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A review of COVID-19 vaccination and the reported cardiac manifestations

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ABSTRACT

In Singapore, 9.03 million doses of the mRNA COVID-19 vaccines by Pfizer-BioNTech and Moderna have been administered, and 4.46 million people are fully vaccinated. An additional 87,000 people have been vaccinated with vaccines in World Health Organization's Emergency Use Listing. The aim of this review is to explore the reported cardiac adverse events associated with different types of COVID-19 vaccines. 42 studies that reported cardiac side effects after COVID-19 vaccination were included in this study. Reported COVID-19 vaccine-associated cardiac adverse events were mainly myocarditis and pericarditis, most commonly seen in adolescent and young adult male individuals after mRNA vaccination. Reports of other events such as acute myocardial infarction, arrhythmia and stress cardiomyopathy were rare. Outcomes of post-vaccine myocarditis and pericarditis were good. Given the good vaccine efficacy and the high number of cases of infection, hospitalisation and death that could potentially be prevented, COVID-19 vaccine remains of overall benefit, based on the current available data.

Keywords: cardiac side effects, COVID-19, myocarditis, pericarditis, vaccination

INTRODUCTION

Coronavirus disease 2019 (COVID-19) has affected more than 219 million individuals and caused over 4.5 million deaths worldwide, resulting in enormous health, economic and social impacts in countries all over the world. The development of effective vaccination against severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), the virus responsible for COVID-19 has shown to be a critical tool in the control of the spread and impact of this pandemic. At present, multiple coronavirus vaccines have been developed, including the mRNA vaccines BNT162b2 (Pfizer-BioNTech/Comirnaty) and mRNA-1273 (Moderna), and adenoviral vector vaccine Ad26.COV2.S (Johnson & Johnson/Janssen), which have been authorized for emergency use by multiple regulatory agencies.[1,2] Other vaccines on the market include the AZD1222 (Oxford-AstraZeneca/Covidshield),[2] the inactivated vaccine CoronaVac (Sinovac Biotech)[3] and WIBP / BBIBP-CorV COVID-19 vaccine (Sinopharm), and the adenoviral vector vaccine Gam-COVID-Vac (Sputnik V). At the time of writing, 6.06 billion vaccine doses have been administered worldwide.[4]

Despite the general success in vaccination rollout, monitoring the safety of COVID-19 vaccines have identified potential cardiac adverse events. Concerns regarding myocarditis and pericarditis were first raised in Israel, after a report of myocarditis incidence rates of 1 in 3000 to 1 in 6000 in 16- to 24-year-olds. On 23 June 2021, the US Centres for Disease Control and Prevention's safety committee published a statement regarding the likely association between Pfizer-BioNTech and Moderna vaccines with myocarditis and pericarditis. As of 26 July 2021, 699 confirmed cases of myocarditis and pericarditis was identified from the Vaccine Adverse Event Reporting System (VAERS), most commonly in male adolescents and young adults aged 16 or older. As increasing numbers of younger individuals are vaccinated, it is important to understand the potential side effects, in order to appropriately counsel patients on the risks and benefits of the COVID-19 vaccine.

The aim of this review is to explore the reported cardiac adverse events associated with different types of COVID-19 vaccines.

