

Effectiveness of Inactivated COVID-19 Vaccines Against COVID-19 Pneumonia and Severe Illness Caused by the B.1.617.2 (Delta) Variant: Evidence from an Outbreak in Guangdong, China

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Abstract

Background

Real-world evidence (RWE) of a vaccine supplements clinical trial data by providing information in populations differing from clinical trial populations, under different epidemiological situations, on alternative outcomes, or against different pathogen lineages. To date, RWE on inactivated COVID-19 vaccines against the highly transmissible SARS-CoV-2 B.1.617.2 (Delta) variant is limited, leaving an important gap in the evidence base of inactivated COVID-19 vaccines for use by immunization programs.

Methods

Between May and June 2021, an outbreak of the B.1.617.2 variant was discovered and traced in Guangdong, China. Before this outbreak, Guangdong province had started mass vaccination using inactivated vaccines approved by China's regulator for use in adults. Using surveillance and vaccination data from the outbreak, we assessed the real-world effectiveness of inactivated vaccines against pneumonia and severe illness caused by the B.1.617.2 variant. We enrolled 10813 subjects who were close contacts of laboratory-confirmed cases, categorizing them as an unvaccinated group, a partially vaccinated (1-dose) group, and a fully vaccinated (2-dose) group. We estimated relative risk (RR) and vaccine effectiveness (VE) of the vaccinated groups in relation to the unvaccinated group.

Findings

Unadjusted and adjusted VE of full vaccination against pneumonia were 77.7% (95% CI 45.1–90.9) and 69.5% (95% CI 42.8–96.3), respectively. Full vaccination was 100% effective against severe illness. Unadjusted and adjusted VE of partial vaccination against pneumonia were 1.4% (95% CI -79.7–45.9) and 8.4% (95% CI -47.6–64.4).

Interpretation

Full vaccination with inactivated vaccines is effective against pneumonia, severe, and critical illness caused by the B.1.617.2 variant. Effort should be placed to ensure full vaccination of target populations.

Funding

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Research in context

Evidence before this study

We searched the PubMed and medRxiv database for studies published from Jan 1, 2020 to Jul 22, 2021, with the combination of key words (vaccin OR immuniz OR immunis) AND (delta OR B.1.617.2) AND (effectiveness OR VE OR real-world) AND (sars-cov-2 OR COVID-19 OR COVID OR Severe Acute Respiratory Syndrome Coronavirus 2) to identify studies on the real-world effectiveness of COVID-19 vaccines against the B.1.617.2 variant. We excluded studies that were not conducted in humans or were not original studies. A retrospective cohort study in Scotland investigated the vaccine effectiveness (VE) of ChAdOx1 nCoV-19 and BNT162b2 vaccines against hospitalization associated with the B.1.617.2 variant. The study found that a vaccination status of at least 28 days after the first or second dose significantly reduced the risk of hospitalization by 62% (95% CI: 42-76). A test-negative case-control study in England, also examining ChAdOx1 nCoV-19 and BNT162b2 vaccines, found that both vaccines were effective against symptomatic infections of the B.1.617.2 variant (VE: 67.0% [95% CI, 61.3–71.8] and VE: 88.0% [95% CI, 85.3–90.1]). However, the magnitude of VE was reduced compared with that against the B.1.1.7 variant for both vaccines. A third study using Canadian data to investigate VE of

mRNA-1273, BNT162b2, and ChAdOx1 nCoV-19 vaccines against multiple types of variants suggested that full vaccination with BNT162b2 provided similar VE against symptomatic cases of the B.1.617.2 variant (87% [95% CI 64–95]) with that against the B.1.1.7 variant (89% [95% CI 86–91]). VE of full vaccination against symptomatic cases of the B.1.617.2 variant could not be estimated for the other two vaccines due to an absence of cases. We also identified studies that examined the effectiveness of inactivated vaccines. One study from Chile was identified, which found that inactivated vaccines were effective for the prevention of COVID-19 (65.9% [95% CI 65.2–66.6]) and COVID-19-related hospitalizations (87.5% [95% CI 86.7–88.2]). No evidence of VE of inactivated vaccines against the B.1.617.2 variant has been documented.

