

BMJ Open SARS-CoV-2 cross-sectional seroprevalence study among public school staff in Metro Vancouver after the first Omicron wave in British Columbia, Canada

Allison W Watts,^{1,2} Louise C Mâsse,^{1,3} David M Goldfarb,^{1,4} Mike A Irvine ⁵, Sarah M Hutchison,^{1,2} Lauren Muttucomaroe,² Bethany Poon,² Vilte E Barakauskas,⁴ Collette O'Reilly,⁶ Else Bosman,^{1,2} Frederic Reicherz,^{1,2} Daniel Coombs,⁷ Mark Pitblado,^{1,2} Sheila F O'Brien,^{8,9} Pascal M Lavoie ^{1,2}

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For numbered affiliations see end of article.

Correspondence to
Dr Pascal M Lavoie;
pavoie@bccchr.ca

ABSTRACT

Objective To determine the SARS-CoV-2 seroprevalence among school workers within the Greater Vancouver area, British Columbia, Canada, after the first Omicron wave.

Design Cross-sectional study by online questionnaire, with blood serology testing.

Setting Three main school districts (Vancouver, Richmond and Delta) in the Vancouver metropolitan area.

Participants Active school staff enrolled from January to April 2022, with serology testing between 27 January and 8 April 2022. Seroprevalence estimates were compared with data obtained from Canadian blood donors weighted over the same sampling period, age, sex and postal code distribution.

Primary and secondary outcomes SARS-CoV-2 nucleocapsid antibody testing results adjusted for test sensitivity and specificity, and regional variation across school districts using Bayesian models.

Results Of 1850 school staff enrolled, 65.8% (1214/1845) reported close contact with a COVID-19 case outside the household. Of those close contacts, 51.5% (625/1214) were a student and 54.9% (666/1214) were a coworker. Cumulative incidence of COVID-19 positive testing by self-reported nucleic acid or rapid antigen testing since the beginning of the pandemic was 15.8% (291/1845). In a representative sample of 1620 school staff who completed serology testing (87.6%), the adjusted seroprevalence was 26.5% (95% CrI 23.9% to 29.3%), compared with 32.4% (95% CrI 30.6% to 34.5%) among 7164 blood donors.

Conclusion Despite frequent COVID-19 exposures reported, SARS-CoV-2 seroprevalence among school staff in this setting remained no greater than the community reference group. Results are consistent with the premise that many infections were acquired outside the school setting, even with Omicron.

INTRODUCTION

The COVID-19 pandemic had a dramatic impact on schools early in the pandemic, causing major disruptions to the education

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ Robust reporting of seroprevalence based on diagnostic serology testing.
- ⇒ Large school staff sample compared with secondary seroprevalence data from a period, demographic and community-matched reference group of blood donors.
- ⇒ Non-random participation may have contributed to selection bias.
- ⇒ The blood donor group could have differed on unmeasured variables related to risk of infection and seroprevalence outcomes.

system, with mental and physical consequences on students and staff.^{1 2} Earlier studies suggest that while SARS-CoV-2 outbreaks repeatedly occurred in schools, most infections among students and school staff were acquired outside the school setting.^{3–9} Accordingly, the risk of infection among school staff remained comparable to the community risk during the 2020–2021 school year, while mitigation measures were in place.^{8 10 11} At the end of 2021, Omicron variants emerged,^{12 13} rapidly replacing other strains, and causing a massive increase in cases across the world due to its highly transmissible nature and ability to evade vaccine protection against reinfection.^{14 15} This new wave of infections raised further concerns regarding the safety of the staff in the school setting.

In British Columbia (BC, Canada), relatively low rates of COVID-19 infections had been reported in the earlier phases of the pandemic compared with other areas of the world. By the summer of 2020, ~1% of

people living in Vancouver had been infected with SARS-CoV-2.^{16–18} By March 2021, about 2%–5% of Vancouver residents showed evidence of prior SARS-CoV-2 infection.¹⁹ With the emergence of highly transmissible Omicron variants, the province experienced a massive corresponding increase in cases in December 2021.^{20 21} As new cases exceeded the provincial testing capacity, BC reprioritised viral testing on selected groups around 17 January 2022. Given this change in wide access to testing, it became nearly impossible for health authorities to accurately track the total number of cases in the community during and after the Omicron wave, and thus, the transmission of SARS-CoV-2 within schools. Consequently, we are not aware of any published data on the risk of SARS-CoV-2 infections in the school setting compared with the corresponding risk of infection in the community after Omicron.

The main objective of this study was to determine the seroprevalence of SARS-CoV-2 infections among the staff of three large school districts within the Greater Vancouver area, after the first Omicron wave in BC and Canada, compared with the community seroprevalence, based on secondary data from blood donors collected over the same period, with the same age, sex and residential area.

MATERIALS AND METHODS

Study design and participants

This study is a cross-sectional analysis of data collected from January to April 2022 as part of the second phase of a prospective longitudinal cohort study.¹⁹ Participants that were current, full or part-time district staff members from three school districts (Vancouver, Richmond and Delta) within the Greater Vancouver area were originally recruited from 3 February to 31 May 2021. Staff were excluded at the time of initial recruitment in 2021 if they were temporary, on leave, on call with no classroom time or working exclusively in adult education. Staff whose status changed over the course of the study remained eligible to this study phase, unless they dropped out or asked to be withdrawn, or they retired, in which case they were not able to retain their district email address used for study communication.

For this second study phase, staff who participated in the first study phase and original recruitment in 2021 (n=2538)¹⁹ were emailed again on 26 January 2022, with subsequent reminder emails in the following weeks. Recruitment ended on 31 March 2022. Blood samples were collected for serology testing between 27 January and 8 April 2022, shortly after the first Omicron wave in BC (online supplemental figure 1). Comparative community data were obtained from Canadian blood donors who did not have COVID-19 at the time of serology collection, which occurred between 1 January and 31 March 2022.

Study setting

The Vancouver, Richmond and Delta school districts include 186 schools (150 elementary and 36 secondary) distributed in the greater metropolitan area of Vancouver, BC, Canada. Together, they serve a population of ~935 000 (2.6 million people live in the greater urban area). During the 2021–2022 school year, schools remained open all year long, as usual, except for planned holidays. COVID-19 mitigation measures implemented in district schools and indications for viral testing are detailed in online supplemental appendix 1.

Data collection

Questionnaire data

Data on sociodemographic factors, occupation, health status and history of COVID-19 exposures, testing, behaviour (eg, masking) and vaccination were collected from the school staff via an online questionnaire.¹⁹ To assess exposure to a COVID-19 case, participants were asked if a household member tested positive for COVID-19 and if anyone outside their household with whom they had close contact (defined as within 2 m and for 2 min or longer) had ever tested positive for COVID-19. Participants were asked if the close contact was a family member from outside the household, a friend, a coworker, a student or someone else (*check all that apply*). COVID-19 exposures were asked since the beginning of the pandemic (ie, a positive test, vaccination and exposure to a case since January 2020). An additional questionnaire that asked about mental health is not reported in this paper.