METHODS

We performed a search on MEDLINE, Embase, Scopus, CENTRAL and clinicaltrials.gov from inception until 19 July 2021. The search terms were ("covid" or "coronavirus" or "SARS-CoV-2") AND ("vaccin*" or "jab" or "immunisation" or "immunization" or "injection" or "BioNTech" or "Pfizer" or "Comirnaty" or "BNT162b2" or "Moderna" or "mRNA-1273" or "Johnson & Johnson" or "Janssen" or "AstraZeneca" or "AZD1222" or "Vaxzevria" or "Covishield" or "Sputnik V" or "CoronaVac" or "Sinovac" or "Sinopharm" or "WIBP-CorV" or "BBIBP-CorV") AND ("heart" or "myocard*" or "cardio*" or "coronary*" or "vascu*"). The seven vaccines chosen for the search were the more commonly used vaccines worldwide. The search was not restricted in time, type or language of publication. The inclusion criteria were clinical studies on (1) COVID-19 vaccination and (2) reported cardiac adverse effects post-vaccination. Additional articles were identified from hand searching of the references of reviews and included articles. Primary research studies including randomised trials, cohort studies, case series and case reports were included, and there were no limitations on publication type. Studies that did not report cardiac side effects e.g. arterial or venous thrombosis only and animal studies were excluded. Titles and abstracts were independently screened by two researchers (JSH and CHS) and discrepancies were resolved by discussion. Data from full texts were extracted onto a standardised form, which included the study type, type and dose of COVID-19 vaccine, patient characteristics, investigations, management and outcomes.

RESULTS

A total of 42 studies reported cardiac side effects post-COIVD-19 vaccination and were included in this study, including 33 case reports or case series, two cohort studies, four randomised controlled trials (RCT), and four studies exploring the data from drug monitoring systems such as the US vaccine adverse event reporting system (VAERS) and World Health Organization (WHO) VigiBase - one study reported both a clinical case and VAERS-based data.[5] A majority of articles reported on the mRNA vaccines BNT162b2 (Pfizer-BioNTech) and mRNA-1273 (Moderna), four articles studied the AZD1222 (Oxford-AstraZeneca), and two studied JNJ-78436735 (Johnson & Johnson). There was one RCT on the inactivated vaccine CoronaVac. There were no studies reporting cardiac manifestations of WIBP-CorV / BBIBP-CorV (Sinopharm). The most common cardiac adverse events were myocarditis, pericarditis, AMI, arrhythmias and stress cardiomyopathy. The reported data on each of the seven vaccines with available articles are summarised in Table 1.

Myocarditis and pericarditis

We identified 314 cases of myocarditis, 59 cases of myopericarditis and 8 cases of pericarditis post-COVID-19 vaccination. This included one RCT, two registry studies and 26 case reports or case series.

Randomised controlled trials and registry studies

One RCT of the Johnson & Johnson vaccine found one case of pericarditis considered related to vaccination in 21,895 patients in the vaccinated arm, and no cases in the control arm.[6] Two studies using data from drug monitoring systems reported 251 cases of myocarditis or myopericarditis.[7,8] One of them reported 15 patients had Pfizer-BioNTech vaccine and 22 had the Moderna vaccine,[7] while the other study included patients who had the Pfizer-BioNTech,

Moderna and other vaccines.[8] Two hundred and fourteen cases of myocarditis were reported after Pfizer-BioNTech, Moderna and other vaccinations on the VigiBase, 22% of whom had associated pericarditis.[8] Only mRNA vaccines (Pfizer-BioNTech and Moderna) were significantly associated with pericarditis in this study.[8]

Case reports and case series

Among the remaining 110 cases of myocarditis from case reports and case series, 60 cases had the Pfizer-BioNTech vaccine, 49 had the Moderna vaccine and one had the Johnson & Johnson vaccine. All 12 cases of myopericarditis were post Pfizer-BioNTech vaccination. Six patients had pericarditis after Pfizer-BioNTech vaccination, and one patient with pericarditis received the Oxford-AstraZeneca vaccine.[9-11] One patient developed pericarditis four days after the first dose and recurrent pericarditis four days after the second dose of Pfizer-BioNTech vaccination.[9]

