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Carditis After COVID-19 Vaccination With a Messenger RNA Vaccine and an Inactivated Virus Vaccine

A Case–Control Study

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Background: Case reports of carditis after BNT162b2 vaccination are accruing worldwide.

Objective: To examine the association of BNT162b2 and CoronaVac (Sinovac) vaccination with carditis.

Design: Case–control study with hospital control participants.

Setting: Territory-wide, public health care database with linkage to population-based vaccination records in Hong Kong.

Patients: Inpatients aged 12 years or older first diagnosed with carditis were selected as case patients. All other hospitalized patients without carditis were treated as control participants. Ten control participants were randomly matched with each case patient by age, sex, and admission date.

Intervention: Vaccination with BNT162b2 or CoronaVac.

Measurements: Incident diagnosis of carditis based on the International Classification of Diseases, Ninth Revision, and elevated troponin levels.

Results: A total of 160 case patients and 1533 control participants were included. Incidence of carditis per 100 000 doses of CoronaVac and BNT162b2 administered was estimated to be 0.31 (95% CI, 0.13 to 0.66) and 0.57 (CI, 0.36 to 0.90), respectively. Multivariable analyses showed that recipients of the BNT162b2 vaccine had higher odds of carditis (adjusted odds ratio [OR], 3.57 [CI, 1.93 to 6.60]) than unvaccinated persons. Stratified by sex, the OR was 4.68 (CI, 2.25 to 9.71) for males and 2.22 (CI, 0.57 to 8.69) for females receiving the BNT162b2 vaccine. The ORs for adults and adolescents receiving the BNT162b2 vaccine were 2.41 (CI, 1.18 to 4.90) and 13.79 (CI, 2.86 to 110.38), respectively. Subanalysis showed an OR of 9.29 (CI, 3.94 to 21.91) for myocarditis and 1.06 (CI, 0.35 to 3.22) for pericarditis associated with BNT162b2. The risk was mainly seen after the second dose of BNT162b2 rather than the first. No association between CoronaVac and carditis with a magnitude similar to that for BNT162b2 was seen.

Limitation: Limited sample size, absence of electrocardiography and other clinical investigative data, and unrecorded overseas vaccination exposure.

Conclusion: Despite a low absolute risk, there is an increased risk for carditis associated with BNT162b2 vaccination. This elevated risk should be weighed against the benefits of vaccination.

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Carditis is an acute condition presenting with inflammation of the heart. Common subtypes include myocarditis (heart muscle) (1) and pericarditis (outer lining of the heart) (2). Viral, bacterial, or parasitic infections are often causes of this condition (1–3). Noninfectious causes include autoimmune, neoplastic, and metabolic risk factors as well as various specific drugs (4). Carditis is rare and mostly self-limiting—the incidence rate of myocarditis is estimated at approximately 20 cases per 100 000 person-years globally (5, 6).

Case reports of carditis after the emergency use of the messenger RNA (mRNA) COVID-19 vaccine BNT162b2 (Pfizer–BioNTech) are rapidly accruing in various populations worldwide (7–10), despite the lack of an observed elevated risk from clinical trial data (phases 1 to 3), which may be limited by a relatively small sample size (11). As shown in a recent study comparing risk differences of carditis after the first and second doses of BNT162b2 (12), a predominant proportion of the cases involved younger male persons presenting with myocarditis after receiving the second dose (13, 14). On 23 August 2021, the U.S. Food and Drug Administration approved the regular use of BNT162b2 for COVID-19 prevention among persons aged 16 years or older. The approval stipulates a population-based postmarketing assessment of the association between carditis and BNT162b2 in both the short and the longer term with regular data updates (15). A recent Israeli retrospective cohort study of nearly 1 million persons reported an elevated risk for myocarditis (identified using routine health care diagnostic codes) associated with receiving BNT162b2 (16), with a risk ratio of 3.24 (95% CI, 1.55 to 12.44) and an additional 2.7 events (CI, 1.0 to 4.6 events) per 100 000 vaccinated persons. Nevertheless, analytic research on this widely speculated association remains scant (14, 17). Published studies comparing the incidence of carditis in

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vaccinated persons with the historical incidence may be biased by changes in the baseline risk for other natural causes of carditis during the pandemic (12), especially regarding infection-related carditis. Further research is needed to provide evidence to assist policymakers and potential vaccine recipients in making informed decisions. To date, no evidence indicates whether this risk is specific to such vaccine technologies as mRNA vaccines. To our knowledge, no research has compared this risk against that of other vaccine platforms, such as inactivated virus vaccines.

