Emergence of SARS-CoV-2 Delta Variant and Effect of Nonpharmaceutical Interventions, British Columbia, Canada

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In British Columbia, Canada, initial growth of the SARS-CoV-2 Delta variant was slower than that reported in other jurisdictions. Delta became the dominant variant (>50% prevalence) within ≈7–13 weeks of first detection in regions within the United Kingdom and United States. In British Columbia, it remained at ≤10% of weekly incident COVID-19 cases for 13 weeks after first detection on March 21, 2021, eventually reaching dominance after 17 weeks. We describe the growth of Delta variant cases in British Columbia during March 1–June 30, 2021, and apply retrospective counterfactual modeling to examine factors for the initially low COVID-19 case rate after Delta introduction, such as vaccination coverage and nonpharmaceutical interventions. Growth of COVID-19 cases in the first 3 months after Delta emergence was likely limited in British Columbia because additional nonpharmaceutical interventions were implemented to reduce levels of contact at the end of March 2021, soon after variant emergence.

Throughout the COVID-19 pandemic, SARS-CoV-2 variants have emerged through viral mutation. Variants demonstrating an increase in transmissibility or virulence; changes in clinical manifestations; or a decrease in the effectiveness of public health measures, diagnostics, vaccines, or therapeutics are designated variants of concern (VOCs) by the World Health Organization (*1*). By June 2021, a total of 4 SARS-CoV-2 variants had been designated VOCs (*1*). Designated a VOC in May 2021, Delta largely replaced the earlier Alpha, Beta, and Gamma VOCs because of its comparatively higher transmissibility (*2*). In India, where it was first detected, Delta outcompeted Alpha and drove an increase of COVID-19 cases beginning in March 2021 (*3*). By mid-August 2021, Delta represented >90% of genetically sequenced SARS-CoV-2 samples submitted to GISAID (https://www.gisaid.org), dominating on a global scale until its decline in favor of Omicron beginning in December 2021 (*4*,*5*).

By March 1, 2021, British Columbia (2021 population 5,214,805), Canada, had reported >80,000 COVID-19 cases and detected Alpha, Beta, and Gamma VOC cases among residents (*6*). The Delta VOC was first detected in British Columbia during the week of March 21, 2021, but did not grow to dominance (>50% prevalence) until 17 weeks later, during the week of July 18, 2021, after major relaxations in public health measures, or nonpharmaceutical interventions (NPIs).

Differences in factors such as NPIs, vaccination rates, competing variants in circulation, and population density and behavior may result in interjurisdictional differences in the transmission and growth rates of variants (*7*–*10*). The initial growth and time to dominance of Delta in British Columbia was slower than in jurisdictions such as England, Scotland, and several US states (*7*–*10*). In England, Delta grew to

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dominance ≈10 weeks after the fifth case was detected in mid-March 2021, reaching 62% prevalence among sequenced cases by mid-May 2021 (*7*). In Scotland, the Delta VOC rapidly replaced Alpha during April–May 2021 (*8*,*9*), and across 6 states in the United States, the average time from first detection of Delta to its dominance was ≈10 weeks (71 days, range 54–92 days) (*10*).

British Columbia and England are adequately comparable because they have universal healthcare systems, similar population age distribution (median age 42.8 years in British Columbia, 40 years for England and Wales in 2021), and similar temperate climates within the main metropolitan areas. Of note, key differences existed in public health policy and vaccination coverage between British Columbia and England around the time of Delta emergence; England ultimately experienced both a shorter time to dominance for Delta and higher subsequent growth in COVID-19 incidence (Appendix Figure 1, https://wwwnc.cdc.gov/EID/article/29/10/23-0055-App1.pdf). In British Columbia, circuit-breaker NPIs, including restricting travel outside the region of residence unless essential; suspending indoor dining, worship services, and adult group fitness activities; and expanding mask requirements in schools to younger age groups, were implemented on March 30, 2021, shortly after Delta variant was detected, in response to rising numbers of Alpha and Gamma variant cases (*11*). Those measures supplemented existing NPIs, which required physical distancing and masks in all public indoor settings, restricted gatherings, and encouraged workplaces to adopt remote working conditions (Appendix Table 1). During March–June 2021, the 7-day rolling COVID-19 incidence rate per 100,000 population in British Columbia peaked at 21.8 in mid-April 2021 before decreasing to a low of 1.0 at the end of June 2021.

Conversely, in the time surrounding Delta introduction and initial growth, England was in the early stages of reopening after lockdown and had begun gradually relaxing measures, including reopening schools to all students, replacing a stay-at-home order with a recommendation to stay local, and stepwise reopening of businesses and public buildings (*12*) (Appendix Table 1). England observed an initial decrease in its 7-day rolling COVID-19 incidence rate per 100,000 population from 77.0 in March 2021 to 20.7 for the beginning of May 2021, before seeing a substantial increase driven by Delta to 229.1 by the end of June 2021 (*13*) (Appendix Figure 1).

However, population COVID-19 vaccine coverage also differed between British Columbia and England; British Columbia had higher coverage among younger age groups (*14*,*15*). COVID-19 vaccination coverage overall and for persons ≥45 years of age were lower in British Columbia than in England during March–June 2021, but rates of first-dose coverage for persons 18–34 years of age in British Columbia exceeded those in England by May 2021 (Appendix Figure 2, panel A). Another key difference was the vaccine product used: most vaccine doses administered during March–June 2021 in British Columbia were the mRNA-based BNT162b2 (Pfizer-BioNTech, https://www.pfizer.com) or mRNA-1273 (Moderna, https://www.modernatx.com), and most administered in England were ChAdOx1 (Oxford-AstraZeneca, https://www.astrazeneca.com) (*16*).

The first objective of this study was to describe the emergence of the Delta VOC in British Columbia with respect to the presence of competing variants and case demographics, vaccination status, and travel history. The second objective was, through counterfactual modeling, to identify the main factors for the initially low rate of COVID-19 transmission in British Columbia after Delta variant introduction. Using England as the counterfactual scenario because of its similarities with British Columbia and the availability of public data from UK Health Security Agency, we explored the effects of differences in the proportion of Delta among all infections, public health measures, and vaccine coverage and type on the modeled number of overall COVID-19 cases in British Columbia.

Methods

SARS-CoV-2 Lineage Data

In British Columbia, SARS-CoV-2 quantitative PCR (qPCR) testing is offered by hospitals, private laboratories, and the British Columbia Centre for Disease Control (BCCDC) Public Health Laboratory (PHL), which serves as the reference laboratory for the province; VOC monitoring is performed primarily by the BCCDC PHL. During March 1–May 29, 2021 (US Centers for Disease Control and Prevention epidemiologic weeks [epiweeks] 9–21), a combined VOC testing strategy using both screening (i.e., targeted VOC single-nucleotide variant qPCR) and whole-genome sequencing (WGS) was applied to monitor VOC prevalence in BC (Appendix Table 2). During this period, the weekly percentage of samples undergoing VOC screening ranged from 80%–99% and the percentage undergoing WGS ranged from 31%–79%. During May 30–June 30, 2021 (epiweeks 22–26), WGS was attempted for all samples; 69%–79% of all weekly positive samples were successfully sequenced. VOC case definitions are provided (Appendix Table 3).

For samples that underwent both VOC screening and WGS, we used lineage results from WGS. We included only samples with ≥85% sequence coverage and no quality control flags in ncov-tools (https://github.com/jts/ncov-tools). We classified cases as having unknown lineage if samples did not undergo VOC screening or WGS, were screened VOC-negative or indeterminate and did not undergo WGS, or were not screened and failed WGS.

Study Population

We linked COVID-19 case investigation and SARS-CoV-2 lineage data by using the patient's full name, date of birth, and personal health number. We performed linkage using SAS version 9.4 (SAS Institute Inc., https://www.sas.com). We included all COVID-19 cases reported in British Columbia with case investigation information and specimen collection during March 1–June 30, 2021. For records with multiple specimen collection dates, we used the earliest positive date. For cases missing specimen collection date (n = 2,637; 4.0% of final study population), we used symptom onset date, followed by date of case report to the regional health authority. We performed data cleaning, analysis, and figure creation using R version 3.5.2 (The R Foundation for Statistical Computing, https://www.r-project.org).

Travel history information was collected during routine case investigation. Information on international travel was supplemented by reason for testing recorded in the BCCDC PHL database (e.g., international arrivals testing). Delta variant case-patients who had a travel history outside British Columbia were assumed to have acquired infection outside the province; those cases were considered Delta introductions.

COVID-19 vaccination status at time of case detection was linked from British Columbia's Provincial Immunization Registry using case identifiers. We considered case-patients fully vaccinated if symptom onset (or positive specimen collection if the onset date was not available) occurred ≥14 days after the second dose of BNT162b2, mRNA-1273, or ChAdOx1; additional doses were not yet approved or recommended during the study period. Case-patients were considered partially vaccinated if they were not fully vaccinated and onset or specimen collection occurred ≥21 days after first dose. Case-patients without any recorded vaccination or with onset or specimen collection <21 days after the first dose were considered unvaccinated.

Counterfactual Modeling Methods

We implemented counterfactual modeling using an established model of COVID-19 transmission dynamics in British Columbia (*17*). The model is an adapted susceptible-exposed-infected-recovered compartmental ordinary differential equation model. Additional modeled compartments included a quarantine compartment and a proportion of the population that participate in social distancing with analogous susceptible-exposed-infected-recovered compartments for the social distancing group. We used a Bayesian statistical model in the inference of the basic reproductive number, the fraction change in social distancing between predefined breakpoints, and a dispersion parameter associated with a negative binomial term to observed cases (*17*). We explored differences in the following factors on the modeled number of COVID-19 cases in British Columbia (Appendix Table 4).

