newsevents/news/2020/estimates-relative-impact-different-covid-19-control-measures-uk
[13] Australian Government (2020). Impact of COVID-19: theoretical modelling of how the health system can respond. https://www.pm.gov.au/sites/default/files/files/covid19-icu-modelling-summary.pdf. [Accessed 09 April 2020].
[14] Moss at al. [Preprint not yet submitted for peer-review]. Modelling the impact of COVID-19 in Australia to inform transmission reducing measures and health system preparedness. https://www.doherty.edu.au/uploads/content_doc/McVernon_Modelling_COVID-19_07Apr1_with_appendix.pdf. [Accessed 09 April 2020].
[15] Institute of Health Metrics and Evaluation (IHME) at the University of Washington. COVID-19 Projections. http://www.healthdata.org/.
[16] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3559929. [Accessed 09 April 2020].
[17] Leung at al. (08/04/2020) First-wave COVID-19 transmissibility and severity in China outside Hubei after control measures, and second-wave scenario planning: a modelling impact assessment. https://www.thelancet.com/action/showPdf?pii=S0140-6736%2820%2930746-7. [Accessed 09 April 2020].
[18] Steinberg E, Balakrishna A, Habboushe J, Shawl A, Lee J. Calculated decisions: COVID-19 calculators during extreme resource-limited situations. *Emerg Med Pract*. 2020;22(4 Suppl):CD1–CD5. Published 2020 Apr 6.
[19] Kim S, Kim YJ, Peck KR, Jung E. School Opening Delay Effect on Transmission Dynamics of Coronavirus Disease 2019 in Korea: Based on Mathematical Modeling and Simulation Study. *J Korean Med Sci*. 2020;35(13):e143. Published 2020 Apr 6. doi:10.3346/jkms.2020.35.e143
[20] Hou C, Chen J, Zhou Y, at al.. The effectiveness of the quarantine of Wuhan city against the Corona Virus Disease 2019 (COVID-19): well-mixed SEIR model analysis [published online ahead of print, 2020 Apr 3]. *J Med Virol*. 2020;10.1002/jmv.25827. doi:10.1002/jmv.25827.
[21] Bayham J, Fenichel EP. Impact of school closures for COVID-19 on the US health-care workforce and net mortality: a modelling study [published online ahead of print, 2020 Apr 3]. *Lancet Public Health*. 2020;S2468-2667(20)30082-7. doi:10.1016/S2468-2667(20)30082-7.
[22] Moghadas SM, Shoukat A, Fitzpatrick MC, at al.. Projecting hospital utilization during the COVID-19 outbreaks in the United States [published online ahead of print, 2020 Apr 3]. *Proc Natl Acad Sci U S A*. 2020;202004064. doi:10.1073/pnas.2004064117.
[23] Sun Y, Koh V, Marimuthu K, at al.. Epidemiological and Clinical Predictors of COVID-19 [published online ahead of print, 2020 Mar 25]. *Clin Infect Dis*. 2020;ciaa322. doi:10.1093/cid/ciaa322.
[24] Mandal S, Bhatnagar T, Arinaminpathy N, at al.. Prudent public health intervention strategies to control the coronavirus disease 2019 transmission in India: A mathematical model-based approach [published online ahead of print, 2020 Mar 23]. *Indian J Med Res*. 2020;10.4103/ijmr.IJMR_504_20. doi:10.4103/ijmr.IJMR_504_20.
[25] Koo JR, Cook AR, Park M, at al.. Interventions to mitigate early spread of SARS-CoV-2 in Singapore: a modelling study [published online ahead of print, 2020 Mar 23] [published correction appears in Lancet Infect Dis. 2020 Mar 27;:]. *Lancet Infect Dis*. 2020;S1473-3099(20)30162-6. doi:10.1016/S1473-3099(20)30162-6.
[26] Martín-Calvo at al. (22/03/2020). Effectiveness of social distancing strategies for protecting a community from a pandemic with a data driven contact network based on census and real-world mobility data. https://comdig.unam.mx/2020/03/25/effectiveness-of-social-distancing-strategies-for-protecting-a-community-from-a-pandemic-with-a-data-driven-contact-network-based-on-census-and-real-world-mobility-data/[Accessed 09 April 2020].
[27] National Academies of Sciences, Engineering, and Medicine (21/3/2020). Rapid Expert Consultation on Data Elements and Systems Design for Modeling and Decision Making for the COVID-19 Pandemic. https://www.nap.edu/catalog/25755/rapid-expert-consultation-on-data-elements-and-systems-design-for-modeling-and-decision-making-for-the-covid-19-pandemic-march-21-2020[Accessed 09 April 2020].
[28] Lin Q, Zhao S, Gao D, at al.. A conceptual model for the coronavirus disease 2019 (COVID-19) outbreak in Wuhan, China with individual reaction and governmental action [published online ahead of print, 2020 Mar 4]. *Int J Infect Dis*. 2020;93:211–216. doi:10.1016/j.ijid.2020.02.058.