COVID-19 in New Zealand and the impact of the national response: a descriptive epidemiological study

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Summary

Background In early 2020, during the COVID-19 pandemic, New Zealand implemented graduated, risk-informed national COVID-19 suppression measures aimed at disease elimination. We investigated their impacts on the epidemiology of the first wave of COVID-19 in the country and response performance measures.

Methods We did a descriptive epidemiological study of all laboratory-confirmed and probable cases of COVID-19 and all patients tested for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in New Zealand from Feb 2 to May 13, 2020, after which time community transmission ceased. We extracted data from the national notifiable diseases database and the national SARS-CoV-2 test results repository. Demographic features and disease outcomes, transmission patterns (source of infection, outbreaks, household transmission), time-to-event intervals, and testing coverage were described over five phases of the response, capturing different levels of non-pharmaceutical interventions. Risk factors for severe outcomes (hospitalisation or death) were examined with multivariable logistic regression and time-to-event intervals were analysed by fitting parametric distributions using maximum likelihood estimation.

Findings 1503 cases were detected over the study period, including 95 (6·3%) hospital admissions and 22 (1·5%) COVID-19 deaths. The estimated case infection rate per million people per day peaked at 8·5 (95% CI 7·6–9·4) during the 10-day period of rapid response escalation, declining to 3·2 (2·8–3·7) in the start of lockdown and progressively thereafter. 1034 (69%) cases were imported or import related, tending to be younger adults, of European ethnicity, and of higher socioeconomic status. 702 (47%) cases were linked to 34 outbreaks. Severe outcomes were associated with locally acquired infection (crude odds ratio [OR] 2·32 [95% CI 1·40–3·82] compared with imported), older age (adjusted OR ranging from 2·72 [1·40–5·30] for 50–64 year olds to 8·25 [2·59–26·31] for people aged ≥80 years compared with 20–34 year olds), aged residential care residency (adjusted OR 3·86 [1·59–9·35]), and Pacific peoples (adjusted OR 2·76 [1·14–6·68]) and Asian (2·15 [1·10–4·20]) ethnicities relative to European or other. Times from illness onset to notification and isolation progressively decreased and testing increased over the study period, with few disparities and increasing coverage of females, Māori, Pacific peoples, and lower socioeconomic groups.

Interpretation New Zealand's response resulted in low relative burden of disease, low levels of population disease disparities, and the initial achievement of COVID-19 elimination.

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Introduction

There is an international imperative to provide evidence of the effectiveness of non-pharmaceutical interventions against COVID-19. Early evidence in Asia, including China, Singapore, and South Korea, showed COVID-19 control using combinations of movement restrictions, physical distancing, hygiene practices, and intensive case and contact detection and management.[1–3] The WHO-China Mission recommended decisive government leadership to rapidly enhance surveillance and apply risk-based non-pharmaceutical interventions with effective population engagement.[2] However, it was unclear how well this could be implemented in societies with little experience of successfully containing a novel respiratory virus.[4]

As evidence emerged that the unique nature of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) required distinct strategic approaches, New Zealand moved from a response guided by national influenza pandemic planning to a COVID-19-tailored approach focusing on suppression (stopping SARS-CoV-2 community spread) over mitigation (slowing down transmission),[5] with a goal of COVID-19 elimination, to reach very low or zero COVID-19 incidence.[6] Risk-informed border restrictions were implemented ahead of WHO advice before the first local case of COVID-19 was confirmed on Feb 28, 2020. Graduated suppression strategies were then applied, escalating to national lockdown (stay-at-home order with few exemptions) within 26 days.

Research in context

Evidence before this study

To identify international epidemiological studies of the effectiveness of non-pharmaceutical interventions on COVID-19 containment and population outcomes, systematic searches of MEDLINE and PubMed were undertaken on July 8, 2020, for peer-reviewed articles published since Jan 1, 2020, using the following keywords: "novel coronavirus" or "nCoV" or "COVID-19" or "severe acute respiratory syndrome coronavirus 2" or "SARS-CoV-2"; and "epidemiolog*" or "public health strateg*" or "reproduction number" or "health loss" or "population impact*" or "effectiveness". Of 2230 articles identified, 24 were included. Among these, three were in high-income democratic Asian settings, seven in western settings, and two examined multiple international settings. Escalation of non-pharmaceutical interventions including movement restrictions (travel bans or physical distancing) were effective in COVID-19 mitigation or suppression to varied extents.

Added value of this study

We use highly complete, prospectively collected national COVID-19 case and testing datasets to comprehensively describe New Zealand's initial public health response to COVID-19. The response was notable for its speed and intensity (including border closure, rapid implementation of national lockdown, and surveillance enhancements) in a high-income, western setting with little previous experience of containing novel respiratory pathogens. This is the first study to our knowledge to assess the impacts of national or subnational non-pharmaceutical intervention escalation and de-escalation decisions on the distribution, transmission patterns, and severity of COVID-19, and the attainment of an explicit national goal of COVID-19 elimination.

Implications of all the available evidence

New Zealand's experience describes the multifaceted components of a national response as a feasible route to COVID-19 elimination, particularly in other high-income or island settings. The study supports WHO recommendations for timely decisive government leadership for evidence-informed, risk-based escalation and de-escalation decisions combining rigorous case detection, isolation, contact tracing, and quarantine measures with population education and engagement. Further research is needed to understand the wider cost benefits of this response.

This response has international relevance, particularly for other island nations, high-income and western settings, and countries with ethnic and social health inequities. New Zealand is a high-income remote Pacific island state of nearly 5 million people, with an ageing population and diverse ethnic structure: approximately 16% Indigenous Māori, 7% Pacific peoples, 15% Asian, and 62% European or other. Inequitable morbidity and mortality for Māori and Pacific peoples, seen during previous influenza pandemics, continue for many communicable diseases today.[7] COVID-19 ethnic and social disparities have been observed overseas.[8,9] New Zealand's response sought to prevent COVID-19 disparities and minimise transit of infection to lower-income Pacific countries.[6]

Here, we investigate the impact of national suppression strategies on the epidemiology of the first wave of COVID-19 in New Zealand and measures of response performance.

Methods

Study population and periods

This descriptive epidemiological study examined a cohort of all confirmed and probable COVID-19 cases and all people tested for SARS-CoV-2 infection in New Zealand up to May 13, 2020, which marked the easing of the most restrictive non-pharmaceutical interventions, after which community transmission ceased. National COVID-19 case definitions applied. Confirmed cases required laboratory definitive evidence (ie, SARS-CoV-2 detection by validated molecular test). Probable cases were close contacts of confirmed cases with clinically compatible presentations where SARS-CoV-2 testing was inconclusive and other causes excluded. New Zealand's communicable disease surveillance and response capabilities have been recently described[10] and details on the four national COVID-19 Alert Levels, their associated non-pharmaceutical interventions, and test and trace guidance have been published.[11,12] Key features of the response timeline are outlined in the panel and figure 1, including non-pharmaceutical interventions required by Alert Levels and key surveillance changes.

