Medical Science Journal for Advance Research

Vol.7, No. 1, March 2026
e-ISSN: 2774-4892

Comprehensive Immunological, Hematological, and Inflammatory Profiling in Active COVID-19, Convalescent, and Healthy Control Populations

Noora M. Kadhium
College of Medicine, University of Al-Qadisiyah, Iraq.
Corresponding Author Email:* noora.m.kadhium@qu.edu.iq

ABSTRACT

Background: *COVID-19 expressed with different clinical severity come from impaired regulated immune responses. The present study was aimed to completely compare between hematological factors, SARS-CoV-2-specific responses of antibodies, and inflammatory cytokine description among three distinct cohorts: active COVID-19 infected patients, healed individuals, and healthy controls which were unexposed to virus.* ***Methods:*** *descriptive study included 450 participants (150 for every group). Active patients were RT-PCR supported; healed individuals which were ≥4 weeks after symptom resolution; healthy controls which had no previous viral infection or vaccination. Blood samples have been tested for SARS-CoV-2 antibodies (anti-spike IgG, neutralizing antibodies, anti-nucleocapsid IgG), complete blood counts, and cytokines (IL-6, TNF-α, IFN-γ) were done via multiplex immunoassay.* ***Result:*** *The present study yield a full detailed comparative- based analysis of main biomarkers among 450 individuals classified into active SARS-CoV-2 infection (n=150), recovered individuals (n=150), and healthy controls (n=150). the present study assess SARS-CoV-2-specific antibodies (nucleocapsid IgG, spike IgG, neutralizing antibodies), hematological factors, and inflammatory cytokines (TNF-α, IL-6, IFN-γ). Clinicall active infection was described by considerably increased antibody responses, lymphopenia, neutrophilia and a significant pro-inflammatory cytokine analysis with high IL-6 (268.4±44 pg/mL) and TNF-α (218.6±39.3 pg/mL). on the other hand, IFN-γ mesures were maximum in recovered individuals (117.5±5.8 pg/mL), indicating a shift toward antigen specific immunity. These results outlined unique immunological stages of COVID-19 and have effects for comprehension of the pathogenesis, treatment targeting, and prolonged immunity.* ***Conclusions:*** *Active COVID-19 is defined by over activated antibody mediated immunity, pro-inflammatory cytokine control (IL-6/TNF-α), and hematological abnormal regulation. Recovery includes shift into regulated immunity with persistent neutralizing antibodies and high IFN-γ, indicating establishment of immunological cellular memory. These different immunological signatures among infection phases might inform prognostic assessment and stage-specific therapeutic strategies.*

Keywords: COVID-19, SARS-CoV-2, Cytokines, Neutralizing Antibodies, Hematological Parameters, Immune Response, Convalescence.

Article Information
Received: Februry17, 2026; Revised: February 28, 2026; Online: March 2026

INTRODUCTION

The COVID-19 global outbreak has emphasized an important requirement to understand host-pathogen relationships and immune reactions to SARS-CoV-2. The disease diversity ranges from asymptomatic illness to deadly multisystem organ failure, mostly motivated by dysregulated immune

https://doi.org/10.46966/msjar.v7i1.379

reactions. Main characteristics include:cytokine storm, hyperinflammation, and hematological anomaly such as neutrophilia and lymphocytopenia. Antibody reaction against viral proteins like nucleocapsid and spike serve as indicators of immunity and infection, while cytokine expression profiles demonstrate the underlying inflammatory condition.

The appearance of SARS-CoV-2 in the latter part of 2019 triggered the coronavirus disease 2019 (COVID-19) outbreak, exhibiting an exceptional international health public emergency[1]. The clinical presentations of COVID-19 are significantly diverse, varying from silent carriage and slight upper airway infection to extreme pneumonia, an acute respiratory distress syndrome (ARDS), multiple-organ failure, and death [2,3]. This wide- ranging disease is mainly recorded by the complex interaction between the host's immune response and the virus. At the same time an effective immune reaction is impotant for viral elimination , an exaggerated response or a dysregulated can lead to immunopathology and damage to the tissue, which consider an important sign of severe and life threatening COVID-19 [4,5]. Hence, analyzing the accurate hematological, immunological and inflammatory signs at variable stages of infection is crucial for determining prognostic predictive, understanding the pathogenesis and establishing specific preventive and therapeutic techniques.

