

Seroprevalence of SARS-CoV-2 anti-spike IgG antibody among COVID-19 vaccinated individuals residing in Surabaya, East Java, Indonesia

Ni Luh Ayu Megasari^{1,2}, Laura Navika Yamani^{2,3},
Juniastuti Juniastuti^{2,4}, Maria Inge Lusida^{2,4} and Yasuko Mori⁵

¹ Postgraduate School, Universitas Airlangga, Surabaya, East Java, Indonesia

² Indonesia-Japan Collaborative Research Center for Emerging and Re-Emerging Infectious Diseases, Institute of Tropical Disease, Universitas Airlangga, Surabaya, East Java, Indonesia

³ Department of Epidemiology, Faculty of Public Health, Universitas Airlangga, Surabaya, East Java, Indonesia

⁴ Faculty of Medicine, Universitas Airlangga, Surabaya, East Java, Indonesia

⁵ Center for Infectious Diseases, Kobe University Graduate School of Medicine, Kobe, Hyogo, Japan

ABSTRACT

Background: To limit the SARS-CoV-2 transmission, the Indonesian government launched a COVID-19 vaccination program in January 2021. Studies on the clinical treatment and implementation of COVID-19 vaccination have shown promising results; however, it is necessary to estimate the effectiveness of the vaccines. With the ongoing COVID-19 pandemic, studies have highlighted the impact of COVID-19 vaccines, especially CoronaVac, on Indonesian healthcare workers. To get a better picture of how the vaccines work in Indonesia, it is necessary to estimate the prevalence of SARS-CoV-2 anti-S IgG antibody induced by the COVID-19 vaccine in individuals who have already received two-to-three doses of vaccines.

Materials and Methods: Four-hundred and ninety-six whole-blood samples were collected from participants residing in Surabaya, East Java, Indonesia, who received a minimum of a two-dose COVID-19 vaccine. Serums were then isolated from the blood and subjected to detect SARS-CoV-2 anti-S IgG antibodies using a lateral flow immunochromatographic assay.

Results: The prevalence of positive anti-S-IgG antibodies was 91.7% (455/496) in all participants receiving a minimum of a two-dose COVID-19 vaccine. As many as 209 (85.3%) and 141 (96.6%) participants were seropositive for receiving CoronaVac and AstraZeneca, respectively. Meanwhile, all participants receiving two-dose CoronaVac with one booster dose of Moderna (105/100%) were seropositive ($p < 0.05$). Age, comorbidity, and time after the last vaccine were significantly correlated with seropositivity ($p < 0.05$).

Conclusion: Different vaccines might produce different antibody responses. Adopting a stronger policy regarding the administration of booster doses might be beneficial to elicit positive anti-S-IgG antibodies, especially among older individuals, those with comorbid diseases, and those with a longer time after the second vaccination dose.

Submitted 6 April 2023
Accepted 29 August 2023
Published 25 September 2023

Corresponding author
Yasuko Mori,
ymori@med.kobe-u.ac.jp

Academic editor
Joël Mossong

Additional Information and
Declarations can be found on
page 9

DOI 10.7717/peerj.16142

© Copyright
2023 Megasari et al.

Distributed under
Creative Commons CC-BY 4.0

OPEN ACCESS

Subjects Virology, Epidemiology, Immunology, Infectious Diseases, COVID-19

Keywords SARS-CoV-2, COVID-19 vaccine, Anti-S-IgG, Indonesia, Seroprevalence

INTRODUCTION

The World Health Organization (WHO) declared the novel coronavirus (COVID-19) outbreak as a global pandemic on March 11, 2020 ([Cucinotta & Vanelli, 2020](#)). COVID-19 came into place due to SARS-CoV-2, identified as the seventh member of the human coronavirus family ([Song et al., 2022](#)). Individuals with SARS-CoV-2 infection may experience a range of clinical manifestations, mainly grouped into asymptomatic, mild, moderate, severe, and critical infection ([COVID-19 Treatment Guidelines Panel, 2022](#)). The first positive COVID-19 case in Indonesia was detected on March 2, 2020 ([Nugraha et al., 2020](#)). Up to December 31, 2020, before the launch of the national COVID-19 vaccination program, a total of 743,198 people were confirmed cases, of which 22,138 were deaths with a case fatality rate of 3.0% ([Manuhutu, 2021](#)). A seroepidemiological study in 2020 reported that up to 13.1% individuals in Indonesia were previously infected by SARS-CoV-2 as confirmed by positive immunoglobulin (Ig)-G (IgG) antibodies ([Megasari et al., 2021](#)).

To limit the SARS-CoV-2 transmission, the Indonesian government implemented the COVID-19 vaccination program in January 2021. The government aimed to reach at least 70% of the vaccination coverage for 181.5 million people by March 2022 to achieve herd immunity. On March 5, 2023, the Indonesian Ministry of Health reported that 74.51% of Indonesian had received two full doses of vaccination, and 29.84% received an additional booster dose of COVID-19 vaccine ([Indonesian Ministry of Health, 2023a](#)).

The WHO recommended several COVID-19 vaccines to use. As of January 12, 2022, nine COVID-19 vaccines have been included in the Emergency Use Listing (EUL). These nine vaccines were the Pfizer/BioNTech Comirnaty (BNT162b2) (referred to as Pfizer), the SII/COVISHIELD and AstraZeneca/AZD1222 (ChAdOx1-S (recombinant)) (referred to as AstraZeneca), the Janssen/Ad26.COV2.S (referred to as Janssen), the Moderna (mRNA-1273) (referred to as Moderna), the Sinopharm COVID-19 (referred to as Sinopharm), the Sinovac-CoronaVac (referred to as CoronaVac), the Bharat Biotech BBV152 COVAXIN, the Covovax (NVX-CoV2373), and the Nuvaxovid (NVX-CoV2373) ([World Health Organization, 2022](#)). Six COVID-19 vaccines have been used nationwide for primary vaccines and booster in Indonesia. These six vaccines include CoronaVac, AstraZeneca, Pfizer, Moderna, Janssen, and Sinopharm ([Indonesian Ministry of Health, 2022](#)).

Vaccines are designed to induce virus-neutralizing antibodies. They prevent COVID-19 infection and avoid unfavorable clinical manifestations. Studies on the clinical treatment and implementation of COVID-19 vaccination have shown promising results on COVID-19 reduction. Reports on the phase III trials using a two-dose regimen showed 95% of Pfizer, 94.1% of Moderna, 67% of AstraZeneca, and 67.7% of CoronaVac efficiently reduced the virus transmission. Studies on individuals who were not previously infected by SARS-CoV-2 showed a two-dose COVID-19 vaccine was sufficient in preventing symptomatic infection ([Polack et al., 2020](#); [Baden et al., 2021](#); [Olliaro, Torreale & Vaillant, 2021](#); [Wei et al., 2021](#); [Jin et al., 2022](#)).