The speed of New Zealand's Alert Level escalation (from Alert Level 1 to 4 between March 21 and March 26, 2020) prevents assessment of individual Alert Levels on study outcomes. Therefore, we considered the effects of national COVID-19 suppression strategies over five phases. Phase 1 was the period of initial travel restrictions, covering Feb 2–March 15, 2020, which comprised Alert Level 1 and a ban on arrivals from mainland China (Feb 2), Iran (Feb 28), northern Italy and South Korea (March 2), and all cruise ships (March 15). Phase 2 was the period of rapid escalation of non-pharmaceutical interventions, covering March 16–25, comprising the requirement for all international arrivals to self-isolate for 14 days, bans on public gatherings of more than 500 people (March 16), border closures except to returning national citizens and residents (March 20), Alert Level 2 (March 22), Alert Level 3 (March 24), and a State of Emergency declared on March 25 activating special legal powers. Phase 3 was the first half of lockdown, covering March 26–April 10, which comprised Alert Level 4 (March 26) and severe movement restrictions including stay-at-home orders with few exemptions; enhancements of contact tracing (eg, National Close Contact Service), testing, isolation, and quarantine capacities including implementing managed quarantine facilities for returning citizens and residents who could not safely self-isolate; and mandatory state-managed quarantine for all returning travellers (April 10). Phase 4 was the second half of lockdown, covering April 11–27, during which Alert Level 4 continued and there were further increases in SARS-CoV-2 testing, including the first asymptomatic population survey (April 16), before any decisions to change Alert Level. Finally, phase 5 was the de-escalation to Alert Level 3 (April 28), covering April 28–May 13, which included easing of population movement restrictions (eg, small gatherings up to ten people permitted). Further population testing surveys were done before de-escalation to Alert Level 2 on May 14.

Data sources

COVID-19 became legally notifiable from Jan 30, 2020. Suspected, probable, and confirmed case data were prospectively recorded on EpiSurv, the national notifiable diseases database, using a standardised COVID-19 case report form. All confirmed and probable case data were extracted on June 16, 2020, including age, sex, location, 2013 New Zealand Index of Deprivation (NZDep) quintile (where quintile 1 is least socioeconomically deprived and quintile 5 most deprived),[13] travel history, occupation, basis for case detection, course of infection or illness, underlying conditions, link to a confirmed case or outbreak, and notification and confirmation dates. Self-determined ethnicity was identified by linkage to the national patient demographics dataset. Ethnicity was grouped by prioritised classification in order of Māori, Pacific, Asian, and European or other, with the remaining cases classified as unknown.[14]

Results of all SARS-CoV-2 molecular tests were extracted on June 3, 2020, from Éclair, the national SARS-CoV-2 test results repository, with the following metadata: age, sex, linked prioritised ethnicity,[14] District Health Board (DHB) location, and NZDep quintile.

Ethical approval for this study was obtained from the University of Otago Human Ethics Committee (Health; HD20/062).

Outcome measures

Cases were assigned to the five phases in two ways to assess different impacts. First, cases were assigned to a phase on the basis of the estimated date of SARS-CoV-2 infection (ie, the exposure period), defined as occurring one incubation period before symptom onset (or notification date, if data on symptom onset were unavailable). Uncertainty in incubation period was incorporated by replicate sampling (n=1000) from a Weibull distribution[15] with means and SEs pooled across replicates. Assigned exposure period was then used to assess the impacts of non-pharmaceutical intervention phases on disease transmission and the characteristics of cases affected. The estimated average daily incidence of New Zealand-acquired case infection was calculated as the number of non-imported cases divided by the number of days in the phase and the national estimated population size.

Case counts, cumulative incidence, relative risks, and prevalence of demographic characteristics were compared by phase and by disease transmission types. Transmission types were either outbreak (linked cases extending outside of a single household) or household cluster (cases living in the same household), and infection source was defined as imported (international travel within 14 days of onset), import related (epidemiological link to an imported case), or locally acquired (no international travel within 14 days and no link to an import-related case).

Characteristics of cases with severe disease outcomes (hospitalisation or death) were compared with non-severe cases. Due to the low number of deaths that occurred (n=22), a separate analysis of mortality as an outcome was not done.

Second, for analyses of response performance, cases were assigned to a phase on the basis of the earliest date of evidence of infection (ie, the presentation period), defined as the date of illness onset (or notification date, if data on illness onset were unavailable). Basis for case detection,

Panel: Major non-pharmaceutical interventions introduced during the first wave by national Alert Levels[11]

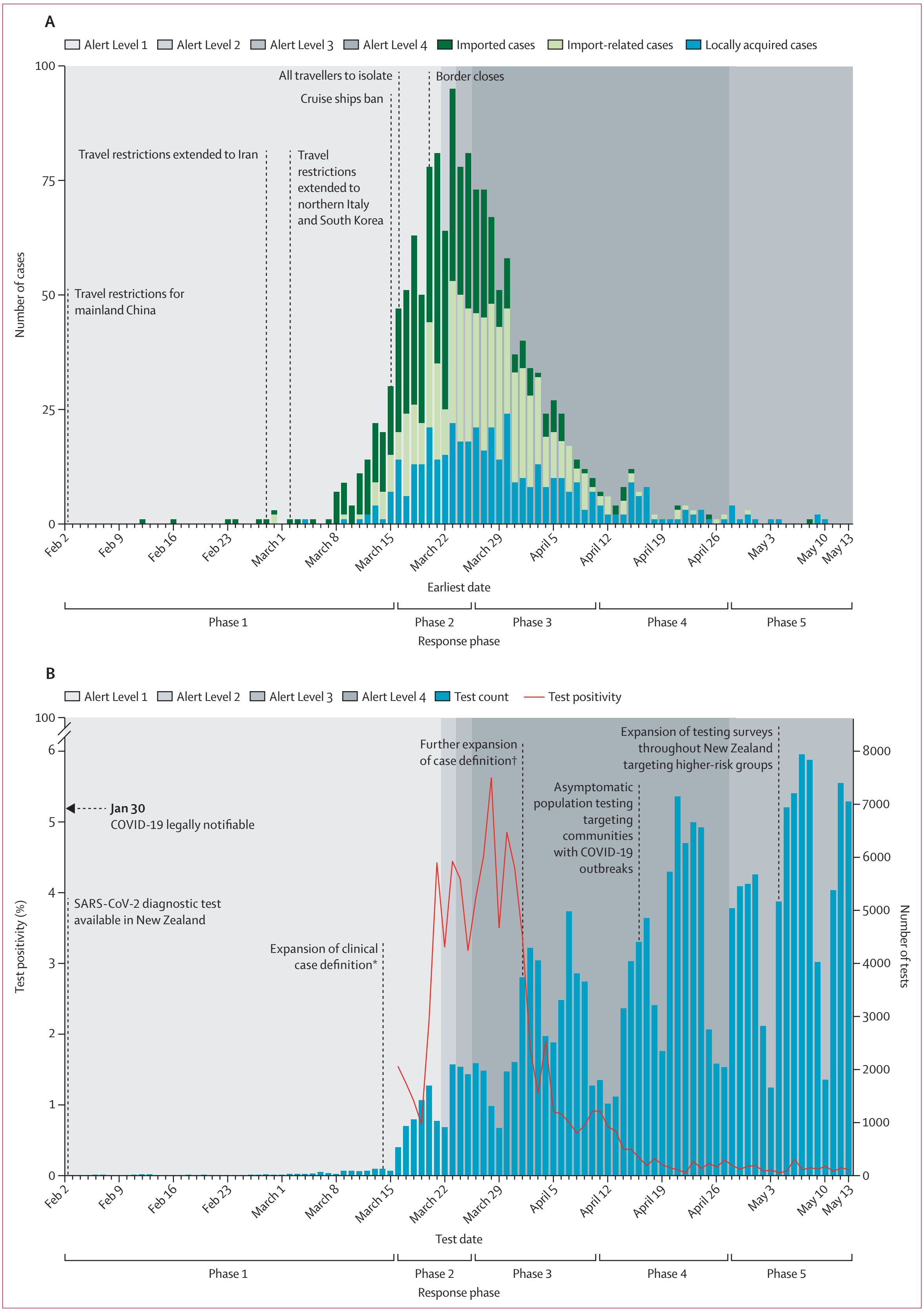
Alert Level 1
Travel restrictions are introduced. National case and contact management guidelines are implemented[12] and communication campaigns are launched (eg, promotion of hand and respiratory hygiene, isolation and testing if symptomatic). Government COVID-19 income support and debt relief is initially established.