Added value of this study

An outbreak of the SARS-CoV-2 B.1.617.2 variant was discovered and traced in Guangdong, China, starting in late May 2021 and lasting through late June 2021. By analyzing data on vaccinated and unvaccinated individuals in mandatory, centralized quarantine identified through the tracing and management of the outbreak, we assessed real-world effectiveness of inactivated vaccines against pneumonia and severe illness caused by the B.1.617.2 SARS-CoV-2 variant. This variant is prevalent globally, yet the effectiveness of inactivated vaccines against the variant remains unknown. As such, evidence on the VE of inactivated vaccines against the B.1.617.2 variant represents an important addition to the knowledge base for policy-making in jurisdictions that have deployed mass vaccination using inactivated vaccines or are considering to do so. Our estimates of unadjusted and adjusted VE of full vaccination against pneumonia were 75.4% (95% CI 39.6–90.0) and 69.6% (95% CI 42.9–96.3), respectively. Full vaccination was 100% effective against severe illness.

Implications of all the available evidence

Our study provides strong evidence that full-series vaccination with inactivated COVID-19 vaccines reduce risk of pneumonia and severe illness from the B.1.617.2 variant. The evidence is consistent with VE studies of other COVID-19 vaccines against the B.1.617.2 variant. To ensure optimal protection of the population, mass vaccination campaigns should focus on completing the full two-dose series.

Introduction

Vaccination is considered an indispensable part of exit strategies from the COVID-19 pandemic.^{1,2} Due to an unprecedented global effort to develop COVID-19 vaccines, several types of vaccines were approved in many jurisdictions by early 2021.²⁻⁴ Among these, at least five were developed using whole-virus inactivation technology and have received partial or full approval in China and many other countries.⁴⁻⁷ Due to their long shelf life without need for ultra-cold chain, inactivated vaccines are relatively easy to store and dispense.⁸⁻¹⁰ Combined with their documented efficacy from randomized clinical trials (RCTs), inactivated vaccines may be a near-ideal candidate for mass immunization programs in low- and middle-income countries.^{8,11,12}

Whereas RCTs are the gold standards to estimate efficacy, their results may be limited in generalizability due subject selection/exclusion criteria and implementation restrictions. Real-world evidence (RWE) supplements RCT data by providing insight on comparative effectiveness among populations excluded or insufficiently included in licensure RCTs, conducted under different settings and epidemiological situations, using alternative outcomes, or are against a different lineage of the pathogen.^{13,14} To date, published RWE on COVID-19 vaccines has largely focused on mRNA vaccines, findings from which compare well with corresponding RCT results.¹⁵⁻¹⁹ Similar evidence on inactivated vaccines remains

sparse. A real-world study in Chile assessed the effectiveness of CoronaVac, an inactivated vaccine used for mass vaccination in over 20 countries.²⁰ That study provided convincing evidence of the protective effect of CoronaVac against COVID-19.²⁰

In late May 2021, an importation-related outbreak of a highly transmissible variant of SARS-Cov-2, the B.1.617.2 (Delta) variant, was discovered and traced in Guangdong, China.²¹ Characterized by spike protein mutations T19R, Δ157-158, L452R, T478K, D614G, P681R, and D950N, the B.1.617.2 variant reproduces at a faster rate than previously lineages seen in China, posing substantial challenges for disease control.^{21,22} The outbreak lasted from May 21 to June 18, 2021, during which 167 infected individuals were identified in clinical settings, during quarantine, or through community screenings. In addition to case identification, contact tracing continued through June 23, 2021. Before the start of this outbreak, China had already started to rapidly roll out mass immunization campaigns, with Guangdong province being one of the forerunners of vaccine deployment. Specifically, over 90 million doses were administered in Guangdong before mid-June 2021. Only inactivated vaccines were supplied in Guangdong by June 11, 2021. As such, the outbreak lent itself as an opportunity to gain insight into the effectiveness of inactivated vaccines against the B.1.617.2 variant.