Hong Kong is among the few jurisdictions to approve the emergency use of COVID-19 vaccines from 2 different technology platforms. The BNT162b2 vaccine was made available on 6 March 2021, soon after the launch of CoronaVac, an inactivated virus vaccine developed by Sinovac, on 23 February 2021 (18). Since the rollout of the public-funded mass vaccination program, more than 7 million doses of the COVID-19 vaccines have been administered, alongside the implementation of a surveillance program for safety monitoring (19). As of 2 August 2021, about 3.29 million (49%) of the population aged 12 years or older (6.7 million) have been vaccinated. In this case–control study, we analyzed a territory-wide, routine, public health care database with linkage to population-based vaccination records to examine the association of BNT162b2 and CoronaVac vaccination with carditis.

METHODS

Study Design and Data Source

We did a case–control study following the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guideline (20). Routine health care records provided by the Hospital Authority (HA) of Hong Kong were linked with population-based vaccination records at the Department of Health to allow case and control identification and exposure (vaccination status) ascertainment. Matching between inpatient and vaccination records for selected case patients and control participants was based on the Hong Kong Identity Card number or other personal identification numbers, such as foreign passports, and was done by the HA.

The HA is the sole provider of public inpatient services and a major provider of public outpatient services in Hong Kong, with a comprehensive electronic health record (EHR) system for clinical management. Each Hong Kong resident has a unique Hong Kong Identity Card number that allows the HA to create a unique EHR for each patient to link attendances to all health care facilities. Data from the HA EHR are deidentified, and pseudoanonymized data are transferred daily to the Clinical Data Analysis and Reporting System (CDARS), a non–claims-based clinical management database with the EHRs of all patients who used HA health care services. The EHRs in CDARS include demographic characteristics, diagnoses, medication dispensing records, outpatient and primary care clinics, emergency department attendances, laboratory tests, and hospitalization details —all comprehensively recorded for research or auditing purposes (21). The database has frequently been used for high-quality pharmacovigilance studies to evaluate the safety of medicines and vaccines at population level (21–23). A previous study showed high coding accuracy for cardiovascular diagnosis in CDARS, with positive predictive values estimated at 85% to 91% (24).

Case and Control Selection

Using the definition from the ACCESS (vACCine covid-19 monitoring readinESS) project funded by the European Medicines Agency (25), we defined case patients as patients first diagnosed with carditis (acute myocarditis or pericarditis; International Classification of Diseases, Ninth Revision, Clinical Modification [ICD-9-CM] codes 420.9, 422.x, 423.9, and 429.0) in an inpatient setting from 23 February to 2 August 2021, identified in CDARS. Patients younger than 12 years and those with any history of carditis were excluded from the analysis. To reduce potential misdiagnosis, case patients with a subsequent diagnosis of myocardial infarction (ICD-9-CM codes 410.x to 411.x) after carditis diagnosis, case patients without laboratory test results of troponin levels, or case patients without an elevated troponin level during admission were excluded to ensure they were "probable cases" according to the Brighton Collaboration's definition (26). We adopted the reference thresholds used for the different testing kits of individual hospitals, which were calibrated independently, to indicate the elevation of troponin levels (**Supplement Table 1**, available at Annals.org). All other hospitalized patients during the same period without a diagnosis of carditis were treated as control participants. Ten control participants were randomly matched with each of the case patients according to age (within the same year), sex, and date of admission (within 1 calendar day).

Exposure

Receipt of any dose of BNT162b2 or CoronaVac before the index date (date of hospital admission) was categorized as an exposure (versus the unvaccinated). In Hong Kong, the recommended dosing intervals (number of days between doses) for BNT162b2 and CoronaVac are 21 and 28 days, respectively (27).

