(Mbinta, J. F. et al., 2024)

Effectiveness of COVID-19 vaccines against hospitalisation, death and infection over time in Aotearoa New Zealand: a retrospective cohort study

James F Mbinta, Andrew A Sporle, Jan Sheppard, Aliitasi Su'a-Tavila, Binh P Nguyen, Nigel French, Colin R Simpson

ABSTRACT

AIMS: This study aimed to evaluate the effectiveness of COVID-19 vaccines in preventing COVID-19 outcomes when the Omicron variant was predominant in Aotearoa New Zealand.

METHODS: We conducted a retrospective cohort study using routinely available data (8 December 2020–28 February 2023). We evaluated the vaccine effectiveness (VE) of COVID-19 vaccines using the Cox proportional-hazards model, adjusting for covariates.

RESULTS: The VE against COVID-19 hospitalisation (VE_H) for the second booster dose compared to no vaccination was found to be 81.8% (95% confidence interval [95% CI]: 73.6–87.5) after 1 month post-vaccination. After 4 months, VE_H was 72.2% (95% CI: 58.5–81.4), and after 6 months VE_H was 49.0% (95% CI: 7.9–71.8). Similarly, VE_H decreased after the first booster dose (1-month VE_H=81.6% [95% CI: 75.6–86.1]; 2 months VE_H=74.7% [95% CI: 68.2–79.9]; and 6 months VE_H=57.4% [95% CI: 45.8–66.6]). VE against COVID-19 death (VE_D) was 92.9% (95% CI: 82.1–97.2) 2 months after the first booster vaccination, with VE_D being sustained until months 5 and 6 (VE_D=87.2%; 95% CI: 67.4–94.9). The VE after the second dose of the vaccine against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection (VE_I) (real-time polymerase chain reaction [RT-PCR]) was sustained at 5 months post-vaccination (40.6%; 95% CI: 25.6–52.5).

CONCLUSION: We provide a comprehensive quantification of both VE and VE waning. These findings can guide policymakers to help evaluate the COVID-19 vaccination programme and minimise the effect of future COVID-19 in Aotearoa New Zealand.

Between the confirmation of the first COVID-19 case in Aotearoa New Zealand and October 2023, there were over 2,470,435 cases, with 31,119 hospitalisations, 878 intensive care unit admissions and 4,849 deaths.[1] The risk of severe COVID-19 and mortality increases with age, relative socio-economic deprivation, disability status and comorbidity, and the age-adjusted COVID-19 mortality is higher among Māori and Pacific peoples compared to the general population.[2–5] At the outset, the Aotearoa New Zealand Government pursued a strategy focussed on suppressing the community spread of SARS-CoV-2 and ultimately achieved extremely low or zero COVID-19 incidence.[3] Throughout the pandemic, the Government adjusted the approach to match the evolving virus, transitioning from elimination to mitigation and ultimately prioritising vaccination.[6]

The national medical regulatory agency granted provisional approval for using the Pfizer–BioNTech COVID-19 vaccine (Comirnaty) on 3 February 2021. The vaccine rollout commenced with priority groups (border and managed isolation and quarantine workers, their household contacts and families) on 20 February 2021.[2] From January 2022, all individuals aged 5 and older in Aotearoa New Zealand became eligible for vaccination. Additionally, in February 2023, vaccination eligibility was extended to certain infants as young as 6 months old.[2] Several additional vaccines were approved and administered to a limited segment of the vaccinated population. These included AstraZeneca (Vaxzevria, approved in July 2021), Janssen (July 2021), Novavax (Nuvaxovid, March 2022) and Bivalent mRNA-CVs (December 2022).[2]

Accurately evaluating vaccine effectiveness (VE) and subsequent VE waning (understanding when VE declines) helps to inform public health decision making during an evolving pandemic. Understanding the waning of VE after the first, second and booster vaccine doses can also help identify who is most likely to benefit from further booster doses or other vaccines or interventions to reduce risk. For instance, a previous United

Kingdom (UK) study found that significant vaccine waning occurred 25 weeks after the second dose of the vaccine.[7] This observational study, among others, contributed to the evidence that was used to design the UK COVID-19 vaccine booster programme.

Using data from the Ministry of Health's national COVID-19 surveillance platform and building on our previous work using routinely collected data in Aotearoa New Zealand,[8–10] we evaluated the VE of COVID-19 vaccines in preventing COVID-19 outcomes (hospitalisation, mortality and infection) over time since vaccination.

Study design

A retrospective, whole-population, matched-cohort study was conducted to evaluate the effectiveness of COVID-19 vaccines and vaccine waning (i.e., the decline in VE) using the national data collections provided by the Ministry of Health in Aotearoa New Zealand.

Data sources

The data used in this study were sourced from the Ministry of Health and the Institute of Environmental Science and Research (ESR; Figure 1 and Appendix Table 1). Additional data were sourced from the 2018 Census, Department of Internal Affairs (DIA) and core data derived by Statistics New Zealand (Stats NZ), including full death dates and address notifications.

A National Health Index (NHI) number is a unique identifier assigned to individuals accessing healthcare services in Aotearoa New Zealand.[11] It serves as a comprehensive record for data linkage and demographic data, encompassing crucial information such as name, address, date of birth, gender, resident or citizenship status, place of birth, ethnicity and, if applicable, date of death.

The Eclair Clinical Data Repository is a national reporting application in Aotearoa New Zealand, created by the Data and Informatics team at the ESR.[12] It compiles COVID-19 test reports, both positive and negative, from various sources across the country. Initially designed for COVID-19 reporting, it was expanded to support eOrdering for polymerase chain reaction (PCR) test and rapid antigen test (RAT) recording via the Eclair RAT Reporting system. This application managed and shared testing data with the government, Eclair users and partners (including researchers).

The COVID-19 Immunisation Register (CIR) is an application based on the National Contact Tracing Solution platform with robust security and authorisation controls.[13] It includes information for monitoring immunisation coverage and the progress of the immunisation campaign. The creation of the CIR in 2020 stemmed from the limitations of the existing National Immunisation Register, which hindered its suitability for promptly facilitating a COVID-19 vaccination rollout on a national scale. It records the immunisations people have received or chosen not to receive. The data collected were necessary for health management, public safety, healthcare planning, research, professional training, statistical reporting and government service enhancement. The COVID-19 vaccination data were released to the public by the Ministry of Health.[14] This was updated weekly to include recent changes in the values of those vaccinated and/or boosted. The spreadsheet released by the Ministry of Health contains a breakdown by district health board (DHB), territorial authority, health service utilisation population, ethnicity, vaccine type and cumulative values. DHBs are used to determine the area of residence for individuals included in this study.

EpiSurv is a secure national reporting and data repository system in Aotearoa New Zealand that tracks notifiable diseases (significant public health risk).[15] It is operated by ESR on behalf of the Ministry of Health and is utilised by public health units for reporting cases. EpiSurv gathers up-to-date information encompassing baseline patient characteristics, clinical presentation, determinants and inter-case relationships used for disease surveillance.

The National Minimum Dataset (NMDS) is a comprehensive repository of hospital discharge information in Aotearoa New Zealand, encompassing data from both public and private healthcare facilities for inpatients and day patients and containing public and private hospitalisation data from 1997 onwards.[16]

The Pharmaceutical Collection is a comprehensive data repository that manages community-dispensed pharmaceutical subsidies in Aotearoa New Zealand and contains over 469 million claims.[17]

The Mortality Collection serves as a data repository on causes of death established in Aotearoa New Zealand.[18] It includes electronic death and stillbirth registrations, medical certificates, data from hospital discharges and other agencies.

Population

The vaccinated cohort included everyone who received the COVID-19 vaccine (Comirnaty) between 8 December 2020 and 28 February 2023 (end of study). Medsafe, the nation's medical regulatory agency, granted provisional approval for the use of Comirnaty in Aotearoa New Zealand on 3 February 2021. The vaccine rollout commenced with priority groups on 20 February 2021.[2] Our start date, 8 December 2020, was when the first COVID-19 vaccine doses were administered outside clinical trials.[19] This date accounts for individuals who might have received the vaccine and returned to Aotearoa New Zealand before its official licensure. The unvaccinated cohort was comprised of people who did not receive any dose of the COVID-19 vaccine during the study period (Figure 2).

We matched vaccinated individuals with unvaccinated individuals based on age, sex, ethnicity and DHB to reduce confounding over time. This resulted in improved precision of estimates of VE. Due to the high vaccination rates in adults, there was a small pool of potential unvaccinated matches for adult vaccine recipients.

Exposure to vaccination

We studied the first and second vaccine doses and boosters (first and second). Most of the Aotearoa New Zealand population received the Pfizer–BioNTech (Comirnaty) vaccine.[2] Vaccination status was ascertained from codes provided directly by the Ministry of Health up to 28 February 2023, the latest date of available records.

Exposure (vaccination) status was defined as time-varying, with an individual defined as exposed from the date of immunisation. Our primary comparison of interest was the time elapsed since receiving the vaccine compared to not having received one. The unvaccinated cohort consisted of individuals who did not receive the vaccine. Controls who had not received a COVID-19 vaccine by the end of the study period were matched 1:1 based on socio-demographic characteristics.

Outcomes

COVID-19 hospitalisation was defined as being admitted to the hospital within 14 days of a confirmed SARS-CoV-2 infection or having an International Classification of Disease-10 (ICD-10) code for COVID-19. COVID-19 hospitalisations were derived as whether someone had never (0) or ever (1) been hospitalised for COVID-19 (with any COVID-related ICD-10-AM code) within 14 days of a positive COVID-19 test, for positive tests up to 28 February 2023 (end of follow-up).[4] They were coded as first, second and third hospitalisations.

COVID-19 death was defined as having COVID-19, an underlying ICD-10 cause of death recorded on the death certificate, or any cause of death within 28 days of a confirmed SARS-CoV-2 infection.[1]

COVID-19 infection was defined as cases of COVID-19 with a positive SARS-CoV-2 test. COVID-19 infection was used as a secondary outcome to determine whether an individual had ever (1) or never (0) recorded a positive COVID-19 test result, either before (PCR) or after (RAT) 16 February 2022. This cutoff point marked the beginning of unsupervised self-testing. As a result, positive or negative test results may not have been officially recorded uniformly, potentially inflating the ratio of positive to negative tests beyond this point.[4] On 6 March 2022, the COVID-19 response minister cautioned that the reported daily case numbers might significantly under-estimate the actual cases due to self-reporting with RATs and delays in reporting results, emphasising that COVID-19 hospitalisations are considered a more reliable tracker of the pandemic.[20]

Covariates

Comorbidity and multimorbidity encompass the presence of multiple distinct health conditions within an individual and are associated with increased healthcare burden, reduced quality of life and poor health outcomes.[21] Multimorbidity was assessed using the Pharmaceutical Prescribing Profile mortality risk index (P3 index) and the MultiMorbidity Measure index (M3 index).[22,23] Age in years, birth month/year and sex (0=men, 1=women) were obtained from the Ministry of Health. Age was divided into 16 age groups. Ethnicity was divided into Māori, Pacific peoples, European, Asian and Middle Eastern, Latin American or African (MELAA). Māori ethnicity was coded for those recorded as Māori only or Māori and at least one other ethnic group.