COVID-19 vaccines are designed to elicit an immune response against the spike (S) glycoprotein of SARS-CoV-2 required for SARS-CoV-2 binding, fusion, and cell entry. Vaccination induces the production of anti-S and anti-receptor binding domain (RBD) and neutralizes antibodies in the blood. Anti-S antibodies block the receptor-binding domain (RBD) on the S protein; thus, vaccines can prevent infection by inhibiting viral docking onto the angiotensin-converting enzyme 2 (ACE2) receptor. Despite producing several structural proteins, such as the S, nucleocapsid (N), membrane (M), and envelope (E), SARS-CoV-2 antibodies against N, M, and E have no neutralizing capability in the absence of anti-S antibodies. Similar to infection, vaccination results in early production of serum antibodies, including the SARS-CoV-2 anti-S-IgG and anti-S-IgM ([Wisniewski, Campillo Luna & Redlich, 2021](#); [Kyriakidis et al., 2021](#); [Wang et al., 2021](#); [Tan et al., 2022](#)). Anti-S-IgG antibody was reported to exert neutralizing effects *in vitro* and become a useful indicator of an effective immune response, including the effectiveness of COVID-19 vaccines ([Van Elslande et al., 2020](#); [Rezaei et al., 2021](#)). Detection and analysis of this parameter are relatively simple but provide a high correlation towards conventional neutralizing tests; thus, it can be highly utilized in both the COVID-19 pandemic and endemic ([Lippi, Henry & Plebani, 2021](#); [Jochum et al., 2022](#)).

The various research settings may influence the outcomes of clinical trials. Continuous surveillance of vaccine effectiveness and the probability of waning immunity should be considered ([Björk et al., 2022](#)). In several African countries, the seroprevalence of SARS-CoV-2 anti-S antibodies in general population was lower than 90% ([Awandu et al., 2022](#); [Onifade et al., 2023](#)), while in several Asian, European, and South American countries, the seroprevalence was reported to be more than 90% ([Kajanova et al., 2022](#); [Decarreaux et al., 2022](#); [Aguilera et al., 2022](#); [Elangovan et al., 2022](#)). In Indonesia, several studies have highlighted the impact of COVID-19 vaccination on the elicitation of antibody responses. However, most studies are performed on healthcare workers receiving CoronaVac ([Santi et al., 2021](#); [Cucunawangsih et al., 2021, 2022](#); [Hidayat et al., 2022](#)). The seroprevalence of SARS-CoV-2-related antibodies among the general population, especially anti-S-IgG antibodies is rarely informed in Indonesia, while it plays an important role in neutralizing capability ([Kyriakidis et al., 2021](#); [Tan et al., 2022](#)).

Up to December 30, 2020, East Java was reported having the second-highest cumulative SARS-CoV-2 infection among Indonesian Provinces, and Surabaya City had the highest cumulative cases in the province ([Indonesian Ministry of Health, 2020](#); [East Java Public Health Office, 2021](#)). Thus, this study aimed to estimate the prevalence of SARS-CoV-2 anti-S IgG antibody of individuals of the general population, who received two to three doses of COVID-19 vaccines in Surabaya, East Java, Indonesia.

MATERIALS AND METHODS

Ethical clearance

This study was approved by the Institutional Ethics Committee of Kobe University Graduate School of Medicine, Kobe, Japan (Approval No. B200600) and the Ethics and Law Committee of Airlangga University Hospital, Surabaya, Indonesia (Approval No. 163/KEP/2021).

Sample collection

Blood samples were collected in a medical research center in Surabaya, East Java, Indonesia, from September 2021 to March 2022. The inclusion criteria for participants determined include (1) Indonesian individuals who were aged 18 years or older; (2) had already received a minimum of a two-dose COVID-19 vaccine according to the Indonesia government's guidelines and as proven by PeduliLindungi digital certificate ([Indonesian Ministry of Health, 2021, 2023b](#)); (3) were vaccinated at least 1 month before the research; and (4) formally consented to enroll in the study (proven by written informed consent letter). Exclusion criteria for the participants include (1) a history of COVID-19 vaccination dropout, (2) SARS-CoV-2 positive as diagnosed by real-time polymerase chain reaction (qPCR) or antigen test between the vaccination period and up to 6 months before sample collection, (3) the presence of COVID-19 related symptoms up to 1 month before sample collection, and (4) immune-system related disorder (immunodeficiency or auto-immune related diseases). Comorbidity was not included as an exclusion criterion. Peripheral blood samples and serum isolation were performed as previously described ([Megasari et al., 2021](#)).

Qualitative detection of SARS-CoV-2 anti-S IgG antibodies

SARS-CoV-2 anti-S IgG antibodies were qualitatively detected using a lateral flow immunochromatographic assay (Assure Tech, Hangzhou, China). The test was done by employing anti-human IgM antibody (test line IgM), anti-human IgG (test line IgG), and goat anti-mouse IgG (control line C) immobilized on a nitrocellulose strip. The conjugate pad contained recombinant SARS-CoV-2 antigen (antigen is recombinant nucleocapsid protein and spike protein (S1)) conjugated with colloid gold. The manufacturer's reported values of the kit's sensitivity and specificity in the COVID-19 IgG detection were 90% and 100%, respectively ([Assure Tech, 2020](#)).

Statistical analysis

Statistical analysis was performed using SPSS Statistics 17.0 (Advanced Analytics, Tokyo, Japan). A Chi-squared test of categorical variables was employed, and test results with $p < 0.05$ were considered significant.

RESULTS

Demographic characteristics of research participants

This study collected 496 individuals who received a minimum of two-dose COVID-19 vaccine. Of the participants, 258 (52%) were male, and most were Javanese (464; 93.5%). Participants were classified into five age groups: 18–29, 30–39, 40–49, 50–59, and ≥ 60 years. Most participants were between 18 to 29 years of age (179; 36.1%). Based on employment, 108 individuals (21.8%) worked as medical or laboratory staff, while the rest (388; 78.2%) worked in non-medical sectors. Forty participants (8.1%) had one or more comorbid diseases, including diabetes mellitus, hypertension, dyslipidemia, and

Table 1 Demographic characteristics and SARS-CoV-2 anti-S-IgG antibody seropositivity of study participants.