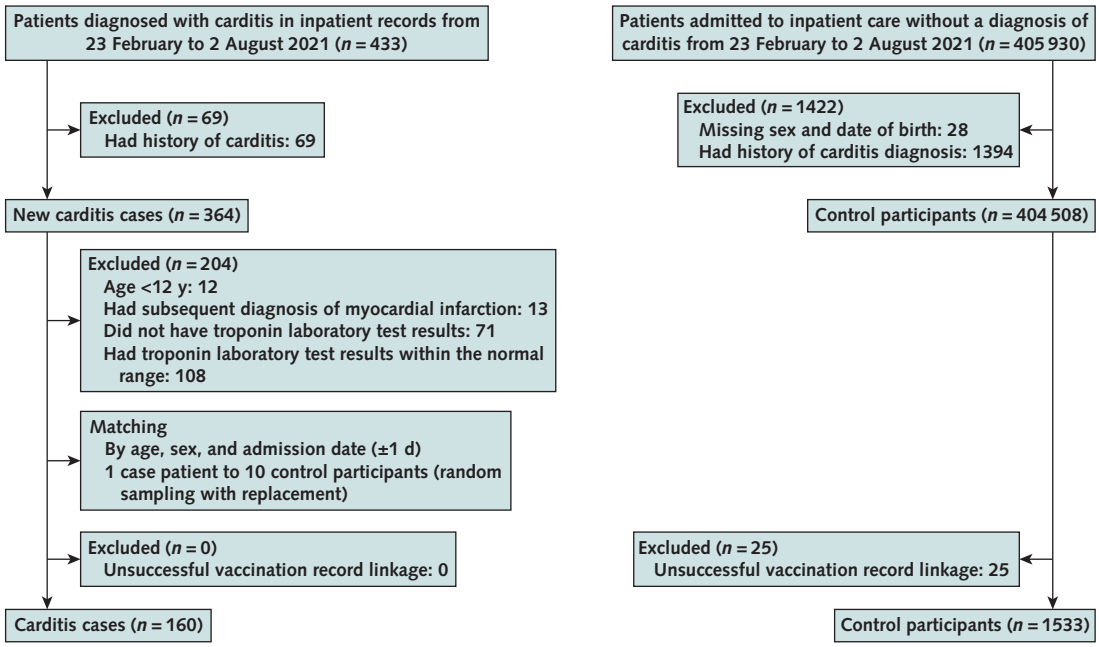
Covariates

Clinical history (since the launch of the EHR system in 1993) of diabetes, hypertension, coronary heart disease, stroke, heart failure, myositis, and encephalitis was included in the main analysis for multivariable adjustment. In addition, we adjusted a binary indicator for any cardiovascular medication prescribed within the past year before admission, including anticoagulants, antiplatelet medications, angiotensin-converting enzyme inhibitors, angiotensin-receptor blockers, β-adrenoceptor blocking drugs, calcium-channel blockers, digoxin, and statins. The corresponding ICD-9-CM codes, British National Formulary codes, and drug names are tabulated in **Supplement Tables 2** and **3** (available at Annals.org).

Statistical Analysis

Conditional logistic regression was used to examine the association of receiving BNT162b2 and CoronaVac

Figure 1. Flow chart showing selection of case patients and control participants for the final sample for analysis.



vaccination with carditis. Adjusted odds ratios (ORs) of carditis in vaccine recipients compared with unvaccinated persons were estimated for BNT162b2 and CoronaVac. Stratified analyses were also done by age group (adults aged ≥18 years and adolescents aged 12 to 17 years) and sex.

A series of sensitivity analyses were done. First, to differentiate the subtypes of carditis, we stratified the cases as pericarditis (ICD-9-CM codes 420.9 and 423.9) and myocarditis (ICD-9-CM codes 422.x and 429.0) and replicated the main analysis. A small number of patients with both diagnoses within the same hospital admission were included in both replications. Second, to compare the risk difference between the first and second doses, we replicated the analysis with vaccination status categorized into the following categories to generate specific ORs for each of these vaccine groups: unvaccinated, received 1 dose of CoronaVac, received both doses of CoronaVac, received 1 dose of BNT162b2, and received both doses of BNT162b2. Third, in addition to myocardial infarction, we removed cases with a subsequent diagnosis of heart failure to minimize the risk for misclassification of cases. Fourth, although Hong Kong had a low COVID-19 infection rate (<12 500 cumulative confirmed cases out of a population of more than 7 million) and the proportion of COVID-19–related hospitalizations in the pool of hospitalizations for the selection of control participants was extremely low (0.15%) (28), we replicated the analysis with 4 COVID-19–related hospitalizations removed from the control group. Fifth, we specified a risk window of 14 days after vaccination and conducted another sensitivity analysis with the most recent dose of vaccine (either CoronaVac or BNT162b2) administered more than 14 days before the index admission recoded as unvaccinated (nonexposed). Sixth, we included those diagnosed with carditis but without a troponin test result and replicated the analysis. Finally, in addition to the covariate adjustment in the main analysis, we further adjusted for covariates, including health care use history, additional preexisting chronic diseases, and other long-term medications, to minimize the residual confounding effects on the results.

