Detecting the re-emergent COVID-19 pandemic after elimination: modelling study of combined primary care and hospital surveillance

Nick Wilson, Markus Schwehm, Ayesha J Verrall, Matthew Parry, Michael G Baker, Martin Eichner

ABSTRACT

AIMS: We aimed to determine the effectiveness of surveillance using testing for SARS-CoV-2 to identify an outbreak arising from a single case of border control failure in a country that has eliminated community transmission of COVID-19: New Zealand.

METHODS: A stochastic version of the SEIR model CovidSIM v1.1 designed specifically for COVID-19 was utilised. It was seeded with New Zealand population data and relevant parameters sourced from the New Zealand and international literature.

RESULTS: For what we regard as the most plausible scenario with an effective reproduction number of 2.0, the results suggest that 95% of outbreaks from a single imported case would be detected in the period up to day 36 after introduction. At the time point of detection, there would be a median number of five infected cases in the community (95% range: 1–29). To achieve this level of detection, an ongoing programme of 5,580 tests per day (1,120 tests per million people per day) for the New Zealand population would be required. The vast majority of this testing (96%) would be of symptomatic cases in primary care settings and the rest in hospitals.

CONCLUSIONS: This model-based analysis suggests that a surveillance system with a very high level of routine testing is probably required to detect an emerging or re-emerging SARS-CoV-2 outbreak within five weeks of a border control failure in a nation that had previously eliminated COVID-19. Nevertheless, there are plausible strategies to enhance testing yield and cost-effectiveness and potential supplementary surveillance systems such as the testing of town/city sewerage systems for the pandemic virus.

One of the challenges with a new pandemic such as COVID-19 is how best to undertake surveillance. Good-quality surveillance is needed to maximise rapid disease control, eg, with case isolation and contact tracing to identify further cases and to quarantine contacts as shown by successful control in China. This surveillance and control capacity is particularly critical for nations that decide to eliminate community transmission entirely as New Zealand aimed to and has succeeded with (as per mid-July 2020 and using a definition from other modelling work on elimination for New Zealand). Most Australian States and Territories had also eliminated community transmission of COVID-19 by mid-July 2020, the exceptions being Victoria and New South Wales. Elimination status is also relevant to the following groupings of island jurisdictions, as per WHO data on 15 July 2020.
1. Those jurisdictions which have avoided any COVID-19 cases at the time of writing (eg, via border controls), but which are still at risk if border controls fail. These mainly include island jurisdictions in the Pacific Ocean (eg, American Samoa, Cook Islands, Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu and Vanuatu).

2. Those jurisdictions which have only experienced sporadic cases and appear (as per mid-July 2020) to have successfully contained spread. These include some islands in the Pacific (eg, Fiji).

3. Those jurisdictions which have had larger outbreaks of COVID-19, but have instituted tight controls and have declining numbers of new cases or no new cases for many weeks (eg, Taiwan).

A recent Australian study suggested that timely detection and management of community transmission of COVID-19 is feasible. This modelling study concluded that “testing for infection in primary care patients presenting with cough and fever is an efficient, effective and feasible strategy for the detection and elimination of transmission chains”. For example, when testing 9,000 people per week (per million population), the authors estimated that no cases of COVID-19 would be missed in some circumstances. This type of surveillance could therefore be relevant to identifying emergent or re-emergent SARS-CoV-2, the pandemic virus causing COVID-19.

Given this background, we aimed to determine the effectiveness of surveillance using testing for the SARS-CoV-2 virus to identify an outbreak arising from a single case of border control failure in a nation that is free of community transmission: New Zealand as per mid-July 2020.

**Methods**

To run pandemic spread scenarios for New Zealand, we used a stochastic SEIR type model with key compartments for: susceptible [S], exposed [E], infected [I] and recovered/removed [R]. The model is a stochastic version of CovidSIM, which was developed specifically for COVID-19 by two of the authors (http://covidsim.eu; version 1.1). Work has been published from version 1.0 of the deterministic version of the model, but in the Appendix we provide updated parameters and differential equations for version 1.1. The stochastic model was built in Pascal and 100,000 simulations were run for each set of parameter values.