Characteristics	CoronaVac (<i>n</i> = 245)		AstraZeneca (<i>n</i> = 146)		Two doses of CoronaVac + 1 booster dose of Moderna (<i>n</i> = 105)		Total (<i>n</i> = 496)	
	IgG positive <i>n</i> (%)	IgG negative <i>n</i> (%)	IgG positive <i>n</i> (%)	IgG negative <i>n</i> (%)	IgG positive <i>n</i> (%)	IgG negative <i>n</i> (%)	IgG positive <i>n</i> (%)	IgG negative <i>n</i> (%)
Sex	<i>p</i> = 0.745		<i>p</i> = 0.755		N/A		<i>p</i> = 0.665	
Female	110 (84.6)	20 (15.4)	37 (97.4)	1 (2.6)	70 (100)	0 (0)	217 (91.2)	21 (8.8)
Male	99 (86.1)	16 (13.9)	104 (96.4)	4 (3.6)	35 (100)	0 (0)	238 (92.2)	20 (7.8)
Age (years)	<i>p</i> = 0.047*		<i>p</i> = 0.895		N/A		<i>p</i> = 0.000*	
18–29	93 (90.3)	10 (9.7)	42 (95.5)	2 (4.5)	32 (100)	0 (0)	167 (93.3)	12 (6.7)
30–39	33 (84.6)	6 (15.4)	38 (97.4)	1 (2.6)	55 (100)	0 (0)	126 (94.7)	7 (5.3)
40–49	32 (91.4)	3 (8.6)	42 (95.5)	2 (4.5)	11 (100)	0 (0)	85 (94.4)	5 (5.6)
50–59	32 (78)	9 (22)	18 (100)	0 (0)	7 (100)	0 (0)	57 (86.4)	9 (13.6)
≥60	19 (70.4)	8 (29.6)	1 (100)	0 (0)	0 (100)	0 (0)	20 (71.4)	8 (28.6)
Ethnicity	<i>p</i> = 0.003*		<i>p</i> = 0.496		N/A		<i>p</i> = 0.118	
Javanese	203 (86.8)	31 (13.2)	129 (96.3)	5 (3.7)	96	0 (0)	428 (92.2)	36 (7.3)
Others	6 (54.5)	5 (45.5)	12 (100)	0 (0)	9	0 (0)	27 (84.4)	5 (15.6)
Occupation	<i>p</i> = 0.136		N/A		N/A		<i>p</i> = 0.121	
Medical/laboratory personnel	14 (73.7)	5 (26.3)	0 (0)	0 (0)	89 (100)	0 (0)	103 (95.4)	5 (4.6)
Non-medical/laboratory related job	195 (86.3)	31 (15.7)	141 (96.6)	5 (3.4)	16 (100)	0 (0)	352 (90.7)	36 (9.3)
Time after the last dose of COVID-19 vaccine	<i>p</i> = 0.000*		<i>p</i> = 0.014*		N/A		<i>p</i> = 0.000*	
1 month	86 (96.6)	3 (3.4)	7 (77.8)	2 (22.2)	59	0 (0)	152 (96.8)	5 (3.2)
2 months	47 (92.2)	4 (7.8)	24 (96)	1 (4)	46	0 (0)	117 (95.9)	5 (4.1)
3 months	28 (80)	7 (20)	104 (98.1)	2 (1.9)	0 (0)	0 (0)	132 (93.6)	9 (6.4)
4 months	8 (66.7)	4 (33.3)	6 (100)	0 (0)	0 (0)	0 (0)	14 (77.8)	4 (22.2)
5 months	8 (61.5)	5 (38.5)	0 (0)	0 (0)	0 (0)	0 (0)	8 (61.5)	5 (38.5)
≥6 months	32 (71.1)	13 (28.9)	0 (0)	0 (0)	0 (0)	0 (0)	32 (71.1)	13 (28.9)
Comorbidity	<i>p</i> = 0.000*		<i>p</i> = 0.683		N/A		<i>p</i> = 0.000*	
Yes	14 (58.3)	10 (41.7)	6 (100)	0 (0)	10 (100)	0 (0)	30 (75)	10 (25)
No	195 (88.2)	26 (11.8)	135 (96.4)	5 (3.6)	95 (100)	0 (0)	425 (93.2)	31 (6.8)

Notes:

N/A, not applicable.

* significant (*p* < 0.05).

cardiovascular diseases. Most participants had taken treatment for 1 to 3 months after the last dose of the COVID-19 vaccine. All participants showed no COVID-19-related symptoms up to 1 month before sample collection, and reported no positive SARS-CoV-2 qRT-PCR or antigen test result up to 6 months before sample collection and between vaccination. Types of vaccine received were CoronaVac (245; 49%), AstraZeneca (146; 29.2%), and two doses of CoronaVac plus one booster (third) of Moderna (105; 21%). The demographic characteristics of participants are displayed in [Table 1](#).

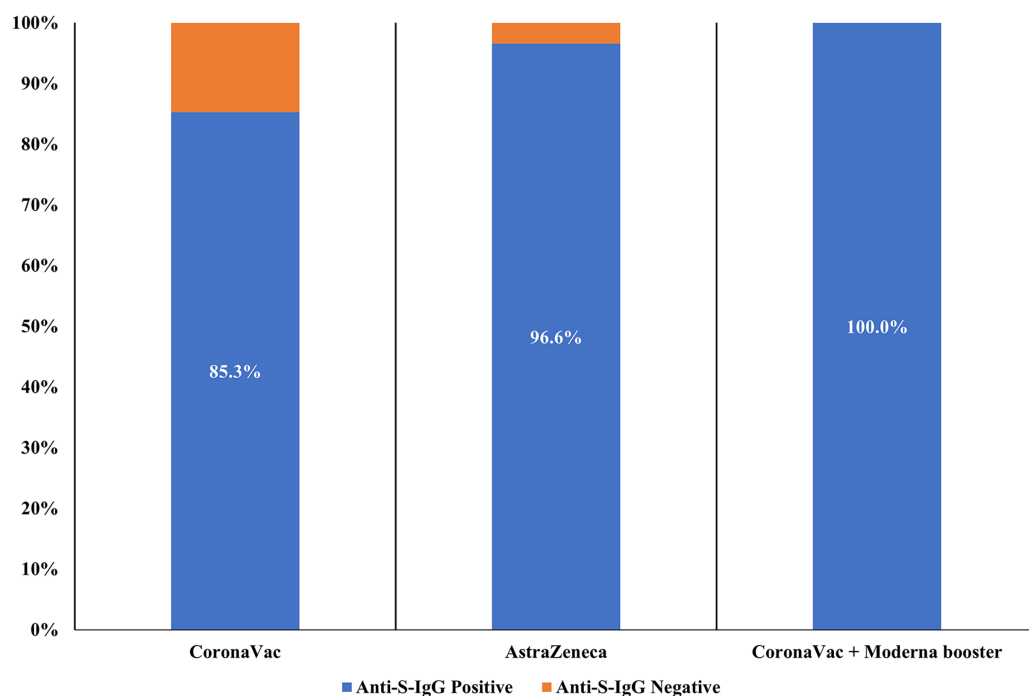


Figure 1 Seroprevalence of SARS-CoV-2 anti-S-IgG in study participants receiving different COVID-19 vaccines ($n = 496$). [Full-size DOI: 10.7717/peerj.16142/fig-1](https://doi.org/10.7717/peerj.16142/fig-1)

Prevalence of SARS-CoV-2 anti-S IgG antibody in vaccinated individuals

The prevalence of positive anti-S-IgG antibodies was 91.7% (455/496) in all two-dose vaccinated participants. Among recipients who received two-dose CoronaVac and AstraZeneca, 209 of 245 (85.3%) and 141 of 146 (96.6%) tested positive for anti-S-IgG antibody, respectively. All participants receiving two-dose of CoronaVac with one booster dose of Moderna (105/105; 100%) were anti-S-IgG positive. The difference in anti-S-IgG antibody seropositivity among individuals receiving a different type of vaccine was statistically significant ($p < 0.05$) (Fig. 1).