Serology testing

Venous blood samples were collected at clinics set up in participating Vancouver schools, at the BC Children's Hospital or outpatient clinical laboratories in the Greater Vancouver area. Samples were sent to the Canadian Blood Services national laboratory in Ottawa, Canada, for testing. Testing for anti-nucleocapsid (N) protein SARS-CoV-2 antibodies was performed using the Health Canada and Food and Drug Administration-licensed qualitative total antibody Roche Elecsys Anti-SARS-CoV-2 anti-nucleocapsid assay (Roche, USA) on a Cobas e601 analyser. Of note, the same serology assay was used and tested at the same facility for both school staff and blood donors. Specimens were considered reactive at a cut-off index ≥ 1.00 (online supplemental figure 2). N antibodies persist in blood with assay sensitivity maintained until at least a year after infection.²²

Secondary blood donor data

SARS-CoV-2 seroprevalence among blood donor data was obtained through a data request to Canadian Blood Services, on venous blood samples collected at outpatient clinics during routine donations. Seroprevalence data in blood donors living in the same geographical area as the school staff (by first two postal code digits), collected between 1 January and

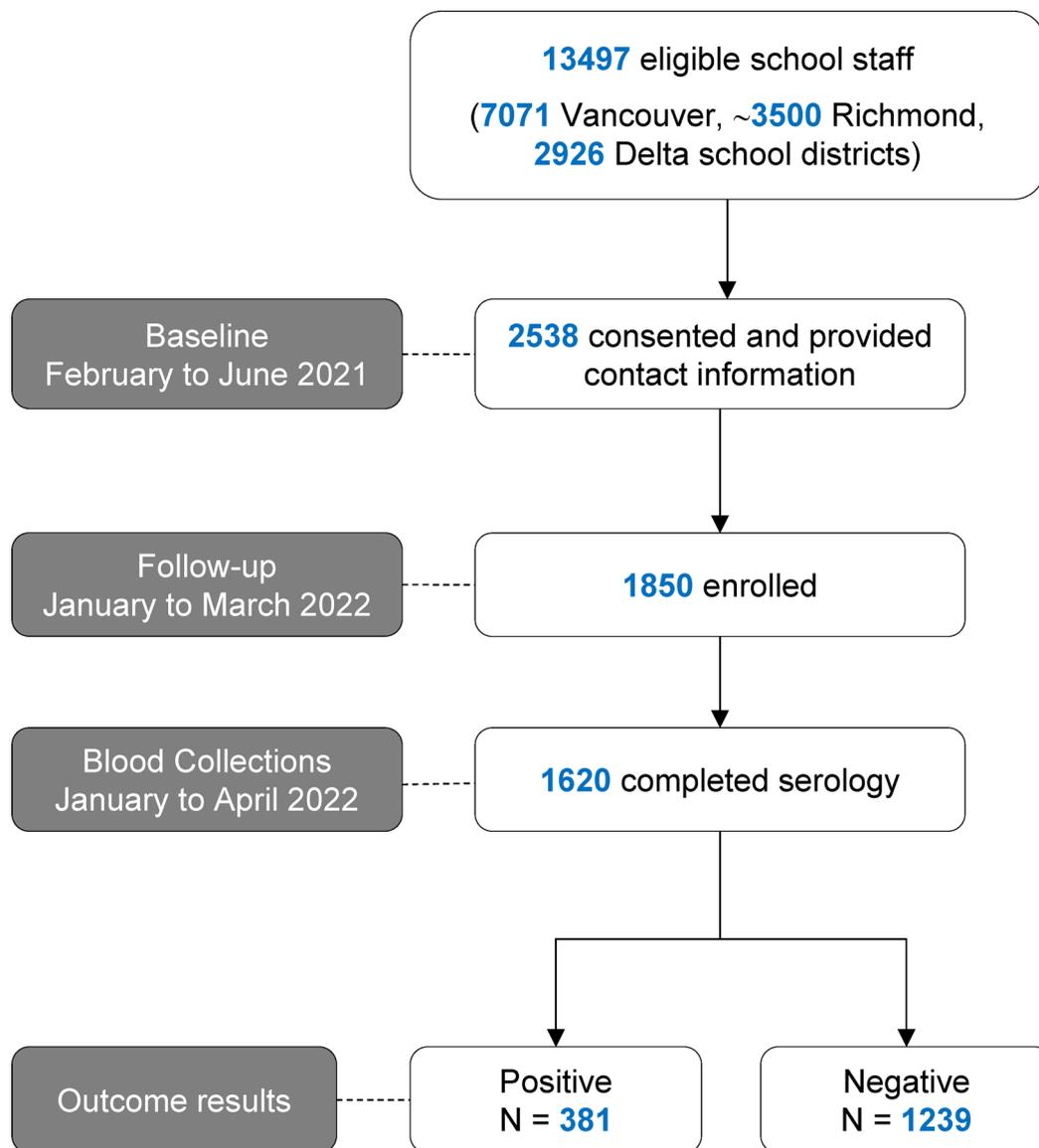


Figure 1 Flow diagram for enrolment of school staff study sample.

31 March 2022, were weighted according to a proportionally identical age, sex, sampling month and first two postal code digits distribution as the school sample, with the SE and 95% CIs calculated using the weighted frequencies. Both the school staff and the blood donors were asked to follow the public health recommendations for quarantine duration, if they had active COVID-19, before they could provide a blood sample. Almost all blood donors (~99%) were fully vaccinated, as confirmed also by spike serology testing.

Bias minimisation strategies

To ensure recruitment bias was minimised, we deployed extensive resources in an active recruitment and facilitation strategy to capture a maximum number of school staff over a defined recruitment period. Before the study began, district leaders, teachers and student support workers, and parent associations were engaged actively. Weekly meetings occurred with school district

representatives from study launching until publication, allowing to adapt our advertisement strategy with school district in real time during the recruitment phase (eg, reminder emails, etc). For serology sampling, blood collection sites were set up in a variety of geographically dispersed schools over lunch and after work or participants could attend one of over 100 private community clinics open on weekends or the BC Children's Hospital (for collection both within and outside normal working hours). A full-time study coordinator was hired to maintain contact with participants 7 days/week and facilitate blood collection with flexible hours, including driving around the city to meet the few participants who were unable to attend the blood clinics. Participants received a \$20 incentive and their serology results. Based on data from local health authorities on COVID-19 cases by school, participants were evenly distributed across schools with high and low reported COVID-19 cases within the Vancouver district, as we reported earlier.¹⁹

**Table 1** Self-reported exposure to COVID-19 cases and other markers of potential exposure to COVID-19 at home and at school among school staff

Variable	n*	School staff (n=1850)	n*	Serology sample (n=1620)
COVID-19 case among household members†, % Yes, n (%)	1842	424 (23.0)	1612	354 (22.0)
Live with children <18 years, n (%)	1845	758 (41.1)	1620	666 (41.1)
Live with essential worker, n (%)	1845	662 (35.9)	1610	572 (35.5)
Occupation of other household members working in an essential service: Agriculture and food production		11 (1.7%)		9 (1.6%)
Community services (waste disposal, emergency response, postal)		45 (6.8%)		41 (7.2%)
Construction, maintenance, skilled trades		89 (13.4%)		72 (12.6%)
Consumer products (hardware, safety, vehicle, sales, garden centres)		11 (1.7%)		9 (1.5%)
Financial services (banking, real estate, insurance)		20 (3.0%)		18 (3.2%)
Food (grocery, convenience, liquor, restaurant)		68 (16.8%)		60 (10.5%)
Healthcare		111 (16.6%)		91 (15.9%)
Social services, education, research		287 (43.4%)		253 (44.2%)
Manufacturing, resources, energy, utilities		19 (2.9%)		18 (3.2%)
Services (pharmacy, gas station, delivery, funeral, vet, etc)		22 (3.3%)		19 (3.3%)
Sports (professional)		5 (0.8%)		5 (0.9%)
Supply chain and transportation		37 (5.6%)		32 (5.6%)
Telecommunications and IT (including the media)		11 (1.7%)		10 (1.8%)
Other		87 (13.1%)		77 (13.5%)
Close contact‡ with a COVID-19 case outside household, n (%)	1845	1214 (65.8)	1615	1045 (64.7)
Another school staff member/work colleague		666 (54.9)		569 (54.5)
Student in classroom setting		625 (51.5)		533 (51.0)
Friend		553 (45.6)		461 (44.1)
Family (non-household member)		417 (34.4)		349 (33.4)
Other		93 (7.7)		81 (7.8)
Wear a mask in public places§, % Always or Often, n (%)	1839	1824 (99.2)	1611	1604 (99.6)
Coworkers wear masks§, % Always or Usually, n (%)	1826	1776 (97.3)	1603	1560 (97.3)
Students wear masks§, % Always or Usually, n (%)	1702	1502 (88.3)	1491	1323 (88.7)
Elementary	1043	892 (85.5)	917	788 (85.9)
Secondary	568	535 (94.2)	494	472 (95.5)

*Number of participants with data available for this variable.