By analyzing vaccination, surveillance, screening, tracing, and quarantine data based on China's COVID-19 prevention and control policies, we were able to assess the real-world effectiveness of inactivated vaccines against pneumonia and severe illness caused by the B.1.617.2 variant. The vaccines we evaluated are approved and recommended by the World Health Organization; more than 2 billion doses of these vaccines have been administered globally.

Methods

Study population and design

We conducted a retrospective cohort analysis of all close contacts of infected individuals identified in the Guangdong outbreak. Close contacts were defined in accordance with national and provincial COVID-19 prevention and control protocols.²³ Briefly, close contacts were defined as all individuals who lived in the same household or stayed in the same public space without protection within close distance within up to four days before illness onset for symptomatic cases, or were identified by the first positive specimen for asymptomatic cases. All close contacts were traced, mandatorily quarantined in centralized managed facilities, and followed up with multiple RT-PCR tests, thereby comprising our study cohort as the outbreak was proceeding and being managed.

A total of 12 501 individuals were identified as cases or close contacts by public health authorities. All positive specimens were subject to whole-genome sequencing. Individuals were excluded if basic demographic information was missing, they received two doses of vaccine but less than 21 days apart, or were younger than 18 years.

Vaccination status

Vaccination histories were obtained by interviewing individuals and reviewing vaccination records. To determine vaccination status, the number of doses received and the time elapsed since the most recent dose were used to define the intervention groups. Based on vaccination history, individuals were assigned to a unvaccinated group, a partially vaccinated (1-dose) group, or a fully vaccinated (2-dose) group. The unvaccinated group consisted of individuals who did not receive any COVID-19 vaccines before their last known contact with a confirmed case. The partially vaccinated group consisted of individuals who received their first dose 21 days or earlier than the last known contact. Individuals who

received their second dose at least 14 days before the last known contact comprised the fully vaccinated group. Our primary analysis was a 3-group comparison. Those who received their first dose within 21 days (intermediate 1st-dose) or their second doses within 14 days (intermediate 2nd-dose) before the last known contact were excluded in the primary analysis to avoid ambiguity in definition. Categorization of the groups is illustrated in Figure 1. In an alternate comparison, the intermediate 2nd-dose group was pooled with the partially and fully vaccinated groups as a single intervention group with any vaccination. The intermediate 1st-dose group was excluded in the alternative comparison.

Outcomes

The two outcomes of interest were pneumonia and severe/critical illness associated with the B.1.617.2 variant of COVID-19. Severity was based on subjects' most serious manifestations during the follow-up period, per judgement of clinicians.

Characteristics and covariates

Epidemiological investigators collected information on basic sociodemographic characteristics, including age, sex, address, occupation, and contact frequency. These variables were used as covariates in subsequent analyses. Age was categorized as 18-34 years old, 35-49 years old, and 50 years old and above. Contact frequency was adjudicated by investigators as occasionally, sometimes, and frequently. Occupation may have been associated with vaccination status, in that professionals in occupations with relatively high likelihood of exposure were granted priority of vaccinating during early 2021, whereas community-dwelling individuals, including unemployed persons were allowed to receive their free vaccines later on. To reflect heterogeneity in the chances of vaccinating, we created indicators for people in the catering industry and for unemployed people. There were two streets that were epicenters of the outbreak. The numbers of cases in these two communities accounted for over 60% of all outbreak cases. As such, residents of these two streets could have experienced higher risks of exposure. Geographic area might affect vaccination status through distribution practices of vaccines and related preventive behaviors. Therefore, an indicator was created for each of the two epicenter streets and used as a covariate in addition to the sociodemographic variables.

Four types of inactivated vaccines have been distributed and administered in China: HB02 (by Sinopharm), WIV04 (by Sinopharm), CoronaVac (by Sinovac), and Biokangtai's inactivated COVID-19 vaccine (BICV).^{4,12} Although not used as covariates in our analyses, we recorded and described the types of inactivated vaccines used by subjects.