Several characteristics were significantly correlated with the anti-S-IgG antibody seropositivity. Without considering the types of COVID-19, age, comorbidity, and time of vaccination after the last dose were significantly correlated to seropositivity ($p < 0.05$). The prevalence of seronegativity was higher among older individuals with comorbid diseases and a longer time after two primary or booster doses of vaccines. Based on the types of COVID-19 vaccine, a similar prevalence was also found in individuals receiving two-dose CoronaVac. In addition, individuals with an ethnicity other than Javanese had a higher prevalence of seronegativity than those of Javanese counterparts. The prevalence of anti-S-IgG antibody in vaccinated individuals can be seen in Table 1.

DISCUSSION

The seroprevalence of SARS-CoV-2-specific antibodies varied worldwide. the administration of COVID-19 vaccines invoked the production of SARS-CoV-2 antibodies.

In several African countries, the seroprevalence of anti-SARS-CoV-2 antibodies was found in different areas, such as 73.8% in Nigeria and 81.1% in Kenya ([Awandu et al., 2022](#); [Onifade et al., 2023](#)). In other countries, such as India, Chile, French, and Slovakia, the seroprevalence was reported to be more than 90% ([Ben Houmich et al., 2022](#); [Kajanova et al., 2022](#); [Decarreaux et al., 2022](#); [Aguilera et al., 2022](#); [Elangovan et al., 2022](#)). Consistent with those findings, 91.7% of participants in this study exhibited anti-S-IgG antibody seropositivity.

This current study revealed that individuals receiving a two-dose primary vaccine *i.e.*, CoronaVac and AstraZeneca had a significantly lower prevalence of anti-S-IgG antibody compared to those receiving two-dose CoronaVac with one booster dose of Moderna ($p < 0.05$). The seroprevalence of anti-S-IgG antibody was the lowest in CoronaVac recipients, followed by AstraZeneca and Moderna booster recipients.

Previous studies confirmed similar findings that anti-S-IgG antibody prevalence and titers of two-dose COVID-19 vaccine recipients were higher in mRNA-vaccine recipients, followed by AstraZeneca recipients, and the lowest were in CoronaVac recipients ([Barin et al., 2022](#); [Tan et al., 2022](#)). Receiving two-dose CoronaVac and mRNA vaccine increased anti-S-IgG antibody titers, up to 7.9 times baseline titers a month after booster ([Barin et al., 2022](#)). Compared to a booster dose using CoronaVac, the mRNA vaccine produces higher anti-S-IgG antibody levels ([Keskin et al., 2022](#); [Barin et al., 2022](#)). Thereby, it is recommended and safe to administer a heterologous booster vaccine, especially using mRNA vaccines, such as Moderna and Pfizer ([Goh et al., 2022](#)). Similar to this study, investigations on Indonesian healthcare workers receiving two-dose CoronaVac and one dose of Moderna booster also showed 100% anti-SARS-CoV-2 antibodies positivity ([Cucunawangsih et al., 2022](#); [Hidayat et al., 2022](#); [Sinto et al., 2023](#)).

Time after the last dose of vaccination significantly affected the anti-S-IgG antibody positivity, especially of CoronaVac recipients. A total of 3 months after vaccination, anti-S-IgG seronegativity turned to be around 20–38.5%, compared to 3.4% and 7.8% in the first and second months of the CoronaVac administration. A similar finding was observed in Malaysia, where individuals' antibodies declined faster after receiving CoronaVac compared to AstraZeneca and mRNA vaccines. The rate of seropositivity was declining to 90% and 60% 3 months after the second vaccination of AstraZeneca and CoronaVac, respectively ([Barin et al., 2022](#)). Meanwhile, fourteen days after the second dose of CoronaVac, the level of SARS-CoV-2 anti-S antibodies was reported to decrease significantly by day 42, although persisting for up to day 98 ([Cucunawangsih et al., 2021](#)). Unlike individuals receiving only two doses of CoronaVac, those with an additional booster dose of Moderna showed 100% seropositivity up to 2 months after vaccination. Anti-SARS-CoV-2 antibodies were reported to decline in 90 days after the administration of either a homologous or heterologous booster ([Lau et al., 2022](#)).

However, an anomaly was observed among AstraZeneca recipients, particularly in the first month after the second dose. More than 20% of recipients (2/9; 22.2%) were seronegative, while the seroconversion rate in AstraZeneca recipients was reported to be more than 90% 2 weeks after the second dose ([Varghese et al., 2022](#); [Chau et al., 2022](#)). This finding persisted likely due to the limited sample size or any unreported or undiagnosed

participant's condition, such as malignancies or immunosuppressive therapies, which might lower seroconversion to 70–85% ([Thakkar et al., 2021](#)).

Several participants' characteristics were significantly correlated with anti-S-IgG antibody seropositivity, especially among CoronaVac recipients. Lower seropositivity was identified among older individuals, those with comorbid diseases, and those of non-Javanese ethnicity.

Older individuals, mostly more than 60 years old, experienced higher seronegativity after taking two doses of almost any type of COVID-19 vaccines, including CoronaVac, AstraZeneca, and Moderna ([Fonseca et al., 2022](#); [Chiarella et al., 2022](#); [Malagón-Rojas et al., 2022](#)). The seronegativity might happen due to immunescence, which may decrease the immune response due to the reduction of T-cell proliferation, naïve T-cell population, cytokine production, and antigen recognition ([Fulop et al., 2009](#)). Moreover, individuals with comorbid diseases, including diabetes mellitus, hypertension, or dyslipidemia, were more likely to be seronegative after receiving two-dose CoronaVac ([Karamese & Tutuncu, 2022](#); [Barin et al., 2022](#); [Fonseca et al., 2022](#)). Similar to age-related immunescence, comorbidities were reported to reduce vaccine immunogenicity and antibody response ([Kwetkat & Heppner, 2020](#)); thus, individuals with more comorbidities were likely to be seronegative with any types of COVID-19 vaccines received ([Huang et al., 2023](#)). An additional booster dose of the COVID-19 vaccine should be considered for older individuals and those with comorbid diseases ([Fonseca et al., 2022](#)). This recommendation lies in the current finding that all participants of all ages and those with or without comorbid diseases were anti-S-IgG antibody positive after receiving one booster dose of Moderna.

In addition to the influence of age and comorbid disease, all vaccines are supposed to elicit antibody responses in all individuals with different ethnicity and race. However, most studies reported the different efficacy of mRNA and recombinant vaccines among races, such as Caucasian, Asian, Hispanic, and African ([Rahman et al., 2022](#); [Salari et al., 2022](#)). A study highlighting antibody responses among a specific ethnicity is very limited; thus, the current finding that mentions lower seropositivity in non-Javanese participants has no similar results to previous research. In general, no difference in seropositivity was observed among people with different ethnicity receiving either two-dose CoronaVac or AstraZeneca or among those receiving one booster dose.