Statistical analysis

The process of 1:1 matching was conducted using the Reclin2 package,[24] a set of tools designed for probabilistic record linkage. It consisted of the

following steps: Pairs of records were generated from vaccinated and unvaccinated cohorts using two blocking variables (age group and sex). The generated pairs of records were compared on a set of variables (ethnicity and DHB) in both datasets (vaccinated and unvaccinated cohorts). The pairs were scored using the expectation–maximisation algorithm to estimate the m- and u-probabilities for each of the linkage variables (ethnicity and DHB). Pairs with a high likelihood were selected, i.e., pairs that met a predetermined threshold (effectively matched according to the potential confounding variables). Finally, using the selected pairs, the final linked dataset was generated.[24] This process was conducted four times (first dose vs unvaccinated, second dose vs unvaccinated, first booster vs unvaccinated and second booster vs unvaccinated).

Baseline patient characteristics, such as age, sex, ethnicity, comorbidity and multimorbidity (M3 score and P3 score), infectiousness, level of susceptibility, immunity (hybrid, infection induced and vaccine induced) and location (DHBs), were presented as frequencies and percentages for the matched cohorts (vaccinated and unvaccinated).

For the vaccinated cohort(s), the index date was the date of vaccination. Each vaccinated individual was monitored from the index date until they either developed the outcome of interest or received the next vaccine dose, or until the end of the study (28 February 2023). Unvaccinated individuals were assigned a pseudo-vaccination date (index date) that matched their paired vaccinated counterparts. The unvaccinated cohort was then monitored from this index date until they either developed the outcome of interest or until the end of the study.

For each outcome (primary and secondary), we evaluated the VE of COVID-19 vaccines (first and second doses, first and second booster doses) using the Cox proportional-hazards model. For each outcome, we fitted a model at each time point during the follow-up period (e.g., 1, 2, 3, 4, 5 and 6 months). Estimating the overall VE is unnecessary and may be misleading, as the impact of COVID-19 vaccines on outcomes depends on the time since vaccination. Our approach aimed to elucidate the trajectory (if any) of waning COVID-19 VE.[25] The model was adjusted for multiple confounders through the process of matching/probabilistic linking and the addition of covariates, including age, sex, ethnicity, DHB, comorbidity and multimorbidity, and numeric variables derived from the agent-based model (infection-induced immunity, vaccine-induced immunity, hybrid immunity, infectiousness and level of susceptibility; Appendix Table 1).

Subgroup analyses were performed by age group, sex and ethnicity. The models were similar, but in situations where there were fewer cases, we concatenated the time-since-vaccination indicators (e.g., 1–3 and 4–6 months, etc.). For each outcome, we estimated an adjusted hazard ratio (aHR) and 95% confidence intervals (CI) for each time-since-vaccination interval in comparison to the unvaccinated group. The VE was estimated as one minus the aHR, scaled as a percentage (1 - aHR * 100). Statistical analyses were carried out using R/R Studio (version R-4.2.2).[26]

Results

Baseline characteristics of the population

A total of 5,269,015 people were included in the analysis. The mean age was 38.8 (standard deviation [SD] =23.2, range = 0–113) years. Between 8 December 2020 and 28 February 2023, a total of 4,318,211 (82.0%) individuals received the COVID-19 vaccine first dose, 4,158,014 (78.9%) received the second dose, 2,737,890 (52.0%) received the first booster dose and 755,107 (14.3%) received the second booster dose of COVID-19 vaccine (Table 3, Appendix Table 2). During the follow-up period, 413,310 (9.5%) individuals aged 15 and above were unvaccinated. Vaccination rates across all doses were highest among older adults, females, Europeans, Asians and people resident in the Capital and Coast DHB. The median times between the first and second doses, the second dose and the first booster dose, and the first and second booster doses were 4 weeks, 5 months and 7 months, respectively (Table 2).

During the follow-up period, there were 1,248,548 recorded COVID-19 infections, 24,370 hospitalisations and 1,006 deaths within 28 days of a positive test for SARS-CoV-2. A total of 5,375 (0.4%) people had a second infection, and 26 had a third. Additionally, 0.7% (169) of hospitalised individuals were readmitted for a second time (Table 1).

The trajectory of the second booster dose VE over time

The estimates of VE against hospitalisation (VE_H) and infection (VE_I) are shown in Table 3. No deaths occurred in the vaccinated cohort after the second booster dose, so death was not included in

the analysis. Against COVID-19 hospitalisation, VE_H was 81.8% (95% CI: 73.6–87.5) in the 1st month, decreased to 72.2% (95% CI: 58.5–81.4) in the 4th month and then further decreased to 49.0% (95% CI: 7.9–71.8) in the 6th month. In the 1st month, the VE against COVID-19 infection was 57.4% (95% CI: 48.4–64.7). By the 4th month, it had decreased to 25.7% (95% CI: 04.8–42.1), and in the 6th month, it further decreased to 9.9% (95% CI: -25.8–35.4).

Waning VE was observed across all sub-groups (Appendix Table 3). The second booster dose VE against COVID-19 hospitalisation for the Māori population was 81.1% (95% CI: 46.0–93.4) in the 1st month, decreased to 51.9% (95% CI: 7.6–74.9) in the 2nd–3rd month and then further decreased to 36.6% (95% CI: -16.8–63.4) in the 4th–6th month. The second booster dose VE against COVID-19 hospitalisation for Pacific peoples was 92.2% (95% CI: 36.6–98.9) in the 1st month and decreased to 56.7% (95% CI: -0.7–81.3) in the 4th to 6th month.

The trajectory of the first booster dose VE over time

For each outcome of interest, VE was highest in the 1st month post-vaccination, then waned over time (Table 4). Against hospitalisation, VE_H was 81.6% (95% CI: 75.6–86.1) in the 1st month, was 74.7% (95% CI: 68.2–79.9) in the 3rd month and decreased to 57.4% (95% CI: 45.8–66.6) by the 6th month. Against COVID-19 death, there was sustained protection over the follow-up period. The VE_D was 92.9% (95% CI: 82.1–97.2) in the 2nd month and was 87.2% (95% CI: 67.4–94.9) during months 5–6 post-vaccination.

Against infection confirmed with real-time polymerase chain reaction (RT-PCR), VE_I was 54.0% (95% CI: 38.8–65.4) in the 1st month and dramatically decreased to 20.0% (95% CI: -88.1–66.0) in the 3rd month. Against infection (determined by both RAT and RT-PCR), VE_I was 20.2% (95% CI: 17.7–22.7) in the 1st month and decreased to 18.9% (95% CI: 16.7–21.0) 2 months post-vaccination. Additional findings on VE by subgroup can be found in the supplemental material (Appendix Table 4).

The trajectory of the second dose VE over time

For each outcome, VE for the second dose was highest in the 1st month post-vaccination, then waned over time (Table 5). Against hospitalisation, VE_H was 92.9% (95% CI: 86.4–96.3) in the 1st month, decreased to 74.7% (95%CI: 63.2–82.6) in the 3rd month and was 72.5% (95% CI: 64.9–78.5) by the 6th month. Against death, there was sustained protection over the follow-up period. The VE_D was 87.3% (95% CI: 53.8–96.5) in the 3rd month and was 86.1% (95% CI: 50.6–96.1) by the 6th month post-vaccination. VE_I against COVID-19 infection confirmed with RT-PCR was 88.2% (95% CI: 85.3–90.5) in the 1st month and decreased to 40.6% (95% CI: 25.6–52.5) in the 5th month. Vaccine waning was similar across all the sub-groups (Appendix Table 5).

The trajectory of the first dose VE over time

The estimates of VE against the outcomes of interest and sub-group analysis are shown in Appendix Table 6. Against hospitalisation, VE_H was 69.6% (95% CI: 50.1–81.5) in the 1st month and increased to 88.5% (95% CI: 80.6–93.1) in the 2nd month. Against death, there was sustained protection over the follow-up period, a VE_D of 87.6% (95% CI: 38.9–97.5). The VE against infection (RT-PCR confirmed) was 63.2% (95% CI: 56.1–69.2) during the follow-up period (1 month).

Discussion

We found that VE against hospitalisation and mortality was most robust in the early post-vaccination period, with VE against hospitalisation waning over time. A moderate waning of VE against death was found. Against COVID-19 infection, there were declines in VE, most notably at 3 months post-vaccination.

Our findings were broadly consistent with those of previous observational studies.[25,27–30] Evidence from a comprehensive systematic review and meta-analysis of 11 randomised control trials involving 161,388 participants and 46 observational studies involving 55,367,053 participants showed that 11 COVID-19 vaccines were effective against five SARS-CoV-2 variants of concern: Alpha, Beta, Gamma, Delta and Omicron.[27] This systematic review found that in the primary COVID-19 vaccine series, the summary measure of overall VE was 88.0% against the Alpha variant, 77.8% against the Delta variant, 73.0% against the Beta variant, 63.0% against the Gamma variant and 55.9% against the Omicron variant. Against the Delta variant, the VE of the booster vaccination was 95.5%, and against the Omicron variant, the summary VE of the booster vaccination was 80.8%.

In a recent systematic review and meta-analysis involving 68 studies from more than

23 countries, VE for the primary COVID-19 vaccine series at baseline (14–42 days) was 92% for hospitalisations and 91% for mortality. This effectiveness was reduced to 79% at 224–251 days for hospitalisations and 86% at 168–195 days for mortality.[28] Against all documented infections, VE was 83% at baseline (14–42 days), decreased to 62% by 112–139 days and then decreased gradually to 47% by 280–307 days. At baseline, the booster doses of the COVID-19 vaccines showed 70% effectiveness in preventing infections and 89% effectiveness in preventing hospitalisations. However, this effectiveness decreased to 43% against infections and 71% against hospitalisations after ≥112 days.