The parameters were based on available publications and best estimates used in the published modelling work on COVID-19. Key components were: a single undetected infected case arriving in New Zealand via a border control failure, 80% of infected COVID-19 cases being symptomatic, 39.5% of cases seeking a medical consultation in primary care settings, and 4% of symptomatic cases being hospitalised (see Appendix Table 1 for further details). We assumed that the initial undetected case could be at any stage of infection—to cover both failures of managing quarantine at the border, but also failures around the management of non-quarantined workers such as air crew and ship crew. Scenarios considered different levels of transmission with the effective reproduction number (Re) of SARS-CoV-2 to be 1.5, 2.0, 2.5 and 3.0 (Appendix Table 1). Given some evidence for superspreading phenomena with this pandemic virus, we also considered scenarios where just 10% of the cases generated 10 times the number of secondary cases as the other cases.

Other scenarios considered the impact of 75% of symptomatic people seeking a medical consultation (eg, as the result of a potential media campaign); and another considered a possible school outbreak (eg, a border control failure involving a teacher or student returning from overseas). The assumptions for the latter involved: Re = 2.0, only 5% of symptomatic cases seek medical consultation, and only 0.5% being hospitalised.

For the detection of COVID-19 cases, we assume testing of 95% of cases of symptomatic respiratory illness seeking medical attention in primary care and of hospitalised cases of respiratory illness. For parameterising the size of these two groups, we used official statistics and results from the Flutracking surveillance system used in...
New Zealand (Appendix Table 1). The sensitivity of the PCR diagnostic test (at 89%) was based on a meta-analysis (Appendix Table 1).

Results

For what we regard as the most plausible scenario with an Re of 2.0 (ie, where people are still practicing some modest level of reduced social contact and/or increased hygiene because of the pandemic in other countries), the results suggest that 50% of outbreaks from a single imported case would be detected in the period up to day 16 and 95% in the period up to day 36 (Table 1, Figure 1). At the time of detection (to day 36), there was an estimated median number of five infected cases in the community (95% range: 1–29). To achieve this level of detection, an ongoing programme of 5,580 tests per day would be required, (1,120 per million people per day) for the whole New Zealand population. The vast majority of this testing (96%) would, however, be in primary care settings and the rest in hospitals.

For all scenarios except for the school scenario, 95% of outbreaks were detected in less than six weeks after introduction. A higher value (71 days) was for the simulated school outbreak where medical consultations were assumed to be much less likely (due to symptoms in young people being typically milder). Increasing the extent by which symptomatic people seek medical consultations to the 75% level (up from that reported by Flutracking at 39.5%), would reduce the time to detection (eg, from 36 to 26 days for the Re = 2.0 scenario at the 95% probability level, Table 1).

When allowing for superspreading events, introductions less frequently lead to outbreaks (Table 1) and these outbreaks have a tendency to be detected earlier (Figure 1).

Discussion

This analysis indicates the challenges for a surveillance system designed to detect the re-emergence of SARS-CoV-2 transmission in a COVID-19-free nation with border controls. A very high level of testing of symptomatic people is typically required in primary care settings and hospitals to detect an outbreak within five weeks after a single border control failure (at least at the 95% level).

Figure 1: Probability of COVID-19 case detection after reintroduction of the infection (the different curves represent the results of 100,000 simulations each, using Re values from 1.5 to 3.0). Dotted lines refer to a scenario where 75% of symptomatic cases seek medical help. Dashed lines refer to scenarios which allow for superspreading events. The dashed-dotted line refers to an outbreak in a school (for further details on parameter settings, see Table 1 and text).
This relatively ideal testing level, at 5,580 tests per day, is somewhat higher than the levels in New Zealand in early May 2020 (ie, the seven-day rolling average at this time was around 4,200 tests per day, although this included some screening of asymptomatic people). It is even higher than the more recent 2,240 tests per day in early July 2020 (seven-day rolling average from 3 to 9 July). This lower level in July was even in the context of publicised “escapes” from border control facilities and it may drop further in the future with enhancements in quarantine facility security. Possibly there is a need for health authorities to regularly remind health professionals to keep offering testing since there is always some (albeit low) risk of quarantine failures, as some people may still excrete virus beyond the 14-day quarantine period.13,14 Work could also be done to research any barriers for getting testing (eg, transport issues to primary care, waiting times and perceptions around cost barriers). Research could also explore why Australia has achieved a higher cumulative level of testing (112,000 tests vs 87,500 tests per million by 8 July 202015), although some of this will be due to the ongoing transmission of disease in states such as Victoria (as per July 2020).