Alert Level 2
Physical distancing is enforced, additional precautions are encouraged for higher-risk groups (eg, people aged >70 years) when leaving home, and specific gatherings (eg, weddings) are permitted if no more than 100 people.

Alert Level 3
Population is asked to stay within so-called bubbles (comprising household close contacts) that can include additional support (eg, carers) and encouraged to work from home, businesses must not physically interact with public, public venues are closed, no gatherings of more than ten people are allowed, telehealth services are encouraged, and only essential inter-regional travel is permitted.

Alert Level 4
Population is required to stay at home except for essential reasons (eg, short periods of exercise), businesses are closed unless offering essential services (eg, supermarkets), educational facilities and public venues are closed, and health-care services are reprioritised. A communication wellbeing campaign entitled Getting Through Together is launched.

For more on **EpiSurv** see https://surv.esr.cri.nz/episurv/index.php


A
Alert Level 1
Alert Level 2
Alert Level 3
Alert Level 4
Imported cases
Import-related cases
Locally acquired cases
Number of cases
All travellers to isolate
Border closes
Cruise ships ban
Travel restrictions extended to Iran
Travel restrictions extended to northern Italy and South Korea
Travel restrictions for mainland China
Earliest date
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Response phase
B
Alert Level 1
Alert Level 2
Alert Level 3
Alert Level 4
Test count
Test positivity
Test positivity (%)
Number of tests
Further expansion of case definition†
Expansion of testing surveys throughout New Zealand targeting higher-risk groups
Asymptomatic population testing targeting communities with COVID-19 outbreaks
Jan 30
COVID-19 legally notifiable
SARS-CoV-2 diagnostic test available in New Zealand
Expansion of clinical case definition*
Test date
Phase 1
Phase 2
Phase 3
Phase 4
Phase 5
Response phase

testing incidence and positivity, and time-to-event intervals were calculated by phase using the presentation period. Time-to-event intervals were average days from illness onset to notification, isolation, or hospitalisation dates.

International arrival numbers,[16] Government Response Stringency Index values,[17] and population mobility changes were summarised for New Zealand. The Government Response Stringency Index is a composite indicator measuring the strictness of government policy responses to COVID-19. Population mobility changes were calculated using mobility data, with daily observed local resident mobility compared against median estimates for each weekday derived from a 4-week baseline (Feb 10–March 15, 2020) to calculate percentage changes.

Statistical analysis

Rates and proportions were calculated with 95% CIs assuming Poisson and binomial distributions, respectively. 2019 New Zealand population projections produced by Stats NZ for the Ministry of Health were used in denominators.

Risk factors for severe outcomes among cases were examined using logistic regression to estimate odds ratios (ORs) and 95% CIs. Crude ORs were calculated for age, sex, source of infection, and exposure phase variables. Due to confounding by age, all other ORs were adjusted for at least age and sex. Aged residential care (ARC) is an important setting for COVID-19 outbreaks internationally, and there is potential error in our socioeconomic status measure for ARC residents because it is based on ARC facility location. Therefore, to assess the impact of key demographic variables on risk of severe outcomes, multivariable analysis estimated ORs for age, sex, ethnicity, and socioeconomic deprivation including adjustment for ARC residency and the presence of at least one underlying condition. There were insufficient data for precise estimates of risk associated with individual underlying conditions, so multivariable analyses were done only for conditions with at least 20 total observations.

Key time-to-event intervals were analysed by fitting parametric distributions using maximum likelihood estimation. Uncertainty intervals (UIs) for key parameters were calculated using bootstrapping techniques.[18] Sensitivity analysis of the inclusion of probable cases (standard national reporting practice) and exposure period based on notification date for 30 cases was assessed by repeating key study analyses with their exclusion. R (version 4·0.2) and STATA (version 15) were used for statistical analyses.

For more on the **mobility data** see https://github.com/dataventuresnz/mobility-index

Role of the funding source

The funders of this study had no role in the study design, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all of the data and final responsibility for the decision to submit for publication.

Results

1503 cases of COVID-19 were detected in New Zealand presenting from Feb 12 to May 10, 2020, of which 1153 (77%) were confirmed and 350 (23%) probable (figure 1; table 1). This was a cumulative incidence of 302·7 cases (95% CI 287·6–318·4) per million people. 95 (6·3%) people with COVID-19 were admitted to hospital, ten admitted to intensive care (0·7%), and 22 (1·5%) died (table 1). The estimated case infection rate per million people per day peaked in phase 2 at 8·5 (7·6–9·4) followed by a 62% decrease to 3·2 (2·8–3·7) in phase 3 (the first half of lockdown), progressively declining thereafter. The main source of infection was overseas acquisition, with the proportion attributable to importation declining from lockdown (ie, from phase 3 onwards). The results of sensitivity analysis with the exclusion of probable cases are shown in the appendix (pp 2–3), with no major impacts on study findings.

See **Online** for appendix

Demographic characteristics were influenced by infection source, with 1034 (69%) imported and import-related cases, and by outbreak settings (table 2; figure 2). COVID-19 incidence was lowest in children for all sources (table 2). Overall, cases were predominantly female, aged 20–34 years, of European or other ethnicity, and had higher socioeconomic status (47% in NZDep quintiles 1–2). People of Māori ethnicity had the second-highest rate of import-related disease after people of European or other ethnicity (table 2), with 30 (46%) Māori cases in this group linked to New Zealand's largest outbreak (see wedding in figure 2). Locally acquired cases showed female predominance, higher incidence among Asian and Pacific peoples, and distribution across deprivation quintiles (table 2). These characteristics, as well as major geographical trends, were evident in the demographics of major locally acquired outbreaks (figure 2).

