Received: 7 April 2022 | Accepted: 31 May 2022
DOI: 10.1002/jmv.27909

RESEARCH ARTICLE

JOURNAL OF MEDICAL VIROLOGY WILEY

Antibody response three months after SARS-CoV-2 infection

Efdal Oktay Gültekin[1] | Onur Gültekin[2] | Arzu Coskun[1] | Tiince Aksak[1]

[1]Department of Medical Services and Techniques, Toros Unıversity, Mersin, Turkey
[2]Tarsus State Hospital, Infectious Diseases, and Clinical Microbiology, Mersin, Turkey

Correspondence
Efdal Oktay Gültekin, Toros Unıversıty, Department of Medical Services and Techniques, Mersin, Turkey.
Email: efdal.gultekin@toros.edu.tr

Funding information
Toros University Scientific Research Projects Unit

Abstract

The coronavirus disease-19 (COVID-19) pandemic became the greatest public health challenge globally. In our study, it was aimed to determine the antibody levels in the third month after the COVID-19 infection and the symptoms that continued until the third month from the onset of the infection. One hundred people who applied to Tarsus State Hospital with the suspicion of COVID-19 and were positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection by real-time reverse transcriptase-polymerase chain reaction were included. We collected serum samples from individuals, who were 3 months postinfection, and tested them in anti-SARS-CoV-2 Quanti-Vac ELISA IgG kit coated with recombinant S1 antigen for testing SARS-CoV-2 antibodies. Antibody levels were found to be higher in those aged ≥55 years, nonsmokers, those with comorbidities, and those who were hospitalized. The four most common symptoms that individuals initially encounter; are weakness, muscle and joint pain, loss of taste and smell, and cough. In 3 months after COVID-19 infection, the most common four symptoms are; muscle and joint pain, insomnia, fatigue, and other problems were determined. In conclusion; more research is needed to determine threshold levels of serum antibodies that could prevent reinfection of SARS-CoV-2.

KEYWORDS
immunoglobulin, immune responses, infection, SARS coronavirus, virus classification

1 | INTRODUCTION

Coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV- 2) infection, was first detected in Wuhan, China in December 2019 and has since become a global epidemic. As of December 19, 2020, 349 641 119 cases of COVID-19 have been confirmed and 5 592 266 related deaths have been reported. These cases have posed significant challenges for health systems.[1] According to recent reports, most patients with COVID-19 have an incubation period of 3–7 days. Fever, cough, and fatigue are the most common symptoms, while nasal congestion, runny nose, and diarrhea occur in only a minority of patients. Severe cases can progress rapidly to acute respiratory distress syndrome (ARDS), septic shock, difficult-to-treat metabolic acidosis, and bleeding and coagulation dysfunction. Some patients with COVID-19 have been reported to have only mild atypical symptoms initially, even in severe and critical cases. Chest computed tomography (CT) scans of COVID-19 patients are characterized by ground-glass opacity and bilateral patchy shading. For laboratory testing, most patients have been reported to have lymphopenia and elevated C-reactive protein. However, the clinical and laboratory features mentioned above are not easily distinguishable from pneumonia caused by other common respiratory pathogens.[2]

Understanding the long-term immunological memory response to SARS-CoV-2 after infection is critical for the development and administration of a SARS-CoV-2 vaccine. Recent studies have shown that most patients continue to have virus-specific antibody response 6–8 months after infection, but there is a tendency for patients to decline in humoral immunity over time. In studies, memory CD8+ and CD4+ T cells specific to SARS-CoV-2 were detected in most patients, but decreased with a half-life of 3–5 months, while virus-specific memory B cells (MBCs) increased or remained unchanged 5–6 months after infection reported to persist.[3]

In our study, it was aimed to determine the antibody levels in the third month after the COVID-19 infection and the symptoms that continued until the third month from the onset of the infection.