As recommended in previous methodological research (29, 30), we applied unconditional exact logistic regression in scenarios when conditional logistic regression returned extreme estimates in some of the subgroup analyses owing to a small sample size. All analyses were done using R, version 4.1.1 (R Foundation for Statistical Computing), and results were cross-checked by 2 independent researchers (K.P. and L.H.) as quality control.

Role of the Funding Source

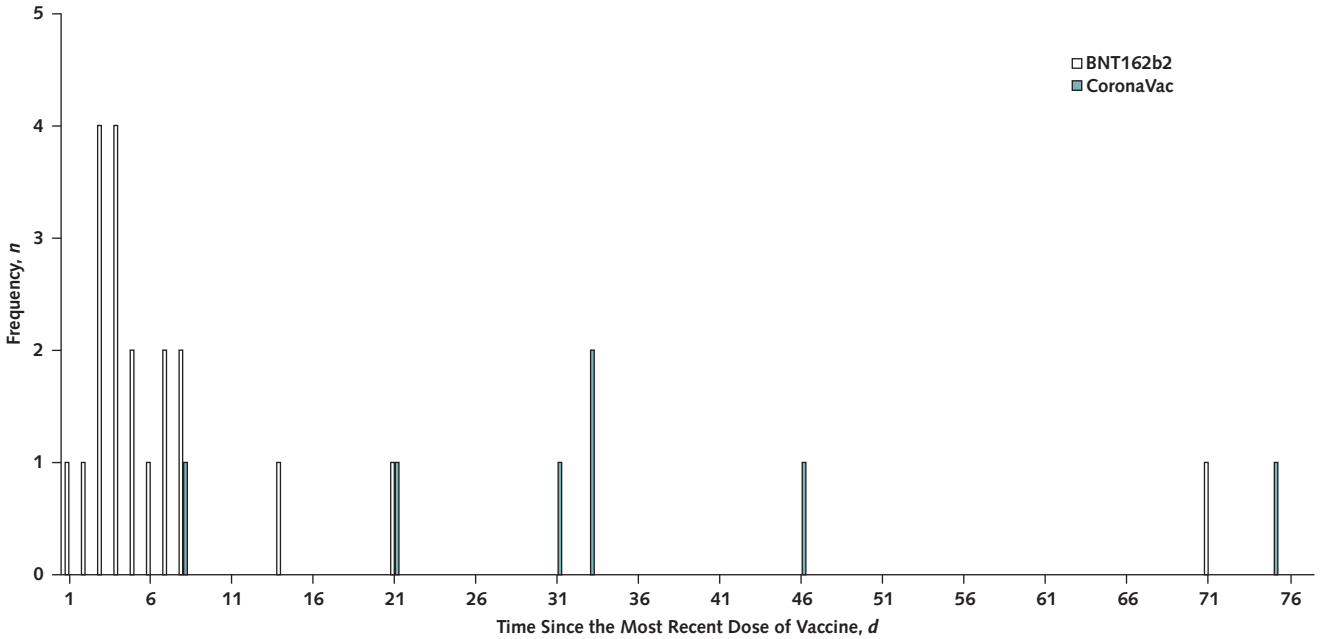
This is a regulatory pharmacovigilance study initiated by the Department of Health and funded by the Food and Health Bureau of the Government of Hong Kong Special Administrative Region, China. The Department of Health has facilitated data extraction but has played no other roles in the study's design, conduct, or reporting.