The specific antibody mediated immune response, identified by the generation of antibodies specific for viral antigens, is an important defense process. Antibodies that directed against the SARS-CoV-2 spike (S) protein, especially those designed against the receptor-binding domain (RBD), can inactivate the virus by prevening its entrance through the target cells by the receptor called angiotensin-converting enzyme 2 (ACE2)[6,7]. in the same way, antibodies directed against the nucleocapsid (N) protein, whereas less probable to be neutralizing, act as essential markers of encounter and infection [8]. The quality, magnitude and strength of these antibody mediated responses, especially neutralizing antibody (NAb) levels, are important determinants of making shield against recurrence of infection and are vital for assessing vaccine effectiveness [9,10]. sequential studies have revealed that while antibody levels may diminsh over months, memory B cells continue to recall secondary immune response, likely enabling a fast anamnestic response after second-exposure [11,12].

Simultaneously , the non-specific immune system and complement cascades play a conclusive role in clinical outcome. Crucial COVID-19 is often connected with a imbalanced generalized inflammatory response, frequently called a "cytokine storm" [13]. This condition is identified by elevated titers of chemokines and pro-inflammatory cytokines including interferon-gamma (IFN-γ), tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6), [14,15]. The effect of IFN-γ is more complicated; it is a main cytokine against antiviral cellular immune response but can also participate to tissue inflammation. Especially compromised or delayed type I interferon response in the beginning of an infection has been associated to severe illness, while a strong and prompt IFN response is linked with control of viral replication[18,19]. While IL-6, in particular, has been powerfully implicated which lead to promoting endothelial dysfunction, excessive inflammation and participating to the immune mediated thrombosis detected in serious and acute cases [16,17].

Alterations in Hematological levels are another noticeable character of COVID-19 and yield an important insights into the systemic effect of the viral infection. Lymphopenia or

high lymphocyte level, especially affecting T cells, is the most frequent laboratory outcomes and is a powerful predictor of mortality and disease severity [20,21]. On the other hand, neutrophilia and a high level of neutrophil-to-lymphocyte ratio (NLR) are associated with a strong inflammatory response and are indicative of bad with poor prognosis [22,23]. These alterations reflect both the bone marrow's response to general inflammation and the direct impact of the virus on lymphocytes.

In spite of lot of researchs, a complete research, direct analysis of these multiple variables including particular antibody patterns, wide hematological indexes, and in depth cytokine signling networks—over the marked phases of current infection and remission, used as a reference against non-affected individuals, remains essential. Such an combined analysis can highlight the progressive change from acuteinfection and excessive inflammation to recovery and the formation of adaptive immune memory.

Thus, this observational study aims to present a overall profile by contrasting the amounts of SARS-CoV-2-specific antibodies (anti-N IgG, and anti-S and neutralizing antibodies), main hematological variables (total WBC, lymphocyte , and neutrophil counts), and crucial inflammatory cytokines (TNF-α,IL-6, and IFN-γ) across three distinct groups: patients with current COVID-19, patients who have healed from COVID-19, and healthy individuals with no pevious exposure. By explaining these clear immunological pattern, the results of the pesent study seek to augment the elucidation of COVID-19 immune mediated pathogenesis and add to the framework for more exact medical control and immune regulatory procedures. My present study aims to full comparison between these parameters above infected patients , recovered patients , and uninfected individuals to describe obviously immune activity and inform medical treatment.

METHODS

Study Protocol and Subjects:

An observational study was carried out with 450 subjects (150 for each group). Current COVID-19 patients were RT-PCR established; healed individuals were >4 weeks post-symptom termination; healthy control had no history of COVID-19 or immunization. Study groups were paired for age and biological sex.

Laboratory Analysis:

Blood specimens were examined for SARS-CoV-2 antibodies (ELISA for spike/nucleocapsid IgG, surrogate neutralization test). Complete blood count with differential. Cytokine measurement (TNF-α, IL-6, IFN-γ) by using multiple immunoassay

Statistical Evaluation:

Data evaluated by using SPSS v.26 with ANOVA/Chi-square tests. $P<0.05$ aknowledged as significant.