†‘Since the last survey, has anyone in your household (not counting yourself) ever tested positive for COVID-19? ([Yes], [Not applicable, I live alone], [No one has been tested], [No, they tested negative], [Not sure, waiting for the result])’.

‡Reported contact with a known COVID-19 case within 2 m and for >2 min.

§Questions about masking were as follows: ‘How often have you worn a mask in public places in the past three months? (Never, Rarely, Occasionally, Often, Always)’; ‘To the best of your knowledge, how often do your co-workers wear a mask in your presence? (Never, Occasionally, Usually, Always)’; ‘To the best of your knowledge, how often do students in your school wear a mask in your presence? (Never, Occasionally, Usually, Always)’.

IT, information technology.

Statistical analyses

To estimate the seroprevalence among education workers, a Bayesian analysis was conducted to account for test specificity and sensitivity, and incorporating a hierarchical design to account also for variation in prevalence between school districts. For this analysis, 182 positive out of a total 205 (viral test-positive) infected samples (based on our own unpublished data in a fully vaccinated adult population), and 10 432 negative out of a total 10 453 uninfected samples (obtained before December 2019, based on data from the manufacturer, at: <https://diagnostics.roche.com/global/en/products/params/electsys-anti-sars-cov-2.html>) were incorporated using a binomial likelihood to account for the true evidence of test sensitivity and specificity. Weakly informative priors were selected for the baseline prevalence, logit sensitivity, logit specificity and scale of the regional variance. Two thousand samples were generated from the posterior with 1000 warm-up iterations and no thinning across four chains using the No-U-Turn Sampler (NUTS) sampling algorithm. Models accounting for variation across each school were also produced. Effective sample size, Gelman-Rubin statistic

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Table 2 Cumulative incidence of self-reported COVID-19 infections among school staff

Variable	n*	School staff (n=1850)	n*	Completed serology testing (n=1620)
Reported having COVID-19 symptoms†, n (%)	1845	301 (16.3)	1615	252 (15.6)
Number tested for COVID-19 (PCR), n (%)		766 (41.5)		668 (41.4)
At least one positive COVID-19 PCR test		120 (6.5)		99 (6.1)
More than one positive COVID-19 PCR test		4 (0.2)		2 (0.1)
All negative COVID-19 PCR tests		639 (35.0)		565 (35.3)
Did not know/could not remember test result		33 (1.8)		33 (4.3)
Number who tested positive by rapid test, n (%)	1842	206 (11.8)	1614	165 (10.2)
Number who tested positive by any test, n (%)	1845	291 (15.8)	1615	212 (13.1)
Hospitalised for COVID-19, n (%)	1845	1 (0.01)	1615	1 (0.06)

*Participants with non-missing data available.
 †Participants who reported that they had COVID-19 symptoms in response to: 'Do you think you've had covid? (Yes/No). If yes, why?'

and visual inspection of posterior sample chains were used to determine convergence, mixing and adequate sample size. Results were reported using the expectation under the posterior with 95% credible intervals (95% CrI). Details of the Bayesian model are further explained in online supplemental appendix 2. Bayesian analyses were conducted in R V.4.1.0 and Stan V.2.21.1.

To compare seroprevalence within school types, occupations and quartiles of contact hours with students, separate mixed effects logistic regression models, with school district as a random effect and age and sex as covariates, were used to obtain ORs, 95% CIs and p values. A p value <0.05 was considered statistically significant. Statistical analyses were done on cases with complete data; all variables had <1.0% missing data. Descriptive statistics were run using STATA V.17.0.

Patient and public involvement

During the study we corresponded daily with some of the study participants. District leaders (CO'R) and a liaison (Kathy O'Sullivan) were engaged before and during the study through weekly meetings, until after publication, to facilitate, provide support and seek feedback on study procedures. At the end, results were shared with study participants in a newsletter, with Canadian public health agencies and publicly as a preprint (<https://www.medrxiv.org/content/10.1101/2022.07.04.22277230v1>).

RESULTS

Characteristics of school staff sample

In total, 1850 school staff were enrolled (figure 1). Among enrolled staff, 80.7% (1485/1841 participants with complete data for this variable) were classroom workers with a median contact time with students of 20.0 (IQR: 6.0–30.0) hours/week. Most staff (1809/1830) had received at least two doses of a COVID-19 vaccine at the time of enrolment. The sample included staff from 185 schools out of 186 schools within the three school districts and lacked representation from one elementary school

in the Richmond school district. Overall, the school staff enrolled were representative of the school district populations in terms of age, proportion of classroom staff and residence area distribution, except for a higher proportion of females (80.8%) in the school staff sample versus the proportion of females (68.4%) in the entire Vancouver school district population (online supplemental table 1).

COVID-19 exposures among school staff

The potential sources of close contact with COVID-19 cases since the beginning of the pandemic among school staff are shown in table 1.

About one-third (662/1845) of staff reported living with an essential worker, 41.1% (758/1845) had children and 23.0% (424/1842) reported a COVID-19 case in the household (table 1). Two-thirds (1214/1845) reported close contact with a COVID-19 case outside the household, of which about half of these close contacts were with a case at school either in a student (625/1214) or coworker (666/1214). Half (960/1845) of school staff reported no close contact with a school case. Most staff reported that coworkers and students wore masks often or always at school in the past 3 months (table 1).

The self-reported cumulative incidence of COVID-19 diagnosed by nucleic acid or rapid antigen testing among the school staff since the beginning of the pandemic was 15.8% (291/1845; table 2).

One school staff required hospitalisation for COVID-19.

SARS-CoV-2 seroprevalence

Of the 1850 school staff enrolled prospectively, 1620 (87.6%) underwent serology testing with a median testing date of 14 February 2022 (online supplemental figure 1). The characteristics of the 1620 school staff who completed serology testing were representative of the 1850 school staff enrolled (table 3).