2 | MATERIALS AND METHODS

This study was approved by the TR Ministry of Health COVID-19 Scientific Research Evaluation Commission (Date: 04.03.2021 and Decision No: 2021-03-02T16_08_22) and Toros University Scientific Research and Publication Ethics Committee approval (Date: 26.03.2021 and Decision No: It was carried out by taking 2021/33).

2.1 | Working group and examples

Hundred patients who applied to Tarsus State Hospital Infectious Diseases and Clinical Microbiology with the suspicion of COVID-19 and whose diagnosis of COVID-19 was confirmed by reverse transcriptase-polymerase chain reaction were included in the study. Three months after the diagnosis, blood samples were taken from the patients.

Age, gender, height, weight, smoking, and COVID-19 infection status were recorded to determine the factors that may affect the SARS-CoV-2 antibody response. 4–5 ml blood samples from the healthcare workers included in the study were taken into tubes with ethylenediaminetetraacetic acid (EDTA) and centrifuged at 3500 rpm for 10 min and serum samples were separated. The obtained serum samples were stored at −80°C until the study.

2.2 | Enzyme-linked assay (ELISA) test

For the quantitative determination of SARS-CoV-2 IgG class antibodies, the Anti-SARS-CoV-2 QuantiVac ELISA IgG (Euroimmun) kit coated with recombinant S1 antigen of SARS-CoV-2 S protein including receptor-binding domain (RBD) was used. Serum samples were diluted 1:101 with sample buffer and tested according to the manufacturer's instructions. At the end of the study, the absorbance of each well was determined spectrophotometrically at 450 nm. Results were calculated by plotting a point calibration curve to the units corresponding to the measured optical density values for six calibrators with concentrations ranging from 1 to 120 relative units (RU/ml). Antibody concentrations were determined in RU/ml by linear regression. Quantitative results obtained in RU/ml were converted to BAU/ml by multiplying by 3.2 by WHO specifications. Samples with antibody concentration <25.6 BAU/ml were considered negative, samples with ≥25.6 BAU/ml ≤35.2 BAU/ml were considered borderline positive, and samples ≥35.2 BAU/ml were considered positive. If the optical density of the samples was above calibrator 1 (120 RU/ml), the serum samples were diluted 1/400 and re-run and the results were multiplied by four.

2.3 | Statistical analysis

Statistical analyzes were performed using a package program called SPSS (IBM SPSS Statistics 24). Frequency tables and descriptive statistics were used to interpret the findings. Parametric methods were used for measurement values suitable for normal distribution. By parametric methods, the Independent Sample-*t* test (*t*-table value) method was used to compare the measurement values of two independent groups. Nonparametric methods were used for the measurement values that did not conform to the normal distribution. By nonparametric methods, the Mann–Whitney *U* test (Z-table value) was used to compare the measurement values of two independent groups, and the Kruskal–Wallis H test (χ^2-table value) method was used to compare the measurement values of three or more independent groups. Bonferroni correction was applied for pairwise comparisons of variables with a significant difference for three or more groups.

3 | RESULTS

It was determined that the mean age of 100 people with COVID-19 infection included in the study was 44.65 ± 12.15 (years) and 42 (42%) were in the 45–54 age group. It was determined that 54 (54%) women were women, 38 (38%) were overweight, and 58 (58%) were not working. It was determined that 86 people (86%) did not smoke, 59 (59%) did not have a comorbidity, 64 (64%) did not have hospitalization, and 24 (66.7%) had a hospitalization period of 10–15 days (Table 1).

The four most common symptoms that individuals initially encounter; are weakness, muscle and joint pain, loss of taste and smell, and cough. In the 3rd month, the most common four symptoms are; muscle and joint pain, insomnia, fatigue, and other problems (hair loss, diabetes due to COVID-19 infection) were determined (Table 2).

It was determined that only 11% of the 100 patients included in the study had an asymptomatic infection. Their mean age was 46 (31–65), 63.6% of them were male and nonsmokers. Mean antibody levels were found to be 129.67232 BAU/ml in these individuals in the third month of infection.