Similarly, a large observational study conducted by Lin et al. described the trajectory of the waning effectiveness of the COVID-19 vaccine (double dose regiment) over 9 months (11 December 2020–8 September 2021) in North Carolina, United States of America.[25] The three vaccines assessed were BNT162b2, mRNA-1273 and Ad26.COV2.S. The VE against COVID-19 infections was 74.8–85.5% in the 1st month, increased to 71.4–95.9% in the 2nd month, then waned gradually to 67.8–77.8% by the 8th month. Against hospitalisations, the VE was 85.8–96.4% in the 2nd month and decreased to 81.7–94.3 by the 6th month. Against mortality, VE ranged from 65.5% to 91.6% in the 1st month, increased to 82.2% to 98.6% in the 2nd month, and gradually decreased to 71.2% to 92.5% during the 6th month.

A strength of our study is that we conducted a 1:1 matched retrospective cohort study using nationwide individual-level data from the Ministry of Health and the ESR, improving the accuracy and completeness of vaccination status, COVID-19 cases, hospitalisation and mortality data. Additionally, we controlled for demographic factors, comorbidity and multimorbidity, susceptibility, infectiousness and immunity (vaccine induced, infection induced and hybrid immunity). This allowed us to control for confounding and enabled us to examine the trajectory of COVID-19 VE as a function of time since vaccination. We have previously used this approach to assess the effectiveness of shingles vaccines in Aotearoa New Zealand.[8]

Our study weaknesses include vaccine coverage being very high in Aotearoa New Zealand, with VE as a function of time post-vaccination in the sub-group analysis becoming under-powered because of the dwindling numbers of eligible unvaccinated populations. Also, under-reporting and unmeasured confounding, particularly in the study when the unvaccinated population was small, may have resulted in an under-estimation or over-estimation of the VE point estimates.[31,32] Potential confounders that are not included in our model but could increase point estimates for VE include personal behaviours (i.e., if the vaccinated had higher mask use and greater social distancing) and antivirals (made available for at-risk populations from May 2022).

Although multiple vaccines are approved and available in Aotearoa New Zealand, almost all people received Pfizer–BioNTech (Comirnaty). However, we could not access the data required to perform a sub-group analysis by vaccine type. Also, VE against specific variants could not be assessed as the Omicron variant predominated during the study period.

RATs were included in our estimates for VE against infection (after 16 February 2022). RATs were used by the public to enable self-management and their use was therefore subject to individual testing behaviours (rather than PCR tests used systematically in clinical settings e.g., to influence treatment options). For instance, individuals may have tested with RATs more frequently if they lived in households with individuals at greater risk of severity (e.g., older adults and/or persons with compromised immune systems).[33] Vaccinated individuals were also twice as likely as unvaccinated individuals to express their intention to undergo COVID-19 testing and report being tested in the past month.[33]

Our findings suggest that COVID-19 vaccines provided longer-term protection against hospitalisation and mortality and shorter-term protection against infection. VE decreased gradually as a function of time post-vaccination, especially against SARS-CoV-2 infection. These findings are based on the use of historical time frames (i.e., up to 28 February 2023). This may lead to discrepancies when compared to alternative analyses or official data (e.g., that which encompass the most up-to-date COVID-19 data).

Future observational studies using well-powered national data will be needed to assess the effectiveness of COVID-19 vaccines beyond 6 months post-vaccination. It is vital to evaluate VE by vaccine type and variant. Additionally, there is a need to understand how VE differs for immunosuppressed people at different stages of disease and treatment. Policymakers, clinicians and patients will be reassured by the VE estimates found for the COVID-19 vaccine, particularly against severe outcomes (hospitalisation

and death). Given the waning effectiveness of these vaccines over time, however, further surveillance should be undertaken to monitor vaccine uptake among groups and the VE of future booster doses (including for bivalent vaccines) or combination vaccines. Also, there is a need to evaluate the cost effectiveness of COVID-19 vaccinations and booster doses specifically in Aotearoa New Zealand. Economic evaluation evidence could help guide decisions on routine annual vaccination coverage, particularly in situations with limited vaccine supply. This information could also inform whether the government should prioritise alternative strategies, like improving ventilation in public settings.

Figure 1: Summary of data sources.

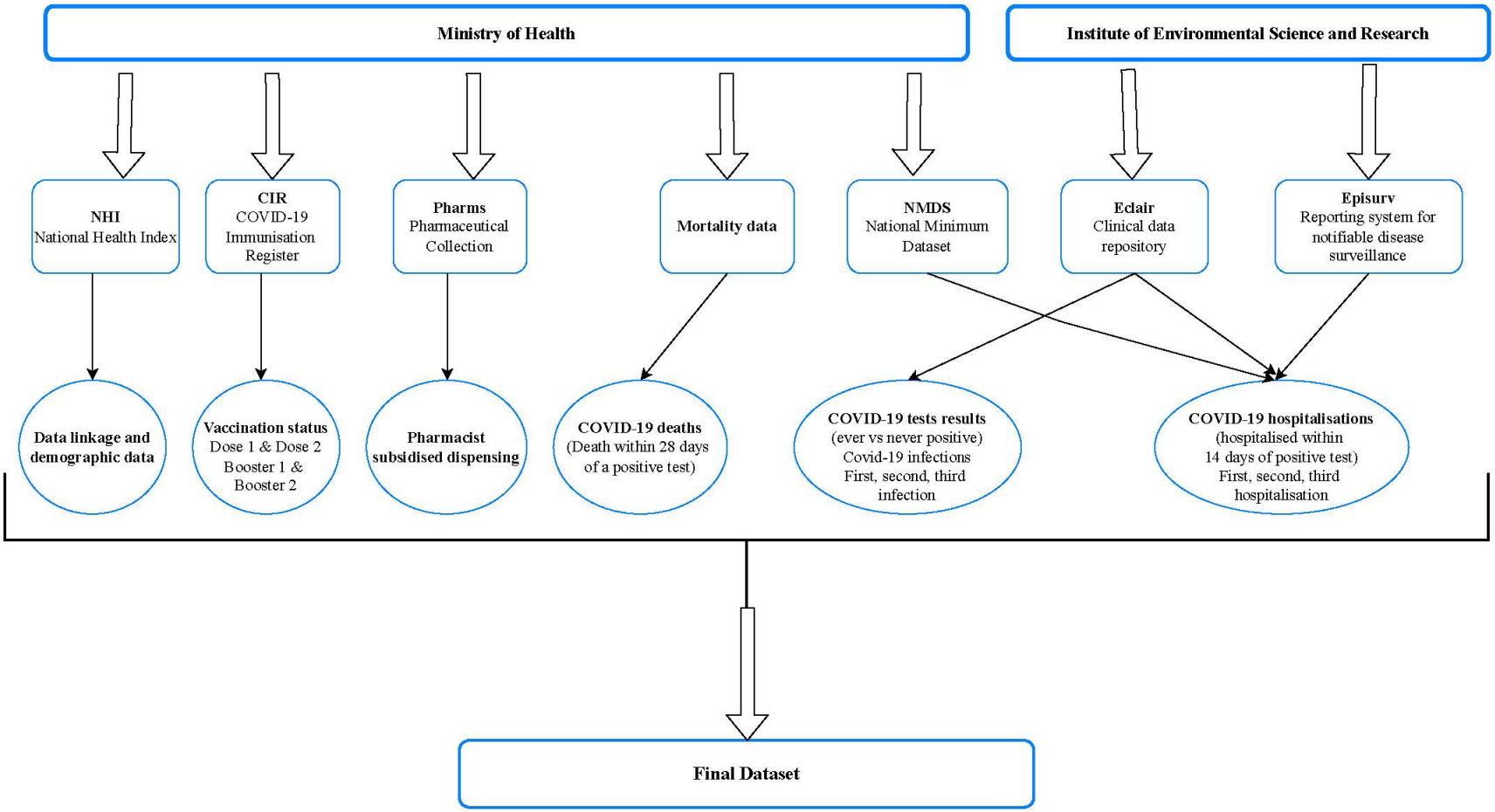
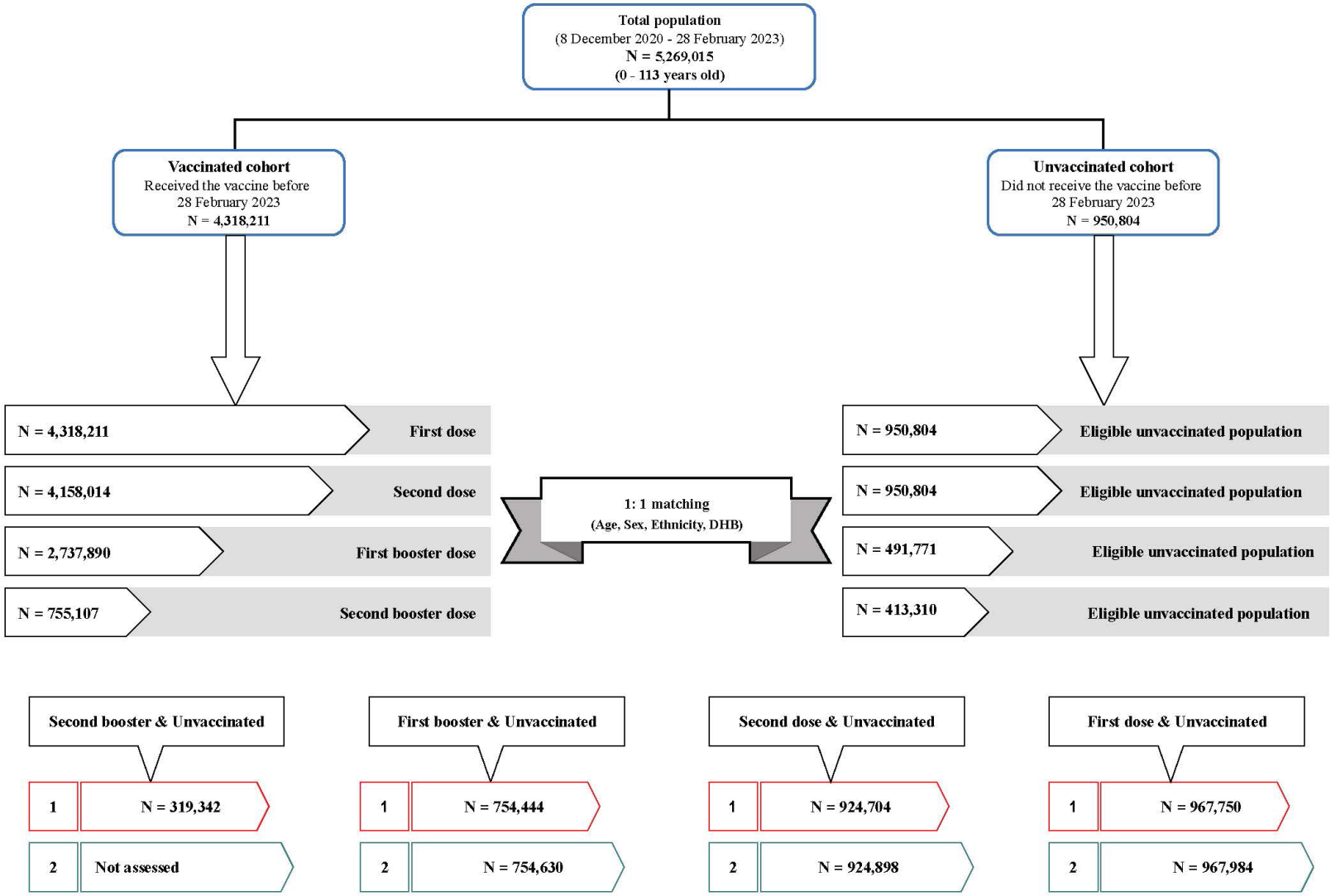


Figure 2: Data flowchart.