From case reports and case series, myocarditis was most commonly reported in healthy young males. The age of individuals who experienced post-vaccination myocarditis ranged from 14 to 67, with 28 out of 62 cases (45.2%) were under 20 years old, and 49 cases (79%) were under 30 years old. The majority of patients were male (243 out of 373 cases, 65.1%). Most patients had no previous co-morbidities, 6 cases had previous COVID-19 infection[7,12-14] and one patient had previous COVID-19-induced myocarditis.[7] In patients with post-vaccination pericarditis, age ranged from 21 to 80 years, and 42.8% were male. They had co-morbidities such as idiopathic pericarditis, immune thrombocytopenic purpura, lupus, hypertension and atrial fibrillation.[9-11]

The most common presenting symptoms of myocarditis and pericarditis were chest pain and dyspnoea, with preceding systemic symptoms such as fever, fatigue and myalgia. One patient with background of heart failure with preserved ejection fraction presented with acute

decompensated heart failure 6 hours after the second Moderna vaccine.[7] The time of onset of symptoms ranged from 6 hours to 25 days post-vaccine, and 99.4% occurred within 7 days of vaccination (333 out of 335 cases). Two cases of cardiac magnetic resonance imaging (CMR)-confirmed myocarditis occurred on day 16 and day 25 post-vaccination.[14,15]

Cases of post-vaccination myocarditis showed abnormalities in cardiac markers, electrocardiogram (ECG) and cardiac imaging. All cases demonstrated elevated cardiac troponin levels, and this ranged from a 10 to 400-fold increase in a case series of 23 patients post-mRNA vaccine.[16] Brain natriuretic peptide (BNP) or N-terminal pro-BNP (NT-pro-BNP) was performed in 20 cases, which was elevated in 11 patients, one of whom had previous heart failure.[7] Levels of C-reactive protein (CRP) ranged from 0.1 to 100 mg/L, and erythrocyte sedimentation rate (ESR) ranged from 4 to 43mm/hour. In contrast, patients with pericarditis had normal troponin levels, but generally raised CRP and ESR.[9-11] Most cases of myocarditis had abnormal ECG (90.1%, 73 out of 81 cases), and ST elevation was the most common abnormality (77.6%, 45 out of 58 cases).[5,11,12,14,15,17-27] Other abnormalities include ST depression,[28] non-specific T-wave changes,[7,16,23] right bundle branch block (RBBB)[29] and PR depression.[12,15,23] Features on echocardiogram suggestive of myocarditis included reduced left ventricular ejection fraction (LVEF) and regional wall motion abnormalities, and 17% of cases had reduced LVEF of 40-50% in the case series by Montgomery et al.[16] These features were often difficult to distinguish from acute coronary syndrome, and 39 cases underwent coronary angiography or CT coronary angiography (CTCA), which were all normal apart from mild non-obstructive coronary artery disease in three patients.[13,23,29] Four cases of pericarditis showed pericardial effusion on echocardiogram.[9-11]

As echocardiogram was often normal or showed non-specific features, CMR was performed in the majority of cases to confirm a diagnosis of myocarditis. The Lake Louis Criteria states that a combination of at least one T2-based criterion (global or regional increase

of T2 relaxation time or an increased signal intensity) and at least one T1-based criterion (increased myocardial T1, extracellular volume or late gadolinium enhancement) has high specificity for diagnosing acute myocarditis. This was reported in 67 cases of post-vaccination myocarditis reported. The gold-standard in the diagnosis of myocarditis is endomyocardial biopsy, which was performed in only one case.[5]

The outcomes of vaccine-induced myocarditis were generally good, 103 patients recovered and were discharged, eight were admitted to intensive care unit,[21,25,27,30,31] and one patient died.[7] The length of hospital stay ranged from 2-8 days, and treatment included colchicine, non-steroidal anti-inflammatory drugs (NSAIDs), intravenous immunoglobulins and prednisolone. One patient had brief episodes of non-sustained ventricular tachycardia (NSVT), which resolved prior to discharge.[11] Cardiac symptoms resolved within one week for 70% of patients, while 30% continued to have chest discomfort.[16] All seven patients with pericarditis recovered with no complications, after treatment with NSAIDs, colchicine and prednisolone.[9-11]