Proportion of Delta variant Among All Infections

We extracted weekly data on the proportion of the Delta variant among cases in England from the July 23, 2021, UK Health Security Agency report (*18*) and included the proportion of all cases that were genotyped. Unlike in British Columbia, the proportion of cases of Delta in England transitioned from <5% to >80% during May–June 2021 (Appendix Figure 2, panel B). We incorporated logistic functions representing the relative proportion of Delta to represent the relative differences in growth between jurisdictions. We directly incorporated that function into the time-varying transmission term for each scenario, representing the per-contact transmissibility increasing in proportion to the changing composition of variants. Because we used the sampled proportion of Delta variant as input in the modeling, we did not directly explore reasons for their differences between jurisdictions within these scenarios.

Levels of Contact Leading to Transmission, Guided by Changes in NPIs

We constructed the transmission scenario for England on the basis of the fitted transmission estimate for British Columbia. We applied an increase in transmission rate to the England scenario after the March 30, 2021, circuit breaker measures were implemented in British Columbia, considering that those NPIs likely led to a reduction in cases in British Columbia but similar measures were not in place in England (Appendix Figure 1).

Vaccination Coverage and Majority Vaccine Product Administered

Data on age-dependent vaccination coverage extracted from the UK Government COVID-19 dashboard (*15*) (for England) and the Provincial Immunization

Registry (for British Columbia) included vaccination coverage by number of doses (1 or 2) and by age group (12–17 years, 18–24 years, 10-year bands for 25–74 years, and ≥75 years) (Appendix Figure 2, panel A). We derived parameters for estimated vaccine efficacy on the Delta variant by product and dose on the basis of previous values (Appendix Table 5) (*12*). To account for differences in vaccination scheduling, we collected data on proportion of vaccine coverage by first and second dose by age group from both jurisdictions and weighted them for British Columbia's population.

We fitted the model using a variational Bayes approach (*17*,*19*) to reported case data for British Columbia during March 1, 2020–July 12, 2021, with 4 transmission segments covering the study period, starting on January 25, March 29, April 5, and May 25, 2021 (Appendix Table 4). This work was conducted under the public health surveillance mandate of the BCCDC, and institutional review board approval was not sought. The planning, conduct, and reporting of this study was in line with the Declaration of Helsinki, as revised in 2013.

Results

Delta VOC Emergence

A total of 66,247 COVID-19 cases were reported in British Columbia during March 1–June 30, 2021; of those, 1,178 (1.8%) were Delta, 37,872 (57.2%) were other VOCs (Alpha, Beta, or Gamma), 6,930 (10.4%) were non-VOC, and 20,267 (30.6%) were of unknown lineage. During the study period, Alpha and Gamma were the most prevalent variants in British Columbia, codominating from April (epiweek 13) onwards; Alpha reached 46.1% of weekly incident cases (51.6% of cases with known lineage) during May 2–15 (epiweeks 18 and 19), and Gamma reached 40.0% of incident cases (48.8% of cases with known lineage) by the end of June 2021 (epiweek 26) (Figure 1). The prevalence of Beta was negligible, accounting for <20 incident cases (≤0.3%) per week.

The Delta VOC was first detected in British Columbia during epiweek 12; the earliest detected case had a specimen collection date of March 21, 2021. Delta case-patients were generally young (65.7% <40 years of age), and a slightly higher percentage were male than female (Table 1). Most Delta variant cases were in unvaccinated persons (83.2%), and most (86.4%) were identified as Pangolin (*20*) lineage B.1.617.2. The prevalence of the Delta variant reached its highest point at the end of the study period; during the last full epiweek (epiweek 25), 44 Delta cases occurred, which represented 10.1% of incident cases (12.9% of cases with known lineage) (Figure 1).

Overall, 14.2% (n = 167) of Delta case-patients had known history of travel outside BC; 91.6% (n = 153)

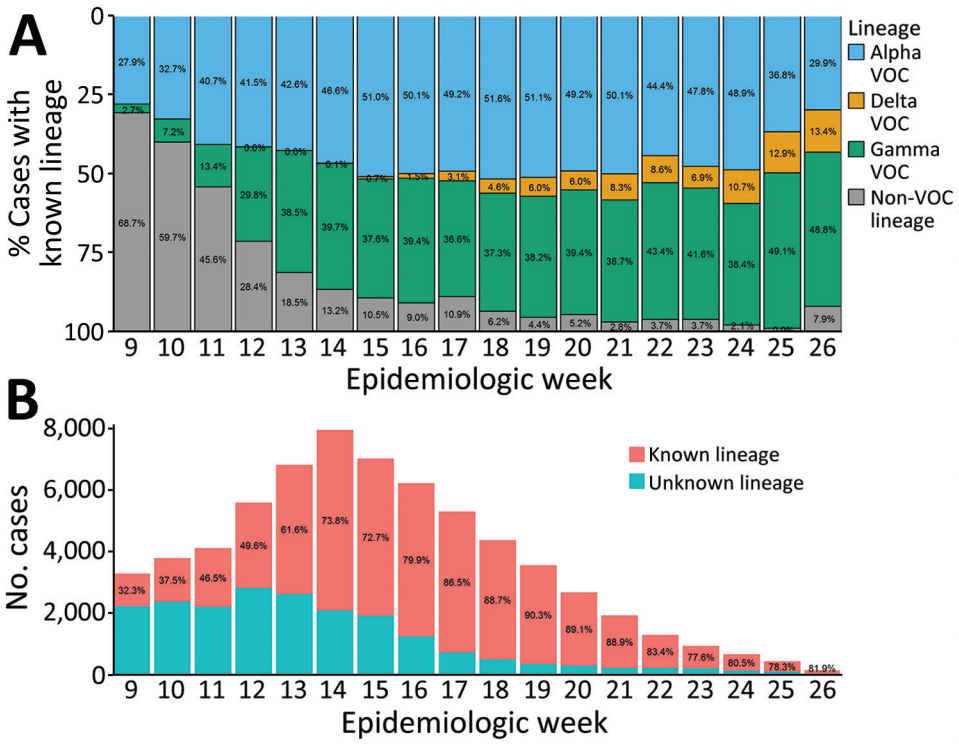

Figure 1. Percentage of COVID-19 cases by SARS-CoV-2 VOC lineage (A) and by known versus unknown lineage (B) reported in British Columbia, Canada, by epidemiologic week of specimen collection, March 1–June 30, 2021 (n = 66,247). Data are incomplete for epiweeks 9 and 26 because of study period date cutoffs. Beta VOC cases are not displayed in the top panel but are accounted for in the rounded percentages; Beta VOC cases did not account for >20 cases (<1% of cases with known lineage) per week in BC during the study period. COVID-19 cases of unknown lineage included cases with samples that did not undergo targeted VOC single-nucleotide variant (SNV) quantitative PCR (qPCR) screening or whole-genome sequencing (WGS), were negative or indeterminate on VOC SNV qPCR screening and did not undergo WGS, or did not undergo VOC SNV qPCR screening and failed WGS. VOC, variant of concern.

had traveled internationally and 8.4% (n = 14) had traveled only within Canada. On the evening of April 22, 2021, a ban on all direct commercial and private passenger flights from India and Pakistan was implemented throughout Canada (*21*,*22*). Most (82.4%; n = 126) international travel–related introductions of the Delta variant occurred before May 3, 2021 (accounting for day 10 postarrival qPCR testing for persons arriving in Canada before April 23) (Figure 2). At least half (50.8%; n = 64) of international travel–related Delta cases with specimen collection date before May 3, 2021, were in persons arriving from India, whereas 2 (7.4%) of 27 international travel–related Delta cases with specimens collected on or after May 3, 2021, were in persons who were known to have traveled from India (Table 2).

Counterfactual Modeling

Vaccine scheduling and coverage (i.e., timing of vaccination campaign rollout and percentage of population vaccinated) equivalent to that in England resulted in a lower counterfactual COVID-19 case rate in British Columbia than was observed across the study period, irrespective of vaccine product, NPIs, or proportional growth of the Delta variant (Figure 3; Appendix Figure 2). Modeled COVID-19 cases lowered further under the counterfactual scenario in which England's vaccine scheduling/coverage was combined with the British Columbia majority vaccine product. Within all NPI and proportion-of-Delta scenarios examined, modeled cases were lowest under England's vaccination scheduling/coverage combined with British Columbia's majority vaccination product (BNT162b2/mRNA-1273) and highest under British Columbia's vaccination coverage with England's majority vaccination product (ChAdOx1) (Figure 3).

Modeling indicates that, without the additional NPIs implemented at the end of March 2021 in British Columbia (Figure 3, panels A, C), a substantially higher COVID-19 caseload would have occurred in British Columbia under the province's vaccination schedule and coverage, especially if the proportional increase in Delta cases that occurred in England had occurred in British Columbia (Figure 3, panel A). Under England's vaccine scheduling and coverage, modeled British Columbia cases were still higher than those reported from June 2021 onward without British Columbia's additional NPIs if England's proportional increase of Delta had occurred (Figure 3, panel A). In the counterfactual scenario in which England's proportional increase of Delta occurred in the context of British Columbia's NPIs and vaccine coverage (Figure 3, panel B), modeled COVID-19 case rates were only slightly higher than reported and much lower than without British Columbia's NPIs (i.e., compared with Figure 3, panel A). Modeled COVID-19 case rates were lowest under British Columbia's NPI scenario and proportional increase of Delta across all vaccination scenarios (Figure 3, panel D).