Despite the high level of testing required for this type of surveillance system, there are potential ways that might improve the yield and cost-effectiveness of such testing:

- Prioritising community testing for those with relevant symptoms (as per Ministry of Health criteria updated in June 202016) in the cities where border control failures are most likely to become evident (ie, those operating international airports and where isolation/quarantine facilities exist: Auckland, Hamilton, Rotorua,

### Table 1: Modeled impacts by the time it takes to obtain at least one positive test result for SARS-CoV-2 infection arising from a border control failure where a single case enters the island nation of New Zealand (all results adjusted for lag times in reporting and obtaining test results, using 100,000 stochastic simulations for each parameter setting).

<table>
<thead>
<tr>
<th>Scenario with variation in the effective reproduction number (Re)</th>
<th>Introduction leads to no further spread (%)</th>
<th>Day when 50% of outbreaks have been detected (median)</th>
<th>Day when 95% of outbreaks have been detected (median)</th>
<th>Mean day of outbreak detection</th>
<th>Expected no. of total tests*</th>
<th>Median (95% range) number of infections from introduction to detection**</th>
</tr>
</thead>
<tbody>
<tr>
<td>Re = 1.5</td>
<td>45.3</td>
<td>15</td>
<td>38</td>
<td>16.8</td>
<td>93,700</td>
<td>4 (1–21)</td>
</tr>
<tr>
<td>Re = 2.0 (most plausible)</td>
<td>36.9</td>
<td>16</td>
<td>36</td>
<td>16.9</td>
<td>94,300</td>
<td>5 (1–29)</td>
</tr>
<tr>
<td>Re = 2.5</td>
<td>31.2</td>
<td>16</td>
<td>33</td>
<td>16.6</td>
<td>92,600</td>
<td>7 (1–38)</td>
</tr>
<tr>
<td>Re = 3.0</td>
<td>26.9</td>
<td>16</td>
<td>31</td>
<td>16.2</td>
<td>90,400</td>
<td>9 (1–49)</td>
</tr>
<tr>
<td>Re = 1.5, but 75% seek medical consultation***</td>
<td>36.1</td>
<td>10</td>
<td>26</td>
<td>11.4</td>
<td>116,000</td>
<td>2 (1–11)</td>
</tr>
<tr>
<td>Re = 2.0, but 75% seek medical consultation***</td>
<td>30.8</td>
<td>11</td>
<td>26</td>
<td>11.7</td>
<td>119,000</td>
<td>3 (1–15)</td>
</tr>
<tr>
<td>School outbreak#</td>
<td>44.7</td>
<td>40</td>
<td>71</td>
<td>40.4</td>
<td>225,000</td>
<td>44 (2–240)</td>
</tr>
<tr>
<td>Re = 1.5, but with superspreaders</td>
<td>56.8</td>
<td>12</td>
<td>33</td>
<td>13.8</td>
<td>77,000</td>
<td>3 (1–26)</td>
</tr>
<tr>
<td>Re = 2.0, but with superspreaders</td>
<td>50.3</td>
<td>16</td>
<td>34</td>
<td>15.0</td>
<td>84,000</td>
<td>4 (1–36)</td>
</tr>
</tbody>
</table>

*From the time of the border control failure to the mean day of outbreak detection. This is around 5,600 tests per day for primary care and hospital sectors combined for the first four listed scenarios.

**Includes those in the latent phase, prodromal phase, asymptomatic infections and symptomatic infections (but not recovered or deceased cases).

***These higher levels of consultation seeking result in a proportionate increase in the tests performed.

#The assumed characteristics for this school outbreak involved: Re = 2.0, only 5% of symptomatic cases seeking medical consultation, and only 0.5% being hospitalised. The level of testing was as per the first four listed scenarios.
Wellington and Christchurch). Similarly, if cargo ship crews travelling from international ports are permitted shore leave in New Zealand in the future, then testing could be focused on these port cities.

- Pooling samples for PCR testing may preserve reagents and be more efficient and cost-effective, but needs to be balanced against potential loss of sensitivity and associated diagnostic delays.

If it became difficult to maintain high levels of testing even in these priority cities, an additional safeguard might be routinely offering testing to all hospital and emergency department attendees with any respiratory symptom (ie, not just those in the Ministry guidelines). Another safeguard would be enhancements to the contact tracing systems used in New Zealand so that they can effectively address any outbreaks that arise.

Study strengths and limitations

This is the first such modelling analysis for a country that has achieved an elimination goal for COVID-19 with the end of all community transmission. Nevertheless, this work could have been refined further by a focus on a narrower range of acute respiratory diseases (eg, excluding the category of hospital admissions for chronic lower respiratory diseases (ICD10 codes: J40–J47). But since hospital admissions for these often involve an acute aspect, eg, acute bronchitis on top of chronic obstructive respiratory disease, we took the parsimonious approach of considering all respiratory diseases.