Acute myocardial infarction

Eleven articles reported AMI after COVID-19 vaccination, including six case reports and case series,[32-37] two cohort studies[38,39] and three randomised controlled trials (RCT).[40-42]

Cohort studies and randomised controlled trials

In a cohort of 8,371 nursing home residents who had one dose of mRNA vaccine, one 56-year old man with previous coronary artery bypass grafting, diabetes mellitus, hypertension, and hyperlipidaemia developed AMI after Pfizer-BioNTech vaccination.[38] A population-based study in Denmark and Norway found that one dose of the Oxford-AstraZeneca vaccine was associated with excess event rate of 0.6 per 100,000 vaccinations for AMI, and a reduction of

2.2 per 100,000 vaccinations for ischemic heart disease without AMI, but both were not statistically significant.[39] There were no cases of unstable angina in 12,021 patients who received the Oxford-AstraZeneca vaccine in a RCT.[43] The RCT of the Moderna vaccine found a similar proportion of myocardial infarction in both vaccinated and placebo arms.[42] The RCT of Sputnik V reported two cases of AMI out of 16,4267 vaccinated patients.[40] For CoronaVac, there were no cases of AMI in 6,646 the vaccinated arm and 1 case in the placebo arm.[41]

Case reports and case series

Of the six patients from the case reports and case series, three had the Pfizer-BioNTech vaccine, one had the Moderna vaccine and two had the Oxford-AstraZeneca vaccine. All of these patients developed AMI after their first dose of vaccine. Patients who developed AMI post-vaccination were generally older than those who developed myocarditis, being aged 54 to 96 years, and 40% were male (2 out of 5 cases). Four patients had cardiovascular co-morbidities such as type 2 diabetes mellitus, hypertension, hyperlipidemia, stroke and previous myocardial infarction. Patients typically presented with chest pain between 1 hour and 12 days post-vaccination. One patient presented with an acute stroke, one patient collapsed 30 minutes after his first inoculation of the Pfizer-BioNTech vaccine, and one patient was found dead 2 days after receiving the first dose of Pfizer-BioNTech vaccine. All of the patients had raised cardiac troponin levels, ischemic changes on ECG, and regional wall motion abnormality on echocardiogram. Primary percutaneous coronary intervention (PCI) was performed in two patients.[33,34] A 54-year-old female who presented with a stroke and thrombosis in the right coronary artery (RCA) underwent plain old balloon angioplasty that restored distal flow to the RCA, but extensive thrombosis persisted. She was admitted to intensive care unit and died after 5 days.[32] One patient had thrombolysis and was discharged 5 days later.[36] One patient declined cardiac catheterisation and was discharged 3 days later.[37] A 73-year-old Chinese

female with hypertension had hemodynamically non-significant left anterior descending artery (LAD) disease, confirmed by fractional flow reserve (FFR 0.83).[33] The outcomes were mixed, with three patients died within 5 days and the remaining patients were discharged within 3 days of hospitalisation.

Arrythmias and other cardiac manifestations

Rare cases of cardiac arrhythmias post-COVID-19 vaccination were reported in one case report and four RCTs of the Sputnik V, Oxford-AstraZeneca, Johnson & Johnson and Moderna vaccine.[40,43,44] A 46-year-old female had a background of implantable cardioverter defibrillator (ICD) for torsades de pointes following the delivery of her child at the age of 40.[44] She had occasional palpitations due to premature ventricular contractions (PVCs) but was previously free from faintness and torsades de pointes for six years. She started to experience frequent palpitations due to frequent PVCs one day after the second dose of Pfizer-BioNTech vaccine, and had NSVT and torsades de pointes recorded by the ICD five days post-vaccination. Her last NSVT occurred eight days post-vaccination and she recovered with no further arrhythmia.