Table 1. Pangolin lineage and patient demographics, vaccination status, and travel history for 1,178 SARS-CoV-2 Delta variant of concern cases reported in British Columbia, Canada, March 1–June 30, 2021

Characteristic	No. (%) Delta cases
Pangolin lineage*	
B.1.617.2	1,018 (86.4)
AY.18	44 (3.7)
AY.15	30 (2.5)
AY.10	22 (1.9)
AY.93	20 (1.7)
Other AY lineages	44 (3.7)
Patient demographics	
Age group, y	
<20	261 (22.2)
20–39	513 (43.5)
40–59	248 (21.1)
60–79	118 (10.0)
≥80	38 (3.2)
Sex	
F	553 (46.9)
M	622 (52.8)
Unknown	3 (0.3)
Vaccination status†	
Fully vaccinated	30 (2.5)
Partially vaccinated	168 (14.3)
Unvaccinated	980 (83.2)
Travel history	
International travel	153 (13.0)
Domestic travel outside BC	14 (1.2)
No known travel or only within BC	1011 (85.8)

*Pangolin version 4.0.5, Usher version 1.6, Pango version 1.6 (*20*). BC, British Columbia.
†Unadjusted proportions; vaccination status shown was at time of symptom onset or specimen collection. Patients were considered fully vaccinated if symptom onset (or positive specimen collection date if onset not available) occurred ≥14 d after second dose of BNT162b2 (Pfizer, https://www.pfizer.com), mRNA-1273 (Moderna, https://www.modernatx.com), or ChAdOx1 (AstraZeneca, https://www.astrazeneca.com). Patients were considered partially vaccinated if not fully vaccinated and onset/specimen collection date occurred ≥21 d after first dose. Persons without any recorded vaccine dose or with onset/specimen collection date <21 d after first dose were considered unvaccinated.

Discussion

The Delta VOC was first detected in British Columbia during March 21–27, 2021 (epiweek 12); the earliest cases were linked to international travel. Although the Delta variant had already been seeded in the community by the time the countrywide travel ban on direct flights to Canada from India was put in place (*21*), the ban appears to have reduced the number of travelers arriving from countries affected early by the Delta variant, thereby decreasing additional introductions (*23*). This targeted approach might have helped to slow early Delta variant growth in British

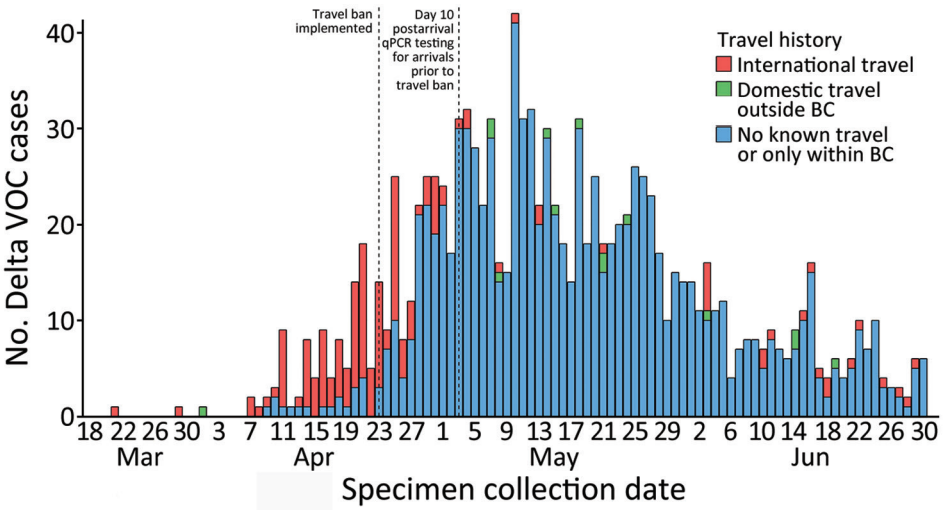

Figure 2. Epidemiologic curve of SARS-CoV-2 Delta VOC cases in British Columbia, Canada, by patient travel history, March 1–June 30, 2021 (n = 1,178). Delta VOC cases classified as having no known travel include 8 cases with missing travel information. Effective at 8:30 P.M. on April 22, 2021 (labeled as April 23 on figure), the government of Canada implemented a ban on all direct commercial and private passenger flights from India and Pakistan (*21*). The travel ban on direct flights from India remained in effect for the rest of the study period, whereas the ban on direct flights from Pakistan was in effect until June 21, 2021 (*21*,*22*). Travelers arriving before the federal travel ban were required to complete day 10 postarrival qPCR testing; as a result, travelers arriving before April 23 might have had specimens collected up to May 2, 2021. BC, British Columbia; qPCR, quantitative PCR; VOC, variant of concern.

Columbia, allowing time to increase population vaccination coverage (*23*).

Most Delta variant case-patients in our study were unvaccinated; 14% were partially vaccinated and 3% were fully vaccinated. Those proportions are reflective of the study period, during which the vaccination campaign in British Columbia was primarily focused on first dose rollout: population dose 1 coverage in British Columbia increased from 5% to 77% during the study period, but dose 2 coverage had only reached 28% by the end of the study. In British Columbia, vaccination rollout was primarily prioritized by age (*14*) and most Delta case-patients were young (<40 years). Studies have shown reduced vaccine effectiveness against symptomatic infection or high viral burden for Delta compared with Alpha (*24*,*25*), reiterating the importance of maximizing multidose coverage to improve conferred protection. On the basis of our counterfactual model, earlier population vaccine rollout akin to that done in England, which resulted in higher population dose 1 coverage (39%) by the start of the study period and 57% dose 2 coverage by the end (*15*), would likely have further decreased COVID-19 cases in British Columbia over the study period.

Our counterfactual modeling results suggest that the restrained early growth of COVID-19 cases in British Columbia after Delta was introduced was mainly because of decreased rates of contact from additional NPIs implemented 9 days after the first Delta case was detected, rather than from higher dose 1 vaccine coverage among younger persons or use of mRNA-based vaccines in British Columbia. Our findings are in line with those of McCrone et al. (*26*), who found that the key predictor for higher Delta growth rates between regions in England was increased levels of contact from population mobility and mixing because of the relaxation of NPIs. Results from a survey on behavioral and contact patterns in British Columbia (*27*) indicate that, whereas rates of contact during March–May 2021 either decreased or remained steady for all ages, contact rates increased in all age groups other than persons ≥65 years of age beginning in June 2021, coinciding with British Columbia's phased reopening (Appendix Figure 3).

Table 2. Information on country of origin for 153 SARS-CoV-2 Delta variant of concern cases reported in British Columbia, Canada, with known history of international travel in periods before and after travel ban and overall, March 1–June 30, 2021

	No. (%) Delta cases with international travel history		
Country of origin	Pre–travel ban period*	Post–travel ban period†	Overall
India	64 (50.8)	2 (7.4)	66 (43.1)
Other country	11 (8.7)	15 (55.6)	26 (17.0)
Missing information	51 (40.5)	10 (37.0)	61 (39.9)
Total for all Delta cases	126 (45.2)	27 (3.0)	153 (13.0)

*The Canadian travel ban on direct flights from India and Pakistan was implemented on the evening of April 22, 2021. Persons arriving in Canada before April 23, 2021, completed quantitative PCR testing 10 d after arrival. Therefore, pre–travel ban cases include Delta variant cases with specimen collection during March 21–May 2, 2021.
†Delta variant cases with specimen collection during May 3–June 30, 2021.

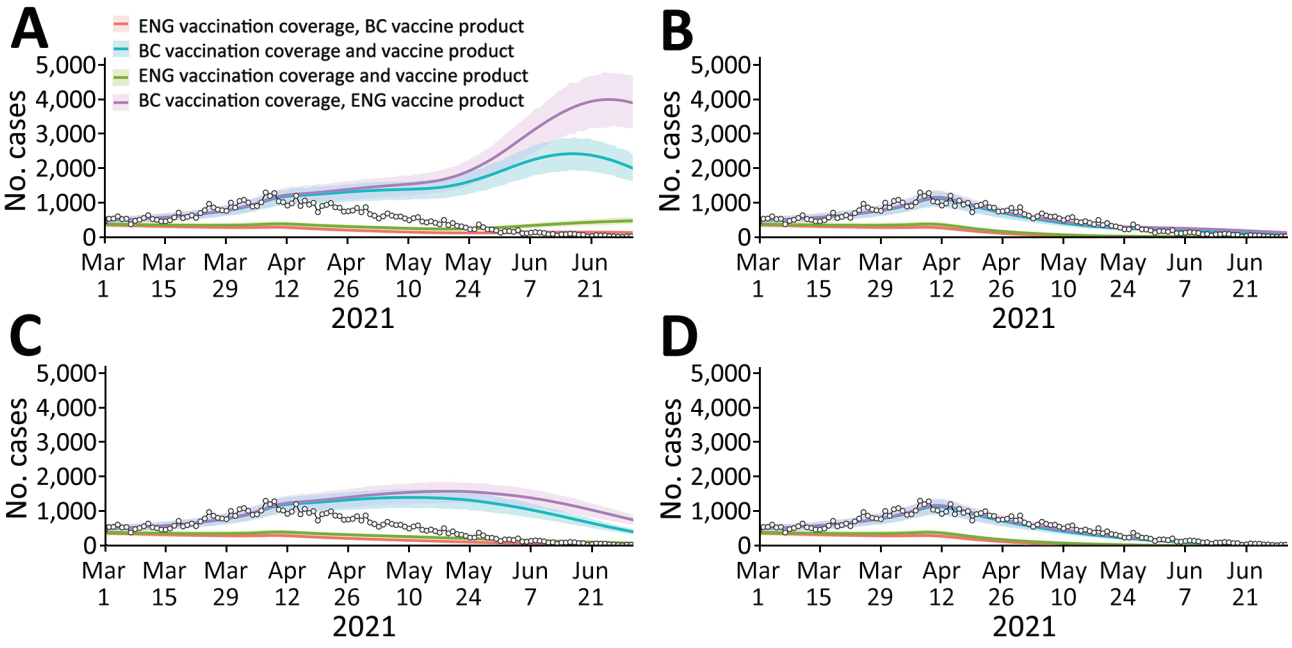

Figure 3. Retrospective counterfactual modeling of COVID-19 transmission in BC, Canada, March 1–June 30, 2021, compared with information from England. Model fitting for March 1, 2020, to July 12, 2021. A) England public health measures and proportion of Delta; B) BC public health measures and England proportion of Delta; C) England public health measures and BC proportion of Delta; D) BC public health measures and proportion of Delta. Each panel represents transmission scenarios derived from 1,000 variational Bayes samples, where measures that affect transmission and the proportion of Delta are reflective of BC or England. Each median line and 90% projection interval shading within each panel represents the vaccination scenario (i.e., population vaccine coverage and majority vaccine product of BC or England). The reported COVID-19 cases for BC are overlaid on each figure as white circles. BC, British Columbia.