According to the data collected to determine the factors affecting the antibody response in the body 3 months after the infection, there was no statistically significant difference in antibody levels according to gender, body mass index (BMI), employment status, and length of hospital stay ($p > 0.05$). A statistically significant difference was found in terms of antibody levels according to age classes ($\chi^2 = 24.680$; $p = 0.000$). Antibody levels in the ≥55 age group were significantly higher than those in the <35 and 35–44 age group. A statistically significant difference was found in terms of antibody levels according to smoking status ($Z = -3.509$; $p = 0.000$). Antibody

TABLE 1 Sociodemographic characteristics of the patients

Variable (*N* = 100)	*n*	%
Age [X̄ ± S.S. → 44,65±12,15(year)]		
<35	24	24.0
35–44	15	15.0
45–54	42	42.0
≥55	19	19.0
Sex		
Female	54	54.0
Male	46	46.0
BMI [X̄ ± S.S. → 27,72±4,96(kg/m^2)]		
Weak	1	1.0
Normal	31	31.0
Overweight	38	38.0
Obese	30	30.0
Working status		
Working	42	42.0
Not working	58	58.0
Smoking		
Yes	14	14.0
No	86	86.0
Comorbidities		
Yes	41	41.0
No	59	59.0
Hospitalization		
Yes	36	36.0
No	64	64.0
Length of stay [X̄ ± S.S. → 13,73±5,57(day)]		
<10 day	4	11.1
10–15 day	24	66.7
>15 day	8	22.2

Abbreviation: BMI, body mass index.

levels of nonsmokers were found to be higher than those of smokers. A statistically significant difference was found in antibody levels according to the accompanying disease ($Z = -4.732$; $p = 0.000$). Antibody levels of those with comorbidities were found to be significantly higher than those without comorbidities.

A statistically significant difference was found in terms of antibody levels according to hospitalization status ($Z = -5.180$; $p = 0.000$). The antibody levels of those who were hospitalized were found to be significantly higher than those who were not hospitalized (Table 3). A statistically significant difference was found in terms of hospitalization time according to the initial symptoms of anorexia ($Z = -2.030$; $p = 0.042$). The length of stay of patients with anorexia symptoms is significantly higher than those without anorexia symptoms. The comparison of hospitalization times according to initial symptom findings is shown in Table 4.

TABLE 2 Distribution of symptom findings at the beginning and third month of infection

Variable	Beginning		Third month	
	n	%	*n*	%
Fever	43	43.0	–	–
Cough	45	45.0	2	2.0
Sore throat	30	30.0	2	2.0
Shortness of breath	31	31.0	5	5.0
Headache	39	39.0	3	3.0
Loss of taste/smell	45	45.0	4	4.0
Joint/Muscle pain	55	55.0	15	15.0
Chest pain	24	24.0	4	4.0
Back pain	44	44.0	9	9.0
Diarrhea	10	10.0	2	2.0
Nausea/Vomiting	11	11.0	3	3.0
Anorexia	41	41.0	2	2.0
Fatigue	63	63.0	9	9.0
Skin rash	2	2.0	1	1.0
Psychological disorder	12	12.0	3	3.0
Palpitation	14	14.0	8	8.0
Loss of memory and concentration	3	3.0	1	1.0
Insomnia	22	22.0	10	10.0
Other	15	15.0	10	10.0

4 | DISCUSSION

SARS-CoV-2 infection can lead to asymptomatic or symptomatic infection, ranging from mild to severe illness and even death. In our study, 89% of the participants were found to be symptomatic, while this data was found to be quite opposite to the symptom situation of the general population, where most of the individuals (91%) were reported as asymptomatic.[4] According to our results, some symptoms were found to persist in 46% of patients after SARS-CoV-2 infection, and the most common symptoms were found to be muscle–joint pain and fatigue, in line with other studies.[5,6]