In RCTs, three cases of atrial fibrillation associated with Sputnik V vaccine were reported,[40] and the Oxford-AstraZeneca vaccine was associated with one case of atrial flutter and one case of complete heart block.[43] There was one case of tachycardia but no cases of atrial fibrillation or atrial flutter associated with the Johnson & Johnson vaccine.[6] Among 15,185 patients vaccinated with the Moderna vaccine, there were four cases of bradycardia and four cases of atrial fibrillation, similar to the placebo arm.[42]

There were two cases of stress cardiomyopathy associated with the Pfizer-BioNTech vaccine.[11,33] A 44-year-old female with a history of mitral valve prolapse and mild mitral regurgitation presented with transient chest pain and palpitations 15 minutes after the first

dose.[33] She had a raised troponin I, ST-segment elevation in inferolateral leads on ECG, apical ballooning with mildly depressed LVEF of 50% on echocardiogram and without significant coronary artery stenosis on CTCA. The second case was a 60-year-old female with a history of PCI to the left anterior descending artery, who presented with exertional chest pain four days after receiving the second dose of vaccine.[11] There were inferolateral T wave inversions on her ECG. Similarly, her echocardiogram showed mildly depressed LVEF with apical akinesis, and she had a patent LAD stent with no obstructive disease on coronary angiogram. Both patients were managed medically.

DISCUSSION

The main reported cardiac side effects associated with COVID-19 vaccines were myocarditis and pericarditis, with a few reports of AMI, arrhythmia and stress cardiomyopathy. Myocarditis and pericarditis were the most common reported post-mRNA vaccine cardiac events particularly in young adolescent males and after the second dose of vaccination. Outcomes of post-vaccine myocarditis and pericarditis were good, and these cardiac side effects must be balanced with the harms of COVID-19 infection when considering whether to recommend COVID-19 vaccination.

The vaccination rollout is currently ongoing, and more than 6.06 billion doses have been administered globally.[4] The Oxford-AstraZeneca vaccine has the most widespread use, being taken up in 181 countries across Europe, Asia, Africa, North and South America and Australia. The mRNA vaccines Pfizer-BioNTech and Moderna are used in 111 countries and 63 countries respectively, mostly in Europe, North America, and parts of Asia including Singapore. In the United States, mRNA vaccines make up 96.1% of the administered COVID-19 vaccines, with remainder being the adenoviral vector vaccine by Johnson & Johnson. In Singapore, a total of 9.03 million doses of the mRNA vaccines by Pfizer-BioNTech and

Moderna have been administered, and 4.46 million people are fully vaccinated. As vaccination programs progress, younger individuals are increasingly vaccinated. In France, the 18-24 year olds account for 26.8% of vaccinations in July 2021, a sharp increase from 3.7% in May 2021. This trend is also expected to be observed in other countries as older groups are fully vaccinated. Combined with the high proportion of mRNA vaccination, it is important to understand the extent and severity of reported myocarditis and pericarditis side effects in this younger population.

Vaccine-associated myocarditis has also been described in other immunisations. Vaccines that may cause myocarditis or pericarditis include the smallpox, meningococcal, typhoid, Japanese encephalitis, and anthrax vaccines, according to data from VAERS in 2011-2015.[45] However, the reported rates from passive surveillance may not be representative of the true incidence, as active surveillance of participants after smallpox vaccine found a 60-times higher incidence of subclinical myocarditis compared to overt clinical myocarditis.[46] The mechanism underlying vaccine-associated myocarditis may be related to hypersensitivity due to significant eosinophilia observed with smallpox vaccine-associated myocarditis. However, this has not been observed with mRNA COVID-19 vaccine-associated myocarditis.[13,24] Proposed theories include the molecular mimicry of the viral spike protein with an unknown myocardial protein or direct spike-mediated toxicity. Whether this explains the relatively strong association of mRNA vaccines with myocarditis compared to other vaccines remains to be studied. The mechanism behind the association of younger males with myo-pericarditis post-vaccination is unclear, and although there are suggestions from animal and *in vitro* studies that testosterone may increase viral binding to myocytes and inhibit anti-inflammatory cell populations in coxsackie virus-induced myocarditis,[47] whether this is applicable to vaccine-induced myocarditis has not been studied.