Red box: outcomes = infection and hospitalisation. Blue box: outcomes = COVID-19 death.

Table 1: Baseline characteristics of study participants.

Characteristics	Vaccinated cohort								Unvaccinated cohort	
	First dose		Second dose		First booster		Second booster			
Age										
Median	10		26		43		68		10	
Interquartile range	9		25		26		17		34	
Mean	16.5		29.6		44.7		66.9		21.9	
Standard deviation	17.3		17.8		17.0		12.7		23.3	
Age group										
0–4	5,179	1.7%	4,975	1.6%	0	0.0%	0	0.0%	301,225	96.7%
5–9	74,478	22.4%	100,682	30.2%	9	0.003%	0	0.0%	157,808	47.4%
10–14	38,916	11.3%	227,906	66.0%	229	0.1%	≤5	0.001%	78,461	22.7%
15–19	4,495	1.4%	195,614	61.3%	92,010	28.8%	752	0.2%	26,237	8.2%
20–24	4,755	1.4%	138,274	41.3%	157,780	47.1%	1,991	0.6%	32,163	9.6%
25–29	5,366	1.4%	145,276	38.0%	181,311	47.4%	3,522	0.9%	47,367	12.4%
30–34	5,255	1.3%	136,060	33.6%	204,571	50.5%	8,155	2.0%	50,714	12.5%
35–39	4,202	1.2%	104,264	29.0%	200,194	55.7%	9,171	2.6%	41,330	11.5%
40–44	3,216	1.0%	81,594	25.1%	193,389	59.6%	12,471	3.8%	33,910	10.5%
45–49	2,795	0.9%	70,921	21.8%	198,071	60.8%	23,388	7.2%	30,735	9.4%
50–54	2,532	0.8%	62,755	18.6%	180,527	53.5%	60,969	18.1%	30,764	9.1%

Table 1 (continued): Baseline characteristics of study participants.

Characteristics	Vaccinated cohort								Unvaccinated cohort	
	First dose		Second dose		First booster		Second booster			
55–59	2,109	0.7%	49,146	15.1%	169,752	52.1%	76,372	23.5%	28,298	8.7%
60–64	1,712	0.6%	36,105	11.8%	145,642	47.7%	96,650	31.7%	25,185	8.3%
65–69	1,257	0.5%	23,635	9.1%	92,189	35.4%	122,470	47.0%	20,979	8.1%
70–74	915	0.4%	15,721	7.0%	66,309	29.6%	125,571	56.0%	15,673	7.0%
75+	3,015	0.8%	27,196	7.3%	100,800	26.9%	213,621	57.0%	29,955	8.0%
Sex										
Female	75,619	2.9%	656,005	24.8%	1,038,879	39.3%	410,991	15.5%	465,211	17.6%
Male	84,455	3.2%	762,175	29.1%	941,015	36.0%	343,995	13.1%	485,128	18.5%
Indeterminate	≤5	1.3%	100	31.2%	184	57.3%	27	8.4%	6	1.9%
Unknown	119	2.3%	1,844	35.3%	2,705	51.8%	94	1.8%	459	8.8%
All deaths										
No	157,160	3.0%	1,404,631	26.9%	1,972,085	37.8%	755,099	14.5%	927,275	17.8%
Yes	3,037	5.8%	15,493	29.4%	10,698	20.3%	8	0.02%	23,529	44.6%
COVID-19 death*										
Yes	29	2.9%	249	24.8%	583	58.0%	0	0.0%	145	14.4%
No	3,008	5.8%	15,244	29.5%	10,115	19.5%	8	0.02%	23,384	45.2%
Prioritised ethnicity (level 1)										
Māori	39,675	4.9%	273,421	33.9%	194,579	24.1%	57,136	7.1%	241,535	23.0%

Table 1 (continued): Baseline characteristics of study participants.

Characteristics	Vaccinated cohort								Unvaccinated cohort	
	First dose		Second dose		First booster		Second booster			
Pacific peoples	17,936	4.6%	134,271	34.2%	124,544	31.7%	26,884	6.9%	89,086	22.7%
European	74,637	2.4%	743,203	24.1%	1,208,638	39.2%	601,011	19.5%	454,489	14.8%
Asian	23,663	2.8%	223,519	26.8%	393,761	47.1%	58,737	7.0%	135,903	16.3%
MELAA	3,044	3.1%	31,087	32.0%	37,366	38.5%	4,482	4.6%	21,197	21.8%
Other ethnicity	366	2.3%	3,798	24.0%	6,417	40.6%	2,082	13.2%	3,162	20.0%
Residual categories	876	2.2%	10,825	27.5%	17,478	44.4%	4,775	12.1%	5,432	13.8%
Ethnicity										
Māori	39,675	4.9%	273,421	33.9%	194,579	24.1%	57,136	7.1%	241,535	30.0%
Pacific peoples	22,132	4.9%	154,107	34.2%	132,837	29.5%	28,021	6.2%	113,49	25.2%
European	96,803	2.8%	863,902	25.0%	1,296,585	37.5%	624,469	18.1%	572,862	16.6%
Asian	25,108	2.9%	231,859	26.8%	405,253	46.8%	61,258	7.1%	142,785	16.5%
MELAA	3,352	3.3%	32,301	31.9%	38,129	37.6%	4,620	4.6%	22,928	22.6%
Others	538	2.8%	4,816	24.7%	7,556	38.8%	2,326	12.0%	4,234	21.8%
District health boards										
Auckland	12,272	2.4%	130,635	25.0%	225,975	43.3%	72,112	13.8%	81,428	15.6%
Bay of Plenty	9,349	3.4%	79,175	28.7%	89,348	32.4%	37,742	13.7%	60,336	21.9%
Canterbury	16,422	2.7%	154,143	25.7%	239,602	39.9%	98,266	16.4%	91,848	15.3%

Table 1 (continued): Baseline characteristics of study participants.

Characteristics	Vaccinated cohort								Unvaccinated cohort	
	First dose		Second dose		First booster		Second booster			
Capital and Coast	7,542	2.3%	74,161	22.6%	142,653	43.4%	61,172	18.6%	42,907	13.1%
Counties Manukau	21,753	3.5%	186,303	30.0%	227,546	36.6%	65,046	10.5%	121,349	19.5%
Hawke's Bay	6,538	3.6%	50,519	27.5%	62,529	34.0%	28,364	15.4%	35,881	19.5%
Hutt Valley	5,016	3.1%	41,352	25.7%	62,267	38.7%	27,095	16.9%	25,017	15.6%
Lakes	4,261	3.6%	34,884	29.2%	37,875	31.6%	16,042	13.4%	26,631	22.3%
MidCentral	6,039	3.2%	50,958	26.7%	68,712	36.0%	30,226	15.8%	34,976	18.3%
Nelson Marlborough	4,976	3.0%	42,000	25.2%	58,654	35.2%	31,322	18.8%	29,750	17.9%
Northland	7,129	3.5%	54,032	26.5%	64,649	31.8%	26,433	13.0%	51,355	25.2%
South Canterbury	2,002	3.2%	15,888	25.1%	23,990	37.9%	10,925	17.2%	10,551	16.7%
Southern	10,126	2.9%	91,813	26.0%	140,401	39.8%	54,623	15.5%	55,978	15.9%
Tairāwhiti	2,073	3.9%	16,100	30.1%	17,016	31.8%	6,748	12.6%	11,633	21.7%
Taranaki	4,014	3.1%	37,142	28.8%	42,985	33.4%	17,701	13.7%	26,979	20.9%
Waikato	15,272	3.4%	131,853	29.1%	155,198	34.3%	57,150	12.6%	93,229	20.6%
Wairarapa	1,758	3.5%	13,178	26.0%	17,323	34.1%	9,830	19.4%	8,657	17.1%
Waitematā	19,545	3.0%	178,541	27.1%	259,553	39.3%	86,158	13.1%	116,115	17.6%
West Coast	974	2.9%	8,900	26.6%	12,180	36.4%	4,968	14.9%	6,418	19.2%
Whanganui	2,200	3.1%	18,191	25.7%	23,075	32.6%	11,950	16.9%	15,340	21.7%
Not specified	936	3.3%	10,356	36.7%	11,252	39.9%	1,234	4.4%	4,426	15.7%

Table 1 (continued): Baseline characteristics of study participants.

Characteristics	Vaccinated cohort								Unvaccinated cohort	
	First dose		Second dose		First booster		Second booster			
Number of infections										
0	108,605	2.7%	993,236	24.7%	1,466,287	36.5%	642,062	16.0%	810,277	20.2%
1	51,469	4.1%	425,093	34.2%	514,053	41.4%	112,546	9.1%	139,986	11.3%
2	123	2.3%	1,787	33.3%	2,430	45.2%	496	9.2%	539	10.0%
3	0	0.0%	8	30.8%	13	50.0%	≤5	11.5%	≤5	7.7%
Hospitalisations										
0	159,667	3.0%	1,415,270	27.0%	1,973,042	37.6%	749,869	14.3%	946,797	18.1%
1	522	2.2%	4,821	19.9%	9,668	40.0%	5,210	21.5%	3,978	16.4%
2	8	4.7%	32	18.8%	73	42.9%	28	16.5%	29	17.1%
3	0	0.0%	≤5	100.0%	0	0.0%	0	0.0%	0	0.0%
MultiMorbidity Measure Index (M3 index)										
0–<1	5,587	1.7%	62,077	18.3%	129,980	38.4%	106,010	31.3%	34,812	10.3%
1–<2	1,350	2.5%	10,389	18.8%	18,465	33.5%	16,699	30.3%	8,304	15.0%
2–<3	672	3.0%	4,446	19.9%	6,529	29.3%	5,206	23.3%	5,470	24.5%
3+	313	4.5%	1,699	24.3%	1,458	20.8%	979	14.0%	2,550	36.4%
NA	152,275	3.1%	1,341,513	27.7%	1,826,351	37.7%	626,213	12.9%	899,668	18.6%
Pharmaceutical Prescribing Profile Mortality Risk Index (P3 index)										
0–<1	30,712	1.6%	377,763	20.1%	822,703	43.7%	464,744	24.7%	186,652	9.9%

Table 1 (continued): Baseline characteristics of study participants.