Cases were detected throughout New Zealand, with the highest incidence per 100 000 population being found in Southern (64·6, 95% CI 56·3–73·8), Waikato (44·4, 38·3–51·2), and Waitemata (37·4, 32·8–42·3)

Figure 1: **Key features of the New Zealand COVID-19 epidemic and response timeline**

Panel A shows the epidemic curve of confirmed and probable COVID-19 cases in New Zealand by source of infection and major non-pharmaceutical interventions (see panel). Travel restriction start dates are highlighted, which include entry restrictions to foreign nationals from specified countries, requirement for all remaining incoming travellers to isolate for 14 days, and border closures to all but New Zealand citizens or residents. Panel B shows daily SARS-CoV-2 molecular testing counts and daily test positivity (for days with ≥100 tests) and major national COVID-19 surveillance changes. SARS-CoV-2=severe acute respiratory syndrome coronavirus 2. *Expanded to include non-febrile presentations of acute respiratory infection (shortness of breath, cough or sore throat, with or without fever), and testing of asymptomatic household contacts. †Removal of epidemiological criteria (travel to COVID-19-affected areas or close contact with a case) as a requirement (with clinical presentations) and expanded clinical criteria to include anosmia and coryza.

	Total		Phase 1: Feb 2–March 15		Phase 2: March 16–March 25		Phase 3: March 26–April 10		Phase 4: April 11–April 27		Phase 5: April 18–May 13	
	Count	Estimate (95% CI)	Count	Estimate (95% CI)	Count	Estimate (95% CI)	Count	Estimate (95% CI)	Count	Estimate (95% CI)	Count	Estimate (95% CI)
Exposure periods*												
Average estimated daily case infection rate†												
Cases per day	..	..	..	4·6 (4·0 to 5·4)	..	42·2 (37·9 to 46·9)	..	16·0 (14·0 to 18·4)	..	2·6 (1·9 to 3·6)	..	0·4 (0·1 to 0·9)
Cases per million people per day	..	..	..	0·9 (0·8 to 1·1)	..	8·5 (7·6 to 9·4)	..	3·2 (2·8 to 3·7)	..	0·5 (0·4 to 0·7)	..	0·1 (0·0 to 0·2)
Percentage rate change from previous phase	..	..	..	..	..	809% (642 to 1014)	..	−62% (−68 to −54)	..	−84% (−89 to −77)	..	−87% (−95 to −63)
Total cases	1503	..	471	..	672	..	305	..	48	..	7	..
Source of infection												
Imported case	575	38% (36 to 41)	271	58% (53 to 62)	251	37% (33 to 41)	49	16% (12 to 21)	3	6·5% (1·8 to 21)	1	9·3% (0·0 to 100)
Import-related case	459	31% (28 to 33)	100	21% (17 to 26)	231	34% (31 to 38)	119	39% (33 to 45)	9	18% (9·0 to 33)	0	..
Locally acquired case‡	469	31% (29 to 34)	100	21% (17 to 26)	190	28% (25 to 32)	137	45% (39 to 51)	36	75% (59 to 86)	6	89% (0·0 to 100)
High-risk worker	237	16% (14 to 18)	49	10% (7·7 to 14)	88	13% (11 to 16)	76	25% (20 to 31)	20	42% (28 to 58)	4	52% (16 to 86)
Health-care worker	166	11% (9·6 to 13)	33	7·0% (4·9 to 10)	51	7·5% (5·6 to 10)	62	20% (16 to 26)	17	37% (23 to 53)	3	40% (11 to 79)
Other§	71	4·7% (3·8 to 5·9)	16	3·3% (1·9 to 5·7)	38	5·6% (4·0 to 7·8)	14	4·6% (2·6 to 8·2)	3	5·6% (1·5 to 19)	1	0·2% (0·0 to 100)
At least one underlying condition	294	20% (18 to 22)	87	18% (15 to 23)	132	20% (16 to 23)	63	21% (16 to 26)	13	26% (15 to 42)	0	..
Outcome¶												
Hospital admission	95	6·3% (5·2 to 7·7)	32	6·8% (4·7 to 9·8)	36	5·3% (3·7 to 7·6)	21	6·8% (4·2 to 11)	6	12% (5·0 to 28)	0	..
ICU admission	10	0·7% (0·4 to 1·2)	3	0·7% (0·2 to 2·3)	5	0·7% (0·3 to 1·9)	1	0·0% (0·0 to 100)	1	0·0% (0·0 to 100)	0	..
Death	22	1·5% (1·0 to 2·2)	1	0·0% (0·0 to 100)	6	0·9% (0·3 to 2·2)	11	3·5% (1·8 to 6·7)	4	7·6% (2·1 to 24)	0	..
Presentation periods‖												
Confirmed cases	1153	77% (74 to 79)	111	85% (77 to 90)	588	85% (83 to 88)	402	68% (64 to 71)	40	53% (41 to 65)	12	80% (52 to 96)
Probable cases	350	23% (21 to 26)	20	15% (9·6 to 23)	100	15% (12 to 17)	192	32% (29 to 36)	35	47% (35 to 59)	3	20% (4·3 to 48)
Total cases used as basis for case detection	1503	..	131	..	688	..	594	..	75	..	15	..
Contact tracing	765	51% (48 to 53)	39	30% (22 to 38)	257	37% (34 to 41)	393	66% (62 to 70)	65	87% (77 to 93)	11	73% (45 to 92)
Border	39	2·6% (1·9 to 3·5)	3	2·3% (0·5 to 6·5)	24	3·5% (2·2 to 5·1)	8	1·3% (0·6 to 2·6)	3	4% (0·8 to 11)	1	6·7% (0·2 to 32)
Health-care presentation	693	46% (44 to 49)	89	68% (59 to 76)	405	59% (55 to 63)	189	32% (28 to 36)	7	9·3% (3·8 to 18)	3	20% (4·3 to 48)
Other**	6	0·4% (0·1 to 0·9)	0	..	2	0·3% (0·0 to 1·0)	4	0·7% (0·2 to 1·7)	0	..	0	..
Incidence rate of SARS-CoV-2 nucleic acid testing (tests per 100 000 person-days)	..	..	..	0·5 (0·5 to 0·5)	..	27·3 (26·9 to 27·8)	..	56·7 (56·1 to 57·2)	..	78·2 (77·6 to 78·8)	..	109·9 (109·1 to 110·6)
Percentage rate change from previous phase	..	..	..	..	..	5259% (4938 to 5600)	..	107% (103 to 111)	..	38% (36 to 40)	..	40% (39 to 42)

Percentages shown are percentages of the total cases unless indicated otherwise. ICU=intensive care unit. SARS-CoV-2=severe acute respiratory syndrome coronavirus 2. *Cases were assigned to study exposure periods by sampling incubation periods from a Weibull distribution before illness onset (or notification date for 30 cases with no illness onset data, 25 of whom were asymptomatic). †New Zealand-acquired infection; excludes imported cases. ‡87 of these cases were the first cases to emerge in the community with no known source. §Includes airline crew and other frontline service workers (eg, police). ¶Outcomes are not mutually exclusive—ie, cases could be assigned to more than one of hospitalisation, ICU admission, and death. COVID-19 was reported as the primary cause of death on the COVID-19 case report form for all deceased cases. ‖Cases were assigned to study presentation periods by date of illness onset (or notification date if no illness onset data). **Includes asymptomatic self-referral for testing outside of case definition or contact tracing protocol.