However, since these symptoms were mild in almost all cases, people were able to resume their normal lives 3 months after infection. Contrary to our data, an Italian study with an average follow-up of 60 days after onset of symptoms reported persistence of symptoms in 125 of 143 COVID-19 patients discharged from the hospital. Consistent with our study, the most frequently reported symptoms were fatigue (53.1%) and dyspnea (43.4%), and a decrease

TABLE 3 Comparison of antibody levels according to sociodemographic characteristics of patients

Variable	n	Antibody level $\bar{X}$ ± S. S.	Median [Min.–Max.]	Statistical analysis* Possibility
Age [$\bar{X}$ ± S.S. → 44,65±12,15(yıl)]	24	40.29 ± 28.13	37.7 [12.1–120.0]	χ^2 = 24.680
<35	15	63.76 ± 43.36	66.1 [7.0–120.0]	***p* = 0.000**
35–44	42	81.72 ± 39.48	88.9 [9.1–120.0]	**[1.2–4] [1–3]**
45–54	19	103.57 ± 33.48	120.0 [21.6–120.0]	
≥55				
Sex				
Female	54	69.94 ± 44.25	65.8 [7.0–120.0]	*Z* = −0.866
Male	46	77.40 ± 41.71	75.1 [9.1–120.0]	*p* = 0.387
BMI [$\bar{X}$ ± S.S. → 27,72±4,96(kg/m^2)]				
Weak	32	68.56 ± 45.95	63.8 [7.0–120.0]	χ^2 = 0.639
Normal	38	74.22 ± 42.91	74.9 [9.1–120.0]	*p* = 0.727
Overweight obese	30	77.61 ± 40.85	75.1 [9.1–120.0]	
Working status				
Working	42	76.51 ± 40.17	75.9 [9.1–120.0]	*Z* = −0.612
Not working	58	71.23 ± 45.16	65.4 [7.0–120.0]	*p* = 0.540
Smoking				
Yes	14	33.48 ± 23.58	28.3 [7.0–69.0]	*Z* = −3.509
No	86	79.04 ± 42.23	88.5 [9.1–120.0]	***p* = 0.000**
Comorbidities				
Yes	41	98.19 ± 31.73	120.0 [15.6–120.0]	*Z* = −4.732
No	59	56.73 ± 41.76	45.2 [7.0–120.0]	***p* = 0.000**
Hospitalization				
Yes	36	103.78 ± 27.08	120.0 [32.6–120.0]	*Z* = −5.180
No	64	56.25 ± 40.95	50.5 [7.0–120.0]	***p* = 0.000**
Length of stay [$\bar{X}$ ± S.S. → 13,73±5,57(gün)]				
<10 day	28	103.43 ± 28.39	120.0 [32.6–120.0]	*Z* = −0.375
10–15 day	8	100.80 ± 26.69	120.0 [63.3–120.0]	*p* = 0.707
>15 day				

*Mann–Whitney *U* test (*Z*-table value) for comparison of measurement values of two independent groups in non-normally distributed data; Kruskal–Wallis H test (χ^2-table value) statistics were used to compare the measurement values of three or more independent groups.

in quality of life as measured by the EuroQol visual analog scale was reported in 44.1% of patients in this study.[7] According to five articles that determined the frequency of symptoms among individuals with a positive COVID 19 test; We found a lower prevalence (45%) for fever (combined prevalence ranging from 78.4% to 92.8%) and cough (47.7% vs. a combined prevalence ranging from 58.3% to 72.2%).

Our estimates for body aches (44.1%) and breathing difficulties (23.1%) were within the ranges reported in the studies (29.4%–51.0% and 20.6%–45.6%, respectively). Finally, the prevalence of headaches in our study (39%) was considerably higher than in the reviews (8.0%–14.0%).[8–12] Changes in smell or taste were not investigated in these studies. In our study, we found the prevalence of loss of taste and smell to be 45%, and this data reported a prevalence ranging from 5.1% to 85.6%, which is consistent with other studies.[13–16]

In a study by Xiong et al.; in a 3-month follow-up survey of 538 COVID-19 patients, they found that physical regression or fatigue, post-activity polypnea, and hair loss were more common in women than in men.[17] Among other symptoms in our study; Diabetes and hair loss associated with COVID-19 infection have been reported, and it is more common in men than in women.