Numerous studies have found NPIs to be associated with reduced COVID-19 transmission and thereby reduced illness, deaths, and strain on healthcare systems (*23*,*28*). Indeed, after a new phase of reopening began in British Columbia on July 1, 2021, including lifting the mask mandate for public indoor spaces and permitting countrywide recreational travel (Appendix Table 6) (*29*), British Columbia experienced a sharp rise in COVID-19 cases (Appendix Figure 4). In the weeks after July 1, 2021 (epiweek 26), a fourth wave of COVID-19 cases occurred in British Columbia, even though population vaccination coverage continued to increase. That wave was driven by the Delta variant, which rapidly grew to dominance, increasing to >70% of weekly incident COVID-19 cases by epiweek 29 (3 weeks later) and >85% by epiweek 30.

The Delta variant was first introduced at a time when British Columbia was experiencing a rise in Alpha and Gamma VOC cases, which required additional NPIs. Dominance of the Delta variant over previous VOCs has been widely reported (*3*,*7*,*8*), but the codominating Alpha and Gamma VOCs in circulation at the time of Delta introduction might have also helped to slow Delta's initial growth in British Columbia (*30*,*31*), which warrants further exploration. A limitation of this study is that the transmission model used is not multistrain but rather incorporates the increased transmissibility of a variant through modifying the time-varying per-contact transmissibility term to account for increasing prevalence of a more transmissible variant. As such, the time to dominance of a variant is fixed a priori and is not changed by model dynamics; the effect of precirculating strains cannot be fully assessed. The counterfactual model was instead intended to elucidate the effects of the change in the proportion of Delta on the number of reported COVID-19 cases.

Our counterfactual model used a simple modification of the rate of transmission to compare NPIs between British Columbia and England; other differences between the 2 jurisdictions that might have an effect on intercountry comparisons (e.g., demographics and contact patterns) were not considered. Rate of contact and probability of transmission per contact are highly dependent on population density and demographics, social factors, and geographic variation, which were not explicitly captured within these scenarios but were instead fitted to British Columbia reported case data

for the 2 transmission scenarios. Hence, the counterfactual model used does not allow for direct comparison of NPI strategies between jurisdictions. Comparison of COVID-19 cases and VOC growth between jurisdictions is further affected by differences in PCR testing rates, as well as VOC detection methods and approach. In this study, we assumed that testing rates were consistent over the study period in each jurisdiction; testing rates in British Columbia (*14*) and England (*32*) did not vary dramatically over this time, indicating relatively consistent case-finding.

In conclusion, spread from returning travelers resulted in community transmission of the emergent Delta VOC in British Columbia beginning in mid-to-late March 2021. However, growth of COVID-19 cases in the initial 3 months after Delta was detected was likely restrained because additional NPIs were implemented soon after variant introduction, including restricting interregional travel and expanding mandatory masking in schools to younger age groups. Our findings highlight the capacity of NPIs to reduce the spread of COVID-19, including highly transmissible variants such as Delta. Maximizing population-level COVID-19 vaccine coverage reduces rates of illness and death and is essential for return to prepandemic ways of life. However, NPIs remain vital for preventing COVID-19–associated burden, especially in the face of variants capable of vaccine escape. Future work should examine the effectiveness of different NPI strategies and the timing of implementing or relaxing NPIs in the context of vaccine coverage, variant-specific vaccine effectiveness, and public acceptance. Identifying the best balance of NPIs to achieve least restrictive means will minimize unintended social, economic, and health-related harms.

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References

1. World Health Organization. Tracking SARS-CoV-2 variants [cited 2022 Dec 10]. https://www.who.int/en/activities/tracking-SARS-CoV-2-variants
2. Campbell F, Archer B, Laurenson-Schafer H, Jinnai Y, Konings F, Batra N, et al. Increased transmissibility and global spread of SARS-CoV-2 variants of concern as at June 2021. Euro Surveill. 2021;26:2100509. https://doi.org/10.2807/1560-7917.ES.2021.26.24.2100509
3. Mlcochova P, Kemp SA, Dhar MS, Papa G, Meng B, Ferreira IATM, et al.; Indian SARS-CoV-2 Genomics Consortium (INSACOG); Genotype to Phenotype Japan (G2P-Japan) Consortium; CITIID-NIHR BioResource COVID-19 Collaboration. SARS-CoV-2 B.1.617.2 Delta variant replication and immune evasion. Nature. 2021;599:114–9. https://doi.org/10.1038/s41586-021-03944-y
4. Elbe S, Buckland-Merrett G. Data, disease and diplomacy: GISAID's innovative contribution to global health. Glob Chall. 2017;1:33–46. https://doi.org/10.1002/gch2.1018
5. GISAID. Tracking of hCoV-19 variants [cited 2022 Dec 10]. https://www.gisaid.org/hcov19-variants
6. BC Centre for Disease Control. Weekly update on variants of concern (VOC): Sep 17, 2021 [cited 2022 Dec 10]. http://www.bccdc.ca/Health-Info-Site/Documents/VoC/VoC_weekly_09172021.pdf
7. Public Health England. SARS-CoV-2 variants of concern and variants under investigation in England: Technical briefing 23 [cited 2021 Sep 19]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1018547/Technical_Briefing_23_21_09_16.pdf
8. Sheikh A, McMenamin J, Taylor B, Robertson C; Public Health Scotland and the EAVE II Collaborators. SARS-CoV-2 Delta VOC in Scotland: demographics, risk of hospital admission, and vaccine effectiveness. Lancet. 2021;397:2461–2. https://doi.org/10.1016/S0140-6736(21)01358-1
9. Public Health Scotland. Tracking the Delta variant in Scotland [cited 2023 Jun 25]. https://publichealthscotland.scot/our-blog/2021/november/tracking-the-delta-variant-in-scotland
10. Earnest R, Uddin R, Matluk N, Renzette N, Turbett SE, Siddle KJ, et al.; New England Variant Investigation Team. Comparative transmissibility of SARS-CoV-2 variants Delta and Alpha in New England, USA. Cell Rep Med. 2022;3:100583. https://doi.org/10.1016/j.xcrm.2022.100583
11. Office of the Premier. Three-week circuit breaker begins now to bend the curve, protect people [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021PREM0023-000578
12. Scientific Advisory Group for Emergencies. SPI-M-O: summary of further modelling of easing restrictions–roadmap step 4 on 19th July 2021, 7 July 2021 [cited 2021 Aug 6]. https://www.gov.uk/government/publications/spi-m-o-summary-of-further-modelling-of-easing-restrictions-roadmap-step-4-on-19-july-2021-7-july-2021
13. UK Health Security Agency. Coronavirus (COVID-19) in the UK: cases in England [cited 2022 Feb 01]. https://coronavirus.data.gov.uk/details/cases?areaType=nation&areaName=England
14. BC Centre for Disease Control. British Columbia (BC) COVID-19 situation report: week 28: July 11–July 17, 2021 [cited 2022 Dec 10]. http://www.bccdc.ca/Health-Info-Site/Documents/COVID_sitrep/Week_28_2021_BC_COVID-19_Situation_Report.pdf
15. UK Health Security Agency. Coronavirus (COVID-19) in the UK: vaccinations in England [cited 2021 Aug 6]. https://coronavirus.data.gov.uk/details/vaccinations?areaType=nation&areaName=England