***Table 1:* Features of New Zealand's national COVID-19 epidemiology and response performance over five phases of the study period**

	Total			Imported			Import related			Locally acquired*		
	Cases	Incidence risk per 100 000 (95% CI)	Relative risk (95% CI)	Cases	Incidence risk per 100 000 (95% CI)	Relative risk (95% CI)	Cases	Incidence risk per 100 000 (95% CI)	Relative risk (95% CI)	Cases	Incidence risk per 100 000 (95% CI)	Relative risk (95% CI)
Sex												
Female	836 (56%)	33·2 (31·1–35·6)	1·22 (1·10–1·35)	285 (50%)	11·3 (10·1–12·7)	0·96 (0·81–1·13)	253 (55%)	10·1 (8·9–11·4)	1·20 (1–1·44)	298 (64%)	11·9 (10·6–13·3)	1·70 (1·41–2·05)
Male	667 (44%)	27·2 (25·2–29·4)	1 (ref)	290 (50%)	11·8 (10·5–13·3)	1 (ref)	206 (45%)	8·4 (7·3–9·6)	1 (ref)	171 (36%)	7·0 (6·0–8·1)	1 (ref)
Age group												
<1 year	4 (0·3%)	6·5 (2·4–17·2)	0·14 (0·05–0·37)	0	··	··	1 (0·2%)	1·6 (0·2–11·5)	0·15 (0·02–1·05)	3 (0·6%)	4·9 (1·6–15·1)	0·41 (0·13–1·29)
1–4 years	18 (1·2%)	7·3 (4·6–11·6)	0·16 (0·1–0·25)	1 (0·2%)	0·4 (0·1–2·9)	0·02 (0·00–0·12)	9 (2·0%)	3·7 (1·9–7·0)	0·33 (0·17–0·65)	8 (1·7%)	3·2 (1·6–6·5)	0·28 (0·13–0·56)
5–19 years	135 (9·0%)	14·1 (11·9–16·7)	0·30 (0·25–0·37)	15 (2·6%)	1·6 (0·9–2·6)	0·07 (0·04–0·11)	54 (12%)	5·6 (4·3–7·3)	0·51 (0·37–0·70)	66 (14%)	6·9 (5·4–8·8)	0·58 (0·43–0·79)
20–34 years	508 (34%)	46·4 (42·5–50·6)	1 (ref)	258 (45%)	23·6 (20·9–26·6)	1 (ref)	121 (26%)	11·0 (9·2–13·2)	1 (ref)	129 (28%)	11·8 (9·9–14·0)	1 (ref)
35–49 years	299 (20%)	32·6 (29·1–36·5)	0·70 (0·61–0·81)	90 (16%)	9·8 (8·0–12·1)	0·42 (0·33–0·53)	101 (22%)	11·0 (9·1–13·4)	1·00 (0·77–1·30)	108 (23%)	11·8 (9·7–14·2)	1·00 (0·77–1·29)
50–64 years	343 (23%)	37·6 (33·9–41·8)	0·81 (0·71–0·93)	132 (23%)	14·5 (12·2–17·2)	0·61 (0·50–0·76)	120 (26%)	13·2 (11·0–15·7)	1·19 (0·93–1·53)	91 (19%)	10·0 (8·1–12·3)	0·85 (0·65–1·11)
65–79 years	157 (10%)	26·5 (22·7–31·0)	0·57 (0·48–0·68)	76 (13%)	12·8 (10·2–16·1)	0·54 (0·42–0·70)	38 (8·3%)	6·4 (4·7–8·8)	0·58 (0·40–0·84)	43 (9·2%)	7·3 (5·4–9·8)	0·62 (0·44–0·87)
≥80 years	39 (2·6%)	21·5 (15·7–29·4)	0·46 (0·33–0·64)	3 (0·5%)	1·7 (0·5–5·1)	0·07 (0·02–0·22)	15 (3·3%)	8·3 (5·0–13·7)	0·75 (0·44–1·28)	21 (4·5%)	11·6 (7·5–17·7)	0·98 (0·62–1·56)
Ethnic group												
Māori	134 (8·9%)	17·2 (14·5–20·4)	0·49 (0·41–0·58)	33 (5·7%)	4·2 (3·0–6·0)	0·27 (0·19–0·39)	65 (14%)	8·3 (6·5–10·6)	0·74 (0·57–0·97)	36 (7·7%)	4·6 (3·3–6·4)	0·55 (0·39–0·78)
Pacific peoples	79 (5·3%)	24·5 (19·7–30·6)	0·70 (0·55–0·88)	11 (1·9%)	3·4 (1·9–6·2)	0·22 (0·12–0·40)	11 (2·4%)	3·4 (1·9–6·2)	0·31 (0·17–0·56)	57 (12%)	17·7 (13·7–23·0)	2·11 (1·58–2·81)
Asian	183 (12%)	23·8 (20·6–27·5)	0·68 (0·58–0·79)	39 (6·8%)	5·1 (3·7–6·9)	0·32 (0·23–0·45)	34 (7·4%)	4·4 (3·2–6·2)	0·39 (0·28–0·56)	110 (23%)	14·3 (11·9–17·3)	1·71 (1·36–2·13)
European or other†	1091 (73%)	35·2 (33·2–37·4)	1 (ref)	484 (84%)	15·6 (14·3–17·1)	1 (ref)	347 (76%)	11·2 (10·1–12·4)	1 (ref)	260 (55%)	8·4 (7·4–9·5)	1 (ref)
Unknown	16 (1·1%)	··	··	8 (1·4%)	··	··	2 (0·4%)	··	··	6 (1·3%)	··	··
NZDep quintile												
1 (least deprived)	342 (23%)	33·3 (30·0–37·1)	1 (ref)	167 (29%)	16·3 (14·0–18·9)	1 (ref)	97 (21%)	9·5 (7·8–11·5)	1 (ref)	78 (17%)	7·6 (6·1–9·5)	1 (ref)
2	362 (24%)	36·2 (32·6–40·1)	1·08 (0·94–1·26)	153 (27%)	15·3 (13·0–17·9)	0·94 (0·75–1·17)	107 (23%)	10·7 (8·8–12·9)	1·13 (0·86–1·49)	102 (22%)	10·2 (8·4–12·4)	1·34 (1·00–1·80)
3	262 (17%)	26·7 (23·6–30·1)	0·80 (0·68–0·94)	95 (17%)	9·7 (7·9–11·8)	0·59 (0·46–0·76)	80 (17%)	8·1 (6·5–10·1)	0·86 (0·64–1·16)	87 (19%)	8·9 (7·2–10·9)	1·16 (0·86–1·58)
4	279 (19%)	28·7 (25·5–32·2)	0·86 (0·73–1·01)	88 (15%)	9·0 (7·3–11·1)	0·56 (0·43–0·72)	96 (21%)	9·9 (8·1–12·0)	1·04 (0·79–1·38)	95 (20%)	9·8 (8·0–11·9)	1·28 (0·95–1·73)
5 (most deprived)	170 (11%)	17·3 (14·9–20·1)	0·52 (0·43–0·62)	81 (14%)	3·3 (2·3–4·6)	0·2 (0·14–0·29)	49 (11%)	5·0 (3·8–6·6)	0·53 (0·37–0·74)	89 (19%)	9·1 (7·4–11·1)	1·19 (0·88–1·61)
Unknown	88 (5·9%)	··	··	40 (7·0%)	··	··	30 (6·5%)	··	··	18 (3·8%)	··	··
Total	1503 (100%)	··	··	575 (100%)	··	··	459 (100%)	··	··	469 (100%)	··	··

NZDep=New Zealand Index of Deprivation. *87 of these cases were first cases to emerge in the community with no known source. †Other group includes 32 cases identifying as Middle Eastern, Latin American, or African.