This current study also did not find a significant difference in anti-S-IgG antibody seropositivity among individuals of different sex and occupation. However, previous studies described a higher risk of SARS-CoV-2 among healthcare workers despite vaccination ([Shah et al., 2022](#)); therefore, the booster is still needed to keep individuals, especially healthcare workers, safe. Previous studies found lower anti-S-IgG titers among males ([Varghese et al., 2022](#); [Barin et al., 2022](#); [Fonseca et al., 2022](#)). This current study also indicates a similar finding that participants of all sexes had a similar seropositivity level ([Chau et al., 2022](#)).

With the evidence generated from this study, it is important to note that this study still has several limitations. This study recruited a disproportionate sample size of participants receiving different types of vaccines (CoronaVac, AstraZeneca, and Moderna booster).

Participants' characteristics, including time after the last dose of vaccination, age, ethnicity, and comorbid disease, should also be considered when determining sample size.

We recommend recruiting a proportionate sample size based on the inclusion criteria for future studies. Multicenter sampling might provide a better picture of COVID-19 vaccine seroprevalence as well. While exclusion criteria have addressed SARS-CoV-2 positive infection, not all participants received regular COVID-19 examination using either qRT-PCR or antigen test; thus, it was not exactly known whether all participants were SARS-CoV-2 negative up to 6 months before sample collection, between vaccination, or during sample collection. Despite six types of COVID-19 vaccines used in Indonesia, this study only managed to include three types of vaccines. Future studies are expected to address these limitations to better investigate the efficacy of COVID-19 vaccines.

CONCLUSIONS

The seroprevalence of positive anti-S-IgG antibodies was 91.7% among individuals residing in Surabaya, East Java, Indonesia, who received two to three doses of COVID-19 vaccines. Two-dose CoronaVac recipients exhibited the lowest seroprevalence compared to those receiving two-dose AstraZeneca and two-dose CoronaVac with one booster dose of Moderna. Higher seronegativity, especially among CoronaVac recipients, was correlated with a longer time after the administration of the second dose, older age, and comorbid disease. Administering a booster dose was beneficial to elicit positive anti-S-IgG antibodies; thus, this action can be used to strengthen booster vaccination policy, particularly in Surabaya and Indonesia in general.

ADDITIONAL INFORMATION AND DECLARATIONS

Funding

This work was supported by the the Japan Initiative for the Global Research Network on Infectious Diseases (J-GRID) from the Ministry of Education, Culture, Sport, Science and Technology in Japan, and the Japan Agency for Medical Research and Development (AMED); and the Institute of Tropical Disease as the Center of Excellence (COE) program by Kementerian Riset, Teknologi, dan Pendidikan Tinggi Republik Indonesia. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Grant Disclosures

The following grant information was disclosed by the authors:
Japan Initiative for the Global Research Network on Infectious Diseases (J-GRID).
Japan Agency for Medical Research and Development (AMED).
Institute of Tropical Disease.

Competing Interests

The authors declare that they have no competing interests.

Author Contributions

- Ni Luh Ayu Megasari performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the article, and approved the final draft.
- Laura Navika Yamani performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Juniastuti Juniastuti performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- Maria Inge Lusida conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.
- Yasuko Mori conceived and designed the experiments, authored or reviewed drafts of the article, and approved the final draft.

Human Ethics

The following information was supplied relating to ethical approvals (*i.e.*, approving body and any reference numbers):

This study was approved by the Institutional Ethics Committee of Kobe University Graduate School of Medicine, Kobe, Japan (approval no. B200600) and the Ethics and Law Committee of Airlangga University Hospital, Surabaya, Indonesia (Ethical approval no. 163/KEP/2021)

Data Availability

The following information was supplied regarding data availability:

The raw data is available in the [Supplemental File](#).

Supplemental Information

Supplemental information for this article can be found online at <http://dx.doi.org/10.7717/peerj.16142#supplemental-information>.

REFERENCES

- Aguilera X, González C, Apablaza M, Rubilar P, Icaza G, Ramírez-Santana M, Pérez C, Cortes LJ, Núñez-Franz L, Quezada-Gaete R, Castillo-Laborde C, Correa J, Said M, Hormazábal J, Vial C, Vial P. 2022. Immunization and SARS-CoV-2 antibody seroprevalence in a country with high vaccination coverage: lessons from Chile. *Vaccines* **10**(7):1002 DOI 10.3390/vaccines10071002.
- Assure Tech. 2020. COVID-19 ecotest; antibody rapid detection test. Available at <https://verifydiagnostics.com/wp-content/uploads/2020/10/EU-AssureTech-Rapid-Antibody.pdf> (accessed 22 May 2023).
- Awandu SS, Ochieng Ochieng A, Onyango B, Magwanga RO, Were P, Atieno Ochung' A, Okumu F, Oloo MA, Katieno JS, Lidechi S, Ogutu F, Awuor D, Kirungu JN, Orata F, Achieng J, Oure B, Nyunja R, Muok EMO, Munga S, Estambale B. 2022. High seroprevalence of Immunoglobulin G (IgG) and IgM antibodies to SARS-CoV-2 in asymptomatic and symptomatic individuals amidst vaccination roll-out in western Kenya. *PLOS ONE* **17**(12):e0272751 DOI 10.1371/journal.pone.0272751.
- Baden LR, El Sahly HM, Essink B, Kotloff K, Frey S, Novak R, Diemert D, Spector SA, Roupheal N, Creech CB, McGettigan J, Khetan S, Segall N, Solis J, Brosz A, Fierro C,