16. Department of Health & Social Care. Policy paper: UK COVID-19 vaccines delivery plan [cited 2022 May 15]. https://www.gov.uk/government/publications/uk-covid-19-vaccines-delivery-plan/uk-covid-19-vaccines-delivery-plan#supply-1
17. Anderson SC, Edwards AM, Yerlanov M, Mulberry N, Stockdale JE, Iyaniwura SA, et al. Quantifying the impact of COVID-19 control measures using a Bayesian model of physical distancing. PLOS Comput Biol. 2020;16:e1008274. https://doi.org/10.1371/journal.pcbi.1008274
18. Public Health England. SARS-CoV-2 variants of concern and variants under investigation in England: Technical briefing 19 [cited 2021 Aug 6]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005517/Technical_Briefing_19.pdf
19. Anderson SC, Edwards AM, Yerlanov M, Mulberry N, Stockdale JE, Falcao RC, et al. Bayesian SEIR modelling for multivariate COVID-19 case data [cited 2022 Dec 10]. https://seananderson.github.io/covidseir/index.html
20. O'Toole Á, Scher E, Underwood A, Jackson B, Hill V, McCrone JT, et al. Assignment of epidemiological lineages in an emerging pandemic using the pangolin tool. Virus Evol. 2021 Jul 30;7(2):veab064. https://doi.org/10.1093/ve/veab064 PMID 34527285
21. Transport Canada. Government of Canada suspends flights from India and Pakistan [cited 2022 Dec 10]. https://www.canada.ca/en/transport-canada/news/2021/04/government-of-canada-suspends-flights-from-india-and-pakistan.html
22. Public Health Agency of Canada. Government of Canada's first phase to easing border measures for travellers entering Canada [cited 2022 Dec 10]. https://www.canada.ca/en/public-health/news/2021/06/government-of-canadas-first-phase-to-easing-border-measures-for-travellers-entering-canada3.html
23. Wells CR, Sah P, Moghadas SM, Pandey A, Shoukat A, Wang Y, et al. Impact of international travel and border control measures on the global spread of the novel 2019 coronavirus outbreak. Proc Natl Acad Sci U S A. 2020;117:7504–9. https://doi.org/10.1073/pnas.2002616117
24. Lopez Bernal J, Andrews N, Gower C, Gallagher E, Simmons R, Thelwall S, et al. Effectiveness of Covid-19 Vaccines against the B.1.617.2 (Delta) Variant. N Engl J Med. 2021;385:585–94. https://doi.org/10.1056/NEJMoa2108891
25. Pouwels KB, Pritchard E, Matthews PC, Stoesser N, Eyre DW, Vihta KD, et al. Effect of Delta variant on viral burden and vaccine effectiveness against new SARS-CoV-2 infections in the UK. Nat Med. 2021;27:2127–35. https://doi.org/10.1038/s41591-021-01548-7
26. McCrone JT, Hill V, Bajaj S, Pena RE, Lambert BC, Inward R, et al.; COVID-19 Genomics UK (COG-UK) Consortium. Context-specific emergence and growth of the SARS-CoV-2 Delta variant. Nature. 2022;610:154–60. https://doi.org/10.1038/s41586-022-05200-3
27. Adu P, Binka M, Mahmood B, Jeong D, Buller-Tylor T, Jean Damascene M, et al. Quantifying contact patterns: development and characteristics of the British Columbia COVID-19 population mixing patterns survey. Int J Infect Dis. 2022;116:S30–1. https://doi.org/10.1016/j.ijid.2021.12.073
28. Scott N, Saul A, Spelman T, Stoove M, Pedrana A, Saeri A, et al. The introduction of a mandatory mask policy was associated with significantly reduced COVID-19 cases in a major metropolitan city. PLoS One. 2021;16:e0253510. https://doi.org/10.1371/journal.pone.0253510
29. Office of the Premier. B.C. shifts to Step 3 of restart plan [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021PREM0043-001268
30. Lemey P, Ruktanonchai N, Hong SL, Colizza V, Poletto C, Van den Broeck F, et al. Untangling introductions and persistence in COVID-19 resurgence in Europe. Nature. 2021;595:713–7. https://doi.org/10.1038/s41586-021-03754-2
31. Russell A, O'Connor C, Lasek-Nesselquist E, Plitnick J, Kelly JP, Lamson DM, et al. Spatiotemporal analyses of 2 co-circulating SARS-CoV-2 variants, New York state, USA. Emerg Infect Dis. 2022;28:650–9. https://doi.org/10.3201/eid2803.211972
32. UK Health Security Agency. Coronavirus (COVID-19) in the UK: testing in England [cited 2022 Jul 15]. https://coronavirus.data.gov.uk/details/testing?areaType=nation&areaName=England

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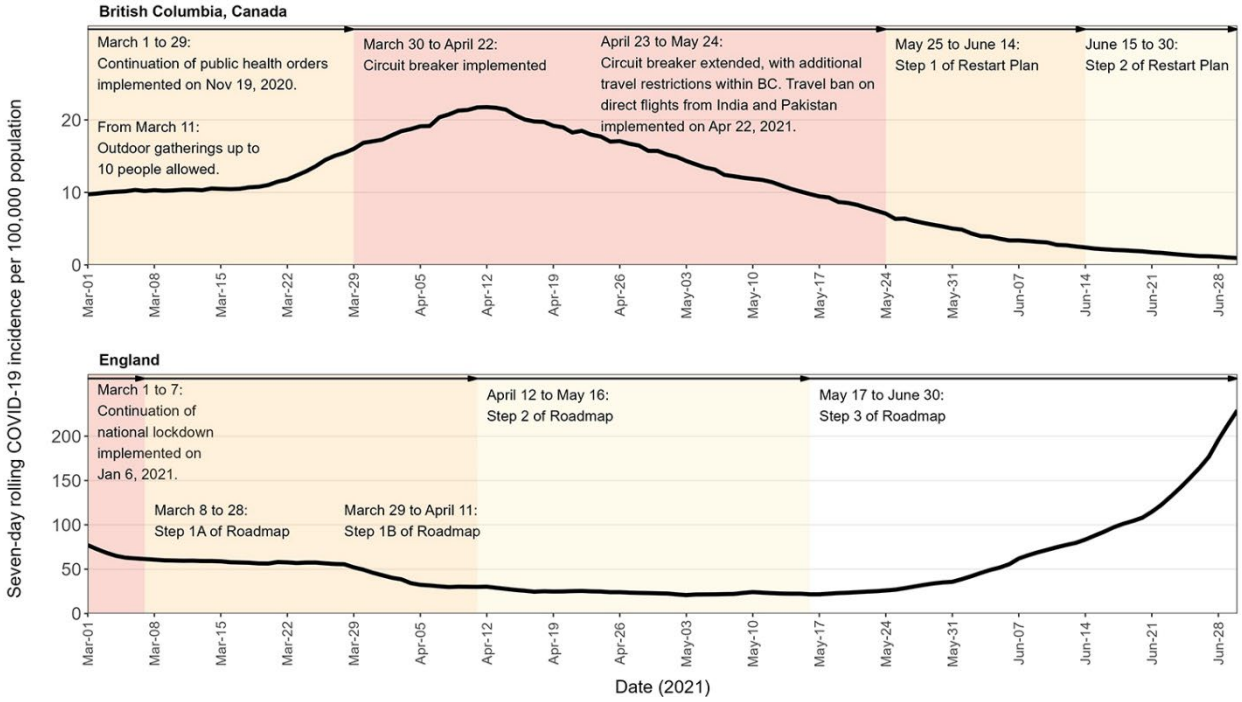
Emergence of SARS-CoV-2 Delta Variant and Effect of Nonpharmaceutical Interventions, British Columbia, Canada

Appendix



Appendix Figure 1. Seven-day rolling COVID-19 incidence rate per 100,000 people and select non-pharmaceutical interventions in place in British Columbia, Canada and England, March 1 to June 30, 2021. See Appendix Table 1 for more information on changes in public health and social measures, or non-pharmaceutical interventions, implemented per jurisdiction over the study period. Data for 7-day rolling COVID-19 incidence rate for England extracted from UK Health Security Agency COVID-19 dashboard (*1*). BC, British Columbia; VOC, variant of concern.

Appendix Table 1. Timeline of nonpharmaceutical interventions in place in British Columbia, Canada and England, March 1 to June 30, 2021

British Columbia (BC)	England
Time period: March 1 to March 29, 2021	**Time period: March 1 to March 7, 2021**
Continuation of mandatory public health orders first implemented in BC on November 19, 2020 (*2*–*4*):	Continuation of England's third national lockdown first implemented on January 6, 2021 (*5*):
• Physical distancing and masks required in public indoor settings	• Stay-at-home order other than for essential reasons, including essential medical needs, food shopping, exercise, and work if cannot be done from home
• All school staff and middle and secondary school students required to wear non-medical masks indoors (other than when at their desks or workstations)	• Outdoor exercise can be done with your household or bubble, or with 1 person from another household
Personal gatherings:	• All schools, colleges, and universities generally closed or switched to remote learning, with some exceptions (e.g., university students taking hands-on subjects such as medicine)
• No indoor gatherings with people outside immediate household or core bubble (maximum of two people outside household)	• Early years settings (e.g., nurseries) remain open
• Starting March 11: outdoor gatherings with people outside household or core bubble of up to 10 people allowed (*6*)	• Indoor worship services continue, with social distancing
Organized gatherings:	• Recreational facilities and outdoor sports venues closed
• All indoor and outdoor events are prohibited, with the exception of baptisms, funerals, and weddings with up to 10 people including an officiant*; no associated receptions in any venue	• Amateur team sports not allowed
• Indoor worship services suspended; limited outdoor worship services allowed	• Restaurants only offering takeaway meals or food delivery; no indoor dining
Travel:	**Time period: March 8 to March 28, 2021**
• All non-essential travel outside of one's community strongly discouraged	Step 1A of UK's Roadmap out of lockdown begins (*7*):
Businesses, offices, and workplaces:	• Primary and secondary schools and colleges reopen with outdoor after-school sports and activities allowed
• Indoor and outdoor dining allowed with own household or core bubble, up to 6 people per table	o Secondary school and college students and staff required to wear face masks indoors, with voluntary twice-weekly at-home COVID-19 testing
• All businesses and workplaces must conduct active daily screening of all workers using their COVID-19 Safety Plans, and masks must be worn in common areas	o Primary school staff expected to wear face masks in corridors and communal areas where social distancing between adults not possible
• Offices should support work-from-home options wherever possible	• University students on practical courses may also return to in-person learning
Sports and exercise:	**Time period: March 29 to April 11, 2021**
• Indoor group low intensity exercise (e.g., Pilates, hatha yoga) allowed	Step 1B of Roadmap (*8*):
• Indoor group high intensity exercise (e.g., dance, spin, power yoga, circuit training) not permitted	*Personal gatherings:*
• Indoor and outdoor team sports not permitted	• Outdoor gatherings of up to 6 people or 2 households allowed
Time period: March 30 to April 22, 2021	*Travel:*
Circuit breaker starts (initially March 30-April 19) (*9*):	• Stay-at-home order replaced with recommendation to "stay local"
• All school staff and students down to Grade 4 now required to wear masks while indoors at school (including at their desks) and on school buses; masks strongly encouraged for students in kindergarten to grade 3	*Sports and exercise:*
Personal gatherings:	• Outdoor sports facilities reopen
• Indoor gatherings continue to be restricted	• Amateur organized team sports allowed, and not subject to the limits on gatherings
• Outdoor gatherings of up to 10 people continue to be allowed	**Time period: April 12 to May 16, 2021**
Organized gatherings:	Step 2 of Roadmap (*10*):
• Indoor worship services suspended. Outdoor worship services may continue.	*Businesses:*
Travel:	• Non-essential retail and personal care open
• Travel within province limited to essential travel only (e.g., work or medical purposes)	• Public buildings (e.g., libraries, community centers) open
• Whistler-Blackcomb ski resort closed, to address and prevent community spread related to non-essential travel	• Self-contained holiday accommodation open
Businesses:	• Outdoor hospitality open
• Indoor dining suspended	• Outdoor attractions and settings open
• Patios remain open, for dining with immediate household or core bubble only	*Sports and exercise:*