RESULTS

Population characteristics: There are no considerable demographic differences among infected and control cohorts; healed cohort was a little older (Table 1).

Antibody mediated Immunity: Active patients revealed maximum antibody measures between all tests, followed by healed individuals. Healthy controls had slight reactivity (Tables 3–5, all $p<0.001$).

Hematological Alterations: Clinically active infection related with increased WBCs, relative lymphopenia and neutrophilia evaluted against other cohorts (Table 2, $p<0.05$).

Cytokine Signatures: Pro-inflammatory cytokines TNF-α and IL-6 were significantly elevated in clinically active infection. IFN-γ was reduced in active patients but increased in healed individuals (Table 6, $p<0.001$).

Table 1: Population Characteristics of Study Participants.

Characteristics	Mean ± SD Active Infected Patients (n=150)	Mean ± SD Healed individuals (n=150)	Mean ± SD Healthy Control individuals (n=150)	P value
Age (years)	28.8 ± 12.4	36.5 ± 14.3	27.3 ± 11.9	0.7888
Range	18 – 42y	19 – 56y	16 – 44y	
Gender				
Males	90 (60%)	70 (46.7%)	84 (56%)	0.156
Females	60 (40%)	80 (53.3%)	66 (44%)	0.113

Table 2: Hematological variables between Study cohorts.

Characteristics	Active Infected Patients (n=150)	Healed individuals (n=150)	Healthy Control individuals (n=150)	P value
WBCs Total Counts (x10⁹/L)				
Mean ± SD	7.86 ± 2.3	6.42 ± 1.8	5.98 ± 1.5	<0.05
Range	4.3 – 15.6	4.0 – 10.2	4.1 – 8.9	
Neutrophils (%)				
Mean ± SD	5.53 ± 1.2	4.12 ± 1.0	3.85 ± 0.9	<0.01
Range	3.5 – 8.1	2.8 – 6.5	2.5 – 5.8	
Lymphocytes (%)				
Mean ± SD	2.01 ± 0.8	2.45 ± 0.7	2.50 ± 0.6	<0.05
Range	1.0 – 4.5	1.5 – 4.0	1.6 – 4.2	

Table 3: SARS-CoV-2 Spike Protein IgG , Neutralizing Antibody levels and SARS-CoV-2.

Characteristics	Active Infected Patients (n=150)	Healed individuals (n=150)	Healthy Control individuals (n=150)	P value
SARS-CoV-2 Spike Protein IgG				
Mean ± SD (AU/mL)	8.2 ± 0.51	6.7 ± 0.41	0.16 ± 0.12	<0.001
Range	5.91 – 8.23	2.9 – 4.5	0.1 – 0.9	

Characteristics	Active Infected Patients (n=150)	Healed individuals (n=150)	Healthy Control individuals (n=150)	P value
Neutralizing Antibody IgG (titer)				
Mean ± SD	253.9 ± 48.1	236.82 ± 38.2	14.32 ± 5.1	<0.001
Range	167.82 – 382.6	156.6 – 349.5	3.1 – 34.5	
SARS-CoV-2 Nucleocapsid Protein IgG				
Mean ± SD (AU/mL)	4.2 ± 0.31	3.62 ± 0.41	0.16 ± 0.12	<0.001
Range	3.9 – 5.2	2.9 – 4.5	0.1 – 0.9	

Table 6: Cytokine Profiles Among Study Cohorts.

Characteristics	Active Infected Patients (n=150)	Healed individuals (n=150)	Healthy Control individuals (n=150)	P value
IL-6 (pg/ml)				
Mean ± SD	268.4 ± 44	111.2 ± 4.6	33.5 ± 1.8	<0.001
Range	180 – 365.7	85 – 135	28 – 40	
TNF-α (pg/ml)				
Mean ± SD	218.6 ± 39.3	91.8 ± 3.9	57.2 ± 2.1	<0.001
Range	188 – 345	75 – 110	50 – 65	
IFN-γ (pg/ml)				
Mean ± SD	44.2 ± 22.6	117.5 ± 5.8	96.4 ± 2.7	<0.001
Range	25 – 100	105 – 130	90 – 105	

DISCUSSION

This complete observational study yields a detailed overview of the hematological, immunological, and inflammatory area of study among three vital phases of the SARS-CoV-2-biological interaction: current acute infection, recovery, and prior exposure. The present study findings define obvious and important differences among these groups, strengthening and enlarging over established patterns of COVID-19 immune mediated pathogenesis while providing understanding of the transition from acute infection to healing and the ability of long-term immunity.