Another limitation is that we did not consider the relatively large seasonal fluctuations in the proportion of people consulting primary care for respiratory conditions (ie, with Flutracking data indicating a four-fold variation in cough/fever symptoms between May and October).

This analysis also did not explore other surveillance options such as routine active surveillance of specific groups who might be considered at increased risk (eg, air-crew, ship-crew, port workers and quarantine facility workers). Similarly, not considered was the testing of town and city sewerage systems for the pandemic virus in wastewater, as is being explored in several jurisdictions internationally. Indeed, in the New Zealand setting, the Crown Research Institute ESR has reported detecting SARS-CoV-2 in wastewater and is continuing to develop this methodology. Such approaches could improve the speed of early detection in the community and allow for lower routine levels of testing people with respiratory symptoms.

Conclusions

In conclusion, this model-based analysis suggests that a surveillance system with a very high level of routine testing is probably required to detect an emerging or re-emerging SARS-CoV-2 outbreak within five weeks of a border control failure in a nation. But further work is required to improve on this type of analysis and to evaluate other potential surveillance system components, particularly the testing of wastewater in sewerage systems.
Appendix

Mathematical description of the CovidSIM model (version 1.1) and model parameters

The stochastic simulations are based on the following differential equations:

**Model dynamics**

**Number of susceptible individuals**

\[
\frac{dS}{dt} = -\lambda S
\]

**Number of individuals in the latent period**

\[
\frac{dE_k}{dt} = -\alpha E_k - \beta S E_k
\]

**Number of individuals in the prodromal period**

\[
\frac{dP_k}{dt} = -\varphi P_k - \gamma P_k - \beta S E_k
\]

**Number of individuals in the early infectious period**

\[
\frac{dI_k}{dt} = \varphi P_k - \delta I_k
\]

**Number of individuals in the late infectious period**

\[
\frac{dL_k}{dt} = \delta I_k - \alpha L_k
\]

**Derived variables**

Total number in latent period

\[ E_{\text{sum}}(t) = \sum_{k=1}^{n} E_k(t) \]

Total number in prodromal period

\[ P_{\text{sum}}(t) = \sum_{k=1}^{n} P_k(t) \]

Total number in early infectious period

\[ I_{\text{sum}}(t) = \sum_{k=1}^{n} I_k(t) \]

Total number in late infectious period

\[ L_{\text{sum}}(t) = \sum_{k=1}^{n} L_k(t) \]

**Contact rate and force of infection**

Contact rate

\[ \beta = \frac{R_s}{c_p D_p + D_l + c_l D_l} \]

Force of infection

\[ \lambda(t) = \frac{\beta}{N}(c_p P_{\text{sum}}(t) + I_{\text{sum}}(t) + c_l L_{\text{sum}}(t)) \]

**Stochastic treatment of the differential equations**

The kind of epidemiologic events and the duration between two consecutive events are calculated using random numbers. The simulations start with a fully susceptible population in which one individual (index case) is infected. The infection stage of the index case is picked at random, taking into consideration the different lengths of the latent, prodromal, early and late infectious period. In each simulation, the sum of all the rates that change the current state of the system is calculated as

\[ \xi = \lambda S + \alpha E_{\text{sum}} + \varphi P_{\text{sum}} + \delta I_{\text{sum}} + \alpha L_{\text{sum}} \]
A uniformly distributed random number \( \eta \in [0, \xi] \) is then chosen, and the time \( \Delta t = -\ln(\eta) / \xi \) after which the next event occurs is calculated. All transition rates are arranged in an arbitrary order, and cumulative rates are calculated by adding their individual rates. A new uniformly distributed random number \( \eta_2 \in (0, \xi] \) is chosen, and the first transition in the order whose cumulative rate is larger than \( \eta_2 \) is performed. If, for example, the event is an infection, one individual is removed from the group of susceptible individuals and added to the group of latent individuals of stage 1. New rates are calculated after each step, and the procedure is repeated. A more detailed description of the transformation of differential equation models to stochastic models can be found in Gillespie (1976).23