Statistical analyses

Characteristics of subjects in each group were described using mean values (SD) and percentages, and tested using χ^2 tests and one-way analyses of variance (ANOVA). To estimate the unadjusted vaccine effectiveness (VE), the relative risks (RR) of each outcome was calculated in reference to the unvaccinated group and subtracted from one. In addition, multivariate logistic regressions were carried out to account for covariates that could potentially confound effect estimations. Adjusted odds ratios (OR) of logistic regressions were reported and used for inference of statistical significance. To estimate adjusted VE (aVE) from multivariate logistic regressions, we first calculated the adjusted relative risk (aRR) that equaled the ratio of the predicted event probability conditioned on being in each vaccination group in relation to that of being unvaccinated.²⁴ The aVE was then calculated as 1-aRR. We used aRRs to calculate aVEs because RRs are intuitively understandable for cohort studies and because ORs

consistently underestimated RRs for protection effects.²⁵ The standard errors of aRRs were estimated using the delta method, which is frequently used for nonlinear transformations of regression coefficients.²⁶ All analyses were conducted using Stata (version 16).

Sensitivity analysis

In a set of sensitivity analysis, vaccination status was defined based on the time since inoculation until the first report of the outbreak (May 21, 2021). In this sensitivity analysis, anyone who received their first dose and the second dose before May 7, 2021 were assigned to the partially vaccinated group and the fully vaccinated group, respectively. Unlike the base case, those who received vaccines after the initial outbreak were excluded. In addition, a between-dose window was not considered when determining vaccination status.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

We applied the inclusion and exclusion criteria to the 12 501 cases and close contacts that were eligible for initial inclusion. Among these, 199 individuals had missing sociodemographic information, 15 had received two doses less than 21 days apart, seven were vaccinated with non-inactivated vaccines, and 1 467 individuals were less than 18 years old. Consequently, 10 813 subjects met all inclusion and no exclusion criteria and were further assigned to different groups of intervention based on their vaccination histories. The sample selection flowchart is displayed in Figure 2.

Of the 10 813 individuals that met inclusion but not exclusion criteria, 5 888 (54.45%) were unvaccinated, 2 287 (21.15%) had an intermediate 1st dose, 843 (7.80%) were partially vaccinated, 388 (3.59%) had an intermediate 2nd dose, and 1 407 (13.01%) were fully vaccinated (Table 1). Among the 4 925 first doses, 2 392 (48.57%) were HB02, 6 (0.12%) were WIV04, 2 526 (51.29%) were CoronaVac, and one (0.02%) was BICV. Among the 1 795 second doses, 745 (41.50%) were HB02, four (0.22%) were WIV04, 1 046 (58.28%) were CoronaVac, and none were BICV.

Across the five groups, age ($p<0.001$), contact frequency ($p<0.001$), living in Zhongnan Street ($p<0.001$), living in Baihedong Street ($p<0.001$), and occupation ($p<0.001$) were statistically significantly different, whereas sex was comparable ($p=0.184$). The unvaccinated group had the greatest mean age (48.03 years, SD: 18.09), the highest proportion of the age group of 50 years and older (46.42%), the highest proportion of occasional contact (41.41%), and the lowest proportion of frequent contact (2.65%). In addition, the unvaccinated group had a higher percentage of Baihedong Street residents (13.69%) than any other groups, whereas its percentage of Zhongnan Street residents (2.51%) was lower than that of the partially and fully vaccinated groups, but not of the intermediate 1st-dose and 2nd-dose groups. The unvaccinated group had a proportion of unemployed individuals (3.09%) that was only second to that of the partially vaccinated group and had the second lowest proportion of catering industry professionals (3.82%) - only surpassed by the fully vaccinated group. Characteristics of the groups are listed in Table 1.

Unadjusted VE estimates are shown in Table 2. The unvaccinated, partially vaccinated, and fully vaccinated groups had 85 (1.44%), 12 (1.42%), and 5 (0.35%) COVID-19 pneumonia cases,

respectively. As such, the RRs of partial and full vaccination were 0.986 (95% CI 0.541–1.797) and 0.223 (95% CI 0.091–0.549), which corresponded to VEs of 1.4% (95% CI -79.7–45.9) and 77.7% (95% CI 45.1–90.9). Any vaccination was associated with an RR of 0.525 (95% CI 0.323–0.852) and a VE of 47.5% (95% CI 14.8–67.7) for COVID-19 pneumonia.