Characteristics	Vaccinated cohort								Unvaccinated cohort	
	First dose		Second dose		First booster		Second booster			
1–<2	4,137	1.3%	57,924	18.0%	133,228	41.3%	102,397	31.8%	24,587	7.6%
2–<3	1,317	2.0%	11,216	16.9%	24,101	36.3%	22,042	33.2%	7,812	11.8%
3+	825	4.0%	4,738	23.1%	5,701	27.8%	4,866	23.7%	4,391	21.4%
NA	123,206	4.1%	968,483	32.5%	997,050	33.5%	161,058	5.4%	727,362	24.4%

*COVID-19 death was defined as having COVID-19, an underlying ICD-10 cause of death recorded on the death certificate or any cause of death within 28 days of a confirmed SARS-CoV-2 infection.

Table 2: Interval between vaccine doses.

Time interval	Frequency	Percentage	Cumulative frequency	Cumulative percentage
First and second doses				
1 week	939	0.02%	939	0.02%
2 weeks	501	0.01%	1,440	0.04%
3 weeks	850,471	20.5%	851,911	20.5%
4 weeks	1,113,769	26.8%	1,965,680	47.3%
5 weeks	509,041	12.2%	2,474,721	59.5%
6 weeks	781,353	18.8%	3,256,074	78.3%
7 weeks	413,169	9.9%	3,669,243	88.2%
8 weeks	186,214	4.5%	3,855,457	92.7%
9 weeks	116,927	2.8%	3,972,384	95.5%
10 weeks	52,226	1.3%	4,024,610	96.8%
11 weeks	30,025	0.7%	4,054,635	97.5%
12 weeks	20,872	0.5%	4,075,507	98.0%
13 weeks	14,863	0.4%	4,090,370	98.4%
14 weeks	10,874	0.4%	4,101,244	98.6%
15 weeks	56,763	1.4%	4,158,007	100.0%
Second dose and first booster dose				
1 month	185	0.01%	185	0.01%
2 months	175	0.01%	360	0.01%
3 months	5,171	0.2%	5,531	0.20%
4 months	469,043	17.1%	474,574	17.3%
5 months	1,089,849	39.8%	1,564,423	57.1%
6 months	505,700	18.5%	2,070,123	75.6%
7 months	393,794	14.4%	2,463,917	90.0%
8 months	138,705	5.1%	2,602,622	95.1%
9 months	65,051	2.4%	2,667,673	97.4%
10 months	28,352	1.0%	2,696,025	98.5%
11 months	13,779	0.53%	2,709,804	99.0%
12 months	8,105	0.3%	2,717,909	99.3%

Table 2 (continued): Interval between vaccine doses.

13 months	6,318	0.2%	2,724,227	99.5%
14 months	5,266	0.2%	2,729,493	99.7%
15 months	8,390	0.3%	2,737,883	100.0%
First and second boosters				
1 month	97	0.01%	97	0.01%
2 months	28	0.004%	125	0.02%
3 months	148	0.02%	273	0.03%
4 months	981	0.1%	1,254	0.2%
5 months	847	0.1%	2,101	0.3%
6 months	33,976	4.5%	36,077	4.8%
7 months	385,729	51.1%	421,806	55.9%
8 months	134,297	17.8%	556,103	73.6%
9 months	60,770	8.0%	616,873	81.7%
10 months	57,511	7.6%	674,384	89.3%
11 months	46,550	6.2%	720,934	95.5%
12 months	23,537	3.1%	744,471	98.6%
13 months	8,701	1.22%	753,172	99.7%
14 months	1,682	0.2%	754,854	100.0%
15 months	253	0.03%	755,107	100.0%

Table 3: Vaccine effectiveness of second booster dose against COVID-19 hospitalisation and infection.

Months since the second booster dose	Vaccine effectiveness (95% confidence interval)	
	COVID-19 hospitalisation	COVID-19 infection (PCR+RAT)*
1	81.8% (73.6–87.5)	57.4% (48.4–64.7)
2	79.4% (66.8–87.2)	33.1% (12.7–48.7)
3	72.2% (58.5–81.4)	04.6% (-29.1–29.4)
4	75.5% (64.4–83.2)	25.7% (04.8–42.1)
5	36.1% (4.0–57.5)	-14.8% (-50.2–12.3)
6	49.0% (7.9–71.8)	09.9% (-25.8–35.4)

*Rapid antigen tests (RATs) were introduced on 16 February 2022.
NB: Deaths were not considered as there was no COVID-related death in the vaccinated cohort (second booster dose) during the follow-up period.

Table 4: Vaccine effectiveness as a function of time elapsed since the first booster dose.

Months since first booster dose	Vaccine effectiveness (95% confidence interval)			
	Hospitalisation	Death	Infection (RT-PCR)	Infection (RT-PCR+RAT)*
1	81.6% (75.6–86.1)	NA**	54.0% (38.8–65.4)	20.2% (17.7–22.7)
2	80.8% (76.0–84.6)	92.9% (82.1–97.2)	45.4% (-7.5–72.3)	18.9% (16.7–21.0)
3	74.7% (68.2–79.9)	89.2% (78.3–94.5)	20.0% (-88.1–66.0)	-10.71% (-14.25–-7.28)
4	65.4% (55.9–72.9)	88.9% (76.7–94.7)	-	-29.10% (-34.02–-24.63)
5	60.7% (49.5–69.4)	87.2% (67.4–94.9)	-	-48.41% (-57.67–-39.69)
6	57.4% (45.8–66.6)			-30.40% (-42.30–-18.75)

*Rapid antigen tests (RATs) were introduced on 16 February 2022.
**Deaths were not considered as there was no COVID-related death in the vaccinated cohort (first booster dose) during the first month.

Table 5: Vaccine effectiveness as a function of time elapsed since the second dose.

Months since second dose	Vaccine effectiveness (95% confidence interval)		
	Hospitalisation	Death	Infection (RT-PCR)
1	92.9% (86.4–96.3)	NA*	88.2% (85.3–90.5)
2	91.1% (83.1–95.3)	87.3% (53.8–96.5)	89.9% (87.5–91.9)
3	74.7% (63.2–82.6)		79.1% (74.3–83.1)
4	72.6% (62.4–80.1)	84.2% (41.4–95.7)	49.3% (39.0–57.8)
5	72.4% (64.1–78.7)	86.6% (69.1–94.2)	40.6% (25.6–52.5)
6	72.5% (64.9–78.5)	86.1% (50.6–96.1)	-

*Deaths were not considered as there was no COVID-related death in the vaccinated cohort (second dose) during the first month.

COMPETING INTERESTS
This work was supported by the Ministry of Health, Aotearoa New Zealand (reference: PROP–053). The sponsors of the study had no role in the design, data collection, data analysis, data interpretation or the writing of this report. There was no input to the methodology and results by any commercial entity

CR Simpson, AA Sporle, J Shephard, A Su'a-Tavila, BP Nguyen and N French report support for the present manuscript from the Ministry of Health (NZ). CR Simpson reports funding from MBIE (NZ), HRC (NZ), Ministry of Health (NZ), MRC (UK) and CSO (UK), leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid with the New Zealand Government Data Ethics Advisory Group as the Chair, outside the submitted work. N French reports grants and consulting fees from MBIE (NZ), the Ministry for Primary Industries, the Ministry of Health (NZ), HRC (NZ), Te Niwha, UK Fleming Fund, Operational Solutions for Primary Industries, the Institute of Environmental Science and Research, and International Commission on Microbial Specifications for Foods, outside the submitted work. BP Nguyen reports grants from MBIE (NZ), and HRC (NZ), outside the submitted work. The remaining authors declare no competing interests.

ACKNOWLEDGEMENTS
Dr Ankit Patel provided assistance with data extraction and statistical analysis for this study.

ETHICS AND PERMISSIONS
Ethics approval (number: 30627) was obtained from the Human Ethics Committee of Te Herenga Waka – Victoria University of Wellington, New Zealand.

AUTHOR INFORMATION
James F Mbinta: School of Health, Wellington Faculty of Health, Te Herenga Waka – Victoria University of Wellington, Wellington, Aotearoa New Zealand.
Andrew A Sporle: iNZight Analytics Ltd; Department of Statistics, Faculty of Science, The University of Auckland, Auckland, Aotearoa New Zealand.
Jan Sheppard: Institute of Environmental Science and Research Limited, Porirua, New Zealand.
Aliitasi Su'a-Tavila: School of Health, Wellington Faculty of Health, Te Herenga Waka – Victoria University of Wellington, Wellington, Aotearoa New Zealand.
Binh P Nguyen: School of Mathematics and Statistics, Wellington Faculty of Engineering, Te Herenga Waka – Victoria University of Wellington, Wellington, Aotearoa New Zealand.
Nigel French: School of Veterinary Science, Massey University, Wellington, Aotearoa New Zealand.
Colin R Simpson: School of Health, Wellington Faculty of Health, Te Herenga Waka – Victoria University of Wellington, Wellington, New Zealand; Usher Institute, The University of Edinburgh, Edinburgh, United Kingdom.