- Schwartz H, Neuzil K, Corey L, Gilbert P, Janes H, Follmann D, Marovich M, Mascola J, Polakowski L, Ledgerwood J, Graham BS, Bennett H, Pajon R, Knightly C, Leav B, Deng W, Zhou H, Han S, Ivarsson M, Miller J, Zaks T, COVE Study Group. 2021. Efficacy and safety of the mRNA-1273 SARS-CoV-2 vaccine. *The New England Journal of Medicine* **384**(5):403–416 DOI [10.1056/NEJMoa2035389](https://doi.org/10.1056/NEJMoa2035389).
- Barin B, Kasap U, Selçuk F, Volkan E, Uluçkan Ö. 2022. Comparison of SARS-CoV-2 anti-spike receptor binding domain IgG antibody responses after CoronaVac, BNT162b2, ChAdOx1 COVID-19 vaccines, and a single booster dose: a prospective, longitudinal population-based study. *The Lancet Microbe* **3**(4):e274–e283 DOI [10.1016/S2666-5247\(21\)00305-0](https://doi.org/10.1016/S2666-5247(21)00305-0).
- Ben Houmich T, Tali A, Debbagh F, Lamrani Hanchi A, Soraa N. 2022. Seroprevalence of SARS-CoV-2 antibodies in vaccinated healthcare workers in Marrakech (Morocco). *International Journal of Immunopathology and Pharmacology* **36**:3946320221133697 DOI [10.1177/03946320221133697](https://doi.org/10.1177/03946320221133697).
- Björk J, Bonander C, Moghaddassi M, Rasmussen M, Malmqvist U, Kahn F, Inghammar M. 2022. Surveillance of COVID-19 vaccine effectiveness: a real-time case-control study in southern Sweden. *Epidemiology and Infection* **150**:1–15 DOI [10.1017/S0950268822000425](https://doi.org/10.1017/S0950268822000425).
- Chau NVV, Nguyet LA, Truong NT, Toan LM, Dung NT, Hung LM, Nhan MT, Man DNH, Ngoc NM, Thao HP, Tu TNH, Mai HK, Hung DT, Ny NTH, Thanh LK, Anh NT, Hong NTT, Nhu LNT, Yen LM, Choisy M, Thanh TT, Thwaites G, Tan LV. 2022. Immunogenicity of Oxford-AstraZeneca COVID-19 vaccine in vietnamese health-care workers. *The American Journal of Tropical Medicine and Hygiene* **106**(2):556–561 DOI [10.4269/ajtmh.21-0849](https://doi.org/10.4269/ajtmh.21-0849).
- Chiarella SE, Jenkins SM, Smith CY, Prasad V, Shakuntulla F, Ahluwalia V, Iyer VN, Theel ES, Joshi AY. 2022. Predictors of seroconversion after coronavirus disease 2019 vaccination. *Annals of Allergy, Asthma & Immunology: Official Publication of the American College of Allergy, Asthma, & Immunology* **129**:189–193 DOI [10.1016/j.anai.2022.05.026](https://doi.org/10.1016/j.anai.2022.05.026).
- COVID-19 Treatment Guidelines Panel. 2022. Coronavirus disease 2019 (COVID-19) treatment guidelines. National Institutes of Health. Available at <https://www.covid19treatmentguidelines.nih.gov/> (accessed 13 January 2023).
- Cucinotta D, Vanelli M. 2020. WHO declares COVID-19 a pandemic. *Acta Bio-Medica: Atenei Parmensis* **91**:157–160 DOI [10.23750/abm.v91i1.9397](https://doi.org/10.23750/abm.v91i1.9397).
- Cucunawangsih C, Wijaya RS, Lugito NPH, Suriapranata I. 2021. Antibody response to the inactivated SARS-CoV-2 vaccine among healthcare workers. *Indonesia International Journal of Infectious Diseases: IJID: Official Publication of the International Society for Infectious Diseases* **113**:15–17 DOI [10.1016/j.ijid.2021.09.078](https://doi.org/10.1016/j.ijid.2021.09.078).
- Cucunawangsih C, Wijaya RS, Lugito NPH, Suriapranata I. 2022. Antibody response after a third dose mRNA-1273 vaccine among vaccinated healthcare workers with two doses of inactivated SARS-CoV-2 vaccine. *International Journal of Infectious Diseases: IJID: Official Publication of the International Society for Infectious Diseases* **118**(6):116–118 DOI [10.1016/j.ijid.2022.02.036](https://doi.org/10.1016/j.ijid.2022.02.036).
- Decarreaux D, Pouquet M, Souty C, Vilcu A-M, Prévot-Monsacre P, Fourié T, Villarroel PMS, Priet S, Blanché H, Sebaoun J-M, Deleuze J-F, Turbelin C, Werner A, Kochert F, Grosgeat B, Rabiega P, Laupie J, Abraham N, Guerrisi C, Noël H, Van der Werf S, Carrat F, Hanslik T, Charrel R, De Lamballerie X, Blanchon T, Falchi A. 2022. Seroprevalence of SARS-CoV-2 IgG antibodies and factors associated with SARS-CoV-2 IgG neutralizing activity among primary health care workers 6 months after vaccination rollout in France. *Viruses* **14**(5):957 DOI [10.3390/v14050957](https://doi.org/10.3390/v14050957).

- East Java Public Health Office. 2021. Dashboard COVID-19 Jawa Timur. Available at <https://infocovid19.jatimprov.go.id/>.
- Elangovan D, Hussain SMS, Virudhunagar Muthuprakash S, Devi Periadurai N, Viswanath Nalankilli A, Volvoikar H, Ramani P, Sivasubramaniam J, Mohanram K, Surapaneni KM. 2022. Impact of COVID-19 vaccination on seroprevalence of SARS-CoV-2 among the health care workers in a tertiary care centre, South India. *Vaccines* 10(11):1967 DOI 10.3390/vaccines10111967.
- Fonseca MHG, de Souza T de FG, de Carvalho Araújo FM, de Andrade LOM. 2022. Dynamics of antibody response to CoronaVac vaccine. *Journal of Medical Virology* 94(5):2139–2148 DOI 10.1002/jmv.27604.
- Fulop T, Pawelec G, Castle S, Loeb M. 2009. Immunosenescence and vaccination in nursing home residents. *Clinical Infectious Diseases* 48(4):443–448 DOI 10.1086/596475.
- Goh YS, Fong S-W, Rouers A, Chang ZW, Tay MZ, Chavatte J-M, Zhuo NZ, Hor PX, Loh CY, Huang Y, Wong JXE, Tan YJ, Lim DRX, Wang B, Ngoh EZX, Salleh SNM, Lee RTC, Pada S, Sun LJ, Ong DLS, Somani J, Lee ES, Wang C-I, Leo Y-S, Lin RTP, Ren EC, Lye DC, Young BE, Lim PL, Ng LFP, Renia L. 2022. Heterologous booster vaccination with CoronaVac following prime vaccination with mRNA vaccine. *Clinical & Translational Immunology* 11(8):e1403 DOI 10.1002/cti2.1403.
- Hidayat R, Mustika AP, Avisha F, Djulianisaa Z, Winari DD, Putri RA, Lisman HM, Davin V, Fathi GC, Widhani A, Aini MH, Yudhistira Y, Azizah S, Rahmadani M, Istanti ND, Giantini A. 2022. Evaluation of SARS-CoV-2 antibody response post third dose COVID-19 mRNA vaccination at Universitas Indonesia hospital. *Acta Medica Academica* 51(2):69–78.
- Huang C-F, Jang T-Y, Wu P-H, Kuo M-C, Yeh M-L, Wang C-W, Liang P-C, Wei Y-J, Hsu P-Y, Huang C-I, Hsieh M-Y, Lin Y-H, Hsiao H-H, Hsu C-M, Huang C-T, Lee C-Y, Chen Y-H, Chen T-C, Lin K-D, Wang S-H, Wang S-F, Huang J-F, Dai C-Y, Chuang W-L, Yu M-L. 2023. Impact of comorbidities on the serological response to COVID-19 vaccination in a Taiwanese cohort. *Virology Journal* 20(1):112 DOI 10.1186/s12985-023-02056-5.
- Indonesian Ministry of Health. 2021. KEPUTUSAN MENTERI KESEHATAN REPUBLIK INDONESIA NOMOR HK.01.07/MENKES/4638/2021 TENTANG PETUNJUK TEKNIS PELAKSANAAN VAKSINASI DALAM RANGKA PENANGGULANGAN PANDEMI CORONA VIRUS DISEASE 2019 (COVID-19). Available at <https://peraturan.bpk.go.id/Home/Details/171640/keputusan-menkes-no-hk0107menkes46382021> (accessed 22 May 2023).
- Indonesian Ministry of Health. 2020. SITUASI TERKINI PERKEMBANGAN NOVEL CORONAVIRUS (COVID-19); Data dilaporkan sampai 30 Desember 2020. Available at <https://infeksiemerging.kemkes.go.id/situasi-infeksi-emerging/situasi-terkini-perkembangan-coronavirus-disease-covid-19-31-desember-2020>.
- Indonesian Ministry of Health. 2022. Tambah Regimen Baru Vaksin Booster, Total Ada 6 Jenis Vaksin COVID-19 yang Dipakai di Indonesia. Available at <https://www.kemkes.go.id/article/view/22030100001/tambah-regimen-baru-vaksin-booster-total-ada-6-jenis-vaksin-covid-19-yang-dipakai-di-indonesia.html> (accessed 14 November 2022).
- Indonesian Ministry of Health. 2023a. Vaksinasi COVID-19 Nasional. Available at <https://vaksin.kemkes.go.id> (accessed 14 November 2022).
- Indonesian Ministry of Health. 2023b. SURAT EDARAN NOMOR HK.02.02/C/380/2023 TENTANG VAKSINASI COVID-19 DOSIS BOOSTER KE-2 BAGI KELOMPOK MASYARAKAT UMUM. Available at <https://www.kemkes.go.id/downloads/resources/download/SE/SE-Vaksinasi-Booster-Masyarakat-Umum.pdf> (accessed 22 May 2023).