There were no severe or critical cases among vaccinated individuals. By contrast, the unvaccinated individuals had 19 severe or critical cases. As such, the RRs and VEs were zero and 100% for both vaccinated groups, and the uncertainty could not be estimated.

The aVEs and aORs from multivariate logistic regressions are presented in Tables 2 and 3. Multivariate analyses of severe and critical cases could not be conducted. Based on aORs and aVEs, partial vaccination was not associated with statistically significantly different incidence of pneumonia from no vaccination. However, the aORs of full vaccination against pneumonia [0.25 (95% CI 0.09–0.68)] was significant. Consistent with the aORs, the aVEs of full vaccination against pneumonia [69.5% (95% CI 42.8–96.3)] were both significant. Any vaccination was effective against COVID-19 pneumonia [aVE: 40.2% (95% CI 11.0–69.5)] in multivariate analyses.

Table S1 (online supplementary materials) shows the sensitivity analyses. Full vaccination consistently had significant VE against both outcomes whereas partial vaccination did not.

Discussion

Our study evaluated the effectiveness of inactivated COVID-19 vaccines against COVID-19 pneumonia and severe and critical COVID-19 caused by the B.1.617.2 variant in a real-world setting. Using close contacts as study subjects, we showed that inactivated VE against the B.1.617.2 (Delta) variant was 70% for COVID-19 pneumonia and 100% for serious/critical COVID-19. Thus, we documented evidence of VE of inactivated COVID-19 vaccines against both outcomes among a fully vaccinated population, but not among a partially vaccinated population.

Our results were robust to an alternative design. Notably, our VE estimates against COVID-19 pneumonia and severe and critical COVID-19 were in line with RCT results and other real-world studies.^{11,12,15,16,20} Our findings confirm that inactivated COVID-19 vaccines will be effective even when the B.1.617.2 variant is prevalent.

Our study has important policy implications. First, it is critically important to continue mass immunization programs to ensure full vaccination of the target population. As indicated by the results, partial vaccination with inactivated vaccines provides insufficient protection. Second, inactivated vaccines are a viable option to construct population immunity in spite of recent mutations of the virus. Third, the VE estimates against pneumonia and severe and critical cases calls for refreshed evaluations of strategies to manage the pandemic in the long term, and should be highlighted in future planning. To our knowledge, this study adds unique contributions to the scientific literature. First, it expanded upon a previous study on the real-world effectiveness of inactivated vaccines by investigating multiple instead of one specific type of vaccine in this class.²⁰ Second, it provided preliminary evidence of the VE of inactivated vaccines against the B.1.617.2 (Delta) variant. Third, it is the first study that documented VE against clinical outcomes other than intermediate endpoints of COVID-19 in mainland China. By combining these features, the present study generated new evidence that helps informed decision-making.

Our study has limitations. First, as with all observational studies, and although we controlled for known covariates, residual unmeasured confounders might have compromised the validity of the analyses. Second, moderate incidence rates and vaccination rates made subgroup analyses not possible. Despite

these two limitations, we believe that our study provides useful insights on the effectiveness of vaccines and suggested that inactivated vaccines may be effective against COVID-19 pneumonia and severe and critical COVID-19 associated with the B.1.617.2 variant of COVID-19, if fully vaccinated.

Contributors

MK, YL, and JH conceptualised and coordinated the study. YJ contributed to the literature search. YJ and YY drafted the manuscript. MC, JL, AD, TH, YY, JZ, ML, and JJ contributed to the epidemiological investigation and collected the data. YY, YJ, and MK accessed, verified and analysed the data. All authors contributed to interpretation of results and revision of the manuscript.

Declaration of interests

We declare no competing interests.

Data sharing

Individual-level data will not be made publicly available with this article. Requests for sharing of deidentified individual-level data for scientific research can be directed to MK (kangmin@yeah.net).