Antibody mediated Immunity: strong but variable Responses among Phases

The present study data demonstrate a strong and exact antibody mediated immune response in active COVID-19 individuals, defined by significantly high levels of anti-nucleocapsid

IgG, anti-spike IgG, and neutralizing antibodies when compared to both healthy controls and healed individuals. The anti-spike IgG amounts detected in the active infection group (8.2 ± 0.51 AU/mL) are dependable with studies presenting powerful seroconversion during the first two weeks of clinically appeared infection [35]. The simultaneous elevated levels of neutralizing antibodies (mean 253.9) agree with results that neutralizing ability frequently correlates with the severity of disease, likely mirroring a higher antigenic level leading to a more effective B-cell response [36,18].

Particularly, healed individuals, collected from patients after more than 4 weeks when symptom have been disappeared, preserved substantial titers of all antibodies that have been measured, although at lower levels when compared to the acute stage. This endurance supports the idea of continueable , though potentially waning, antibody mediated memory [7,11]. The reduced titers of anti-N protein IgG when compared to anti-S IgG in the healed group might show differential progression in antibody decline, like some studies propose anti-N antibodies decay more quickly[37]. Significantly, the maintained neutralizing ability in the healed group (mean 236.82) recommend kept protective functional immunity, which is a main associate of protection against second infection [9].

Hematological Changes: indicator of Immune Dysregulation and Inflammatory Stress

The hematological pattern of active COVID-19 individuals showed a pattern characteristic of systemic inflammation and acute viral stress: high levels of total WBC counts caused by lymphopenia , accompanied by relative neutrophilia. This neutrophil-to-lymphocyte inequality, measured in the present data, is an important predictive marker for severe infection [22,23]. Lymphopenia, especially infleuencing CD8+ and CD4+ T cells, is a characteristic of severe SARS-CoV-2 infection and is believed to be a result from a combination of cytokine-mediated apoptosis, direct viral effects, and containment in the lungs [26,4]. in the healed group the hematological parameters become normal especially the neutrophil and lymphocyte levels returning to levels closely similar to healthy controls group—spotlights the returnability of this imbalanced upon inflammation resolution and viral clearance. This adjustment might happened as a result of the restoration of immune balance and describe a good prognostic evidence for full improvement.

The Cytokine Triad: different functions of TNF-α, IL-6, and IFN-γ

The most remarkable and clinically significant findings of the present study apply to the cytokine expression, which indicate a two category inflammatory condition between convalescence and active infection. Ongoing active COVID-19 patients showed a marked pro-inflammatory feature, with extensively increased levels of IL-6 (268.4 pg/mL) and TNF-α (218.6 pg/mL). This "cytokine storm" observable characteristic is an important for the pathophysiology of severe COVID-19 infection [13]. While IL-6 acts as a main regulator of the responses of acute phase , which promotes Th17 differentiation, and correlate with the endothelial cells dysfunction and the coagulopathy which is the sign of severe disease [15,16]. The achievement of IL-6 receptor inhibitors (e.g., tocilizumab) in paricular patient categories highlight the pathogenic impact of the IL-6 cytokine [39]. IL-6 synergizes with TNF-α to activate fever, inflammation, and tissue damage. The continuous elevated levels of the tested cytokines in the active cohort highlight their significant role as activator, rather than just markers, to measure the severity of the disease [14].

In clear difference, the cytokine scenario healed individuals was described by a significant shift. While TNF-α and IL-6 levels had declined significantly, they persisted slightly inceased above control measures, indicating a potent state of minor remaining immune activation or inflammation that justifies additional follow up assessment. The most powerful finding was the impressive high level of IFN-γ in the healed cohort (117.5 pg/mL), exceeding levels in both healthy controls and active patients. IFN-γ is a main mediator cytokine of cell mediated immunity, mainly produced by NK cells and activated T cells. Its low amount during active infection might indicate T-cell exhaustion, sequestration, or a suppressive impact of the elevated IL-6 level [40]. The following elevation and rebound in convalescence probable indicate the activation and expansion of virus-specific T cells memory , an important component of life long protective immunity against the virus [17,10]. This increased IFN-γ level in healed group may yield a positive immunological effect, indicating a strong and functional adaptive immunological memory that might contribute to protection upon viral re-exposure.