- Jin L, Li Z, Zhang X, Li J, Zhu F. 2022. CoronaVac: a review of efficacy, safety, and immunogenicity of the inactivated vaccine against SARS-CoV-2. *Human Vaccines & Immunotherapeutics* 18(6):2096970 DOI 10.1080/21645515.2022.2096970.
- Jochum S, Kirste I, Hortsch S, Grunert VP, Legault H, Eichenlaub U, Kashlan B, Pajon R. 2022. Clinical utility of elecsys anti-SARS-CoV-2 S assay in COVID-19 vaccination: an exploratory analysis of the mRNA-1273 phase 1 trial. *Frontiers in Immunology* 12:798117 DOI 10.3389/fimmu.2021.798117.
- Kajanová I, Lukaciková L, Jelenská L, Grossmannová K, Radiková Z, Vlček M, Klempa B, Kollar R, Bodová K, Kopáček J, Pastoreková S. 2022. Seroprevalence of SARS-CoV-2 IgG antibodies in the staff of the Slovak Academy of Sciences in response to COVID-19 and/or vaccination: situation in August 2021. *Acta Virologica* 65(4):420–432 DOI 10.4149/av_2021_407.
- Karamese M, Tutuncu EE. 2022. The effectiveness of inactivated SARS-CoV-2 vaccine (CoronaVac) on antibody response in participants aged 65 years and older. *Journal of Medical Virology* 94(1):173–177 DOI 10.1002/jmv.27289.
- Keskin AU, Bolukcu S, Ciragil P, Topkaya AE. 2022. SARS-CoV-2 specific antibody responses after third CoronaVac or BNT162b2 vaccine following two-dose CoronaVac vaccine regimen. *Journal of Medical Virology* 94(1):39–41 DOI 10.1002/jmv.27350.
- Kwetkat A, Heppner HJ. 2020. Comorbidities in the elderly and their possible influence on vaccine response. *Interdisciplinary Topics in Gerontology and Geriatrics* 43:73–85 DOI 10.1159/issn.2297-3486.
- Kyriakidis NC, López-Cortés A, González EV, Grimaldos AB, Prado EO. 2021. SARS-CoV-2 vaccines strategies: a comprehensive review of phase 3 candidates. *NPJ Vaccines* 6(1):28 DOI 10.1038/s41541-021-00292-w.
- Lau CS, Thundiyil J, Oh MLH, Phua SK, Liang YL, Li Y, Huo J, Huang Y, Zhang B, Xu S, Aw TC. 2022. Neutralizing and Total/IgG spike antibody responses following homologous CoronaVac vs. BNT162b2 vaccination up to 90 days post-booster. *Antibodies* 11(4):70 DOI 10.3390/antib11040070.
- Lippi G, Henry BM, Plebani M. 2021. Anti-SARS-CoV-2 antibodies testing in recipients of COVID-19 vaccination: why, when, and how? *Diagnostics* 11(6):941 DOI 10.3390/diagnostics11060941.
- Malagón-Rojas J, Mercado-Reyes M, Toloza-Pérez YG, Galindo M, Palma RM, Catama J, Bedoya JF, Parra-Barrera EL, Meneses X, Barbosa J, Tavera-Rodríguez P, Bermúdez-Forero A, Ospina-Martínez ML. 2022. Comparison of anti-SARS-CoV-2 IgG antibody responses generated by the administration of Ad26.COV2.S, AZD1222, BNT162b2, or CoronaVac: longitudinal prospective cohort study in the Colombian population, 2021/2022. *Vaccines* 10:1609 DOI 10.3390/vaccines10101609.
- Manuhutu R. 2021. Situasi Terkini Perkembangan Coronavirus Disease (COVID-19) 01 Januari 2021. Available at <https://infeksiemerging.kemkes.go.id/situasi-infeksi-emerging/situasi-terkini-perkembangan-coronavirus-disease-covid-19-01-januari-2021> (accessed 30 November 2022).
- Megasari NLA, Utsumi T, Yamani LN, Juniastuti, Gunawan E, Furukawa K, Nishimura M, Lusida MI, Mori Y, Di Gennaro F. 2021. Seroepidemiological study of SARS-CoV-2 infection in East Java, Indonesia. *PLOS ONE* 16(5):e0251234 DOI 10.1371/journal.pone.0251234.
- Nugraha B, Wahyuni LK, Laswati H, Kusumastuti P, Tulaar AB, Gutenbrunner C. 2020. COVID-19 pandemic in Indonesia: situation and challenges of rehabilitation medicine in Indonesia. *Acta Medica Indonesiana* 52:299–305.