Table 2: **Demographic characteristics of COVID-19 cases stratified by source of infection**

DHBs—popular tourist areas and epicentres of the three largest outbreaks (figure 2). 34 outbreaks accounted for 702 (47%) cases. Most New Zealand-acquired outbreak-related transmission (424 [67%] cases) occurred before lockdown. The ten largest outbreaks were multigenerational, with the largest following a super-spreading event at a wedding (figure 2). Outbreaks showed female predominance, particularly those associated with institutional settings. European or other case ethnicity predominated; however, relative to New Zealand's

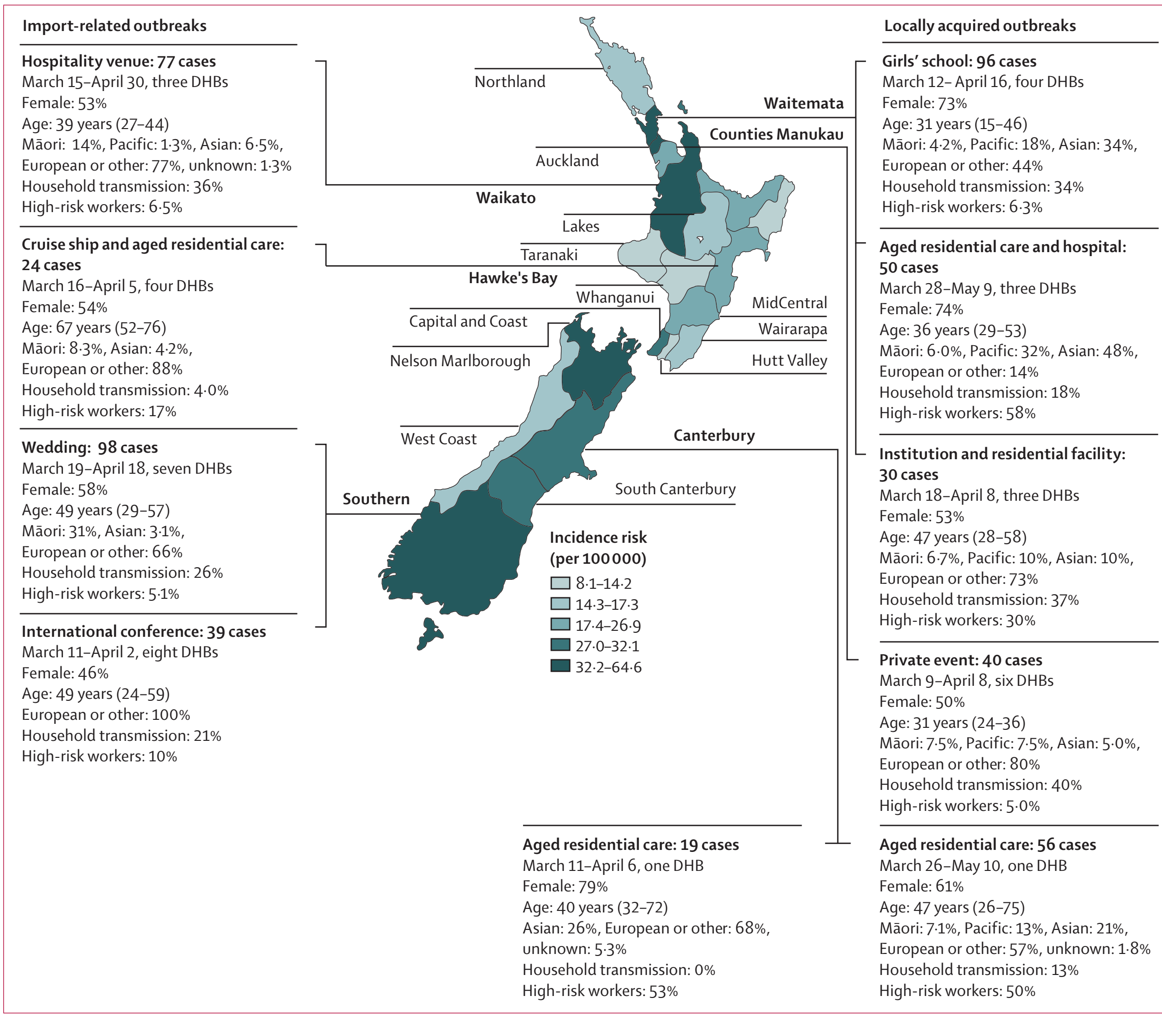


***Figure 2:* COVID-19 cumulative incidence by DHB, indicating epicentres and summary characteristics of the ten largest COVID-19 outbreaks**
Outbreak summaries show outbreak settings, number of linked cases, date range of illness onset, number of DHBs involved, female cases as percentage of total, median age (IQR), cases by ethnicity (Māori, Pacific peoples, European or other ethnicities, or unknown) as a percentage of total, percentage of total cases infected due to within household transmission, and percentage of cases identified as high-risk workers. Household transmission excludes cases from household clusters that introduced SARS-CoV-2 to the household and any other cases in a household with symptom onset within 1 day of the first case. DHB=District Health Board. SARS-CoV-2=severe acute respiratory syndrome coronavirus 2.

population structure, Asian or Pacific peoples were disproportionately affected in eight outbreaks and Māori in the largest (figure 2). Among 782 (52%) cases linked to 316 COVID-19 household clusters, only nine (1·2%) cases in people younger than 15 years of age were the first cases in their household.

Case symptoms are summarised in the appendix (p 10). Only 501 (34%) of 1472 cases presented with cough and fever. Severe outcomes were associated with older ages: multivariable adjusted ORs ranged 2·72 (95% CI 1·40–5·30) for 50–64 year olds to 8·25 (2·59–26·31) for people aged 80 years or older, compared with 20–34 year olds (appendix pp 4–5). After age-sex adjustment, having reported at least one underlying condition was associated with severe outcomes (OR 1·81 [1·16-2·83]) as was ARC residency (3·86 [1·59–9·35]; appendix pp 4–5). There was no clear association of lower socioeconomic status with severe outcomes after adjusting for ARC residency, as well as for age, sex, ethnicity, and having at least one underlying condition (appendix pp 4–5). Higher odds of severe outcomes were associated with Pacific peoples (2·76 [1·14–6·68]) and Asian (2·15 [1·10–4·20]) ethnicity versus European or other ethnicity after multivariable adjustment (appendix pp 4–5), although no Asian or Pacific peoples died. Higher odds of severe outcomes associated with locally acquired infection (2·32 [1·40–3·82] compared with imported) and exposure in later phases (3·08 [1·22–7·77] in phase 4 compared with phase 1) is explained by the timing and occurrence of locally acquired outbreaks in vulnerable-population settings (eg, ARC; figure 2; appendix pp 4–5).