**Parameters**

- \( N \): Population size
- \( \lambda \): Force of infection
- \( R_e \): Effective reproduction number
- \( \beta \): Effective contact rate
- \( D_e \): Average duration of the latent period
- \( n_e \): Number of stages for the latent period
- \( \varepsilon \): Stage transition rate for the latent period \((\varepsilon = n_e / D_e)\)
- \( D_p \): Average duration of the prodromal period
- \( n_p \): Number of stages for the prodromal period
- \( \phi \): Stage transition rate for the prodromal period \((\phi = n_p / D_p)\)
- \( c_p \): Contagiousness in the prodromal period (relative to the contagiousness in the early infectious period)
- \( D_i \): Average duration of the early infectious period
- \( n_i \): Number of stages for the early infectious period
- \( \gamma \): Stage transition rate for the early infectious period \((\gamma = n_i / D_i)\)
- \( D_l \): Average duration of the late infectious period
- \( n_l \): Number of stages for the late infectious period
- \( \delta \): Stage transition rate for the late infectious period \((\delta = n_l / D_l)\)
- \( c_l \): Contagiousness in the late infectious period (relative to the contagiousness in the early infectious period)
Appendix Table 1: Input parameters used for modelling the potential spread of the COVID-19 pandemic with the stochastic version of CovidSIM (v1.1) with New Zealand as a case study.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/s used</th>
<th>Further details for parameter inputs into the modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population size</td>
<td>4,951,500</td>
<td>We used the estimated New Zealand population as per December 2019 (ie, 4,951,500²⁴).</td>
</tr>
<tr>
<td>Infections that lead to sickness</td>
<td>80%</td>
<td>We used the same proportion (80%) of symptomatic cases as per a Chinese study,¹ and as per an Australian modelling study.⁴ This value is higher than the 57% value found in an Icelandic study²⁵ but this study did not involve long-term follow-up of the asymptomatic cases (ie, some of the asymptomatic cases might subsequently have developed symptoms). But it is also lower than that found in another Chinese study (at 94% symptomatic).²⁶</td>
</tr>
<tr>
<td>Sick people who seek medical attention in primary care</td>
<td>39.5% (75% in a scenario analysis)</td>
<td>We used the result from the New Zealand Flutracking surveillance system for people with “fever and cough” in the weekly surveys who report seeking medical attention for these symptoms.¹⁹ This is very similar to international estimates for people with influenza who seeking medical attention at 40%, eg, as used in other modelling.⁷ In scenario analyses we raised this to 75% on the assumption that a media campaign could encourage attendance for relatively mild respiratory symptoms.</td>
</tr>
<tr>
<td>Sick people need hospitalisation</td>
<td>4%</td>
<td>At the time of writing on 3 May 2020, there were eight people hospitalised in New Zealand with COVID-19 (out of a total of 201 actively infected cases, ie, 4.0%).²⁷ Of note is that modellers in the UK have used 4.4% (of all infected cases),²⁸ and for modelling in the US 3%, 5% and 12% have been proposed.²⁹ The length of hospitalisation was assumed to be 10 days which is similar to other modelling work eg, 10.4 days for the UK.³⁰</td>
</tr>
<tr>
<td>Effective reproduction number (Re)</td>
<td>2.0 as the most plausible value for New Zealand (1.5, 2.5 and 3.0 used in scenario analyses)</td>
<td>This estimate of 2.0 is in the lower end of the range for the basic reproduction number (R₀) reported on 6 March by the WHO (ie, 2.0–2.5³⁰). This is because we assumed some level of ongoing physical distancing and enhanced hygiene practices in New Zealand relative to the pre-pandemic world. Of note is that an earlier review of 12 studies,³¹ suggested estimates that ranged from 1.4–6.49, with a mean of 3.28, a median of 2.79 and interquartile range of 1.16. UK modelling work has used an estimate of 2.4 (range: 2.0–2.6).²⁸ Australian modelling studies have used Rₐ values in the 2.2–2.7 range.²⁸ For the Re = 1.5 and 2.0 values we also considered scenarios with superspreading (as explained in the main text).</td>
</tr>
<tr>
<td>Relative contagiousness in the prodromal period</td>
<td>50%</td>
<td>There is uncertainty around this value but we used the same estimate as in recent UK modelling.²⁹ This has biological plausibility as while there is similarity in viral loads between asymptomatic and symptomatic COVID-19 patients,³³ it would be expected that those who are fully symptomatic (with a cough, etc) would be more likely to transmit infection. Of note is an estimate from the Diamond Princess cruise ship outbreak, that 17.9% of COVID-19 infections were from asymptomatic individuals (95% credible interval 15.5–20.2%).³⁴ But it is unclear how generalisable this finding is given the crowded cruise ship conditions and the typically elderly nature of the passengers.</td>
</tr>
<tr>
<td>Latency period</td>
<td>4 days</td>
<td>We used an average duration of four days as per Read et al.,³⁶ with a standard deviation (SD) of 25% (one day) (calculated using 16 stages; Erlang distribution). This is similar to the estimate in a Chinese study which reported a median latent period of 3.69 days.³⁶</td>
</tr>
<tr>
<td>Prodromal period</td>
<td>1 day</td>
<td>There is as-yet insufficient data on this for COVID-19, so we used an assumed value for influenza (SD = 25%; 0.25 days, Erlang distribution).</td>
</tr>
<tr>
<td>Symptomatic period</td>
<td>10 days (split into 2 periods of 5 days each)</td>
<td>The WHO-China Joint Mission report stated that “the median time from onset to clinical recovery for mild cases is approximately two weeks and is 3–6 weeks for patients with severe or critical disease.”³² But given that mild cases may have been missed in this particular assessment, we used a slightly shorter total time period of 10 days (SD = 25%; 2.5 days, Erlang distribution).</td>
</tr>
</tbody>
</table>
Contagiousness during the two symptomatic periods