British Columbia (BC)	England
Offices and workplaces: • All workers strongly encouraged to work from home, where possible *Sports and exercise:* • Indoor, adult group fitness activities suspended • Gyms and fitness centers restricted to individual or one-on-one activities	• Indoor leisure facilities (e.g., gyms, swimming pools) open for individuals or within-household groups • All indoor children's activities, including sport, resume • Indoor parent and child groups of up to 15 people (not including children <5 y) resume
Time period: April 23 to May 24, 2021	**Time period: May 17 to June 30, 2021**
Circuit breaker extended on April 19, with additional travel restrictions implemented April 23 (*12*): • Continuation of circuit breaker measures put in place on March 30, 2021 • Additional travel restriction enforcement within province to further discourage non-essential travel The Government of Canada implemented a travel ban on direct flights from India and Pakistan beginning the evening of April 22, 2021.	Step 3 of Roadmap (*11*): • Face coverings no longer required in schools *Personal gatherings:* • Indoor gatherings allowed for up to 6 people or 2 households • Outdoor gatherings allowed for up to 30 people *Organized gatherings:*
Time period: May 25 to June 14, 2021	• Outdoor sporting events allowed up to 4,000 people or at 50% of venue's capacity, whichever is lower. Large outdoor seated venues, where crowds can be distributed, allowed up to 10,000 people or 25% of total seated capacity, whichever is lower • Increased attendance allowed at events such as weddings and funerals (e.g., weddings allowed to have more than 30 guests from June 21st) *Travel:* • International travel to "green list" countries resumes *Businesses:* • Indoor hospitality, entertainment venues, and hotels open *Offices and workplaces:* • Continued recommendation to work from home if possible *Sports and exercise:* • Adult indoor group sports and exercise classes resume Step 4 postponed from June 21st until after the study period due to rising Delta variant cases.
Step 1 of BC's Restart Plan (*13*): • Physical distancing and masks continue to be required in public indoor settings *Personal gatherings:* • Indoor gatherings of up to 5 people or 1 other household • Outdoor gatherings of up to 10 people continue *Organized gatherings:* • Indoor seated gatherings of up to 10 people* • Outdoor seated gatherings (e.g., weddings) of up to 50 people* • Indoor or outdoor worship services of up to 50 people* *Travel:* • Recreational travel within own travel zone • Non-essential travel between the government's three designated travel zones still restricted *Businesses:* • Indoor and outdoor dining for groups up to 6 people, not restricted to own household or core bubble • Liquor served until 10pm *Offices and workplaces:* • Start of gradual return to workplaces • Employers must continue to have a COVID-19 Safety Plan and daily health check in place *Sports and exercise:* • Low-intensity indoor fitness classes (e.g., Pilates) resume with limited capacity • Outdoor team sports are allowed for all ages, without spectators	
Time period: June 15 to June 30, 2021	
Step 2 of BC's Restart Plan (*14*): • Physical distancing and masks continue to be required in public indoor settings. *Personal gatherings:* • Outdoor gatherings of up to 50 people (e.g., birthday parties, backyard BBQs, block parties) • Indoor gatherings of up to 5 people or 1 other household *Organized gatherings:* • Indoor seated gatherings of up to 50 people* • Outdoor gatherings of up to 50 people* • Indoor or outdoor worship services of up to 50 people* *Travel:* • Recreational travel within BC *Businesses:*	

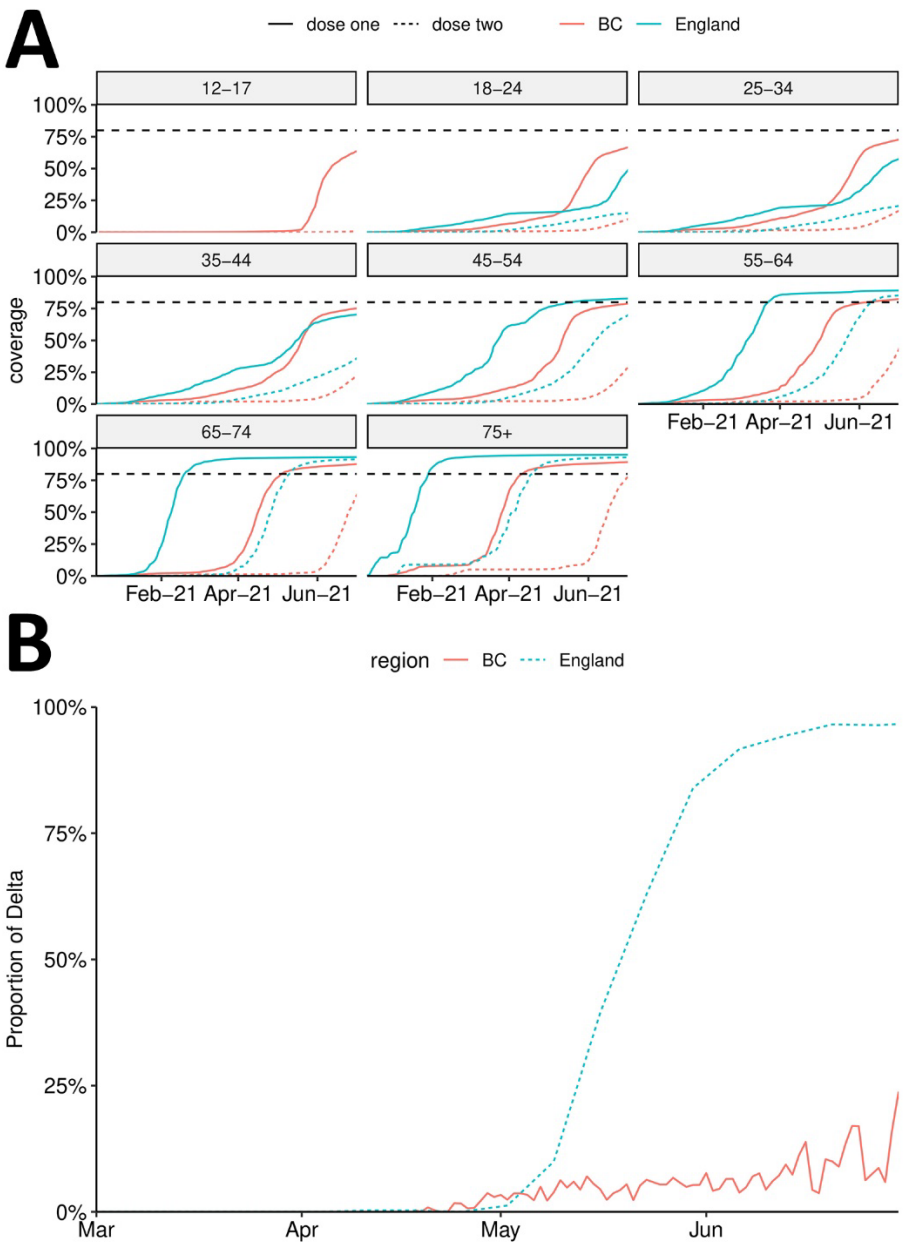
British Columbia (BC)	England
• Indoor and outdoor dining for groups up to 6 people, not restricted to own household or core bubble • Liquor served until midnight • Banquet halls reopen with limited capacity* *Offices and workplaces:* • Continued return to workplaces • Small, in-person meetings allowed • Employers must continue to have a COVID-19 Safety Plan and daily health check in place *Sports and exercise:* • Indoor high- and low-intensity group exercise allowed with reduced capacity • Indoor and outdoor team sports allowed for all ages • Up to 50 spectators allowed outdoors, no spectators at any indoor sport activities	

*With an approved BC COVID-19 Safety Plan.

Appendix Table 2. Combined screening and detection strategy for variants of concern in British Columbia, Canada, March 1 to June 30, 2021*

Dates	VOC detection strategy
March 1 to May 29, 2021	Combined VOC testing strategy using targeted VOC SNP qPCR ("screening") and whole-genome sequencing (WGS):
	• Under the combined testing strategy, ≈80 to 99% of positive samples were screened for VOCs each week; a subset of screened cases were further confirmed by WGS. See below for details on screening methods and proportion of screened cases further confirmed by WGS, by time period.
	• A separate subset of positive samples underwent WGS, including: a random sample for baseline surveillance, those associated with clusters/outbreaks, hospitalization, re-infection, and vaccine breakthrough, and those associated with international travelers arriving at the BC border.
March 1 to 31, 2021:	VOC SNP qPCR screening methods in BC primarily only detected the N501Y mutation (present in Alpha, Beta, and Gamma VOCs). One hospital in BC implemented K417T mutation screening for Gamma VOC detection from March 21, 2021 onwards. During this time period, all presumptive positive SNP qPCR results were confirmed by WGS at the BCCDC PHL.
April 1 to May 29, 2021:	VOC SNP qPCR screening methods were modified to incorporate both N501Y and E484K mutation screening at the BCCDC PHL (E484K mutation is detected in Beta and Gamma VOCs, but rarely in Alpha VOC). Specimens that tested positive for N501Y alone were identified as presumptive B.1.1.7 lineage; ~10% were confirmed by WGS. In addition, only ~25% of specimens that tested positive for N501Y and another mutation were confirmed by WGS. Based on epidemiology at the time, VOC screening results with both E484K and N501Y mutations were assumed to be Gamma VOC, given the very low prevalence of Beta VOC in BC.
May 30 to June 30, 2021	All positive samples in BC had WGS attempted.