- Olliaro P, Torreele E, Vaillant M. 2021. COVID-19 vaccine efficacy and effectiveness-the elephant (not) in the room. *The Lancet Microbe* 2(7):e279–e280 DOI 10.1016/S2666-5247(21)00069-0.
- Onifade AA, Fowotade A, Rahamon SK, Edem VF, Yaqub SA, Akande OK, Arinola OG. 2023. Seroprevalence of anti-SARS-CoV-2 specific antibodies in vaccinated and vaccine naïve adult Nigerians. *PLOS ONE* 18(1):e0280276 DOI 10.1371/journal.pone.0280276.
- Polack FP, Thomas SJ, Kitchin N, Absalon J, Gurtman A, Lockhart S, Perez JL, Pérez Marc G, Moreira ED, Zerbini C, Bailey R, Swanson KA, Roychoudhury S, Koury K, Li P, Kalina WV, Cooper D, Frenck RW, Hammitt LL, Türeci Ö, Nell H, Schaefer A, Ünal S, Tresnan DB, Mather S, Dormitzer PR, Şahin U, Jansen KU, Gruber WC. 2020. C4591001 clinical trial group, safety and efficacy of the BNT162b2 mRNA COVID-19 vaccine. *The New England Journal of Medicine* 383(27):2603–2615 DOI 10.1056/NEJMoa2034577.
- Rahman MM, Masum MHU, Wajed S, Talukder A. 2022. A comprehensive review on COVID-19 vaccines: development, effectiveness, adverse effects, distribution and challenges. *VirusDisease* 33(1):1–22 DOI 10.1007/s13337-022-00755-1.
- Rezaei M, Sadeghi M, Korourian A, Tabarsi P, Porabdollah M, Askari E, Mortaz E, Mahmoudi S, Marjani M, Velayati AA. 2021. Comparative evaluation of SARS-CoV-2 IgG assays against nucleocapsid and spike antigens. *Human Antibodies* 29(2):109–113 DOI 10.3233/HAB-210440.
- Salari N, Vepa A, Daneshkhah A, Darvishi N, Ghasemi H, Khunti K, Mohammadi M. 2022. Efficacy of COVID-19 vaccines by race and ethnicity. *Public Health* 208(3):14–17 DOI 10.1016/j.puhe.2022.04.009.
- Santi T, Samakto BD, Kamarga L, Hidayat FK, Hidayat F. 2021. Factors associated with SARS-CoV-2 antibody titer after sinovac vaccination among health care workers. *Acta Medica Indonesiana* 53:374–384.
- Shah MM, Spencer BR, Feldstein LR, Haynes JM, Benoit TJ, Saydah SH, Groenewold MR, Stramer SL, Jones JM. 2022. Occupations associated with severe acute respiratory syndrome coronavirus 2 infection and vaccination, US blood donors, may 2021–december 2021. *Clinical Infectious Diseases* 76(7):1285–1294 DOI 10.1093/cid/ciac883.
- Sinto R, Utomo D, Suwarti, Nelwan EJ, Surendra H, Natasha C, Fransiska, Theresia D, Ranitria AF, Subekti D, Nuraeni N, Handayani W, Rahardjani M, Baird JK, Dunachie S, Shankar AH, Hamers RL. 2023. Antibody responses and reactogenicity of a heterologous, full-dose messenger RNA-1273 booster in heavily SARS-CoV-2-exposed CoronaVac-vaccinated health-care workers in Indonesia: a real-world observational study. *The American Journal of Tropical Medicine and Hygiene* 108(1):115–123 DOI 10.4269/ajtmh.22-0256.
- Song C, Li Z, Li C, Huang M, Liu J, Fang Q, Cao Z, Zhang L, Gao P, Nie W, Luo X, Kang J, Xie S, Lyu J, Zhu X. 2022. SARS-CoV-2: the monster causes COVID-19. *Frontiers in Cellular and Infection Microbiology* 12:835750 DOI 10.3389/fcimb.2022.835750.
- Tan CS, Noni V, Melina WUHU, Abdorahman US, Bimbang JN, Malik NMA, Hossen ME, Rahman MM, Su'ut L, Said A, Chen C, Sepop B, Samat MA, Chew JCM, Mamora D, Tan SK. 2022. Antibody dynamics post-Comirnaty and CoronaVac vaccination in Malaysia. *Scientific Reports* 12(1):15665 DOI 10.1038/s41598-022-19776-3.
- Thakkar A, Gonzalez-Lugo JD, Goradia N, Gali R, Shapiro LC, Pradhan K, Rahman S, Kim SY, Ko B, Sica RA, Kornblum N, Bachier-Rodriguez L, McCort M, Goel S, Perez-Soler R, Packer S, Sparano J, Gartrell B, Makower D, Goldstein YD, Wolgast L, Verma A, Halmos B. 2021. Seroconversion rates following COVID-19 vaccination among patients with cancer. *Cancer Cell* 39(8):1081–1090.e2 DOI 10.1016/j.ccell.2021.06.002.

- Van Elslande J, Decru B, Jonckheere S, Van Wijngaerden E, Houben E, Vandecandelaere P, Indevuyst C, Depypere M, Desmet S, André E, Van Ranst M, Lagrou K, Vermeersch P. 2020. Antibody response against SARS-CoV-2 spike protein and nucleoprotein evaluated by four automated immunoassays and three ELISAs. *Clinical Microbiology and Infection* 26(11):1557.e1–1557.e7 DOI 10.1016/j.cmi.2020.07.038.
- Varghese S, Mateethra G, George G, Chandran V, John G, Varghese L, Mammen N, Vinayak V. 2022. A study on seroconversion following first & second doses of ChAdOx1 nCoV-19 vaccine in Central Kerala. *Indian Journal of Medical Research* 155(5&6):499–504 DOI 10.4103/ijmr.ijmr_1917_21.
- Wang Z, Schmidt F, Weisblum Y, Muecksch F, Barnes CO, Finkin S, Schaefer-Babajew D, Cipolla M, Gaebler C, Lieberman JA, Oliveira TY, Yang Z, Abernathy ME, Huey-Tubman KE, Hurley A, Turroja M, West KA, Gordon K, Millard KG, Ramos V, Da Silva J, Xu J, Colbert RA, Patel R, Dizon J, Unson-O'Brien C, Shimeliovich I, Gazumyan A, Caskey M, Bjorkman PJ, Casellas R, Hatzioannou T, Bieniasz PD, Nussenzweig MC. 2021. mRNA vaccine-elicited antibodies to SARS-CoV-2 and circulating variants. *Nature* 592(7855):616–622 DOI 10.1038/s41586-021-03324-6.
- Wei J, Stoesser N, Matthews PC, Ayoubkhani D, Studley R, Bell I, Bell JI, Newton JN, Farrar J, Diamond I, Rourke E, Howarth A, Marsden BD, Hoosdally S, Jones EY, Stuart DI, Crook DW, Peto TEA, Pouwels KB, Eyre DW, Walker AS, Thomas T, Black R, Felton A, Crees M, Jones J, Lloyd L, Sutherland E, Pritchard E, Vihta K-D, Doherty G, Kavanagh J, Chau KK, Hatch SB, Ebner D, Ferreira LM, Christott T, Dejnirattisai W, Mongkolsapaya J, Cameron S, Tamblin-Hopper P, Wolna M, Brown R, Cornall R, Sreaton G, Lythgoe K, Bonsall D, Golubchik T, Fryer H, Cox S, Paddon K, James T, House T, Robotham J, Birrell P, Jordan H, Sheppard T, Athey G, Moody D, Curry L, Brereton P, Jarvis I, Godsmark A, Morris G, Mallick B, Eeles P, Hay J, VanSteenhouse H, Lee J. 2021. Antibody responses to SARS-CoV-2 vaccines in 45,965 adults from the general population of the United Kingdom. *Nature Microbiology* 6(9):1140–1149 DOI 10.1038/s41564-021-00947-3.
- Wisniewski AV, Campillo Luna J, Redlich CA. 2021. Human IgG and IgA responses to COVID-19 mRNA vaccines. *PLOS ONE* 16(6):e0249499 DOI 10.1371/journal.pone.0249499.
- World Health Organization. 2022. Coronavirus disease (COVID-19): vaccines. Available at [https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-\(covid-19\)-vaccines](https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-(covid-19)-vaccines) (accessed 16 December 2022).