CORRESPONDING AUTHORS
James F Mbinta: School of Health, Wellington Faculty of Health, Te Herenga Waka – Victoria University of Wellington, Wellington, New Zealand. Ph: +64 21 0819 7312. E: james.mbinta@vuw.ac.nz
Prof Colin R Simpson: School of Health, Wellington Faculty of Health, Te Herenga Waka – Victoria University of Wellington, Wellington, New Zealand; Usher Institute, The University of Edinburgh, Edinburgh, United Kingdom. Ph: +64 21 589 192. E: colin.simpson@vuw.ac.nz

URL
https://nzmj.org.nz/journal/vol-137-no-1602/effectiveness-of-covid-19-vaccines-against-hospitalisation-death-and-infection-over-time-in-aotearoa-new-zealand-a-retrospective

REFERENCES
1. Health New Zealand – Te Whatu Ora. COVID-19: Case demographics [Internet]. 2024 [cited 2024 Feb 12]. Available from: https://www.tewhatuora.govt.nz/our-health-system/data-and-statistics/covid-19-data/covid-19-case-demographics/#details-of-covid-19-deaths
2. Health New Zealand – Te Whatu Ora. Immunisation Handbook 2024, version 1 [Internet]. New Zealand; 2024 [cited 2024 Apr 17]. Available from: https://www.tewhatuora.govt.nz/for-health-professionals/clinical-guidance/immunisation-handbook
3. Jefferies S, French N, Gilkison C, et al. COVID-19 in New Zealand and the impact of the national response: a descriptive epidemiological study. Lancet Public Health. 2020;5(11):e612-e23. doi: 10.1016/S2468-2667(20)30225-5.
4. Satherley N, Diamond T, Sporle A. More than just living in a deprived area: An equity-focused analysis of policy amenable factors associated with Māori COVID-19 outcomes. Auckland, New Zealand: iNZight Analytics Ltd, The National Hauora Coalition; 2023.
5. Sonder G, Grey C, Mischewski B, Ryan D. Pacific COVID-19 Intelligence Gathering and Analysis Project: Evaluation of the August 2020 outbreak [Internet]. Ministry of Health – Manatū Hauora; 2022 [cited 2023 Oct 30]. Available from: https://www.health.govt.nz/about-ministry/information-releases/general-information-releases/

pacific-covid-19-intelligence-gathering-and-analysis-project-evaluation-august-2020-outbreak
6. Ministry of Health – Manatū Hauora. COVID-19: Protecting Aotearoa New Zealand [Internet]. 2023 [cited 2023 Oct 30]. Available from: https://www.health.govt.nz/our-work/diseases-and-conditions/covid-19-novel-coronavirus/covid-19-response-planning/covid-19-protecting-aotearoa-new-zealand
7. Katikireddi SV, Cerqueira-Silva T, Vasileiou E, et al. Two-dose ChAdOx1 nCoV-19 vaccine protection against COVID-19 hospital admissions and deaths over time: a retrospective, population-based cohort study in Scotland and Brazil. Lancet. 2022;399(10319):25-35. doi: 10.1016/S0140-6736(21)02754-9.
8. Mbinta JF, Wang AX, Nguyen BP, et al. Herpes zoster vaccine effectiveness against herpes zoster and postherpetic neuralgia in New Zealand: a retrospective cohort study. Lancet Reg Health West Pac. 2022 Sep 26;31:100601. doi: 10.1016/j.lanwpc.2022.100601.
9. Mbinta JF, Wang AX, Nguyen BP, et al. Herpes zoster vaccine safety in the Aotearoa New Zealand population: a self-controlled case series study. Nat Commun. 2023;14(1):4330. doi: 10.1038/s41467-023-39595-y.
10. Nguyen T, Adnan M, Nguyen BP, et al. COVID-19 vaccine strategies for Aotearoa New Zealand: a mathematical modelling study. Lancet Reg Health West Pac. 2021;15:100256. doi: 10.1016/j.lanwpc.2021.100256.
11. Health New Zealand – Te Whatu Ora. National Health Index [Internet]. 2023 [cited 2023 Oct 3]. Available from: https://www.tewhatuora.govt.nz/our-health-system/digital-health/health-identity/national-health-index
12. Institute of Environmental Science and Research. Clinical Data Repository [Internet]. [cited 2023 Oct 3]. Available from: https://www.esr.cri.nz/expertise/public-health/health-information-systems/#ClinicalDataRepository
13. Health New Zealand – Te Whatu Ora. National Immunisation Registers [Internet]. [cited 2023 Oct 3]. Available from: https://www.tewhatuora.govt.nz/health-services-and-programmes/vaccine-information/national-immunisation-registers
14. Health New Zealand – Te Whatu Ora. COVID-19 vaccine data [Internet]. 2024 [cited 2024 Feb 12]. Available from: https://www.tewhatuora.govt.nz/our-health-system/data-and-statistics/covid-vaccine-data/
15. Institute of Environmental Science and Research. EpiSurv Notifiable Disease Database [Internet]. [cited 2023 Oct 3]. Available from: https://www.esr.cri.nz/expertise/public-health/health-information-systems/#EpiSurvnotifiablediseasedatabase
16. Health New Zealand – Te Whatu Ora. National Minimum Dataset (hospital events) [Internet]. [cited 2023 Oct 3]. Available from: https://www.tewhatuora.govt.nz/for-health-professionals/data-and-statistics/nz-health-statistics/national-collections-and-surveys/collections/national-minimum-dataset-hospital-events/
17. Health New Zealand – Te Whatu Ora. Pharmaceutical Collection [Internet]. 2021 [cited 2023 Oct 3]. Available from: https://www.health.govt.nz/nz-health-statistics/national-collections-and-surveys/collections/pharmaceutical-collection
18. Health New Zealand – Te Whatu Ora. Mortality Collection [Internet]. Wellington, New Zealand: Ministry of Health; 2024 Jan [cited 2023 Oct 3]. Available from: https://www.tewhatuora.govt.nz/for-health-professionals/data-and-statistics/nz-health-statistics/national-collections-and-surveys/collections/mortality-collection/
19. Watson OJ, Barnsley G, Toor J, et al. Global impact of the first year of COVID-19 vaccination: a mathematical modelling study. Lancet Infect Dis. 2022;22(9):1293-1302. doi: 10.1016/S1473-3099(22)00320-6.
20. Health New Zealand – Te Whatu Ora. News and updates [Internet]. [cited 2023 Sep 28]. Available from: https://www.tewhatuora.govt.nz/corporate-information/news-and-updates/
21. Valderas JM, Starfield B, Sibbald B, et al. Defining comorbidity: implications for understanding health and health services. Ann Fam Med. 2009;7(4):357-63. doi: 10.1370/afm.983.
22. Stanley J, Doughty RN, Sarfati D. A Pharmaceutical Dispensing-based Index of Mortality Risk From Long-term Conditions Performed as well as Hospital Record-based Indices. Med Care. 2020;58(2):e9-e16. doi: 10.1097/MLR.0000000000001217.
23. Stanley J, Sarfati D. The new measuring multimorbidity index predicted mortality better than Charlson and Elixhauser indices among the general population. J Clin Epidemiol. 2017;92:99-110. doi: 10.1016/j.jclinepi.2017.08.005.
24. van der Laan DJ. reclin2: a Toolkit for Record Linkage and Deduplication. R Journal. 2022;14(2):320-328.
25. Lin DY, Gu Y, Wheeler B, et al. Effectiveness of Covid-19 Vaccines over a 9-Month Period in North

Carolina. N Eng J Med. 2022;386(10):933-41. doi: 10.1056/NEJMoa2117128.
26. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing; 2022.
27. Zeng B, Gao L, Zhou Q, et al. Effectiveness of COVID-19 vaccines against SARS-CoV-2 variants of concern: a systematic review and meta-analysis. BMC Med. 2022;20(1):200. doi: 10.1186/s12916-022-02397-y.
28. Wu N, Joyal-Desmarais K, Ribeiro PAB, et al. Long-term effectiveness of COVID-19 vaccines against infections, hospitalisations, and mortality in adults: findings from a rapid living systematic evidence synthesis and meta-analysis up to December, 2022. Lancet Respir Med. 2023;11(5):439-52. doi: 10.1016/S2213-2600(23)00015-2.
29. Ghazy RM, Ashmawy R, Hamdy NA, et al. Efficacy and Effectiveness of SARS-CoV-2 Vaccines: A Systematic Review and Meta-Analysis. Vaccines (Basel). 2022;10(3):350. doi: 10.3390/vaccines10030350.
30. Harder T, Koch J, Vygen-Bonnet S, et al. Efficacy and effectiveness of COVID-19 vaccines against SARS-CoV-2 infection: interim results of a living systematic review, 1 January to 14 May 2021. Euro Surveill. 2021;26(28):2100563. doi: 10.2807/1560-7917.ES.2021.26.28.2100563.
31. Brookmeyer R, Morrison DE. Estimating Vaccine Effectiveness by Linking Population-Based Health Registries: Some Sources of Bias. Am J Epidemiol. 2022;191(11):1975-80. doi: 10.1093/aje/kwac145.
32. Nørgaard M, Ehrenstein V, Vandenbroucke JP. Confounding in observational studies based on large health care databases: problems and potential solutions - a primer for the clinician. Clin Epidemiol. 2017;9:185-93. doi: 10.2147/CLEP.S129879.
33. Glasziou P, McCaffery K, Cvejic E, et al. Testing behaviour may bias observational studies of vaccine effectiveness. J Assoc Med Microbiol Infect Dis Can. 2022;7(3):242-6. doi: 10.3138/jammi-2022-0002.

Appendix

Appendix Table 1: Data dictionary.

Variable	Variable type	Definition
master_hcu_id	Character	Character variable indicating unique identifier for observation (i.e., primary NHI [Master HCU ID])
gender_code	Character	Character variable denoting gender (M=male or F=female)
date_of_birth	Date	Date variable indicating date of birth
date_of_death	Date	Date variable indicating date of death (where applicable)
age	Numeric	Numeric variable indicating age
ethnicity_priority_l1	Character	Character variable indicating priority 1 ethnicity
ethnicity_priority_l2	Character	Character variable indicating priority 2 ethnicity
ethnicity_is_euro	Numeric	Binary variable indicating whether the observation ethnicity is European
ethnicity_is_maori	Numeric	Binary variable indicating whether the observation ethnicity is Māori
ethnicity_is_pacific	Numeric	Binary variable indicating whether the observation ethnicity is Pacific
ethnicity_is_asian	Numeric	Binary variable indicating whether the observation ethnicity is Asian
ethnicity_is_melaa	Numeric	Binary variable indicating whether the observation ethnicity is MELAA
ethnicity_is_other	Numeric	Binary variable indicating whether the observation ethnicity is Other
dhb_domicile_name	Character	Character variable indicating DHB name
date_last_infected	Date	Date variable indicating date of last infection
dose_1	Date	Date variable indicating date of first dose
dose_2	Date	Date variable indicating date of second dose
booster_1	Date	Date variable indicating date of booster 1 dose
booster_2	Date	Date variable indicating date of booster 2 dose
first_infection	Date	Date variable indicating date of first infection
second_infection	Date	Date variable indicating date of second infection
third_infection	Date	Date variable indicating date of third infection
fourth_infection	Date	Date variable indicating date of fourth infection
most_recent_hospital-isation	Date	Date variable indicating date of most recent hospitalisation

Appendix Table 1 (continued): Data dictionary.

primary_clinical_code	Character	Character variable indicating primary_clinical as at code
primary_category_ short_description	Character	Character variable indicating primary_category_short as at description
primary_category_ long_description	Character	Character variable indicating primary_category_long as at description
vaccination_status	Character	Character variable indicating the number of doses and boosters received (i.e., dose 1, dose 2 etc.)
date_last_vaccinated	Date	Date variable indicating date of the last vaccination
age_group	Character	Character variable indicating age group (5-year age bands)
number_of_infections	Numeric	Numeric variable indicating number of infections
m3score	Numeric	Numeric variable indicating m3 score—indices for adjusting for comorbidity and multimorbidity
p3score	Numeric	Numeric variable indicating p3 score—indices for adjusting for comorbidity and multimorbidity
infectious	Numeric	Binary variable indicating whether the observation is infected or not (1=yes, 0=no)
immunity_hybrid	Numeric	Numeric variable derived from an ABM (agent-based model) indicating level of hybrid immunity (greater the number i.e., closer 1, the more hybrid immunity)
immunity_infection_ induced	Numeric	Numeric variable derived from an ABM indicating level of infection-induced immunity (greater the number i.e., closer 1, the more infection-induced immunity)
immunity_vaccine_ induced	Numeric	Numeric variable derived from an ABM indicating level of vaccine-induced immunity (greater the number i.e., closer 1, the more vaccine-induced immunity)
susceptible	Numeric	Numeric variable derived from an ABM indicating level of susceptibility to infection (greater the number i.e., closer 1, the more susceptible)

Appendix Table 2: Uptake of COVID-19 vaccines.