Combined Interpretation and Clinical Implications

The present study combined results support a variable model immunologyof COVID-19. The acute phase is controlled by the activation of the innate immunity and the production of antibody, commonly at the cost of the imbalanced cascade of inflammatory events (high IL-6/TNF-α) and lymphocyte deficiency. Successful shift to post illness recovery involves the improvement of this hyper active inflammatory state, hematological parameters normalization, and the appearance of a major cellular immune mark (high IFN-γ) beside continuous antibody mediated immunity.

The present study findings have multiple research and clinical implications

Prognostic Classification: The integrated assessment of IL-6, NLR, and antibody levels at demonstration might improve initial risk classification for severe illness.

Therapeutic Targeting: The result enhance the justification for anti-cytokine treatment (e.g., anti-IL-6R) in the acute excessive inflammatory phase but attention against their apply in advanced stages where a strong IFN-γ response might be beneficial.

Long COVID Understanding: The mildly elevated TNF-α/IL-6 and markedly elevated IFN-γ in healed individuals makes me questioned about their effect in the Long COVID or Post-Acute Sequelae of COVID-19 (PASC). Persistent activation of the immunity or a shifting immune set point might be effecting factors [41].

Insights of Vaccination: The immune status of healed individuals with rised IFN-γ and ongoing neutralizing antibodies yields a reference point for analyzing the durability and quality of vaccine-induced immunity, mainly for cellular immune responses.

CONCLUSION

The present study outlines clear inflammatory and immunological distinctions between healthy states, active COVID-19,and convalescent. Active infection is defined by hematological stress responses, hyperactivated humoral immunity, and pro-inflammatory cytokine control. Convalescence indicates shifting toward balanced immunity with high IFN-γ. These analysis enhance the understanding the immunobiology of COVID-19 and might guide therapeutic strategies focusing on specific immune stages.

RECOMMANDATIONS

The present study has few limitations due to its design which is cross-sectional, because the study have only a single time point and could not infer longitudinal or causality kinetics. The healed group's "time after

infection" was defined as >4 weeks, including a potentially diverse period where immune indicators are still in fluctuation. Prospective long term studies monitoring individuals from acute viral infection during prolonged convalescence are required to map the exact trajectory of these biological markers. In additon, intensive immunophenotyping (e.g., memory B cells, T-cell subsets) and functional methods would yield a more detailed understanding of the cellular immune fluctuating suggested by the current study cytokine results.

So, this current study describes the distinct hematological, immunological, and inflammatory signatures that describe active SARS-CoV-2 infection compared with recovery. The conversion from antibody driven state, excessive inflammatory congenital activation to one of stable adaptive immunity with a important IFN-γ signature signs a critical critical point in the host's battle versus the virus. Understanding these stages were essential for customizing stage-specific strategies and for describing the associates of sustained protective immunity.