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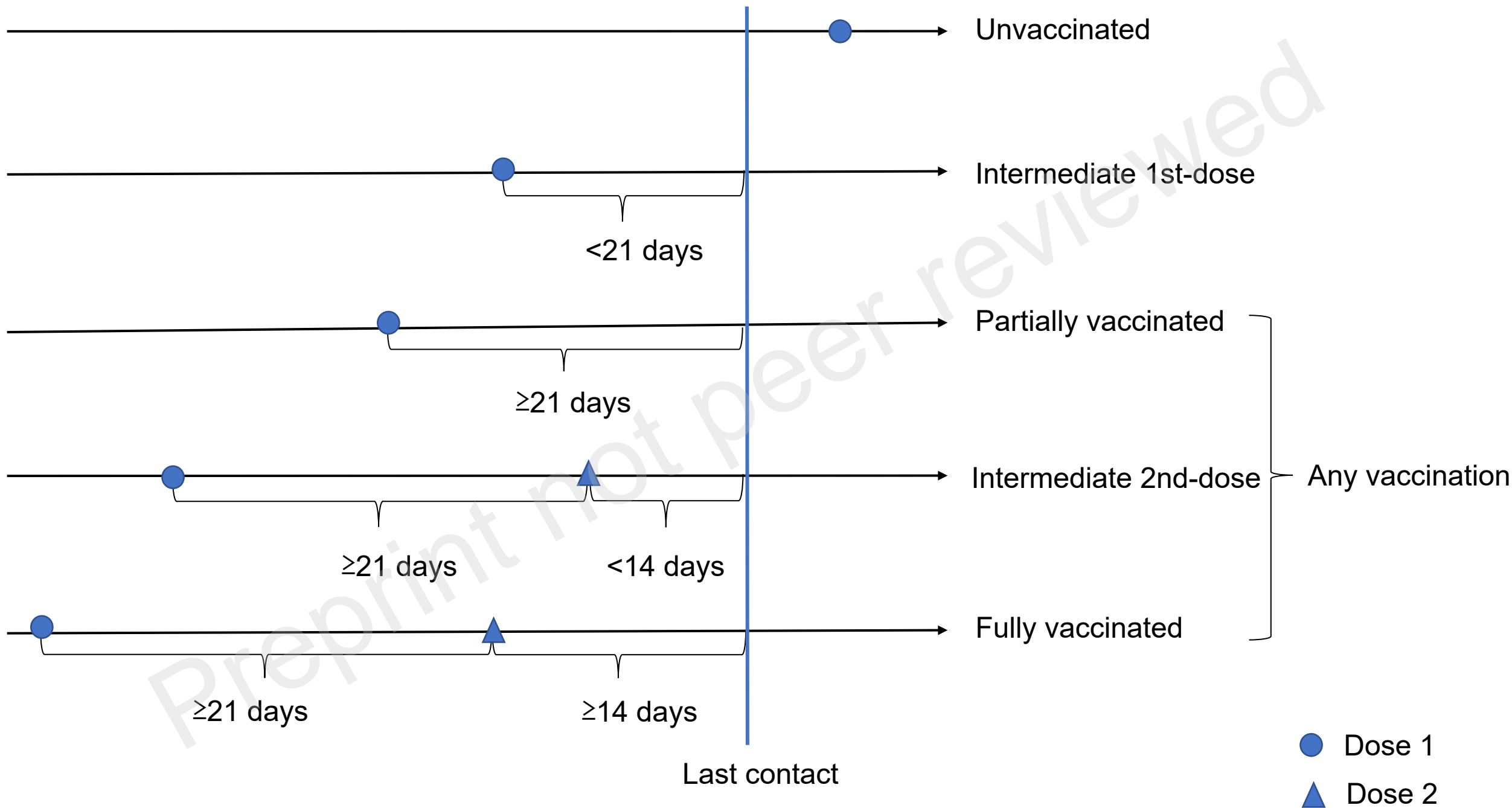
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Figure legends