RESULTS

Incidence of Carditis

In Hong Kong, 2 291 444 doses of CoronaVac and 3 496 629 doses of BNT162b2 were administered as of 2 August 2021 (27). We identified 433 patients with a diagnosis of carditis from CDARS according to ICD-9-CM codes. After applying the exclusion criteria to cases, we selected 160 case patients and 1533 control participants

Figure 2. Onset distribution of carditis after BNT162b2 (n = 20) and CoronaVac (Sinovac) (n = 7) COVID-19 vaccination (the most recent dose).



for the analysis. Twenty-five control participants whose vaccination record and EHR failed to match on a valid Hong Kong Identity Card number or other personal identification numbers were excluded. These are likely due to foreign workers who used passport numbers for booking vaccinations and Hong Kong Identity Card numbers for HA services or vice versa. Figure 1 details the sample selection process. There were 7 and 20 cases of carditis identified after CoronaVac and BNT162b2 vaccination, respectively. Cumulative incidence of carditis after vaccination was 0.57 (CI, 0.36 to 0.90) per 100 000 doses for BNT162b2 (first dose: 0.25 [CI, 0.09 to 0.62]; second dose: 1.00 [CI, 0.58 to 1.70]) and 0.31 (CI, 0.13 to 0.66) per 100 000 doses for CoronaVac (first dose: 0.08 [CI, 0.00 to 0.50]; second dose: 0.60 [CI, 0.24 to 1.37]).

Figure 2 shows the onset time distribution of included cases of carditis among vaccine recipients. After BNT162b2 vaccination, the onset time of carditis was concentrated during the first week (75.0% of all cases), and 5 out of all 7 case patients (71.4%) who received CoronaVac had carditis occur more than 30 days after vaccination. Subsequent intensive care unit (ICU) admission and death were rare among the carditis cases identified. Of 160 carditis cases, 14 patients without vaccination, 2 after CoronaVac vaccination, and none after BNT162b2 vaccination were admitted to the ICU. Only 1 case patient who received CoronaVac and 12 case patients without vaccination died within the observation period.

Sample Characteristics

Table 1 shows the sample characteristics by case patients and control participants. There were no marked differences between the groups in chronic disease history, with approximately half of both groups prescribed cardiovascular medications in the past year. There was a higher proportion of case patients with a preexisting heart failure diagnosis than control participants (12.9% vs. 8.0%), whereas a higher proportion of control participants had diabetes compared with case patients (20.7% vs. 11.9%). A similar proportion of around 4% in both groups had received CoronaVac but a much higher proportion of patients having received BNT162b2 was seen among case patients (12.5%) than among control participants (4.2%).

Table 2 shows the characteristics of control participants by vaccination status. Although the CoronaVac and unvaccinated groups had about the same mean age of 59 years, the BNT162b2 group was only 37 years on average. All chronic conditions were more prevalent among the unvaccinated group than among the 2 vaccinated groups. The proportion of patients having received the second dose was similar between the 2 vaccinated groups (around 60%). Supplement Table 4 (available at Annals.org) shows the characteristics of case patients by vaccination status.

Case–Control Analysis

Multivariable conditional logistic regression showed that the adjusted OR of carditis was 3.57 (CI, 1.93 to 6.60) among those receiving BNT162b2 compared with unvaccinated persons (Table 3). Stratified by sex, the adjusted OR was 4.68 (CI, 2.25 to 9.71) for males and 2.22 (CI, 0.57 to 8.69) for females. A positive association was seen in both adults aged 18 years or older (OR, 2.41 [CI, 1.18 to 4.90]) and adolescents aged 12 to 17 years (OR, 13.79 [CI, 2.86 to 110.38]). Owing to a lack of

Table 1. Sample Characteristics of Selected Case Patients and Control Participants

Characteristic	Case Patients (*n* = 160)	Control Participants (*n* = 1533)	Standardized Mean Differences
Demographic characteristic			
Male, *n* (%)	100 (62.5)	944 (61.6)	0.009
Mean age (SD), *y*	57.48 (24.23)	58.38 (23.78)	−0.038
Aged ≤17 y, *n* (%)	13 (8.1)	110 (7.2)	0.009
Clinical history, *n* (%)			
Diabetes	19 (11.9)	318 (20.7)	−0.088
Hypertension	58 (36.2)	609 (39.7)	−0.035
Coronary artery disease	0 (0.0)	7 (0.5)	−0.005
Stroke	15 (9.4)	170 (11.1)	−0.017
Heart failure	20 (12.5)	123 (8.0)	0.045
Myositis	1 (0.6)	9 (0.6)	0.000
Encephalitis	0 (0.0)	2 (0.1)	−0.001
Cardiovascular medications*	78 (48.8)	860 (56.1)	−0.073
Vaccination status, *n* (%)			
Unvaccinated	133 (83.1)	1408 (91.8)	−0.087
Received BNT162b2	20 (12.5)	65 (4.2)	0.083
Received CoronaVac (Sinovac)	7 (4.4)	60 (3.9)	0.005
Received the second dose	21 (13.1)	77 (5.0)	0.081