Of the 1620 school staff who underwent serology testing, 381 (23.5%) were positive by nucleocapsid antibodies, with a marginal difference in seroprevalence between females (23.9%; 95% CI 21.6% to

**Table 3** Characteristics of school staff sample

Variable	n*	Completed questionnaire (n=1850)	n*	Completed serology testing (n=1620)
Age (mean±SD)	1850	46.9±10.2	1620	47.5±10.1
Sex, % female, n (%)	1842	1510 (82.0)	1616	1331 (82.4)
Canadians of indigenous origin, n (%)	1845	33 (1.8)	1617	27 (1.7)
Ethnicity, n (%)	1850		1620	
White, Caucasian		1303 (70.4)		1118 (69.2)
South Asian		68 (3.7)		59 (3.7)
Chinese		309 (16.7)		288 (17.8)
Black		10 (0.5)		8 (0.5)
Filipino		31 (1.7)		28 (1.7)
Latin American		27 (1.5)		22 (1.4)
Arab		5 (0.3)		3 (0.2)
Southeast Asian		31 (1.7)		28 (1.7)
West Asian		1 (0.2)		3 (0.2)
Korean		14 (0.8)		13 (0.8)
Japanese		47 (2.5)		42 (2.6)
Other/no answer		56 (3.0)		45 (2.8)
Classroom workers†, n (%)	1841	1485 (80.7)	1611	1292 (80.2)
Contact time with students (hours/week), median (IQR)‡	1810	20.0 (6.0–30.0)	1585	20.0 (6.0–30.0)
Vaccination status, n (%)	1830		1613	
Not vaccinated		15 (0.8)		13 (0.8)
One dose		6 (0.3)		6 (0.4)
Two doses		249 (13.6)		213 (13.2)
Three or more doses		1560 (85.3)		1382 (85.6)
School level, n (%)	1837		1609	
Elementary		1081 (58.9)		947 (58.9)
Secondary		587 (32.0)		509 (31.6)
Work at multiple levels		59 (3.2)		51 (3.2)
School district office/other		110 (6.0)		102 (6.3)
At least one comorbidity§, n (%)	1845	491 (26.6)	1620	434 (26.8)
Smoker, n (%)	1836	26 (1.4)	1608	22 (1.4)

*Participants with non-missing data available.

†Including participants who reported being a teacher, teacher librarian, resource teacher, student support worker or family and youth worker in response to the question: 'What is your job title? (Teacher, Teacher Librarian, Resource Teacher, Student Support Worker, Family and Youth Worker, Administrator [Principal, Vice Principal], Administrative Assistant, Maintenance Staff, School Board Office Staff, Other)', and those who responded 'Other' and listed student-facing positions such as student aide, counsellor, speech language pathologist, etc.

‡29 staff indicated that they were on leave at the time they completed the survey and their responses were omitted from the contact time with students variable.

§Included the following conditions: hypertension, diabetes, asthma, chronic lung disease, chronic heart disease, chronic kidney disease, liver disease, cancer, chronic blood disorder, immunosuppression, chronic neurological disorder.

26.3%) and males (21.9%; 95% CI 17.2% to 27.2%). Of those who tested positive, 272 (71.4%) believed they had COVID-19 and 194 (50.9%) reported a previous positive viral test. The sampled posterior for the Bayesian seroprevalence model showed good convergence with Gelman-Rubin statistic 0.999–1 for all parameters. The unadjusted seroprevalence was

23.7% (95% CrI 21.7% to 26.0%) among all school staff, which was comparable after adjustment by school (online supplemental figure 3).

In mixed effects logistic regression models examining group differences in seropositivity by school level, occupation and contact with students, the unadjusted seroprevalence among all school staff was similar to staff working in

Table 4 COVID-19 seroprevalence by school education level and occupation

	Seropositivity	
	n (%)†	OR*
School level		
Elementary	220 (23.2)	Reference
Secondary	123 (24.1)	1.10 (0.85–1.43)
Multiple/mixed levels	11 (21.6)	0.87 (0.44–1.74)
School board office	21 (24.1)	1.14 (0.68–1.91)
Occupation		
Classroom worker	306 (23.7)	Reference
Other	73 (22.9)	1.07 (0.79–1.43)
Contact with students (hours/week), quartiles		
<6	85 (22.9)	Reference
6 to <20	93 (22.0)	0.91 (0.65–1.27)
20 to <30	87 (27.0)	1.18 (0.83–1.67)
>30	114 (23.1)	0.89 (0.64–1.24)
Total	381 (23.5)	n/a

*Individual mixed effects logistic regression models examining group differences in seropositivity by school level, occupation and contact with students were non-significant ($p > 0.05$).

†Cases by group based on those with non-missing data for each variable (<1% missing data); therefore, cases by variable do not add up to total cases.

n/a, not available.

a classroom setting, between staff working in elementary and secondary schools and among staff categorised by quartile of time spent in contact with students (table 4).

After taking into account the sensitivity and specificity of the serology test and regional variation, the adjusted seroprevalence was 26.5% (95% CrI 23.9% to 29.3%) among the staff of all school districts and 25.8% (95% CrI 22.9%–28.8%) after weighting by school. In comparison, the period-weighted, sex-weighted, age-weighted and residency location-weighted seroprevalence was 32.4% (95% CrI 30.6% to 34.5%) among 7164 blood donors, after taking into account the sensitivity and specificity of the serology test (online supplemental table 2). When examined for each district separately, seroprevalence rates were similar (online supplemental table 3).

DISCUSSION

This study found that one-quarter of school staff working within three of the largest school districts in the Greater Vancouver area in BC, Canada (serving approximately 83 000 students, and altogether, representing about one-third of all public school staff in BC), showed evidence of a past SARS-CoV-2 infection. The seroprevalence among the school staff was not higher compared with the community, represented by a demographically and regionally similar group of blood donors. To the best of our knowledge, this study is the first to report

seroprevalence estimates among school staff after the emergence of the highly transmissible Omicron variants. Findings are in keeping with other Canadian data^{19 23} and with a systematic review and meta-analysis performed in May 2021, of screening, contact tracing and seroprevalence studies from other areas of the world,²⁴ before the emergence of more transmissible SARS-CoV-2 variants. A major strength of this study is that it used sensitive antibody testing to account for asymptomatic SARS-CoV-2 infections that may not have come to clinical attention, using N-based serology testing,²⁵ in a large, representative Canadian sample of school staff.

About one-quarter of all COVID-19 cases reported in BC during the study period occurred in the regional health authority where the participating school districts are located. Despite a 10-fold increase in seroprevalence among school staff after the first Omicron wave in BC, compared with seroprevalence data obtained during the 2020–2021 school year,¹⁹ these findings suggest that the risk of SARS-CoV-2 infection in a highly vaccinated cohort of school workers remained no greater than the risk of infection in a group with similar demographics in the community. These findings contrast with the abundance of COVID-19 cases reported within schools throughout Canada, Europe and the USA and with concerns expressed in the media in BC and around the world throughout the pandemic. Understandably, hearing about COVID-19 cases in schools fuelled a high level of stress among the staff and students attending those schools and their families.^{2 26} Thus, it is important to provide tangible evidence to support or refute public claims. Despite frequent COVID-19 exposures in schools the data here support that many school COVID-19 cases were acquired outside, rather than within the school setting.^{8 27 28}

The statistically lower seroprevalence among school staff compared with the blood donor reference group in this study should be interpreted with caution. While blood donors are a particularly healthy group and may not be representative of the general population, they are likely representative of school staff compared with other socioeconomic groups at higher risk of COVID-19.^{29 30} However, it is important to state that the current study was not designed to determine whether the risk of COVID-19 infection in schools could be lower than the community. Potentially, some of the differences may be explained by differences in vaccination rates between school workers and the general population. Most importantly, the CrIs used to present the estimates in each group depend on the sensitivity of the serology tests for which there are little data in the context of a vaccinated population or Omicron. In another study, the crude seroprevalence in residents 30–59 years old of the Vancouver metropolitan area was 44.2% (265/600; 95% CI 40.2% to 48.2%),³¹ whereas in comparison, it was 36.8% (25/68; 95% CI 25.4% to 49.3%) when we consider only school staff in our study of the same age range sampled over the exact same period between 13 and 24 March 2022. This further supports that the risk of infection among

the school staff in this study was no higher than the risk in the community.