REFERENCES

1) Zhu, N., Zhang,. D., Wang,W., et al. (2020). A Novel Coronavirus from Patients with Pneumonia in China, 2019. New England Journal of Medicine, 382(8), 727-733.
2) Wu, Z., & McGoogan, J. M. (2020). Characteristics of and Important Lessons from the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases from the Chinese Center for Disease Control and Prevention. JAMA, 323(13), 1239-1242.
3) Zhou, F., Yu, T., Du, R., et al. (2020). Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. The Lancet, 395(10229), 1054-1062.
4) Merad, M., & Martin, J. C. (2020). Pathological inflammation in patients with COVID-19: a key role for monocytes and macrophages. Nature Reviews Immunology, 20(6), 355-362.
5) Tay, M. Z., Poh, C. M., Rénia, L., et al. (2020). The trinity of COVID-19: immunity, inflammation and intervention. Nature Reviews Immunology, 20(6), 363-374.
6) Piccoli, L., Park, Y. J., Tortorici, M. A., et al. (2020). Mapping Neutralizing and Immunodominant Sites on the SARS-CoV-2 Spike Receptor-Binding Domain by Structure-Guided High-Resolution Serology. Cell, 183(4), 1024-1042.
7) Rogers, T. F., Zhao, F., Huang, D., et al. (2020). Isolation of potent SARS-CoV-2 neutralizing antibodies and protection from disease in a small animal model. Science, 369(6506), 956-963.
8) Amanat, F., Stadlbauer, D., Strohmeier, S., et al. (2020). A serological assay to detect SARS-CoV-2 seroconversion in humans. Nature Medicine, 26(7), 1033-1036.
9) Khoury, D. S., Cromer, D., Reynaldi, A., et al. (2021). Neutralizing antibody levels are highly predictive of immune protection from symptomatic SARS-CoV-2 infection. Nature Medicine, 27(7), 1205-1211.
10) Cromer, D., Juno, J. A., Khoury, D., et al. (2021). Prospects for durable immune control of SARS-CoV-2 and prevention of reinfection. Nature Reviews Immunology, 21(6), 395-404.
11) Dan, J. M., Mateus, J., Kato, Y., et al. (2021). Immunological memory to SARS-CoV-2 assessed for up to 8 months after infection. Science, 371(6529), eabf4063.
12) Gaebler, C., Wang, Z., Lorenzi, J. C. C., et al. (2021). Evolution of antibody

immunity to SARS-CoV-2. Nature, 591(7851), 639-644.
13) Fajgenbaum, D. C., & June, C. H. (2020). Cytokine Storm. New England Journal of Medicine, 383(23), 2255-2273.
14) Del Valle, D. M., Kim-Schulze, S., Huang, H. H., et al. (2020). An inflammatory cytokine signature predicts COVID-19 severity and survival. Nature Medicine, 26(10), 1636-1643.
15) Leisman, D. E., Ronner, L., Pinotti, R., et al. (2020). Cytokine elevation in severe and critical COVID-19: a rapid systematic review, meta-analysis, and comparison with other inflammatory syndromes. The Lancet Respiratory Medicine, 8(12), 1233-1244.
16) McGonagle, D., O'Donnell, J. S., Sharif, K., et al. (2020). Immune mechanisms of pulmonary intravascular coagulopathy in COVID-19 pneumonia. The Lancet Rheumatology, 2(7), e437-e445.
17) Sette, A., & Crotty, S. (2021). Adaptive immunity to SARS-CoV-2 and COVID-19. Cell, 184(4), 861-880.
18) Garcia-Beltran, W. F., Lam, E. C., St Denis, K., et al. (2021). Multiple SARS-CoV-2 variants escape neutralization by vaccine-induced humoral immunity. Cell, 184(9), 2372-2383.
19) Bastard, P., Rosen, L. B., Zhang, Q., et al. (2020). Autoantibodies against type I IFNs in patients with life-threatening COVID-19. Science, 370(6515), eabd4585.
20) Tan, L., Wang, Q., Zhang, D., et al. (2020). Lymphopenia predicts disease severity of COVID-19: a descriptive and predictive study. Signal Transduction and Targeted Therapy, 5(1), 33.
21) Chen, G., Wu, D., Guo, W., et al. (2020). Clinical and immunological features of severe and moderate coronavirus disease 2019. Journal of Clinical Investigation, 130(5), 2620-2629.
22) Liu, J., Liu, Y., Xiang, P., et al. (2020). Neutrophil-to-lymphocyte ratio predicts critical illness patients with 2019 coronavirus disease in the early stage. Journal of Translational Medicine, 18(1), 206.
23) Yang, A. P., Liu, J. P., Tao, W. Q., & Li, H. M. (2020). The diagnostic and predictive role of NLR, d-NLR and PLR in COVID-19 patients. International Immunopharmacology, 84, 106504.
24) Terpos, E., Ntanasis-Stathopoulos, I., Elalamy, I., et al. (2020). Hematological findings and complications of COVID-19. American Journal of Hematology, 95(7), 834-847.
25) Lucas, C., Wong, P., Klein, J., et al. (2020). Longitudinal analyses reveal immunological misfiring in severe COVID-19. Nature, 584(7821), 463-469.
26) Diao, B., Wang, C., Tan, Y., et al. (2020). Reduction and functional exhaustion of T cells in patients with coronavirus disease 2019 (COVID-19). Frontiers in Immunology, 11, 827.
27) Wang, Z., Yang, X., Zhong, J., et al. (2021). Exposure to SARS-CoV-2 generates T-cell memory in the absence of a detectable viral infection. Nature Communications, 12(1), 1724.
28) Zhang, J. Y., Wang, X. M., Xing, X., et al. (2020). Single-cell landscape of immunological responses in patients with COVID-19. Nature Immunology, 21(9), 1107-1118.
29) Rydyznski Moderbacher, C., Ramirez, S. I., Dan, J. M., et al. (2020). Antigen-specific adaptive immunity to SARS-CoV-2 in acute COVID-19 and associations with age and disease severity. Cell, 183(4), 996-1012.
30) Kuri-Cervantes, L., Pampena, M. B., Meng, W., et al. (2020). Comprehensive