* Cardiovascular medications included statins, angiotensin-converting enzyme inhibitors, angiotensin-receptor blockers, anticoagulants, antiplatelets, β-adrenoceptor blocking drugs, calcium-channel blockers, and digoxin.

sufficient variation of vaccination status within matched sets, the OR for adolescents was estimated using exact logistic regression. No association was seen for CoronaVac in the main and sensitivity analyses.

As shown in Supplement Table 5 (available at Annals.org), highly consistent results were obtained from the sensitivity analyses, with case patients with subsequent heart failure diagnoses (and their control participants) removed, 4 COVID-19 hospitalizations removed as control participants, and additional covariates adjusted. The adjusted OR for BNT162b2 was 2.23 (CI, 0.80 to 6.26) for the first dose and 4.41 (CI, 2.22 to 8.75) for the second dose. Within a 14-day risk window, the adjusted OR for BNT162b2 was 7.78 (CI, 3.76 to 16.13). If only myocarditis was considered, the adjusted OR for BNT162b2 was estimated at 9.29 (CI, 3.94 to 21.91), whereas if only pericarditis was considered, it was 1.06 (CI, 0.35 to 3.22). After further inclusion of cases with ICD-9-CM diagnosis without troponin test results, the adjusted OR for BNT162b2 was 2.22 (CI, 1.28 to 3.87).

Discussion

To the best of our knowledge, this is the first case–control study analyzing carditis risk associated with 2 different COVID-19 vaccine technologies. We found an elevated risk for carditis after the use of the mRNA BNT162b2 vaccine but not the inactivated virus vaccine CoronaVac. This risk increase associated with BNT162b2 was predominant in males. Among both adults and adolescents, there was an increased risk for carditis, with a larger OR estimated for adolescents. Sensitivity analysis suggested the association was driven by myocarditis, not pericarditis. In addition, this risk increase was more likely to be after the second dose of BNT162b2 rather than the first. A stronger association was seen with BNT162b2, with the specification of a 14-day risk window after vaccination. Nevertheless, the absolute risk for carditis after BNT162b2 vaccination remains very low–with only approximately 0.25 cases per 100 000 first doses identified from the territory-wide routine health care database and approximately 1 case per 100 000 second doses administered according to our operational case definition. Moreover, none of the 20 case patients with carditis after BNT162b2 vaccination were admitted to the ICU or died within the observation period, compared with 14 of 133 unvaccinated patients admitted to the ICU and 12 deaths. Our observations and published studies have shown that, to date, most reported carditis cases after BNT162b2 are self-limiting with good prognosis.

Given the rare incidence of carditis, it is difficult to capture cases in clinical trials with typically no more than a few tens of thousands of participants. To our knowledge, no clinical trials have reported the occurrence of carditis after COVID-19 vaccination (11, 31–33). In the literature, aside from a recent Israeli retrospective cohort study (16), only case series or case reports examining the association between BNT162b2 and carditis were available (7–10). Our findings are consistent with these reports in that the distribution of carditis occurrence is concentrated in young male persons after the second dose (13, 14, 34), which is also supported by a recent meta-analysis of these cases. Earlier research before the pandemic has shown a similar marked sex difference in carditis incidence (35). The Israeli study identified a 3-fold elevated risk for myocarditis and, like our findings, did not identify a significant elevated risk for pericarditis (16). Owing to the wide variety of outcomes investigated, they relied on the validity of the diagnosis codes without considering further criteria on the validity of the diagnosis codes or further criteria on the definition of cases (16, 36). In the current case–control study, we applied a more stringent case definition for the operationalization of the study to ensure case validity.