Among 22 COVID-19 deaths, the mean age was 81·5 years (SD 10·0; range 62–99), 11 (50%) were male, 20 (91%) were of European or other ethnicity, two (9%) were Māori, and 16 (73%) lived in ARC facilities. 11 (50%) cases had at least one underlying condition.

Initially, cases were mostly identified through clinical health-care presentations, but predominantly through contact tracing from phase 3 onwards (table 1). 212 001 SARS-CoV-2 tests were done up to May 13, with a 220-times increase in testing incidence from phase 1 to phase 5, and less than 5% national daily test positivity from March 29 (figure 1; table 1). A dramatic drop in international passenger arrivals and considerably reduced population mobility were observed from phase 2 (appendix p 11).

Testing increased over the study period among all demographic groups (figure 3; appendix pp 6–7). Females had consistently higher testing rates than males (figure 3). In phase 1, testing rates were highest in people of Asian ethnicity, adults aged 20–34 years, and people of higher socioeconomic status (figure 3; appendix pp 6–7). Subsequently, Pacific peoples, adults aged 50–64 years, and people of lower socioeconomic status had higher rates. People younger than 20 years of age had lower testing rates in every phase (appendix pp 6–7).

Key time-to-event intervals declined by phase, except for time to hospitalisation where numbers were too small to stratify (median 8 days [IQR 4 to 11; range 0 to 39]; appendix pp 8–9, 12). Between phases 1 and 4, the average time from illness onset to notification reduced from 9·7 days (95% UI 8·8 to 10·7) to 1·7 days (1·2 to 2·2) and average isolation intervals from 7·2 days (6·3 to 8·2) to –2·7 days (–4·7 to –0·8) days, where negative days represent isolation before illness onset (appendix p 12). Small counts in phase 5 prevented maximum likelihood estimations. Numbers were also too small for phase-based stratification by source of infection or basis for case detection. Sensitivity analysis with the exclusion of probable cases found no significant differences in timeliness, except for a shorter average onset to notification interval in phase 3 (appendix pp 8–9).

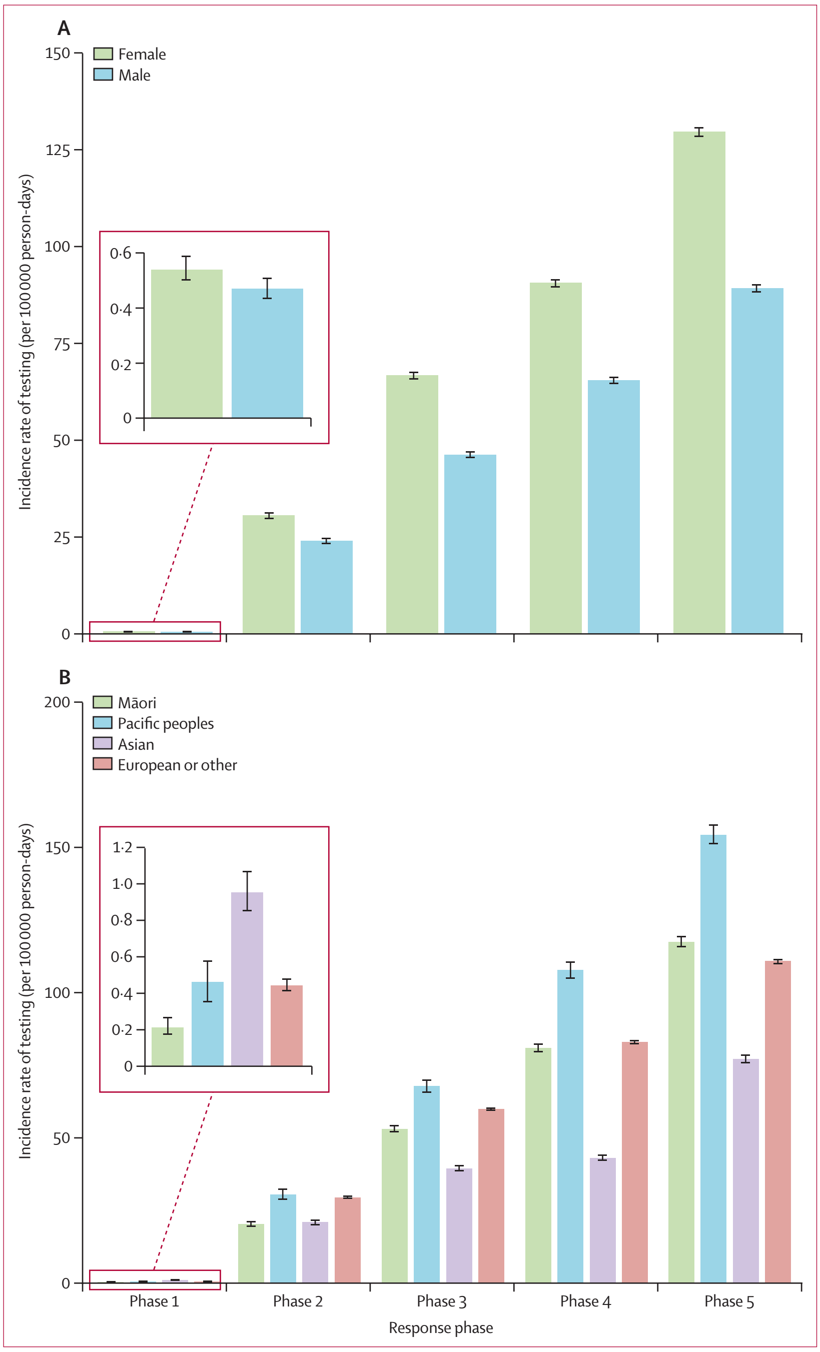


Figure 3: **Incidence rates of SARS-CoV-2 testing by sex and response phase (A) and by ethnic group and response phase (B)**
Incidence rates are presented per 100 000 person-days at risk with 95% CIs. SARS-CoV-2=severe acute respiratory syndrome coronavirus 2.

Discussion

New Zealand experienced one of the lowest cumulative case counts, incidence, and mortality among higher-income countries in its first wave of COVID-19 following early implementation and rapid escalation of national COVID-19 suppression strategies.[19,20] New Zealand effectively achieved control with progressive, risk-informed border closures reducing the burden of imported disease driving the epidemic. This was followed, only 15 days after first case confirmation, by a phase of rapid escalation of non-pharmaceutical interventions to national lockdown. This 10-day escalation phase had the highest average daily case infection rate during the study period. Within 2 weeks, lockdown was associated with a substantial reduction in daily case infection rate and improving response performance measures: the majority of cases were detected by contact tracing, and there were decreasing average times to case notification and isolation and increasing population testing with effective targeting of higher-risk groups.