Limitations

This study has limitations. First, although we invested substantial efforts to facilitate blood sampling among school staff we cannot exclude a recruitment bias due to the non-random participation. However, the data comparing the staff sample with the whole district workforce suggest that these differences are negligible and likely due to chance. Our sample did include a higher proportion of females than the whole district workforce; in another study where samples were collected between 13 and 24 March 2022 among Vancouver metropolitan area residents, seroprevalence estimates were similar between females (43.1%) and males (41.9%).³¹ In the current study, crude seroprevalence estimates were also remarkably similar between females and males, so the difference in representation between the school staff sample and the district workforce is unlikely to have significantly impacted the results. Third, data were collected through self-reported questionnaires; therefore, recall biases may have impacted how participants responded, such as when reporting their masking behaviours. Although blood donors tend to be more health conscious than the general population, they are likely representative of school workers. Fourth, we did not obtain data on blood donors, so we cannot exclude that they may have differed by risk of infection. Finally, this study was conducted before mask mandates were lifted in schools in BC, so ongoing monitoring is warranted to determine if these conclusions will continue to hold true in later phases of the pandemic and restriction measures.

CONCLUSIONS

In conclusion, this study confirmed that a substantial proportion (26.5%) of sampled school staff working in three Metro Vancouver public school districts were infected with SARS-CoV-2 after a major and first Omicron wave in BC. Taking a conservative approach and considering the limitations of this study, these findings suggest that the risk of SARS-CoV-2 infection among school staff was not significantly higher than the risk of the community after the first wave of infections with Omicron in BC in early 2022.

Author affiliations

¹BC Children's Hospital Research Institute, Vancouver, British Columbia, Canada

²Department of Pediatrics, The University of British Columbia Faculty of Medicine, Vancouver, British Columbia, Canada

³School of Population and Public Health, The University of British Columbia, Vancouver, British Columbia, Canada

⁴Department of Pathology and Laboratory Medicine, The University of British Columbia, Vancouver, British Columbia, Canada

⁵British Columbia Centre for Disease Control, Vancouver, British Columbia, Canada

⁶Vancouver School Board, Vancouver, British Columbia, Canada

⁷Department of Mathematics and Institute of Applied Mathematics, The University of British Columbia, Vancouver, British Columbia, Canada

⁸Canadian Blood Services, Ottawa, Ontario, Canada

⁹School of Epidemiology and Public Health, University of Ottawa, Ottawa, Ontario, Canada

Twitter Pascal M Lavoie @Pascal_M_Lavoie

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Contributors LCM and PML obtained funding for this study. AWW, DMG, SMH, MAI, DC, PML and LCM designed the study. LM set up and coordinated the recruitment of participants. EB created the data management platform. BP processed the blood samples under the supervision of PML and VEB. MAI performed the statistical analyses. FR helped review the literature. SFO'B provided the matched data from Canadian blood donors. AWW and MP performed the data analyses. CO'R facilitated the communications within the Vancouver district. AWW and PML wrote the first draft of the manuscript. All other authors revised the manuscript and approved its final version. PML is responsible for the overall content as the guarantor.

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Competing interests CO'R is an employee of the Vancouver School District, but the latter was not involved in the design, analysis, interpretation of data or the drafting of this manuscript. LifeLabs played no role in the study other than providing a service for the collection of blood samples.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by The University of British Columbia Children's and Women's Research Ethics Board (H20-03593). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. Deidentified participant data and data dictionaries will be made available after publication through requests to the Government of Canada's COVID-19 Immunity Task Force.

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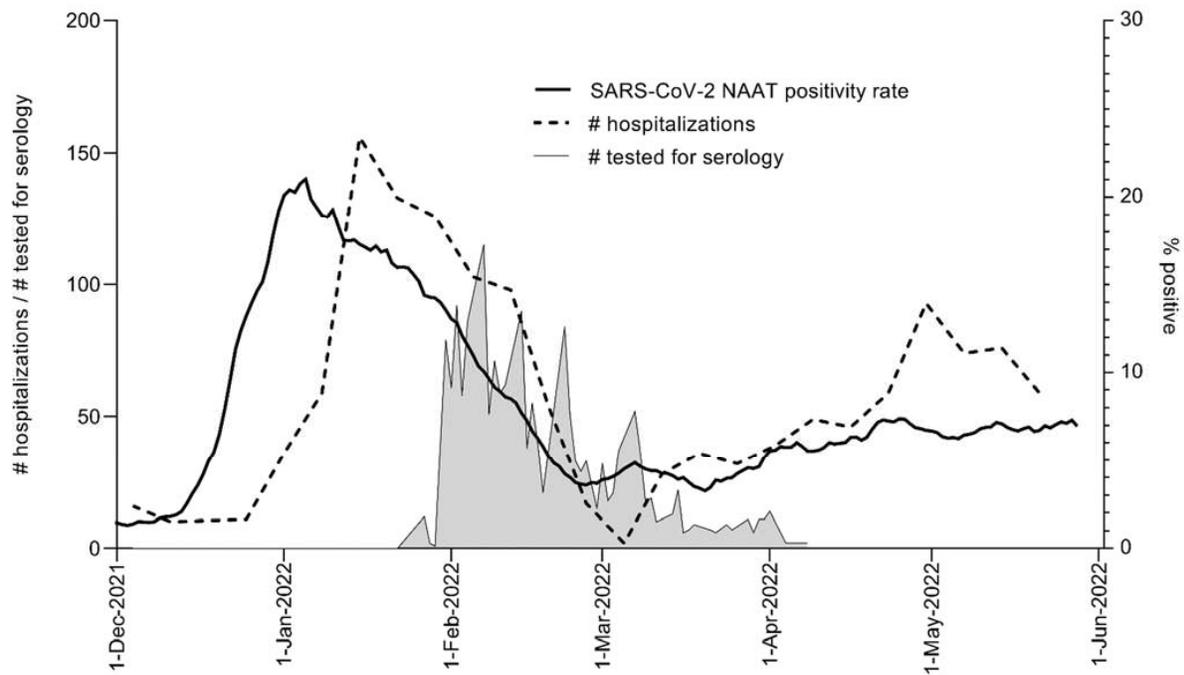
ORCID iDs