At 6 months after the onset of symptoms, fatigue or muscle weakness and sleep difficulties were the main symptoms of patients

TABLE 4 Comparison of hospitalization times according to the initial symptom findings of the patients

	Hospitalization times				Statistical analysis*
	Symptom (+)		Symptom (−)		
Initial symptoms	X̄ ± S. S.	Median [Min.–Max.]	X̄ ± S. S.	Median [Min.–Max.]	Possibility
Fever	15.19 ± 7.17	14.0 [7.0–30.0]	12.35 ± 3.12	13.0 [6.0–18.0]	$Z = -0.985$ $p = 0.325$
Cough	13.57 ± 5.26	14.0 [7.0–30.0]	14.00 ± 6.31	13.0 [6.0–30.0]	$Z = -0.095$ $p = 0.925$
Sore throat	14.53 ± 5.79	15.0 [7.0–30.0]	13.20 ± 5.50	12.0 [6.0–30.0]	$Z = -0.970$ $p = 0.332$
Shortness of breath	14.89 ± 6.68	14.0 [6.0–30.0]	12.14 ± 3.13	10.5 [7.0–17.0]	$Z = -0.978$ $p = 0.328$
Headache	14.14 ± 6.21	14.5 [7.0–30.0]	13.42 ± 5.19	13.0 [6.0–30.0]	$Z = -0.240$ $p = 0.811$
Loss of taste/smell	15.67 ± 7.23	15.0 [6.0–30.0]	12.11 ± 3.05	11.0 [7.0–19.0]	$t = 1.778$ $p = 0.092$
Joint/Muscle pain	13.43 ± 5.26	14.0 [6.0–30.0]	14.40 ± 6.48	12.0 [9.0–30.0]	$Z = -0.099$ $p = 0.921$
Chest pain	14.85 ± 5.38	14.0 [10.0–30.0]	13.00 ± 5.70	11.0 [6.0–30.0]	$Z = -1.194$ $p = 0.232$
Back pain	14.47 ± 5.34	14.0 [7.0–30.0]	12.71 ± 5.92	10.0 [6.0–30.0]	$Z = -1.457$ $p = 0.145$
Nausea/Vomiting	15.00 ± 9.11	14.0 [6.0–30.0]	13.50 ± 4.91	13.0 [7.0–30.0]	$Z = -0.025$ $p = 0.980$
Anorexia	14.86 ± 6.07	15.0 [6.0–30.0]	11,45±3,64	10.0 [9.0–22.0]	$Z = -2.030$ **$p = 0.042$**
Fatigue	14.24 ± 6.07	14.0 [6.0–30.0]	12,12±3,39	10.5 [9.0–19.0]	$Z = -0.893$ $p = 0,372$
Psychological disorder	15.80 ± 8.61	11.0 [10.0–30.0]	13,35±4,98	13.5 [6.0–30.0]	$Z = -0.458$ $p = 0.647$
Palpitation	16.00 ± 7.13	15.0 [7.0–30.0]	13,00±4,92	11.0 [6.0–30.0]	$Z = -1.149$ $p = 0.251$
Insomnia	16.82 ± 7.70	15.0 [7.0–30.0]	12,18±3,39	10.5 [6.0–19.0]	$Z = -1.818$ $p = 0.069$

*Mann–Whitney *U* test (*Z*-table value) for comparison of measurement values of two independent groups in non-normally distributed data; Kruskal–Wallis H test (χ^2-table value) statistics were used to compare the measurement values of three or more independent groups.