*BC, British Columbia; BCCDC PHL, British Columbia Centre for Disease Control Public Health Laboratory; SNP qPCR, single-nucleotide polymorphism quantitative PCR; VOC, variant of concern; WGS, whole-genome sequencing.



Appendix Figure 2. Comparison of England and British Columbia vaccination coverage (A) and proportion of genotyped cases identified as Delta variant of concern (B). Vaccine dose coverage includes the coverage of both dose one and dose two by age group, with the 80% coverage highlighted as a dashed line for clarity. Population vaccination coverage data were extracted from the UK Government COVID-19 dashboard (*15*) for England and from the Provincial Immunization Registry for BC. Note that England had not started vaccination of the adolescent group (ages 12–17) before July 2021. Data for the Delta variant in England was extracted from the UK Health Security Agency Technical Briefing 19 (*16*) of all available genotyped cases. British Columbia Delta variant prevalence was extracted from all cases genotyped through screening and background surveillance.

Appendix Table 3. Case definitions for variants of concern*

VOC	Case definition (* denotes any number indicating a sub-lineage)†
Delta	SARS-CoV-2-positive cases whose samples were confirmed through whole-genome sequencing as Pangolin lineage B.1.617.2 or AY.*
Alpha	SARS-CoV-2-positive cases whose samples were confirmed through whole-genome sequencing as Pangolin lineage B.1.1.7 or Q.*, or screened as N501Y-positive and E484K-negative
Gamma	SARS-CoV-2-positive cases whose samples were confirmed through whole-genome sequencing as Pangolin lineage P.1 or P.1.*, screened as N501Y- and E484K-positive, or screened as K417T-positive
Beta‡	SARS-CoV-2-positive cases whose samples were confirmed through whole-genome sequencing as Pangolin lineage B.1.351 or B.1.351.*

*VOC, variant of concern.
†Screening employed targeted single-nucleotide polymorphism quantitative polymerase chain reaction (SNP qPCR).
‡Based on epidemiology at the time, VOC screening results with both E484K and N501Y mutations were assumed to be Gamma VOC, given the very low prevalence of Beta VOC in BC.

Appendix Table 4. Modeling approach and parameters used for each counterfactual scenario

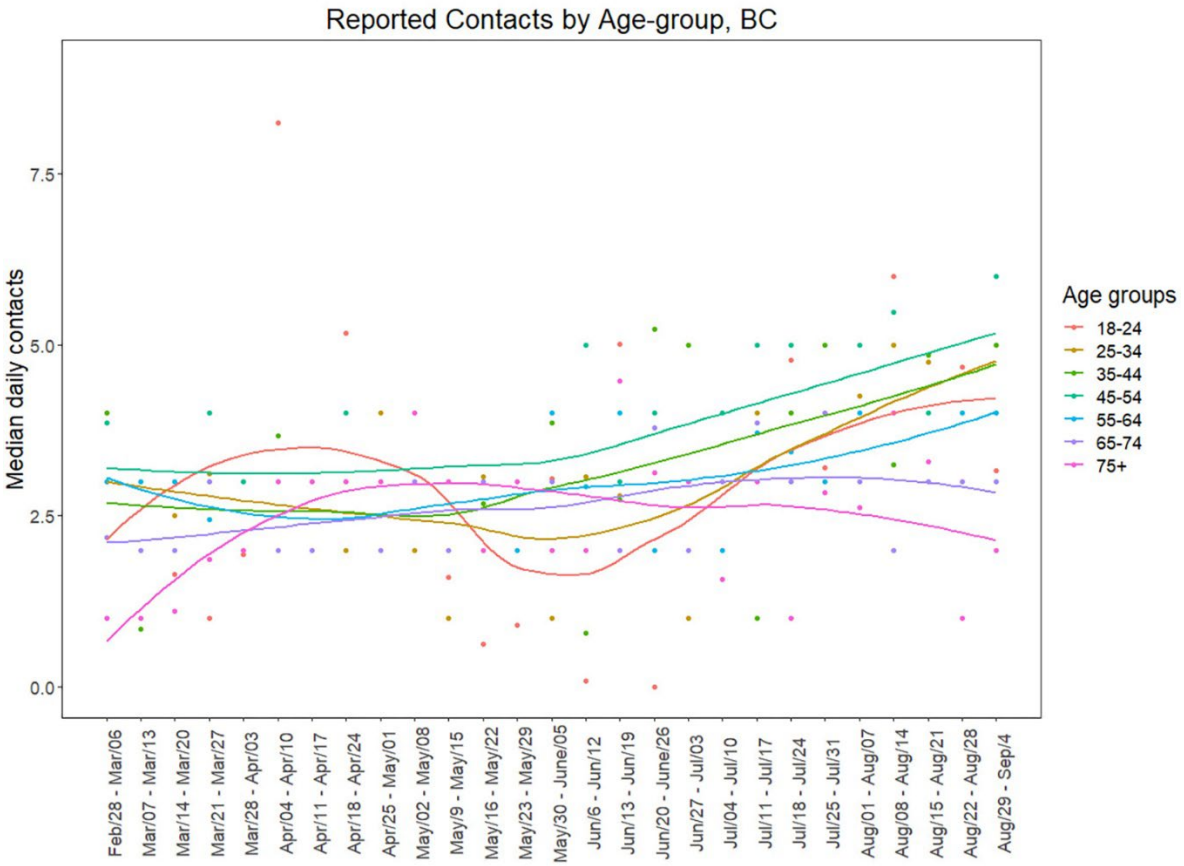
Scenario	Modeling approach	Parameters and explanation
Baseline	Baseline transmission was fit using a Bayesian approach to daily BC PCR-confirmed COVID-19 cases. Transmission was modeled as a piecewise constant function with pre-specified breakpoints.	Breakpoints were selected based on changes in public health measures or population behavior. The start dates for each segment were: 2020–03–15, 2020–05–10, 2020–09–08, 2020–09–21, 2020–11–10, 2021–01–25, 2021–03–29, 2021–04–05, 2021–05–25.
Introduction of Delta variant	Logistic growth curve multiplied by transmission rate β to replicate the relative increase in transmission as the Delta variant became dominant. The parameters include the time of introduction and the time to the proportion of Delta being 90% among all variants.	The BC scenario ramp had a start date of 2021–05–25 and a time to dominance of 25 weeks. The England scenario had a start date of 2021–05–01 and a time to dominance of 4 weeks to reflect the differences in the proportional change in Delta between both jurisdictions. For each scenario, Delta increased transmission by 50% (*17*).
Public health measures and health behavior	A further change in the transmission was included to characterize the changes in public health measures and behavior following their introduction on 2021–04–05 in BC. This was modeled as a step-change in the transmission term after implementation of the measures.	In the BC scenario, the transmission term was fitted to historical data and so no further changes needed to be included. For the England scenario, the transmission term is multiplied by a factor of 50% reflecting no changes in public health measures following 2021–04–05.
Vaccination roll-out and coverage	The exact proportion of vaccination by age group were extracted for both BC and England jurisdictions. For each vaccination coverage, an estimate of BC's population structure and contact rates by age group were used to derive an age-adjusted vaccination rate for each scenario.	Proportion of each age group vaccinated based on data for BC and England. Number of weekly contacts per age group based on BC-Mix survey data (*18*) were: <2 y: 6, 2–5 y: 12, 6–17 y: 13, 18–24 y: 44, 25–34 y: 44, 35–44 y: 48, 45–54 y: 48, 55–64 y: 24, 65–74 y: 21, >75 y: 17.
Vaccination product	The vaccine transmission-blocking effectiveness was selected for each scenario based on the dominant vaccine product for each jurisdiction during the study period. In BC this was BNT162b2 and in England this was ChAdOX1.	Vaccine effectiveness for the BC scenario was 71.8% after one dose and 89% after two doses. Vaccine effectiveness for the England scenario was 58% after one dose and 77% after two doses.

*BC, British Columbia.