Mike A Irvine <http://orcid.org/0000-0003-4785-8998>

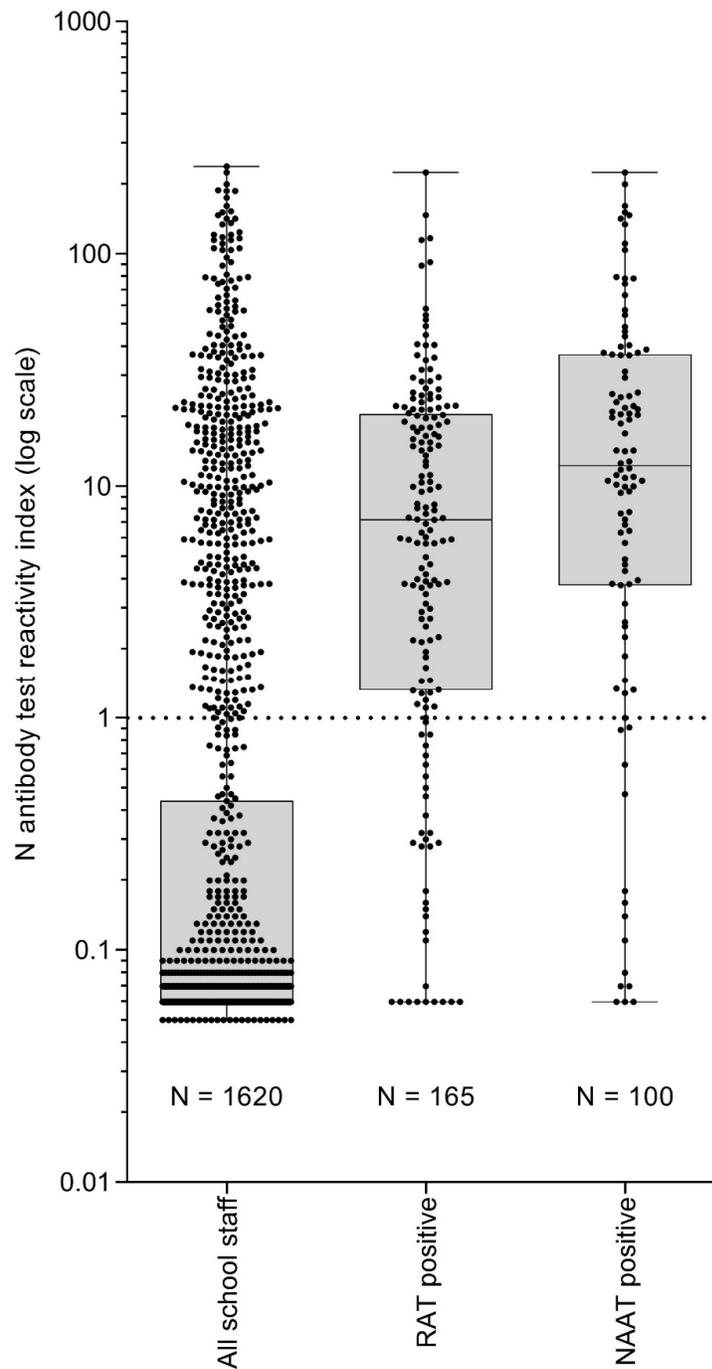
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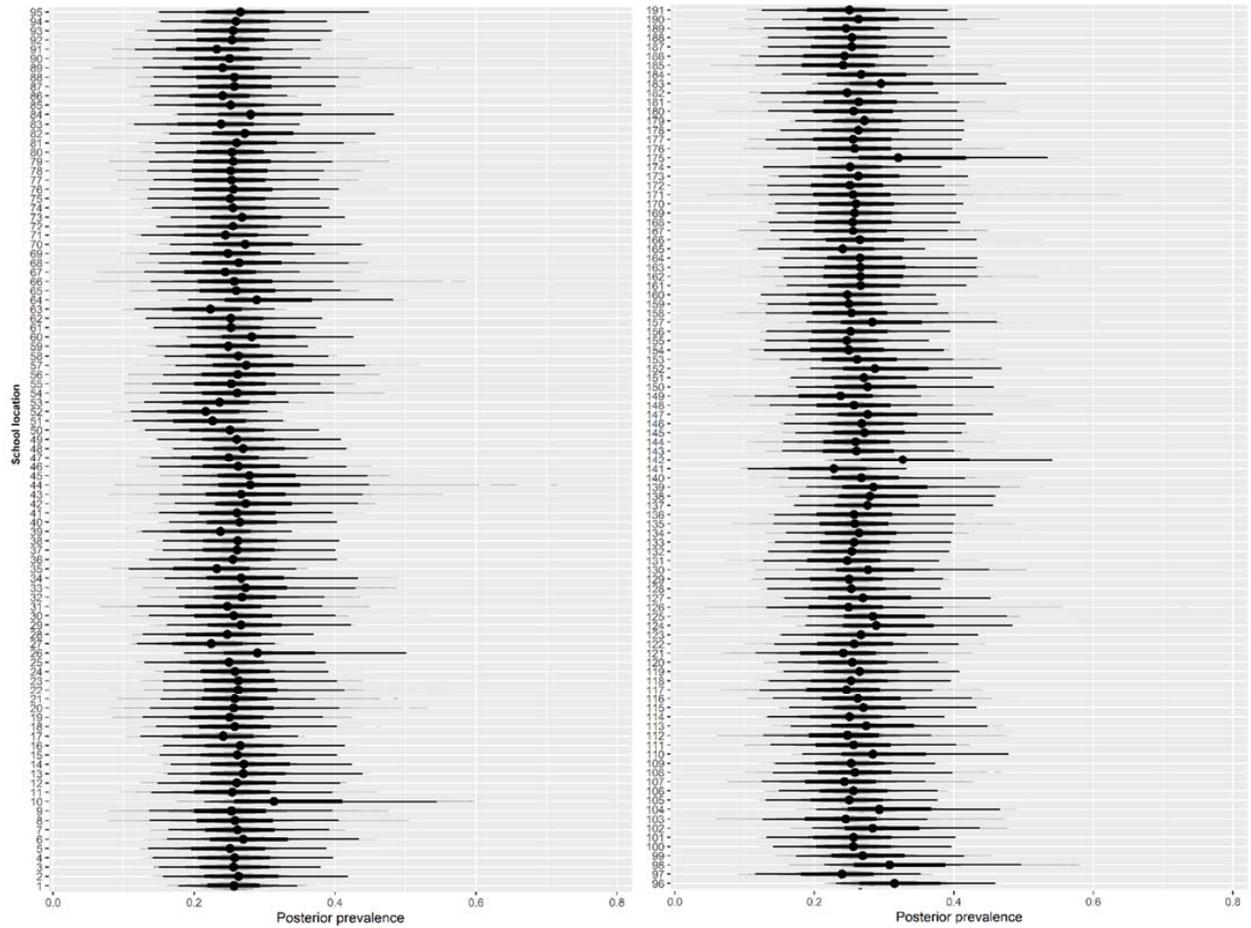
Supplemental Figure 1: Serology sampling in school staff in relation to COVID-19-related hospitalizations and viral Nucleic Acid Amplification Testing (NAAT) positivity rates in British Columbia - Dec 1, 2021 to June 1, 2022.



Supplemental Figure 2: Median antibody reactivity indices among a) all school staff, b) school staff who reported a positive SARS-CoV-2 Rapid Antigen Test (RAT) and c) school staff who reported a positive Nucleic Acid Amplification Test (NAAT). Boxes (median, with 25th and 75th centiles) and whiskers (min to max values). Dotted line = positivity threshold ≥ 1.00 reactivity index.



Supplemental Figure 3: Marginal posteriors for prevalence by school location under Bayesian hierarchical model with partial-pooling of school location. Points represent the median, with thicker line denoting the inter-quartile range and thin line denoting the 5th and 95th percentile.



Supplemental Table 1: Characteristics of school staff with serology data (n=1620) versus the entire corresponding school Districts.

Variable	School district					
	Vancouver		Richmond		Delta	
	Staff sample (n = 1147)	Population (n = 6872) ^{&}	Staff sample (n = 266)	Population (n ~ 3500)	Staff sample (n = 199)	Population (n = 2926)
Age (mean ± SD)	47.3 ± 9.8	47.6 ± 11.9	47.2 ± 10.4	NA	48.7 ± 10.7	45.3 ± 12.1
Female, %	80.8	68.4	86.8	NA	85.4	77.6
School type*, %						
Elementary School	65.9	64.7	59.8	NA	66.7	58.9
Secondary School	34.1	35.3	40.2		33.3	41.1
Classroom Staff ^α , %	80.2	78.7	81.2	NA	78.4	NA
Area of residency (by 2 digits postal code), %						
V0	0.3	0.3	0	NA	0	0.1
V1	0	0.1	0.4		0	0.7
V2	0.3	0.8	0		0.5	1.3
V3	7.0	11.0	5.7		22.2	26.3
V4	1.9	3.2	7.9		64.1	56.6
V5	52.1	50.5	10.2		7.6	6.5
V6	29.6	26.4	29.1		4.0	4.9
V7	8.7	7.7	46.8		1.5	3.1
V8	0	0.2	0		0	0.1
V9	0.1	0.3	0		0	0.1
Other	0.1	0.09	0	0	0.3	

*of those who report working exclusively in either an elementary or secondary school;

^αClassroom staff include teaching staff (including resource, counsellors, adjunct education staff who work with students), student support workers/education assistants, and family and youth workers;

NA = Data were not be provided by school authorities for the two smaller districts;

8 participants moved to other school districts and therefore have been excluded from this table.