recovering from COVID-19. The risk of anxiety or depression as a major psychological complication and impaired pulmonary diffusion capacities were higher in patients with more severe diseases. These results support the need for post-discharge care for those with severe illnesses. Longer follow-up studies in a larger population are needed to understand the full spectrum of health outcomes from COVID-19.[18]

Asymptomatic individuals are potential sources of SARS-CoV-2 infection, which exhibits strong infectivity and rapid transmission during the incubation period. Therefore, a much larger portion of the population may have been exposed to much more viruses than has been documented. Therefore, estimating the prevalence of these unreported infections is critical to understanding the overall prevalence and pandemic potential of this disease.[18] In asymptomatic cases, the prevalence ranges from 4% to 75% in the literature[8,9,19–23]; in our study, it was 11%.

Titers of anti-Spike (S) antibodies targeting the RBD (associated with cell entry) are widely thought to be associated with protection from re-infection. In persons with strong neutralizing antibody titers, these can be maintained for at least 6 months. In our study, it was aimed to determine the antibody titers and ongoing symptoms in the third month after the COVID 19 infection. In our study, IgG antibody levels against N-protein were still found to be high in the serum samples of patients with COVID-19 after 3 months, while a study conducted in India reported that 40% of them were negative for IgG antibodies against N-protein.[24] Almost all confirmed patients achieve IgG or IgM seroconversion within 20 days of symptom onset, as evidenced by both the cross-sectional analysis and the follow-up study. This finding suggests that SARS-CoV-2 infection can be ruled out if antibodies to SARS-CoV-2 are still not detectable 20 days after onset of symptoms or 23 days after exposure.

Our study found that after 3 months, approximately 3% of serum samples were negative for IgG against S protein, whereas a similar study in the United States detected SARS-CoV-2 IgG negative in only 7.7% 3–6 months after symptom. Although the difference was statistically insignificant, males had higher titers than females at the end of 12 weeks. Twenty-one of these male patients were hospitalized and the mean antibody level was determined as 73.4166 RU/ml.[25] A study in Brazil (initial investigation) and Spain reported similar elevations of antibodies across age groups, with seroprevalence among adults older than 65 years lower than those in Santa Clara County, CA, USA, and between 5 and 65 years of age, and in Greece and Iceland.[26] It has been reported to be higher in older adults according to the data we obtained from other studies, it was determined that the antibody levels were higher in those aged ≥55 years. In our study, no significant correlation was found between the height of antibodies and gender, in a study conducted in Switzerland; A higher seroprevalence was found in men.[27]

It has been reported that chronic diseases such as hypertension, diabetes, respiratory system disease, and cardiovascular disease may be associated with your COVID-19 pathogenesis. It shares several features with infectious diseases, such as a proinflammatory state and weakening of the innate immune response. For example, diabetes occurs in part because the accumulation of activated innate immune cells in metabolic tissues leads to the release of inflammatory mediators, particularly IL-1β and TNF-α, which promote systemic insulin resistance and β-cell damage.[10] Studies[5,10] have generally revealed that patients treated in intensive care units and undergoing invasive mechanical ventilation are predominantly male, elderly, and have various comorbidities. It has been reported that approximately 32% of COVID-19 patients admitted to hospitals in Wuhan have underlying diseases such as diabetes, hypertension, and cardiovascular disease.[5] Yang et al.[10] evaluated the prevalence of comorbidity in COVID-19 patients in seven different studies in the Chinese population, and consistent with our study, common comorbidities were found to be hypertension. and found that he had diabetes. Similarly, our findings suggest that IgG antibody is higher in people with underlying diseases.

The most important limitation of this study is that we planned a longitudinal follow-up cohort study of patients in our study. Antibody levels would be monitored by taking blood samples from the patients at 3, 6, 9, and 12 months after the onset of COVID 19 symptoms. However, since the vaccination policy has changed in our country, we could only measure antibody levels in the third month after infection.