Figure 1. Definition of Different Vaccination status

Figure 2. Sample selection

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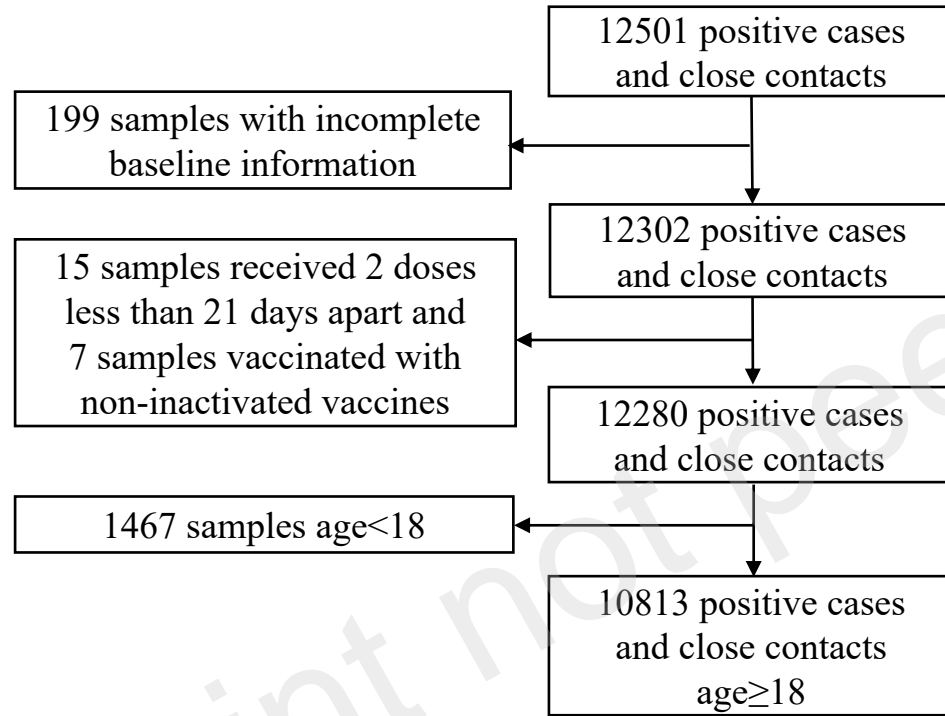


Table1. Characteristics by Vaccination status

Characteristics	No. (%)					Total (N=10813)	p value
	Unvaccinated (N=5888, 54.45%)	Intermediate 1st- dose (N=2287, 21.15%)	Partially vaccinated (N=843, 7.80%)	Intermediate 2nd- dose (N=388, 3.59%)	Fully vaccinated (N=1407, 13.01%)		
Sex							
Male	3174 (53.91)	1198 (52.38)	454 (53.86)	189 (48.71)	772 (54.87)	5787 (53.52)	0.184
Female	2714 (46.09)	1089 (47.62)	389 (46.14)	199 (51.29)	635 (45.13)	5026 (46.48)	
Age, mean (SD)	48.03 (18.09)	38.31 (11.40)	38.53 (10.92)	38.76 (10.71)	39.30 (10.54)	43.77 (15.98)	<0.001
Age groups							
18–34 yr	1798 (30.54)	967 (42.28)	336 (39.86)	154 (39.69)	513 (36.46)	3768 (34.84)	<0.001
35–49 yr	1357 (23.05)	877 (38.35)	340 (40.33)	160 (41.24)	608 (43.21)	3342 (30.91)	
≥50 yr	2733 (46.42)	443 (19.37)	167 (19.81)	74 (19.07)	286 (20.33)	3703 (34.25)	
Contact frequency							
Occasionally	2438 (41.41)	880 (38.48)	327 (38.79)	134 (34.54)	496 (35.25)	4275 (39.54)	<0.001
Sometimes	3294 (55.94)	1343 (58.72)	473 (56.11)	234 (60.31)	829 (58.92)	6173 (57.08)	
Frequently	156 (2.65)	64 (2.80)	43 (5.10)	20 (5.15)	82 (5.83)	365 (3.38)	
Street							
Zhongnan	148 (2.51)	44 (1.92)	47 (5.58)	7 (1.80)	45 (3.20)	291 (2.69)	<0.001
Baihedong	806 (13.69)	130 (5.68)	81 (9.61)	30 (7.74)	141 (10.02)	1188 (10.99)	
Others	4934 (83.80)	2113 (92.39)	715 (84.81)	351 (90.46)	1221 (86.78)	9334 (86.32)	
Occupation							
Catering	225 (3.82)	186 (8.14)	48 (5.69)	22 (5.67)	34 (2.42)	515 (4.76)	<0.001
Unemployed/home	182 (3.09)	60 (2.62)	27 (3.20)	7 (1.80)	27 (1.92)	303 (2.80)	
Others	5481 (93.09)	2041 (89.24)	768 (91.10)	359 (92.53)	1346 (95.66)	9995 (92.44)	
First dose							