Table 2. Sample Characteristics of Control Participants by Vaccine Status

Characteristic	Not Vaccinated (*n* = 1408)	BNT162b2 (*n* = 65)	CoronaVac (Sinovac) (*n* = 60)
Demographic characteristic			
Male, *n* (%)	859 (61.0)	49 (75.4)	36 (60.0)
Mean age (SD), *y*	59.36 (23.87)	37.18 (18.92)	58.43 (13.76)
Aged ≤17 y, *n* (%)	96 (6.8)	14 (21.5)	0 (0.0)
Clinical history, *n* (%)			
Diabetes	308 (21.9)	5 (7.7)	5 (8.3)
Hypertension	591 (42.0)	5 (7.7)	13 (21.7)
Coronary artery disease	7 (0.5)	0 (0.0)	0 (0.0)
Stroke	163 (11.6)	2 (3.1)	5 (8.3)
Heart failure	123 (8.7)	0 (0.0)	0 (0.0)
Myositis	8 (0.6)	0 (0.0)	1 (1.7)
Encephalitis	2 (0.1)	0 (0.0)	0 (0.0)
Cardiovascular medications*	821 (58.3)	14 (21.5)	25 (41.7)
Vaccination status, *n* (%)			
Received the second dose	–	38 (58.5)	39 (65.0)

* Cardiovascular medications include statins, angiotensin-converting enzyme inhibitors, angiotensin-receptor blockers, anticoagulants, antiplatelet, β-adrenoceptor blocking drugs, calcium-channel blockers, and digoxin.

Our findings have important scientific and health policy implications. An indication bias of "healthy vaccine-recipient effect"—those who received the vaccines are, in general, healthier than those who are not vaccinated—is widely reported in COVID-19 vaccine safety investigations (37, 38). Analytic studies are often challenged by such bias, and the risk comparison between vaccine recipients and nonvaccinated persons can be biased as a result (16). However, recipients of CoronaVac should have reasonably similar health statuses as recipients of BNT162b2, but we did not find notably increased or reduced carditis risk after CoronaVac. Such findings further support the validity of observed increased risk for carditis associated with BNT162b2 vaccination.

Moreover, the differences in the risk after immunization with the 2 vaccines imply the presence of potential mechanisms specific to the mRNA platform, which is illustrated in the onset distribution (**Figure 2**), with carditis cases typically occurring within a short period after BNT162b2 vaccination. For cases after CoronaVac vaccination, it was more evenly distributed. The potential mechanism underlying this observed association between BNT162b2 and carditis is unclear. Of note, a recent animal experiment using a mouse model suggested in vivo evidence that inadvertent intravenous injection of COVID-19 mRNA vaccines may induce carditis (39). Although the extrapolation of animal research to humans warrants great caution, this finding plausibly suggests the possibility that unintended intravenous injection may be 1 potential mechanism to explain the association. This is because no histopathologic changes of carditis were seen in mice randomly allocated to receive intramuscular BNT162b2 injection (39). Further research is warranted to identify the physiologic response triggered by COVID-19 vaccination in relation to carditis and inform further hypothesis-driven studies.

Postvaccination carditis should be particularly closely monitored in persons receiving BNT162b2. From the observed onset distribution, more than 1 month after either dose of vaccine, vaccine recipients and physicians should be aware of symptoms related to probable carditis. The symptoms include chest pain, palpitation, shortness of breath, and fatigue and the subsequent elevated risk for carditis, especially among the young and males. As some countries have already begun the rollout of the third dose, the associated risk for carditis and long-term safety profile of the vaccines should continue to be closely monitored. Regarding further vaccination of adolescents and children, the risks and benefits should be considered thoughtfully in accordance with the local epidemic situation. Nonetheless, although the estimated OR is large, the absolute risk for carditis is low, with the number of carditis cases per 100 000 doses of administered BNT162b2 estimated at 0.57. If we assume the carditis cases after CoronaVac vaccination is the background incidence—that is, 0.31 per 100 000 doses, the approximate absolute risk increase is 0.26 per 100 000 doses overall and 0.17 per 100 000 doses and 0.4 per 100 000 doses for the first and second doses, respectively. On the other hand, the risk for carditis and other serious complications after SARS-CoV-2 infection (16), including an approximate 16-times increased risk for myocarditis shown in a retrospective cohort study of 36 million persons in the United States, are also concerning (36). The risk seen in this study for carditis after BNT162b2 vaccination should be weighed against the benefits of vaccination.