Enhancements in response capacity also supported de-escalation decisions. The daily test positivity was less than 5% from March 29 (day 4 of lockdown), as recommended by WHO before easing of restrictions, and only 25 cases of asymptomatic infection were detected despite routine testing of asymptomatic contacts, population testing surveys targeting asymptomatic and high-risk groups, and high testing rates by phase 5. Moreover, despite full de-escalation to Alert Level 1 on June 9, New Zealand effectively eliminated COVID-19, as currently defined,[6] to very low numbers detected at border quarantine facilities for an extended period.[20]

Furthermore, rapid suppression of community transmission limited overall disease disparities for populations most vulnerable to severe outcomes. Most cases were linked to imported cases, with predominant features of healthy travellers: younger adults, European ethnicity, and higher socioeconomic status. Locally acquired disease was less common, but tended to reach more vulnerable populations (ie, older people, ARC residents, and minority ethnic groups) and was associated with more severe outcomes. Female case predominance in this group probably relates to the settings where locally acquired outbreaks occurred, including a girls' school, and ARC facilities where residents and carers were more likely to be female, but is potentially influenced by testing bias. Higher female testing incidence might reflect female predominance in certain high-risk groups targeted for testing, such as health-care workers, which is also considered a potential reason for slight female case predominance described in England.[8] Higher male mortality reported overseas was not seen in New Zealand,[2,8,21] and although the crude OR for severe outcomes was slightly higher for males, this estimate was imprecise and did not persist after multivariable adjustment. In keeping with some international findings, children appeared to have had a lesser role in household transmission and outbreaks—even at a school—in New Zealand, despite intensive testing of asymptomatic contacts.[2,21] However, with lower national testing rates in children, detection bias cannot be excluded.

High-risk workers and indigenous Māori people did not appear to be disproportionately affected in the first wave. Rapid control of community transmission through mandatory physical distancing provided time to enhance the response, including prioritised testing of higher-risk groups, also ensuring that COVID-19 did not overburden health system capacity. Nonetheless, after adjustment for confounders, older people, ARC residents, people reporting at least one underlying condition, and Asian and Pacific peoples were at higher risk of severe outcomes than other populations. These findings align with international risk associations.[2,8,9,21,22] Our study supports the ongoing need for the response to address systemic barriers, such as health-care access, to achieving equitable health outcomes for minority and higher-risk groups, particularly in the absence of elimination.[23]

There are contextual features of New Zealand's experience that have implications for generalisability to other settings. New Zealand's small, non-federated health system proved responsive, including rapid test development and early reprioritisation of health-care services, with readiness probably facilitated by delay in the first case arriving due to border measures. The pandemic's commencement during New Zealand summertime with low seasonal respiratory infections meant an initially restricted testing resource could be more readily targeted. Despite these advantages, there was some early undetected community transmission, with the first locally acquired case presenting on March 4 when the national case definition targeted febrile illness, a less frequent feature of COVID-19 in the New Zealand cohort and overseas. In New Zealand, only a low proportion of asymptomatic infection was detected relative to other countries despite widespread testing, and the low level of community transmission that occurred might have contributed to this. Serological studies are required to quantify this further.

New Zealand's border response has implications for island states where borders can be more readily controlled. Samoa and Fiji, for example, also exercised early border closures to non-citizens and non-residents, aligning with strategies effective during the 1918 pandemic, and so far maintain zero or very low COVID-19 counts.[19,24] While clearly effective in limiting disease importation, there remain questions about the costs and sustainability of these measures. Although New Zealand-based research before the pandemic suggested a net health economic benefit from complete border closure in a modelled pandemic scenario,[25] the potential indirect health effects of the national response are under surveillance and the net impacts yet to be determined. Cost-effectiveness analysis lay outside the scope of our study but focused research in this area is essential. Furthermore, Taiwan has shown that COVID-19 control can be achieved in the absence of complete border closure, although using advanced technological systems and ongoing strict disease suppression strategies in a society that had already normalised some of these measures from previous novel virus exposures.[19,26]

Finally, the speed and intensity of the national response to limit the epidemic is unprecedented internationally; New Zealand had the fastest trajectory to reach the highest country score in the Government Response Stringency Index.[17] The observed impact of lockdown on inhibiting disease transmission aligns with reproductive number estimates for before and after lockdown produced for New Zealand and other countries.[21,27,28] It is likely this early, intense response, which also enabled relatively rapid easing while maintaining strict border controls, prevented the burden of disease experienced in other high-income countries with slower lockdown implementation, including Australia, the UK, and Italy—the latter initially taking mitigation approaches.[28–30] Integral to New Zealand's response has been decisive governance, effective communication, and high population compliance—in an earthquake-prone country, communities and emergency management systems are primed for disaster response.[10,31]

This study has methodological advantages. It uses two comprehensive national datasets: one employing standardised national case questionnaires prospectively applied to every notified case for the primary purpose of COVID-19 surveillance, and the other recording every SARS-CoV-2 test done using nationally validated methodology. Moreover, data were extracted for the study period in mid-June, enabling completeness, and preventing right censoring of the epidemic curve. Furthermore, following the end of the study period, case numbers remained very low, including a 25-day period where no cases were notified.[20]

There are also limitations. It was not possible to differentiate impacts of individual non-pharmaceutical interventions due to the rapid and overlapping implementation of response measures. Moreover, the relatively small case dataset has statistical limitations for comparative analyses. The categorisation of phases and presentation and exposure periods incorporated assumptions. In particular, the modelled incubation period applied to all cases was not derived from New Zealand data and some cases might have been incorrectly assigned to an exposure period. Misclassification of imported cases is also possible, although 98% of cases became symptomatic in phase 1 within 5 days of arrival from overseas. Finally, as an observational study using surveillance data, results are prone to errors including inter-operator differences in defining and recording case data. Notably, that cases were on average recorded as being isolated before symptom onset from phase 3 onwards suggests that quarantine (or self-isolation) dates were reported. Although the impacts of movement restrictions cannot be differentiated from the timeliness of case management here, this still measures response performance.

In conclusion, our study indicates that early and intense implementation of national COVID-19 suppression strategies have effectively altered the course of New Zealand's epidemic and limited the burden of disease and inequities in this high-income democratic setting, initially achieving COVID-19 elimination. This supports the WHO recommendations for timely decisive national leadership for evidence-informed, risk-based escalation and de-escalation decisions combining rigorous case detection, isolation, contact tracing, and quarantine measures with population education and engagement. Further surveillance and research are needed to understand the cost benefits, particularly the indirect population health and social impacts, of this response.

Contributors

SJ led study design with inputs from PP, NF, PM, NP, JM, VH, and CM. CG and SJ led data collection, with PM also obtaining data. CG, NP, GG, SP, JSh, SJ, JM, AM, PM, and LY analysed the data and contributed to interpretations with all other authors. SJ led the development of figures with PM. JSc and SJ reviewed the literature. SJ led manuscript writing, with all authors contributing to the final draft.

Declaration of interests

NP reports funding from GlaxoSmithKline, outside of the submitted work. All other authors declare no competing interests.

Data sharing

All study data were extracted from the national databases EpiSurv and Éclair, and can be obtained for research purposes by contacting data-enquiries@health.govt.nz and following the COVID-19 data request process.

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