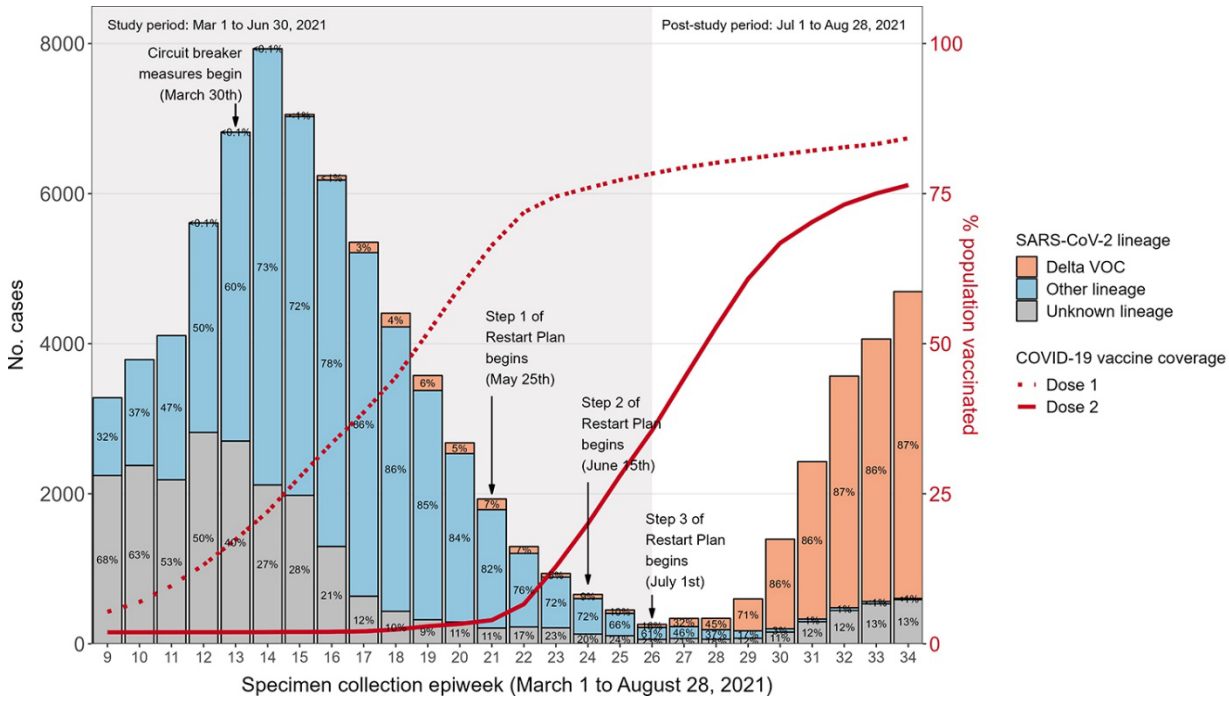
Appendix Table 5. Transmission-blocking efficacy parameters used in counterfactual modeling by vaccine product and first and second dose

Vaccine product	Dose one	Dose two
BNT162b2 (Pfizer)	71.8%	89%
ChAdOx1 (AstraZeneca)	58%	77%

*Efficacy parameters for vaccination incorporated both a reduction in the probability of incidence infection as well as reduction in onward transmission if infected while vaccinated. Estimates for vaccine transmission-blocking efficacy and onward-transmission efficacy were derived from values presented in the UK Scientific Pandemic Influenza Group on Modeling, Operational subgroup (SPI-M-O) of the Scientific Advisory Group for Emergencies (SAGE) July 7th modeling group report (*19*) where a range of optimistic to more pessimistic vaccine assumptions were provided by different modeling groups. The total transmission blocking probability is 1-(1–0.6)*(1–0.45) = 0.78 under the optimistic scenario and 1-(1–0.53)*(1–0.4) = 0.718 under the pessimistic scenario for BNT162b2, rising to 0.89 under the second dose. For ChAdOx1, after one dose, this is 0.58 under the pessimistic and 0.65 under the optimistic scenarios, rising to 0.77 under the second dose pessimistic and 0.8 under the optimistic scenarios, respectively. Scenarios in British Columbia were more in line with pessimistic assumptions for BNT162b2, so for ChAdOx1 we also selected the pessimistic assumption.



Appendix Figure 3. Sample median number of contacts by age group in British Columbia, Canada, February 28 to September 4, 2021. Reported contacts by age group in BC extracted from BC Mix COVID-19 Survey data (*18*). Fitted lines constructed using local polynomial regression with LOESS method. BC, British Columbia.



Appendix Figure 4. COVID-19 cases in British Columbia, Canada by Delta variant of concern, other lineage, or unknown lineage, with specimen collection date between March 1 and August 28, 2021, overlaid with 12 year and older population COVID-19 vaccination coverage by dose received. Step 3 of BC's Restart Plan included lifting of the mask mandate in indoor public spaces, removal of limits on indoor and outdoor personal gatherings, increased capacity for indoor and outdoor organized gatherings, allowing of Canada-wide recreational travel, increased capacity at indoor sports and exercise facilities, re-opening of casinos and nightclubs, and return to normal hours for liquor service at restaurants, bars and pubs, with no group limits for tables (*20*) (Appendix Table 6). BC, British Columbia; VOC, variant of concern.

Appendix Table 6. Changes to public health and social measures in British Columbia, Canada following July 1, 2021 move to Step 3 of provincial Restart Plan

British Columbia
Implemented on July 1, 2021
Step 3 of BC's Restart Plan (*20*):
• Masks recommended until fully vaccinated, but not mandatory, in public indoor spaces
• Physical distancing remains in place
Personal gatherings:
• No limits on personal gathering sizes indoors or outdoors
Organized gatherings:
• Indoor organized gatherings of up to 50 people, or 50% capacity, allowed with a COVID-19 Safety Plan
• Outdoor organized gatherings of up to 5,000 people, or 50% capacity, allowed with a COVID-19 Safety Plan
• Fairs, festivals, and trade shows return to normal, with Communicable Disease Plan in place
Travel:
• Recreational travel within Canada allowed
Businesses, offices, and workplaces:
• No limits on group sizes for indoor or outdoor dining
• Return to regular liquor service
• Bingo halls, casinos, and nightclubs reopen with reduced capacity
• Seminars and bigger meetings allowed for offices and workplaces
Sports and exercise:
• Return to normal for sports and exercise facilities, with Communicable Disease Plan in place
While BC's state of public health emergency remained in effect to support amended public health orders from the provincial health officer, Step 3 of BC's Restart Plan also signaled the end of BC's provincial state of emergency in response to the COVID-19 pandemic, which had been in place since March 2020 (*20*). The provincial state of emergency had granted the BC government additional powers such as the ability to enforce the mandatory mask policy and travel restrictions that had been in place.

*BC, British Columbia.

References

1. UK Health Security Agency. Coronavirus (COVID-19) in the UK: Cases in England [cited 2022 Feb 1]. https://coronavirus.data.gov.uk/details/cases?areaType=nation&areaName=England

2. BC Ministry of Health. Joint statement on B.C.'s COVID-19 response, latest updates [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2020HLTH0061-001949

3. British Columbia Ministry of Health. Public Health Guidelines for Group Low Intensity Exercise [cited 2022 Dec 10]. https://www2.gov.bc.ca/assets/gov/health/about-bc-s-health-care-system/office-of-the-provincial-health-officer/covid-19/covid-19-public-health-guidelines-low-intensity-exercise.pdf?bcgovtm=20200506_GCPE_AM_COVID_9_NOTIFICATION_BCGOV_BCGOV_EN_BC__NOTIFICATION

4. Ministry of Education. Enhanced safety measures for K-12 schools [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021EDUC0011-000201

5. Prime Minister's Office. 10 Downing Street and The Rt Hon Boris Johnson MP. Press release: Prime Minister announces national lockdown [cited 2022 Dec 10]. https://www.gov.uk/government/news/prime-minister-announces-national-lockdown

6. BC Ministry of Health. Joint statement on B.C.'s COVID-19 response, latest updates [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021HLTH0020-000457

7. Cabinet Office. Guidance: COVID-19 Response – Spring 2021 (Summary) [cited 2022 Dec 10]. https://www.gov.uk/government/publications/covid-19-response-spring-2021/covid-19-response-spring-2021-summary

8. Prime Minister's Office. 10 Downing Street and Department of Health and Social Care. COVID-19: Restrictions in England From 29 March [cited 2022 Dec 10]. https://www.gov.uk/government/publications/covid-19-restrictions-posters-29-march-2021

9. Office of the Premier. Three-week circuit breaker begins now to bend the curve, protect people [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021PREM0023-000578

10. Prime Minister's Office. 10 Downing Street. Press release: Further easing of Covid restrictions confirmed for 12 April [cited 2022 Dec 10]. https://www.gov.uk/government/news/further-easing-of-covid-restrictions-confirmed-for-12-april

11. Prime Minister's Office. 10 Downing Street. Press release: Further easing of COVID restrictions confirmed for 17 May [cited 2022 Dec 10]. https://www.gov.uk/government/news/further-easing-of-covid-restrictions-confirmed-for-17-may

12. BC Ministry of Health. Joint statement on B.C.'s COVID-19 response, latest updates [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021HLTH0079-000742

13. Office of the Premier. B.C. launches restart plan to safely bring people back together [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021PREM0037-001008

14. Office of the Premier. B.C. prepares to safely move to Step 2 of its restart plan [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021PREM0041-001155

15. UK Health Security Agency. Coronavirus (COVID-19) in the UK: Vaccinations in England [cited 2021 Aug 6]. https://coronavirus.data.gov.uk/details/vaccinations?areaType=nation&areaName=England

16. Public Health England. SARS-CoV-2 variants of concern and variants under investigation in England: Technical briefing 19 [cited 2021 Aug 6]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1005517/Technical_Briefing_19.pdf

17. Scientific Advisory Group for Emergencies. SPI-M-O: Consensus statement on COVID-19, 3 June 2021 [cited 2022 May 26]. https://www.gov.uk/government/publications/spi-m-o-consensus-statement-on-covid-19-3-june-2021

18. Adu P, Binka M, Mahmood B, Jeong D, Buller-Tylor T, Jean Damascene M, et al. Quantifying contact patterns: development and characteristics of the British Columbia COVID-19 Population Mixing Patterns Survey [cited 2022 Dec 10]. Int J Infect Dis. 2022;116:S30–1. https://doi.org/10.1016/j.ijid.2021.12.073

19. Scientific Advisory Group for Emergencies. SPI-M-O: Summary of further modelling of easing restrictions - Roadmap Step 4 on 19th July 2021 [cited 2021 Aug 6]. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1001169/S1301_SPI-M-O_Summary_Roadmap_second_Step_4.2__1_.pdf

20. Office of the Premier. B.C. shifts to Step 3 of restart plan [cited 2022 Dec 10]. https://news.gov.bc.ca/releases/2021PREM0043-001268