As a result; we report the results of a comprehensive health assessment of patients 3 months after infection with COVID-19. Our results determined that 3 months after COVID-19, a significant proportion of patients continued to have symptoms, such as mild. Threshold levels of serum antibodies that could prevent reinfection of SARS-CoV-2 are still unknown and further research is needed. It is currently unclear why some patients experience long-term symptoms after COVID-19. Potential causes for different outcomes of infection are thought to be viral dose as well as host-dependent factors such as genetic susceptibility or induction of anti-inflammatory cells and proteins.

AUTHOR CONTRIBUTIONS

Dr. Öğr. Üyesi Efdal Oktay Gültekin: Conception, design, supervision, materials, data collection and/or processing, analysis and/or interpretation. literature review, writing, critical review. **Dr. Onur Gültekin**: Conception, design, supervision, materials, data collection and/or processing, critical review. **Arzu Coskun**: Materials, data collection and/or processing, literature review. **Tiince Aksak**: Literature review, critical review.

ACKNOWLEDGMENT

This study was supported by the Toros University Scientific Research Projects Unit as the BAP project numbered 2021-SHMYO-EOG-1.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Efdal Oktay Gültekin https://orcid.org/0000-0002-0962-152X
Onur Gültekin http://orcid.org/0000-0003-3444-9044
Arzu Coskun http://orcid.org/0000-0003-4771-1558
Tiince Aksak http://orcid.org/0000-0001-7841-8456

REFERENCES

1. Ozgur D, Tutuncu E. COVID-19 enfeksiyonu geçiren ve geçirmeyen sağlık çalışanlarında iki doz inaktive SARS-CoV-2 aşısı sonrası antikor yanıtı: prospektif gözlemsel Calışma. *Mikrobiyol Bul*. 2022;56(1):36-48. doi:10.5578/mb.20229904
2. ZHAO J, Yuan Q, Wang H, et al. Antibody responses to SARS-CoV-2 in patients with novel coronavirus disease 2019. *Clin Infect Dis*. 2020;71(16):2027-2034.