Cohorts	Received dose	Total number	Percentage	Cumulative percentage
Vaccinated cohort				
First dose	160,197	4,318,211	3.0%	82.0%
Second dose	1,420,124	4,158,014	27.0%	78.9%
First booster	1,982,783	2,737,890	37.6%	52.0%
Second booster	755,107	755,107	14.3%	14.3%
Unvaccinated cohort				
Unvaccinated	N/A	950,804	18.0%	

NB: This table represents the vaccine uptake for everyone in Aotearoa New Zealand across all age groups, ranging from 0–113 years.

Appendix Table 3: Vaccine effectiveness as a function of time elapsed since the second booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% CI)	
	Hospitalisation	Infections (PCR+RAT)*
Age (10–49 years)		
1	89.4% (71.6–96.0)	53.2% (31.8–68.3)
2	47.9% (5.3–71.3)	23.4% (-43.5–59.1)
3		-23.2% (-117.30–30.2)
4		-7.1% (-119.2–47.6)
5		34.0% (-9.9–60.4)
6		
Age (50–69 years)		
1	85.9% (75.1–92.2)	61.8% (49.4–71.2)
2	81.0% (58.1–91.4)	35.1% (3.9–56.2)
3	77.6% (59.3–89.7)	-4.4% (-66.0–34.4)
4	79.2% (60.7–89.7)	18.1% (-20.7–44.4)
5	62.0% (34.8–76.7)	-22.0% (-87.6–20.6)
6		12.5% (-42.2–46.1)
Age (≥70 years)		
1	73.9% (54.2–85.2)	61.0% (43.3–73.1)
2	79.0% (58.8–89.3)	48.8% (18.3–67.9)
3	78.3% (55.8–89.6)	25.6% (-28.1–56.8)
4	34.3% (56.4–86.4)	17.2% (-12.1–38.8)
5		
6		-9.1% (-79.2–33.6)
Sex (female)		
1	72.0% (54.3–82.8)	51.5% (35.6–63.4)
2	82.3% (65.8–90.9)	29.1% (0.2–49.6)
3	64.8% (37.7–80.1)	-5.8% (-60.0–30.0)
4	74.5% (58.7–84.6)	20.0% (-15.7–44.7)
5	53.7% (25.6–71.2)	-0.6% (-40.7–28.1)
6		26.2% (-14.5–52.4)

Appendix Table 3 (continued): Vaccine effectiveness as a function of time elapsed since the second booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% CI)	
	Hospitalisation	Infections (PCR+RAT)*
Sex (male)		
1	89.0% (80.3–93.9)	62.0% (50.4–70.8)
2	75.5% (50.6–90.8)	38.2% (5.2–59.7)
3	77.6% (60.3–89.3)	12.1% (-39.2–44.5)
4	41.9% (16.6–59.5)	30.4% (-0.4–51.8)
5		-29.5% (-89.5–11.5)
6		-10.3% (-67.8–27.5)
Ethnicity (Māori)		
1	81.1% (46.0–93.4)	55.4% (21.4–74.7)
2	51.9% (7.6–74.9)	65.0% (21.7–84.4)
3		10.9% (-84.4–56.9)
4	36.6% (-16.8–63.4)	37.8% (0.4–61.2)
5		
6		
Ethnicity (Pacific peoples)		
1	92.2% (37.6–98.9)	75.8% (43.5–89.6)
2	80.2% (23.8–95.2)	64.9% (1.0–87.5)
3		24.5% (-59.6–64.3)
4	56.7% (-0.7–81.3)	-55.6% (-148.6–50.7)
5		
6		
Ethnicity (European)		
1	79.8% (69.2–87.7)	56.9% (45.6–65.9)
2	84.0% (71.7–92.6)	33.5% (8.0–52.0)
3	73.8% (57.2–83.6)	-6.6% (-58.3–28.2)
4	75.7% (62.0–84.5)	12.0% (-6.1–27.0)
5	40.8% (01.2–64.5)	
6	45.9% (-7.5–29.3)	

Appendix Table 3 (continued): Vaccine effectiveness as a function of time elapsed since the second booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% CI)	
	Hospitalisation	Infections (PCR+RAT)*
Ethnicity (Asian and MELAA)		
1	83.4% (54.5–93.9)	42.2% (7.0–64.1)
2	61.6% (12.9–73.0)	9.3% (-93.2–57.4)
3		26.2% (-58.0–65.6)
4		24.4% (-12.9–49.5)
5	17.0% (-136.6–70.9)	
6		

*Rapid antigen tests (RATs) were introduced on 16 February 2022.
NB: Deaths were not considered as there was no COVID-19-related death in the vaccinated cohort (second booster dose) during the follow-up period.

Appendix Table 4: Vaccine effectiveness as a function of time elapsed since first booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)			
	Hospitalisation	Death	Infection (PCR)	Infection (PCR+RAT)*
Age (10–49 years)				
1	86.8% (72.2–93.4)	-	42.8% (21.5–58.2)	30.6% (25.4–35.5)
2	83.7% (72.6–90.3)	-		19.9% (15.0–24.4)
3	59.8% (22.9–79.0)	-		-11.4% (-19.9–-3.6)
4	47.5% (18.5–66.2)	-	-	-28.9% (-40.1–-18.5)
5		-	-	-48.7% (-72.0–-28.6)
6		-	-	-41.6% (-76.0–-24.0)
Age (50–69 years)				
1	79.3% (61.5–88.8)	-	68.9% (50.6–80.4)	32.7% (26.3–38.5)
2	81.6% (72.5–92.5)	83.8% (60.2–93.4)		28.0% (23.3–32.3)
3	80.5% (71.2–86.7)			9.1% (2.9–14.8)
4	75.3% (61.4–84.2)	92.8% (67.1–98.4)	-	-12.4% (-20.8–-4.5)
5	61.8% (38.6–76.3)		-	-38.7% (-53.8–-25.0)
6	66.9% (50.8–77.8)		-	-11.3% (-29.8–4.6)
Age (≥70 years)				
1	92.4% (79.6–97.2)	-	40.0% (-90.8–81.1)	46.4% (27.4–60.4)
2	89.2% (80.7–93.9)	92.0% (83.3–96.2)		27.6% (14.2–38.9)
3	86.2% (77.0–91.7)			17.9% (5.5–28.6)

Appendix Table 4 (continued): Vaccine effectiveness as a function of time elapsed since first booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)			
	Hospitalisation	Death	Infection (PCR)	Infection (PCR+RAT)*
4	68.6% (50.6–80.1)	85.8% (73.7–92.3)	-	-24.2% (-43.9–-7.3)
5	64.0% (44.6–76.7)		-	-65.2% (-96.6–-38.0)
6	54.7% (32.9–69.4)		-	-13.1% (-41.6–9.6)
Female				
1	81.7% (73.7–87.7)	-	56.4% (37.4–69.6)	19.2% (15.7–22.6)
2	79.9% (73.1–85.1)	96.9% (77.7–99.6)		20.7% (17.8–23.5)
3	74.6% (65.4–81.4)	91.1% (73.7–97.0)		-6.5% (-11.1–-2.0)
4	61.3% (46.8–71.4)	92.1% (73.3–97.7)	-	-22.1% (-28.3–-16.2)
5	59.0% (41.9–71.1)	92.2% (65.5–98.2)	-	-44.1% (-56.1–-33.0)
6	53.8% (34.6–67.4)		-	-28.3% (-44.0–-14.3)
Male				
1	81.3% (70.6–88.8)	-	45.1% (21.1–61.8)	21.4% (17.8–24.8)
2	82.2% (75.0–88.0)	89.0% (67.2–96.3)		16.6% (13.3–19.9)
3	74.8% (64.6–82.1)	87.7% (67.8–95.3)		-16.2% (-21.8–-10.9)
4	70.4% (56.7–79.8)	87.0% (63.2–94.7)	-	-39.1% (-47.3–-31.3)
5	62.2% (45.9–73.8)	80.3% (25.0–94.8)	-	-53.8% (-68.7–-40.2)
6	59.7% (43.5–71.2)		-	-33.4% (-52.7–-16.5)

Appendix Table 4 (continued): Vaccine effectiveness as a function of time elapsed since first booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)			
	Hospitalisation	Death	Infection (PCR)	Infection (PCR+RAT)*
Māori				
1	77.5% (62.4–86.5)	-	75.1% (52.0–87.1)	22.8% (18.0–27.2)
2	84.0% (75.4–89.6)	95.6% (66.1–99.4)		21.5% (17.2–26.6)
3	70.2% (52.0–80.5)			-11.2% (-19.2–-3.7)
4	61.6% (38.3–76.1)	93.5% (44.1–99.3)	-	-29.1% (-41.0–-18.3)
5	53.0% (30.2–68.4)		-	-55.6% (-81.2–-33.5)
6		-	-	-47.8% (-86.2–-17.4)
Pacific peoples				
1	83.5% (71.3–90.4)	-	37.8% (5.2–59.2)	15.9% (9.1–22.2)
2	91.0% (83.8–95.0)	95.5% (83.0–98.8)		2.0% (-6.8–10.1)
3	76.7% (56.1–76.7)	94.4% (47.4–99.4)		-19.4% (-34.5–-6.0)
4	80.6% (60.7–80.6)	85.4% (44.3–96.2)	-	-68.0% (-97.9–-42.5)
5	61.6% (7.8–77.0)		-	-84.8% (-145.2–-58.6)
6	61.6% (5.0–75.0)		-	-41.1% (-105.2–-70.0)
European				
1	84.4% (76.0–89.9)	-	68.6% (51.2–79.8)	26.5% (23.5–29.5)
2	77.7% (70.1–83.3)	89.6% (53.0–97.7)		24.0% (21.5–26.4)
3	78.2% (70.8–82.2)	83.8% (64.0–92.7)		-5.8% (-9.7–-1.9)
4	66.3% (54.4–73.1)	89.1% (70.9–95.9)	-	-27.7% (-33.4–-22.3)