Post-vaccine myocarditis associated with mRNA COVID-19 vaccines typically occurred around four days after the second dose, in adolescent or young adult males. VAERS data on 300 million doses of mRNA Pfizer-BioNTech and Moderna vaccine identified 1226 preliminary reports of myocarditis and pericarditis, predominately affecting men who are adolescents and young adults which is similar to the findings of our review. In males aged 12-17 years, the approximate rate of myocarditis is 56-69 per million vaccinated.[48] Compared to a baseline incidence of 1 to 22 per 100,000 person-years the observed numbers in a study of healthy members of the US military were around 2-4 times higher.[16] The Health Science Authority of Singapore received 12 reports of myocarditis and pericarditis after 5.5 million doses of mRNA vaccines, seven of whom were males aged below 30 years.[49] The overall local incidence rate of myocarditis is 0.22 per 100,000 doses and pericarditis is 1.24 per 100,000 doses in males below 30 years old. A recently published cohort study involving 2 million individuals in forty hospitals in the US reported 20 cases of vaccine related myocarditis (1.0 per 100,000 vaccine doses) and 37 cases of pericarditis (1.8 per 100,000 doses).[50] Up to 21 July, the UK MHRA had received 134 reports of myocarditis and 117 reports of pericarditis following 20.4 million first doses and 12.9 million second doses of Pfizer-BioNTech vaccine. Out of 1.3 million first doses and 0.3 million second doses of Moderna vaccine, there were 19 reports of myocarditis and 20 reports of pericarditis. Additionally, there were 82 reports of myocarditis and 135 reports of pericarditis following 24.7 million first doses and 23.2 million second doses of Oxford-AstraZeneca vaccine in the same period. This suggests that adenoviral vector COVID-19 vaccines may also be associated with myocarditis and pericarditis, although less commonly reported.

While COVID-19 vaccination is associated with myocarditis and pericarditis, COVID-19 infection itself is also observed to cause myocarditis. In a study of US competitive collegiate athletes with recent COVID-19 infection, the prevalence of clinical and subclinical myocarditis

was 2.3% on CMR.[51] In other reports, myocarditis caused by COVID-19 was relatively rare despite myocardial injury and raised cardiac markers being common in severe disease.[52] The prevalence of myocarditis was approximately 1% in a cohort of 1169 hospitalised COVID-19 patients, but data in larger cohorts are lacking. In 12-17 year old males who have the highest risk of vaccine-associated myocarditis, at a rate of 56-69 per million vaccinated individuals, it is estimated that 5700 cases of COVID-19, 215 hospitalisations, 71 intensive care unit admissions and 2 deaths would be prevented by COVID-19 vaccination.[48] As such, the balance of benefits to vaccination exceed the potential adverse effects of vaccination in the context of a pandemic.

Other possible adverse cardiac events reported include AMI, arrhythmia and cardiomyopathy. AMI is generally not thought to be attributed to COVID-19 vaccination, although by coincidence, it would be expected that a proportion of individuals may experience AMI in the days and weeks following vaccination.[49] Cases of AMI were rare in the COVID-19 vaccine RCTs, and the rates of AMI were similar to rate expected in the general population.[39,40,43] Similarly, arrythmias and cardiomyopathy post-vaccination were very rarely described and limited to a few case reports. On balance, the benefit of COVID-19 vaccination even in young male populations exceeds the risk of cardiac adverse events. Considering that the outcomes of myocarditis and pericarditis post-vaccination are good, vaccine uptake in this population should be encouraged in view of the current data. In contrast to the COVID-19 vaccine, adverse reactions to other vaccines are well-known but not as widely publicised. Taken together with the risk benefit ratio of COVID-19 vaccination being highly in favour of vaccination, vaccine hesitancy to the COVID-19 vaccine needs to be addressed actively to encourage higher uptake in the general population.