Supplemental Table 2: Weighted seroprevalence among Canadian blood donors.

		School staff	Blood donor community	
		N (%)	Unweighted N (%)	Weighted N[#] (%)
Month	Jan	94 (5.9)	1911 (26.7)	419 (5.9)
	Feb	1131 (70.4)	2443 (34.1)	5042 (70.4)
	Mar	363 (22.6)	2520 (35.2)	1618 (22.6)
	April	19 (1.2)	290 (4.1)	85 (1.2)
Sex	F	1327 (82.6)	3579 (50.0)	5910 (82.5)
	M	280 (17.4)	3585 (50.0)	1254 (17.5)
Age (years)	17-24	4 (0.25)	61 (0.85)	18 (0.25)
	25-39	367 (22.8)	2715 (37.9)	1636 (22.8)
	40-59	1059 (65.9)	3088 (43.1)	4721 (65.9)
	≥60	177 (11.0)	1300 (18.2)	789 (11.0)
FSA2	V0	4 (0.25)	92 (1.3)	18 (0.25)
	V1	2 (0.13)	97 (1.4)	9 (0.12)
	V2	5 (0.31)	231 (3.2)	22 (0.31)
	V3	140 (8.9)	2026 (28.3)	624 (8.7)
	V4	176 (11.0)	1183 (16.5)	785 (11.0)
	V5	634 (39.5)	1543 (21.5)	2826 (39.5)
	V6	414 (25.8)	1293 (18.1)	1846 (25.8)
	V7	228 (13.4)	511 (7.1)	1016 (14.2)
	V8	3 (0.19)	118 (1.7)	13 (0.19)
Other	1 (0.06)	70 (0.98)	4 (0.06)	
Total		1607* (99.2 ^{&})	7164	
ROCHE N, positive			1987 (27.7)	2077 (29.0)

Weights were created by comparing (month*fsa2*sex*agegroup) frequency distribution in BC samples and CBS samples (i.e., BC proportion divided by CBS proportion). Each sample was multiplied by a weighting factor that would make it “count” for more or less to be comparable to the study group. For example, in January there were 100 17-24 year old males in V0 FSA of 1607 school staff (6.22%), and there were 200 17-24 year old males in V0 FSA of 7,164 blood donors (2.79%). Each donor’s result in that donor group was multiplied by 2.23 (=6.22 divided by 2.79) to weight it up to 6.22% of the sample.

*with data available (some staff had missing age, sex, or a residency location outside the “V” postal code).

[&]Percentage of entire school staff sample (n = 1620).

Supplemental Table 3: SARS-CoV-2 seroprevalence among school staff sample by school district.

Variable	School district		
	Vancouver (n = 1277)	Richmond (n = 1277)	Delta (n = 1277)
Unadjusted seroprevalence, % [95%CrI]	23.2% [20.9% to 25.6%]	24.2% [20.3% to 28.9%]	25.3% [21.3% to 31.6%]
Adjusted seroprevalence, % [95%CrI]	25.9% [23.0% to 29.0%]	27.1% [22.5% to 32.6%]	28.3% [23.6% to 35.6%]

Unadjusted seroprevalence is the raw rate of positive serology results. Adjusted seroprevalence is the the rate of positive serology results adjusted for the specificity and sensitivity of the serology test; 95%CrI: 95% credible intervals.

APPENDIX 1: COVID-19 mitigations measures in Vancouver schools (2021-2022 school year).

In August, prior to school opening 2021, the District implemented the 2021-2022 Communicable Disease Prevention Plan including additional COVID-19 Specific Prevention Measures - version 1, September 2, 2021. This document was revised as provincial guidance changed through to March 2022 - version 8: <https://www.vsb.bc.ca/COVID-19/updates/Pages/default.aspx>.

This CD Prevention Plan was based on guidance from the Provincial COVID-19 Health & Safety Guidelines for K-12 Settings:

- The BC Ministry of Education Guidance document: *K-12 COVID-19 Health and Safety Guidelines*: <https://www2.gov.bc.ca/assets/gov/education/administration/kindergarten-to-grade-12/safe-caring-orderly/k-12-covid-19-health-safety-guidelines.pdf>,
- The BC Centre of Disease Control (BCCDC) document: *COVID-19 Public Health Guidance for K-12 School Settings*: http://www.bccdc.ca/Health-Info-Site/Documents/COVID_public_guidance/Guidance-k-12-schools.pdf,
- The advice of the regional public health authority, Vancouver Coastal Health (VCH).

The purpose of this document is to lay out communicable disease prevention and control measures, including COVID-19, and address school specific matters as they relate to prevention. The document serves the district's employees, students, parents/guardians, volunteers, contractors, and visitors by providing appropriate information that can be used to prevent and reduce the risk of contracting and transmitting communicable disease in the district schools and workplaces.

The communicable disease prevention measures and controls included: public health measures (e.g., protocols for testing PCR and Rapid Antigen Tests, contact tracing), environmental measures (e.g., spread out to reduce crowding in classrooms / other school spaces, cleaning and disinfection 1x/day, improved fresh air intake), administrative measures (e.g., reducing crowding indoors - staggered recess/snack, lunch and class transition times, occupancy limits, scheduling appointments for parents/guardians/essential visitors, sign in and out procedures), personal measures (e.g., daily health checks, stay home if sick, physical distancing, hand hygiene, respiratory etiquette), and the use of personal protective equipment (PPE) (e.g. non-medical face masks) by all staff while indoors and for students Gr. 4-12 from school opening on September 7, 2021. This was followed by expanding mask requirements for students K-3 September 27, 2021, by the Vancouver School Board.

Formal Daily Health Assessments were required by all staff and students (via parents) prior to arriving at school and confirmed upon arrival. Anyone with even minor symptoms of cold or flu-like illness was to stay home or go home if these symptoms developed mid-day. Classrooms and other spaces were arranged to maximize distance between students and staff. Class sizes were set by grades: 20 students / class for kindergarten; 22 for grades 1 to 3; 30 for grades 4 to 12. School staff and their students were assigned specific classrooms which were between 75 m² – 83 m² for elementary students (K to grade 7) and 75 m² – 80 m² for secondary students (grades 8 to 12) with larger spaces available for elective courses (e.g., physical education, food studies, metal, woodworking, automotive).

The plan included school schedules for both Elementary students (K-7) and Secondary students (grade 8 to 12) to receive full day in-class instruction. Remote learning was no longer required or an option.

Ventilation measures included refurbishing ventilation and heating systems (HVAC) to ensure proper design operation; scheduling ventilation systems to run 2 hours prior to and after occupancy; increasing

outside air component in all systems through louvre adjustments, adding higher efficiency filters (MERV13); and ensuring occupant control over windows and louvres wherever possible to add fresh air flow in spaces.