Appendix Table 4 (continued): Vaccine effectiveness as a function of time elapsed since first booster dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)			
	Hospitalisation	Death	Infection (PCR)	Infection (PCR+RAT)*
5	63.4% (50.4–72.9)	90.5% (66.9–97.3)	-	-47.5% (-58.2–-37.5)
6	52.8% (36.9–64.7)		-	-33.6% (-48.3–-20.4)
Asian and MELAA				
1	80.5% (56.6–91.3)	-	37.4% (-18.9–62.6)	-18.2% (-32.9–-5.2)
2	72.5% (43.2–86.6)	92.3% (62.0–98.4)		-22.1% (-35.1–-10.3)
3	61.6% (10.5–83.5)	93.4% (63.8–98.8)		-54.0% (-74.0–-36.3)
4	61.5% (9.4–90.6)		-	-26.2% (-43.4–-11.0)
5	54.3% (5.4–80.0)	-	-	-41.9% (-72.0–-17.1)
6	69.1% (36.1–85.0)	-	-	-10.6% (-41.1–-58.9)

*Rapid antigen tests (RATs) were introduced on 16 February 2022.

Appendix Table 5: Vaccine effectiveness as a function of time elapsed since the second dose (sub-group analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)		
	Hospitalisation	Infection (PCR)	Infection (PCR+RAT)*
Age (10–49 years)			
1	91.2% (82.6–95.6)	87.55% (84.31–89.88)	75.56% (65.64–82.62)
2	88.9% (77.4–94.6)	89.65% (86.94–91.80)	60.20% (48.22–69.40)
3	71.0% (55.6–81.0)	77.07% (71.35–81.65)	22.44% (6.56–35.62)
4	73.2% (61.4–81.4)	43.39% (30.72–53.64)	22.87% (13.30–31.29)
5	72.6% (62.6–79.9)	34.45% (15.68–49.05)	48.03% (43.50–52.30)
6	67.3% (54.8–76.3)	-	71.26% (68.81–73.52)
Age (50–69 years)			
1	98.8% (90.8–99.8)	92.35% (87.73–95.23)	77.04% (69.71–82.59)
2		92.83% (86.37–96.22)	77.25% (68.95–84.86)
3	92.9% (78.2–97.7)	88.75% (79.93–93.69)	46.40% (32.46–57.45)
4	71.5% (34.9–87.5)	75.17% (59.13–85.31)	19.13% (5.33–30.92)
5	75.9% (58.1–86.2)	67.61% (44.65–81.04)	54.71% (49.65–59.65)
6	79.9% (67.2–87.6)	-	76.80% (74.44–79.45)
Age (≥70 years)			
1	86.0% (23.8–97.4)	84.95% (25.34–96.70)	75.64% (-12.20–87.80)
2			-0.60% (-233.90–-69.71)
3	60.0% (10.7–82.1)	78.76% (-17.00–96.15)	51.68% (-11.90–88.10)
4		36.32% (-282.20–89.39)	30.01% (-24.60–60.68)
5	61.5% (35.5–77.1)	-69.70% (-4663.00–49.12)	36.62% (7.94–56.37)
6		-	69.89% (57.35–78.74)
Female			
1	91.7% (79.5–96.7)	85.45% (80.53–89.13)	61.51% (58.15–64.61)
2	86.8% (68.6–94.5)	88.26% (84.26–91.24)	40.98% (35.68–46.84)
3	70.9% (51.8–82.5)	77.34% (70.94–82.68)	11.60% (5.17–17.60)
4	68.3% (52.9–78.6)	52.47% (38.88–63.80)	2.97% (-2.10–7.90)
5	69.1% (56.8–77.8)	44.63% (23.03–60.17)	29.85% (27.58–32.58)
6	69.9% (58.8–78.1)	-	51.44% (49.43–53.37)

Appendix Table 5 (continued): Vaccine effectiveness as a function of time elapsed since the second dose (subgroup analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)		
	Hospitalisation	Infection (PCR)	Infection (PCR+RAT)*
Male			
1	93.9% (84.5–97.6)	90.82% (87.10–92.90)	57.82% (54.23–60.12)
2	94.0% (84.4–97.0)	91.56% (88.30–93.92)	43.01% (38.09–47.53)
3	78.6% (62.5–87.7)	81.07% (74.24–84.92)	10.74% (4.15–16.88)
4	78.9% (63.6–87.7)	45.70% (28.79–58.60)	2.56% (-2.80–7.60)
5	77.0% (64.9–84.9)	36.32% (13.43–53.17)	23.56% (20.43–26.56)
6	76.2% (64.6–84.0)	-	45.3% (43.0–47.5)
Māori			
1	90.0% (69.9–96.7)	83.7% (78.1–87.9)	50.9% (44.6–56.4)
2	86.1% (65.0–94.6)	93.4% (90.3–95.5)	42.7% (36.3–48.4)
3	65.2% (37.8–80.5)	85.4% (78.1–89.1)	4.3% (-3.4–9.6)
4	79.2% (63.0–88.3)	75.6% (64.1–83.3)	0.0% (-6.1–6.4)
5	70.9% (49.2–82.5)	67.7% (44.9–75.9)	23.4% (19.2–27.3)
6	73.1% (56.4–83.5)	-	41.3% (37.8–44.6)
Pacific peoples			
1	91.2% (72.7–97.2)	86.5% (79.0–91.3)	54.6% (46.8–62.0)
2	95.8% (79.6–99.1)	84.6% (78.1–89.1)	46.6% (37.5–54.3)
3	75.6% (50.0–88.1)	68.3% (56.2–77.0)	0.83% (-11.5–8.8)
4	60.7% (23.1–79.9)	30.6% (3.2–50.3)	-11.4% (-21.9–-1.8)
5	73.5% (56.3–84.0)	22.4% (-10.6–37.6)	13.4% (6.9–19.3)
6	79.2% (61.6–88.8)	-	34.3% (28.1–40.9)
European			
1	94.6% (84.2–98.1)	93.4% (90.1–95.5)	60.0% (57.1–62.7)
2	90.5% (76.6–96.1)	92.7% (89.1–95.1)	36.7% (31.6–41.5)
3	87.2% (74.8–93.5)	87.2% (80.7–91.5)	18.4% (12.6–23.9)
4	73.3% (56.3–83.7)	53.7% (36.5–64.6)	8.1% (3.4–13.6)
5	62.7% (46.2–74.1)	53.4% (30.0–69.9)	32.7% (30.2–35.0)
6	75.1% (65.4–82.0)	-	51.9% (50.2–53.6)

Appendix Table 5 (continued): Vaccine effectiveness as a function of time elapsed since the second dose (subgroup analysis).

Baseline characteristic	Vaccine effectiveness (95% confidence interval)		
	Hospitalisation	Infection (PCR)	Infection (PCR+RAT)*
Asian and MELAA			
1	85.4% (12.5–97.6)	77.0% (53.2–60.3)	65.4% (59.0–70.8)
2	90.5% (20.8–98.9)	87.5% (73.0–94.2)	51.6% (41.8–59.8)
3	74.5% (45.7–88.0)	74.4% (54.2–54.8)	39.4% (26.8–49.8)
4		24.7% (-27.1–75.3)	6.9% (-8.9–20.4)
5	68.1% (39.2–83.2)	34.9% (-8.4–58.4)	7.4% (-2.9–17.1)
6		-	31.3% (24.2–37.8)

*Rapid antigen tests (RATs) were introduced on 16 February 2022.

Appendix Table 6: Vaccine effectiveness as a function of time elapsed since the first dose.

Months	Vaccine effectiveness (95% confidence interval)			
	Hospitalisation	Death	Infection (PCR)	Infection (PCR + RAT)*
1	69.6% (50.1–81.5)	87.6% (38.9–97.5)	63.2% (56.1–69.2)	46.4% (43.0–49.6)
2	88.5% (80.6–93.1)		-	46.5% (44.6–48.5)
3	-		-	-

Baseline characteristics	Vaccine effectiveness (95% confidence interval)		
	Hospitalisation	Infection (PCR)	Infection (PCR+RAT)*
Age (10–49 years)			
1	69.1% (46.6–82.1)	63.8% (56.5–69.9)	61.7% (39.4–75.7)
2	87.5% (78.4–92.8)	-	93.6% (89.2–96.2)
Age (50–69 years)			
1	71.0% (9.3–90.7)	65.0% (32.3–68.3)	53.2% (19.2–72.9)
2	96.4% (72.0–99.5)	-	86.7% (76.8–92.3)
Age (≥70 years)			
1	92.1% (22.7–99.2)	-	-
2		-	-
Female			
1	76.1% (50.7–88.4)	65.5% (55.5–73.2)	50.1% (45.8–54.5)
2	86.5% (72.6–93.3)	-	46.5% (43.6–49.3)

Appendix Table 6: Vaccine effectiveness as a function of time elapsed since the first dose.

Male			
1	61.3% (22.3–80.8)	60.8% (49.7–69.4)	42.5% (37.4–47.2)
2	90.1% (79.4–95.2)	-	46.2% (43.4–48.9)
Māori			
1	77.2% (47.0–90.2)	54.3% (41.3–64.5)	35.0% (27.4–41.8)
2	84.9% (64.9–93.5)	-	45.7% (41.2–49.8)
Pacific peoples			
1	54.6% (-13.9–81.7)	54.8% (38.2–66.9)	51.0% (45.3–56.4)
2	87.9% (64.9–95.9)	-	52.1% (47.0–56.7)
European			
1	78.7% (49.5–91.0)	67.9% (55.1–77.1)	41.5% (36.5–46.5)
2	83.9% (68.2–91.9)	-	40.4% (37.7–43.0)
Asian and MELAA			
1	72.4% (-6.2–93.8)	82.4% (72.2–88.9)	61.6% (55.5–66.8)
2	84.8% (41.1–96.1)	-	50.5% (45.7–54.7)

*Rapid antigen tests (RATs) were introduced on 16 February 2022.