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value/s used</th>
<th>Further details for parameter inputs into the modelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contagiousness during the two symptomatic periods</td>
<td>100% and 50%</td>
<td>In the first five days of symptoms, cases were considered to be fully contagious. In the second five-day period, this was assumed to be at 50%. The latter figure is highly uncertain, but is broadly consistent with one study on changing viral load.37</td>
</tr>
</tbody>
</table>

Provision of testing and test sensitivity assumed

| Background hospital admissions for respiratory conditions in New Zealand | 234 admissions per day | Using 85,439 respiratory disease admissions to New Zealand public hospitals in the year 2016/2017 (for all Chapter X ICD10 codes: J00 to J99).38 |
| Background medical consultations in primary care for respiratory conditions in New Zealand | 5,640 consultations per day | Data from the New Zealand arm of the Flutracking surveillance system was used. This indicates that approximately 3% of respondents in the period from April to October report “fever and cough” in the weekly surveys.39 Of these 39.5% report seeking medical attention for their symptoms. However, we assumed a lower annual rate of 2% to account for the period outside of the influenza season (e.g., Flutracking reporting is closer to 1% for weekly “fever and cough” at the start of May when the surveillance system begins for the year). In the New Zealand population of five million this would suggest 14,300 new cases developing “cough and fever” per day of whom 5,640 would be expected to seek medical attention. |

Coverage in patients with respiratory symptoms who seek medical attention in primary care

| Coverage in patients with respiratory symptoms who seek medical attention in primary care | 95% coverage | These coverage values were further adjusted for the test sensitivity of 89% (see below). With 95% coverage and 89% test sensitivity, 84.55% of cases would be detected. |

Coverage in hospitalised patients with respiratory symptoms

| Coverage in hospitalised patients with respiratory symptoms | 95% coverage | As above. |

PCR test sensitivity

| PCR test sensitivity | 89% | A meta-analysis has reported this as 89% (95%CI: 81 to 94%).39 This sensitivity is not ideal as while infection can be in the lungs, the sampling is from the nasopharynx, which may contain lower levels of virus at some stages of infection. Specificity is close to 100% for the PCR test. |

Lag times (for health sector interaction and testing delays)

| Delay from symptom onset until a test has been performed and the result has become available | 5 days plus 1 day for the testing delay | There is a delay between symptom onset and the performance of the test for SARS-CoV-2. For the first part of the delay we considered a study in Beijing, China, which reported the interval time from between illness onset and seeing a doctor was 4.5 days.40 Another Chinese study of 710 patients with pneumonia41 reported that those dying had a median duration from onset of symptoms to radiological confirmation of pneumonia of 5 (IQR: 3–7) days. For the testing delay we noted that the aim in New Zealand is to obtain the result of the tests in under 24-hours regardless of the primary care or hospital setting. But this may not always be the case for rural and small-town settings. In our simulations, test results were available on average 5.94 days after symptom onset (SD: 1.36 days). |
Competing interests:
Dr Verrall reports this paper was written in Dr Verrall’s capacity as Senior Lecturer at the University of Otago, not in her capacity as a candidate for Parliament. The views in this paper are not necessarily the views of the New Zealand Labour Party.

Acknowledgements:
Dr Schwehm is supported by the University of Tübingen and the IMAAC-NEXT Association. Professor Wilson is supported by the New Zealand Health Research Council (Grant 16/443) and Ministry of Business Innovation and Employment (MBIE) funding of the BODE3 Programme (Grant UOOX1406).

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