HB02	NA	1316 (57·54)	333 (39·50)	146 (37·63)	597 (42·43)	2392 (48·57)	<0·001
WIV04	NA	0 (0)	2 (0·24)	1 (0·26)	3 (0·21)	6 (0·12)	
CoronaVac	NA	970 (42·41)	508 (60·26)	241 (62·11)	807 (57·36)	2526 (51·29)	
BICV	NA	1 (0·04)	0 (0)	0 (0)	0 (0)	1 (0·02)	
Second dose							
HB02	NA	NA	NA	163 (42·01)	582 (41·37)	745 (41·50)	0·960
WIV04	NA	NA	NA	1 (0·26)	3 (0·21)	4 (0·22)	
CoronaVac	NA	NA	NA	224 (57·73)	822 (58·42)	1046 (58·28)	
BICV	NA	NA	NA	0 (0)	0 (0)	0 (0)	
Pneumonia							
Yes	85 (1·44)	16 (0·70)	12 (1·42)	3 (0·77)	5 (0·36)	121 (1·12)	0·001
No	5803 (98·56)	2271 (99·30)	831 (98·58)	385 (99·23)	1402 (99·64)	10692 (98·88)	
Severe/Critical							
Yes	19 (0·32)	0 (0)	0 (0)	0 (0)	0 (0)	19 (0·18)	0·003
No	5869 (99·68)	2287 (100)	843 (100)	388 (100)	1407 (100)	10795 (99·82)	

Notes: *p* value is obtained from chi-square tests or one-way analysis of variance, depending on whether the variable is categorical or continuous.

Table2. Vaccine effectiveness in preventing pneumonia, severe/critical cases by vaccination status

Outcomes	Vaccination status	N (%)	RR (95% CI)	Unadjusted VE (95% CI)	aVE (95% CI)
Pneumonia	Unvaccinated	85 (1·44)	Ref	-	-
	Partially vaccinated	12 (1·42)	0·986 (0·541–1·797)	1·4% (-79·7–45·9)	8·4% (-47·6%,64·4%)
	Fully vaccinated	5 (0·35)	0·223 (0·091–0·549)	77·7% (45·1–90·9)	69·5% (42·8%,96·3%)
	Any vaccination	20 (0·76)	0·525 (0·323–0·852)	47·5% (14·8–67·7)	40·2% (11·0%,69·5%)
Severe/ Critical	Unvaccinated	19 (0·32)	Ref	-	-
	Partially vaccinated	0 (0)	0 (NA)	100% (NA)	-
	Fully vaccinated	0 (0)	0 (NA)	100% (NA)	-
	Any vaccination	0 (0)	0 (NA)	100% (NA)	-

Notes: CI: confidence interval; VE: vaccine effectiveness; aVE: adjusted vaccine effectiveness.

Table 3. Adjusted odds ratios (aORs) from multivariate logistic regressions

Covariates	Pneumonia
Vaccination statuses (Ref: Unvaccinated)	
Partially vaccinated	0.90 (0.43–1.86)
Fully vaccinated	0.25** (0.09–0.68)
Sex (Ref: female)	0.44*** (0.28–0.69)
Age groups (Ref: 18–34 yr)	
35–49 yr	1.81 (0.80–4.12)
≥50 yr	4.25*** (2.06–8.79)
Occupation (Ref: Others)	
Catering	3.24 (0.94–11.15)
Unemployed/home	11.17*** (6.24–19.98)
Street (Ref: Others)	
Zhongnan	6.94*** (3.15–15.28)
Baihedong	11.89*** (7.31–19.35)
Contact frequency (Ref: Sometimes)	
Occasionally	1.51 (0.92–2.50)
Frequently	29.91*** (16.47–54.28)

Note: Adjusted odds ratios and 95% confidence intervals are shown.

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.