The main limitation of this review was that the majority of included studies consisted of case reports and series, and thus may not be generalisable to the wider vaccinated population.

Second, the diagnostic criteria of myocarditis cases were unclear in some reports, especially as not all studies were explicit in their method of exclusion of significant coronary artery disease, which may lead to an overestimation of cases of myocarditis. Similarly, as most patients who developed AMI or arrhythmia post-vaccination already had a degree of pre-existing heart disease, it was unclear if they were direct consequences of the vaccine or an acceleration of underlying cardiac pathology by factors such as psychological stress associated with vaccination. Third, as the younger population is likely the last cohort to be vaccinated in most countries, it would be expected that the published data would underestimate the incidence of myo-pericarditis post COVID-19 vaccination. Furthermore, under-reporting may also be an issue in developing countries with less stringent adverse reactions reporting systems. We did not find any reported cardiac manifestations with WIBP-CorV / BBIBP-CorV (Sinopharm). This result must be taken critically, as while the lack of associated cardiac manifestations could be a possibility, an alternative explanation could be that there is a lack of published data on this vaccine. There is a need to continuously study and monitor for the adverse reactions of all the vaccines reviewed. As new data on the adverse reactions to the COVID-19 vaccine are published, what is known presently about the cardiac manifestations may change, particularly as booster doses of vaccines are increasingly rolled out.

In conclusion, reported COVID-19 vaccine-associated cardiac adverse events include mainly myocarditis and pericarditis, which are most common in adolescent and young adult male individuals after mRNA vaccination. Reports of other events such as AMI, arrhythmia and stress cardiomyopathy are rare. Given the good vaccine efficacy and high number of cases of infection, hospitalisation and death that could potentially be prevented, COVID-19 vaccine remains of overall benefit with the current available data.

CONFLICT OF INTERESTS

All the authors of this paper have been voluntarily and fully vaccinated with COVID-19 vaccines.

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Table 1: Comparison of the characteristic, efficacy and safety of seven vaccines against COVID-19

Vaccine	BNT162b2 (Pfizer-BioNTech)	mRNA-1273 (Moderna)	AZD1222 (Oxford-AstraZeneca)	Ad26.COV2.S (Johnson & Johnson)	Sinovac-CoronaVac (Sinovac Biotech)	BBIBP-CorV (Sinopharm)	Gam-COVID-Vac (Gamaleya Research Institute)
Type of vaccine	mRNA	mRNA	Adenoviral vector	Adenoviral vector	Inactivated	Inactivated	Adenoviral vector
Trade names	Cominarty	Spikevax	Covishield, Vaxzevria	Janssen	CoronaVac	Sinopharm	Sputnik V
Number of doses	2	2	2	1	2	2	2
Mechanism	mRNA encoding a mutated form of the spike protein of SARS-CoV-2	mRNA encoding spike protein of SARS-CoV-2	Replication-deficient simian adenovirus vector containing coding sequence of spike protein of SARS-CoV-2	Replication-incompetent human adenovirus Ad26 vector containing coding sequence of spike protein of SARS-CoV-2	Inactivated SARS-CoV-2 with adjuvant aluminium hydroxide	Inactivated SARS-CoV-2 with adjuvant aluminium hydroxide	Two recombinant replication-defective human adenoviruses (Ad26 and Ad5) containing coding sequence of spike protein of SARS-CoV-2
Reported cardiac side effects	Myocarditis, pericarditis, AMI, arrhythmia, stress cardiomyopathy	Myocarditis, AMI	AMI, pericarditis	Myocarditis	None reported	None reported	AMI

Abbreviations: AMI – acute myocardial infarction