Other measures included hand sanitizer in classrooms and common areas, directional traffic flow within the schools was controlled and transitioned to regular patterns, provision of plexiglass as provided for certain staff roles where mask wearing was not always an option and reception areas that were public facing, and the training of all staff on the safety plan and protocols. Regular daily cleaning by custodial staff continued and high touch surfaces were cleaned 1x daily or as required. Shared items in classrooms managed by teachers cleaned frequently as well at secondary school, the students were permitted to disinfect equipment. Non-medical face mask use was required Gr. K-12 for all staff and students while indoors at school sites and on school buses. This guidance did not apply if staff or students did not tolerate a mask for health or behavioural reasons. Most enrolled staff did not wear face shields. Face shields were made available to student support staff who work near students with diverse needs and to first aid attendants. As of March 24, 2022, the mask requirement was lifted and students, staff, and visitors could choose to wear, or not wear, masks, face shields or other personal protective equipment in schools and on school buses. Schools and worksites became “mask friendly” and wearing a mask became a personal choice. As of April 4, 2022, plexiglass barriers no longer recommended in alignment with public health recommendations.

SARS-CoV-2 nucleic acid amplification testing (PCR) was available for anyone with symptoms through the provincial health system and advised for students or staff with fever or new symptoms which persisted for over 24 hours. Tests were generally processed within 24 hours, and positive tests were automatically available to public health which investigated and contact traced cases, beginning within 24 hours. Symptomatic close contacts were asked to seek testing; testing was not used to release COVID-19 cases or contacts from isolation on an earlier timeline. Prior to COVID-19 vaccinations, close contacts, including close contacts at school, were isolated for at least 14 full days. Public Health offered COVID-19 vaccination clinics (secondary school sites only) October - November 2021 for those unable to see their health provider or attend their local community clinics. Mature minor consent was required for students in secondary school (under 19) and families in the community were welcomed. Fully vaccinated individuals under 18 years old with mild symptoms and testing is not recommended are to stay home and self-isolate for 5 days and return to school when symptoms subside. For those not fully vaccinated, isolation was recommended for at least 10 days until symptoms pass. See: <http://www.bccdc.ca/health-info/diseases-conditions/covid-19/if-you-have-covid-19#self-isolation>

In January 2022, due to Omicron and its subvariants bringing high transmission rates, public health revised their protocols and PCR testing, notification of individuals, and contact tracing ceased. Under the guidance of public health in consultation with the school district, rolling absentee thresholds are used for monitoring the school and grade level absenteeism. High rates of school and or grade level absenteeism over three consecutive days were to be reported to public health for further advisement. Further pandemic supports on January 20, 2022, included Rapid Antigen Test Kits distributed in a phased approach to all employees and students in the K-12 sector. Immunization rates were high, 89% fully vaccinated in the health region (September 2021 to June, 2022). School closures to control transmission were not required during the study period and no schools were required to functionally close due to staff shortages.

Last day of classes was June 29th, 2022, and June 30, 2022 was the last day for staff (administrative day).

APPENDIX 2: Description of Bayesian logistic regression model

We adapted the Bayesian hierarchical model of (1) and (2), incorporating a hierarchical structure across school districts. We had previously explored modeling the increasing rate of seroconversion in the population across surveys, however given the time-periods between surveys, changes in vaccination rates, and potential waning we opted for a more flexible approach at the potential cost of some increase in uncertainty. A full description of the model for each time-period and serotype is as follows.

First the sero-prevalence rate (π_i) for each district (i) was constructed using a global intercept term (b), and a hierarchical term (a_i) through the following equation,

$$\pi_i = \text{logit}^{-1}(b + a_i).$$

Where the parameters are transformed to represent a probability using the logistic function, $\text{logit}^{-1}: \mathbb{R} \rightarrow (0,1)$,

$$\text{logit}^{-1}(v) = \frac{1}{1 + \exp(-v)}.$$

For the hierarchical term we assume a simple hierarchical structure where each group are drawn from a distribution with mean zero and the same variance,

$$a_i \sim \text{normal}(0, \sigma_a),$$

Where the variance is drawn from the standard half-normal hyper-prior,

$$\sigma_a \sim \text{normal}_+(0,1).$$

We use an uninformative prior for the global intercept,

$$b \sim \text{logistic}(0,1).$$

The half-normal prior was used for for the variances as these constrain the variance to be higher, but can allow them to be arbitrarily small under sufficient evidence (3). The scale of the half-normals was set at 1, which makes them weak for this model (1). Given an observed number of positive tests (y_i) out of a given total number of tests for each district group (n_i), the positive tests are modeled as being binomially distributed with the corresponding sero-prevalence rate (π_i),

$$y_i \sim \text{binomial}(n_i, \pi_i).$$

As a sensitivity analysis we explored the impact of test sensitivity and specificity on the resulting sero-prevalence rate. For a given serotype with a logistic sensitivity θ_1 and a logistic specificity of θ_0 , and the disease prevalence rate π_i , the probability of getting a positive test result is

$$\Pr[x = 1] = \pi_i \cdot \text{logit}^{-1}(\theta_1) + (1 - \pi_i) \cdot \left(1 - \text{logit}^{-1}(\theta_0)\right).$$

For a total of n_i independent tests, the number of positive tests is distributed binomially with the preceding probability of success,

$$y_i \sim \text{binomial}\left(n_i, \pi_i \cdot \text{logit}^{-1}(\theta_1) + (1 - \pi_i) \cdot \left(1 - \text{logit}^{-1}(\theta_0)\right)\right).$$

The sensitivity and specificity were modeled using the positive and negative control samples, with y^{sens} positive samples out of n^{sens} samples in the positive controls and y^{spec} negative samples out of n^{spec} samples in the negative controls. The positive samples in the positive controls were modeled as a binomially-distributed random variable,

$$y^{sens} \sim \text{binomial}(n^{sens}, \text{logit}^{-1}(\theta_1)).$$

Similarly the negative samples in the negative controls are also modeled as a binomially-distributed random variable,

$$y^{spec} \sim \text{binomial}(n^{spec}, \text{logit}^{-1}(\theta_0)).$$

The priors for the logistic sensitivity and specificity were both drawn from a weakly informative normal distribution prior,

$$\theta_i \sim \text{normal}(4,2).$$

The priors were chosen here to produce a 95-percentile range of 0.5 – 1.0 for both sensitivity and specificity. The marginal posterior of the prevalence has been shown to be robust to specification of these priors for this model (1).

As a sensitivity analysis, the same model was applied to data stratified by school as opposed to region. The model still incorporated a single level representing the variation in sero-prevalence rates between schools. In addition, as a proportion of the sample included individuals where school location was not known or was missing, an additional sampling was performed of the between-school distribution to model the prevalence rates in the sample with missing location. For individual with missing location indexed by j ,

$$a_j \sim \text{normal}(0, \sigma_a).$$

The test result for individual j (I_j) is then modeled as a Bernoulli trial with an individual prevalence rate,

$$\rho_j = \text{logit}^{-1}(b + a_j).$$

The corresponding rate is then adjusted for the test characteristics as,

$$I_j \sim \text{Bern}\left(\rho_j \cdot \text{logit}^{-1}(\theta_1) + (1 - \rho_j) \cdot (1 - \text{logit}^{-1}(\theta_0))\right).$$

Post-stratification (4) was performed on the resulting posterior sero-prevalence rate samples (π_i) by marginalizing across the appropriate cells to adjust and stratify by district (i). Given the population size for an age group, sex and health region (p_i), the post-stratification sero-prevalence rate estimate is,

$$\hat{\pi}^{PS} = \frac{\sum_{i=1}^{10} p_i \cdot \pi_i}{\sum_{i=1}^{10} p_i}.$$

Median, 2.5th and 97.5th percentiles are estimated by sampling of the posterior. All models were implemented in Stan using No U-Turn Sampling (NUTS) with 1000 warm-up draws and 1000 post-warmup draws per 4 chains (5). The Gelman-Rubin statistic and visual inspection of the chains were used to determine convergence and mixing (6).

Additional references

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