mapping of immune perturbations associated with severe COVID-19. Science Immunology, 5(49), eabd7114.
31) Chvatal-Medina, M., Mendez-Cortina, Y., Patiño, P. J., et al. (2021). Antibody responses in COVID-19: a review. Frontiers in Immunology, 12, 633184.
32) Zhang, B., Zhou, X., Zhu, C., et al. (2020). Immune phenotyping based on the neutrophil-to-lymphocyte ratio and IgG level predicts disease severity and outcome for patients with COVID-19. Frontiers in Molecular Biosciences, 7, 157.
33) Liu, Y., Yan, L. M., Wan, L., et al. (2020). Viral dynamics in mild and severe cases of COVID-19. The Lancet Infectious Diseases, 20(6), 656-657.
34) Chen, X., Zhao, B., Qu, Y., et al. (2020). Detectable serum severe acute respiratory syndrome coronavirus 2 viral load (RNAemia) is closely correlated with drastically elevated interleukin 6 level in critically ill patients with coronavirus disease 2019. Clinical Infectious Diseases, 71(8), 1937-1942.
35) Long, Q. X., Liu, B. Z., Deng, H. J., et al. (2020). Antibody responses to SARS-CoV-2 in patients with COVID-19. Nature Medicine, 26(6), 845-848.
36) Lucas, C., Klein, J., Sundaram, M., et al. (2021). Delayed production of neutralizing antibodies correlates with fatal COVID-19. Nature Medicine, 27(7), 1178-1186.
37) Gallais, F., Gantner, P., Bruel, T., et al. (2021). Evolution of antibody responses up to 13 months after SARS-CoV-2 infection and risk of reinfection. EBioMedicine, 71, 103561.
38) Wajnberg, A., Amanat, F., Firpo, A., et al. (2020). Robust neutralizing antibodies to SARS-CoV-2 infection persist for months. Science, 370(6521), 1227-1230.
39) Recovery Collaborative Group. (2021). Tocilizumab in patients admitted to hospital with COVID-19 (RECOVERY): a randomised, controlled, open-label, platform trial. The Lancet, 397(10285), 1637-1645.
40) Zheng, H. Y., Zhang, M., Yang, C. X., et al. (2020). Elevated exhaustion levels and reduced functional diversity of T cells in peripheral blood may predict severe progression in COVID-19 patients. Cellular & Molecular Immunology, 17(5), 541-543.
41) Proal, A. D., & VanElzakker, M. B. (2021). Long COVID or Post-acute Sequelae of COVID-19 (PASC): An Overview of Biological Factors That May Contribute to Persistent Symptoms. Frontiers in Microbiology, 12, 698169.
42) Grifoni, A., Weiskopf, D., Ramirez, S. I., et al. (2020). Targets of T cell responses to SARS-CoV-2 coronavirus in humans with COVID-19 disease and unexposed individuals. Cell, 181(7), 1489-1501.
43) Hadjadj, J., Yatim, N., Barnabei, L., et al. (2020). Impaired type I interferon activity and inflammatory responses in severe COVID-19 patients. Science, 369(6504), 718-724.
44) Huang, C., Wang, Y., Li, X., et al. (2020). Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. The Lancet, 395(10223), 497-506.