3. Yao L, Wang GL, Shen Y, et al. Persistence of antibody and cellular immune responses in coronavirus disease 2019 patients over nine months after infection. *J Infect Dis*. 2021;224.4:586-594.
4. Kumar N, Hameed SK, Babu GR, et al. Descriptive epidemiology of SARS-CoV-2 infection in Karnataka state, South India: transmission dynamics of symptomatic vs. asymptomatic infections. *EClinicalMedicine*. 32, 2021:100717.
5. Huang C, Huang L, Wang Y, et al. 6-Month consequences of COVID-19 in patients discharged from hospital: a cohort study. *Lancet*. 2021;397: 220-232.
6. Sudre CH, Murray B, Varsavsky T, et al. Attributes and predictors of long COVID. *Nat Med*. 2021;27:626-631.
7. Carfì A, Bernabei R, Landi F. Gemelli against COVID-19 post-acute care study group. persistent symptoms in patients after acute COVID-19. *JAMA*. 2020;324:603-605.
8. Zhu J, Zhong Z, Ji P, et al. Clinicopathological characteristics of 8697 patients with COVID-19 in China: a meta-analysis. *Fam. Med. Community Health*. 2020;8:e000406.
9. Fu L, Wang B, Yuan T, et al. Clinical characteristics of coronavirus disease 2019 (COVID-19) in China: a systematic review and meta-analysis. *J Infect*. 2020;80:656-665.
10. Yang J, Zheng Y, Gou X, et al. Prevalence of comorbidities and its effects in patients infected with SARS-CoV-2: a systematic review and metaanalysis. *Int J Infect Dis*. 2020;94:91-95.
11. Rodriguez-Morales AJ, Cardona-Ospina JA, Gutiérrez-Ocampo E, et al. Clinical, laboratory and imaging features of COVID-19: a systematic review and meta-analysis. *Travel Med Infect Dis*. 2020;34: 101623.
12. Sun P, Qie S, Liu Z, Ren J, Li K, Xi J. Clinical characteristics of hospitalized patients with SARS-CoV-2 infection: a single arm meta-analysis. *J Med Virol*. 2020;92:612-617.
13. Hoang MP, Kanjanaumporn J, Aeumjaturapat S, Chusakul S, Seresirikachorn K, Snidvongs K. Olfactory and gustatory dysfunctions in COVID-19 patients: a systematic review and meta-analysis. *Asian Pac J Allergy Immunol*. 2020;38(3):162-169.
14. Lechien JR, Chiesa-Estomba CM, De Siati DR, et al. Olfactory and gustatory dysfunctions as a clinical presentation of mild-to-moderate forms of the coronavirus disease (COVID-19): a multicenter european study. *Eur Arch Otorhinolaryngol*. 2020;277: 2251-2261.
15. Passarelli PC, Lopez MA, Bonaviri MGN, Garcia-Godoy F, Daddona A. Taste and smell as chemosensory dysfunctions in COVID-19. *Infect Am J Dent*. 2020;33:135-137.
16. Mao L, Jin H, Wang M, et al. Neurological manifestations of hospitalized patients with COVID-19 in Wuhan China: a retrospective case series study. *JAMA Neurol*. 2020;77(6):683-690.
17. Xiong Q, Xu M, Li J, et al. Clinical sequelae of COVID-19 survivors in Wuhan, China: a single-centre longitudinal study. *Clin Microbiol Infection*. 2020;0(0):23.
18. Menezes AMB, Victora CG, Hartwig FP, et al. High prevalence of symptoms among Brazilian subjects with antibodies against SARS-CoV-2. *Sci Rep*. 2021;11(1):13279.
19. Zhou X, Li Y, Li T, Zhang W. Follow-up of asymptomatic patients with SARS-CoV-2 infection. *Clin Microbiol Infect*. 2020;26:957-959.
20. Day MCovid-19. Identifying and isolating asymptomatic people helped eliminate virus in Italian village. *BMJ*. 2020;368:1165.
21. Kronbichler A, Kresse D, Yoon S, Lee KH, Effenberger M, Shin JI. Asymptomatic patients as a source of COVID-19 infections: s systematic review and meta-analysis. *Int J Infect Dis*. 2020;2:180-186.
22. Buitrago-Garcia D, Egli-Gany D, Counotte MJ, et al. Occurrence and transmission potential of asymptomatic and presymptomatic SARS-CoV-2 infections: a living systematic review and meta-analysis. *PLoS Med*. 2020;17(9):e1003346.
23. Gao Z, Xu Y, Sun C, et al. A systematic review of asymptomatic infections with COVID-19. *J Microbiol Immunol Infect*. 2021;54(1):12-16.
24. Choudhary HR, Parai D, Dash GC, et al. IgG antibody response against nucleocapsid and spike protein post-SARS-CoV-2 infection. *Infection*. 2021; 49(5):1045-1048.
25. Maine GN, Lao KM, Krishnan SM, et al. Longitudinal characterization of the IgM and IgG humoral response in symptomatic COVID-19 patients using the Abbott architect. *J Clin Virol*. 2020;133:104663.
26. Murhekar MV, Bhatnagar T, Selvaraju S, et al. SARS-CoV-2 antibody seroprevalence in India, August–September, 2020: findings from the second nationwide household serosurvey. *Lancet Global Health*. 2021;9(3):e257-e266.
27. Stringhini S, Wisniak A, Piumatti G, et al. Seroprevalence of anti-SARS-CoV-2 IgG antibodies in Geneva, Switzerland (SEROCoV-POP): a population-based study. *Lancet*. 2020;396:313-319.

How to cite this article: Oktay Gültekin E, Gültekin O, Coskun A, Aksak T. Antibody response three months after SARS-CoV-2 infection. *J Med Virol*. 2022;94:4712-4718.
doi:10.1002/jmv.27909