Despite the strengths of a stringent case definition as well as the availability of accurate information on vaccination statuses before the onset of the outcome, there are limitations to this study. First, we did not have a sufficient sample size for the application of conditional logistic regression to the adolescent group because of the lack of variation in vaccination status within matched sets. The modest sample size also resulted in relatively wide CIs, limiting the precision of the estimates and conclusions, especially regarding CoronaVac. Hence, the interpretation of the results should be cautious. Second, in common with other large-scale epidemiologic studies using EHR databases, we were dependent on ICD-9-CM codes to identify cases. We used troponin levels as a means

Table 3. Odds Ratios of Carditis Among Vaccinated Patients Compared With Unvaccinated Patients

Vaccination Status	Control Participants, *n* (%)	Case Patients, *n* (%)	Crude Odds Ratio (95% CI)	Adjusted Odds Ratio (95% CI)*
Overall				
Unvaccinated	1408 (91.8)	133 (83.1)	1 (reference)	1 (reference)
CoronaVac†	60 (3.9)	7 (4.4)	1.29 (0.57–2.91)	1.21 (0.53–2.75)
BNT162b2	65 (4.2)	20 (12.5)	3.66 (1.99–6.75)	3.57 (1.93–6.60)
Male				
Unvaccinated	859 (91.0)	78 (78.0)	1 (reference)	1 (reference)
CoronaVac	36 (3.8)	5 (5.0)	1.58 (0.59–4.23)	1.44 (0.53–3.92)
BNT162b2	49 (5.2)	17 (17.0)	4.51 (2.22–9.18)	4.68 (2.25–9.71)
Female				
Unvaccinated	549 (93.2)	55 (91.7)	1 (reference)	1 (reference)
CoronaVac	24 (4.1)	2 (3.3)	0.85 (0.19–3.75)	0.88 (0.19–3.99)
BNT162b2	16 (2.7)	3 (5.0)	1.94 (0.52–7.29)	2.22 (0.57–8.69)
Adults aged ≥18 y				
Unvaccinated	1312 (92.2)	128 (87.1)	1 (reference)	1 (reference)
CoronaVac	60 (4.2)	7 (4.8)	1.23 (0.54–2.79)	1.15 (0.51–2.63)
BNT162b2	51 (3.6)	12 (8.2)	2.52 (1.25–5.11)	2.41 (1.18–4.90)
Adolescents aged 12–17 y				
Unvaccinated	96 (87.3)	5 (38.5)	1 (reference)	1 (reference)
BNT162b2	14 (12.7)	8 (61.5)	14.43 (2.83–135.03)‡	13.79 (2.86–110.38)§

* Adjusted variables include clinical history of diabetes, hypertension, coronary heart disease, stroke, heart failure, myositis, encephalitis, and cardiovascular medications prescribed within the past year before admission.
† Manufactured by Sinovac.
‡ Estimated using exact logistic regression (100 million iterations), adjusted for age and sex because of extreme estimates from conditional logistic regression.
§ Estimated using exact logistic regression (100 million iterations), adjusted for age, sex, and covariates listed above because of extreme estimates from conditional logistic regression.

of validation to ensure our cases were, at a minimum, classified as probable cases according to Brighton Collaboration's definition (26). Our study design could only detect cases requiring medical attention and was unable to detect mild asymptomatic cases not necessitating medical attention; hence, we may have underestimated the true incidence of carditis after vaccination. Consequently, our findings are only applicable to cases requiring medical attention. Third, the observational nature of this research limits the causal inference about the potential effect of the vaccines. Although we detected an association between BNT162b2 and carditis, the causal relationship remains to be substantiated. Fourth, we were unable to compare between different ethnic backgrounds because the Hong Kong population is predominantly ethnic Chinese (40); however, our results are consistent with studies based on White populations (16). Fifth, long-term postdischarge outcomes were also not investigated because only a short observation period was allowed for this urgent investigation of the association of vaccines with carditis. The Hong Kong government obtained consent from patients and guardians, and a further study on the long-term outcomes is under planning. Sixth, overseas vaccine exposure was not recorded in the database, although this should be rare given various restrictions on international travel and unlikely to have a substantial effect on our results. Finally, the hospitalized control participants selected for this study may not be sufficiently representative of the risk set of the underlying cohort, and the validity of the study results largely depend on the key assumption that the selection of control participants was independent of exposure. There is no evidence that such an assumption was violated because our results are consistent with previously published data in other populations.

In conclusion, we observed an increased risk for carditis associated with the use of BNT162b2, particularly in young male persons receiving the second dose. Although the absolute risk is very low, this elevated risk should be made known to vaccine recipients and physicians and be weighed against the benefits of vaccination.

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