BENHA MEDICAL JOURNAL bmj
Print ISSN 1110-208X
Online ISSN 2357-0016

Original article

Hematological Impact of COVID-19: Anemia in Post-COVID

Taher Abdel-Aziz [a], Ghada N. Abd El Aziz[b], Mai Fawzy[c], Nagwa I. EL Dosoky[d], Hanaa I. Hegab[e], Ismail Dahshan[f]

[a] Clinical Research Unit, Ministry of Health and Population, Egypt. [b] Department of pharmacotherapy, Ministry of Health and Population, Egypt. [c] Department of Radiology, Benha Fever Hospital, Ministry of Health and Population, Egypt. [d] Department of Pediatrics, Specialized Kafr Shokr Hospital, Ministry of Health and Population, Egypt. [e] Department of Chemical and Clinical Pathology, Specialized Kafr Shokr Hospital, Ministry of Health and Population, Egypt. [f] Department of Family Medicine, Faculty of Medicine, Sues Canal University, Egypt

Corresponding to: Taher Abdel-Aziz. Clinical Research Unit, Ministry of Health and Population, Egypt.

Email:

taheralnomany@yahoo.com

Received: 25 October 2023

Accepted:9 March 2024

ABSTRACT

Purpose: This study's purpose was to assess the relationship between COVID-19 and hematological variations on admission and 6 months after discharge. **Patients and Methods:** In a prospective observational study at Kafr Shokr Specialized Hospital from September 2021 to September 2022, 292 adult patients with PCR-confirmed COVID-19 were categorized into hospitalized and non-hospitalized groups. Comprehensive clinical evaluations, including blood assessments- were conducted. The hospitalized patients were re-evaluated for anemia six months after discharge. **Results:** Hemoglobin (Hb) levels were significantly higher in the non-hospitalized group, with a mean of 14.13 g/dL, compared to the hospitalized group with 12.43 g/dL ($p < 0.001$). Anemia affected 18.005% of the non-hospitalized group, compared to 45.3% of the hospitalized group. At 6-month follow-up, hospitalized patients showed a decrease in Hb levels and platelet counts and an increase in white blood cell counts. Logistic regression identified baseline anemia, lower Hb, and reduced MCH levels as predictors for post-COVID anemia. **Conclusion:** The study revealed that COVID-19 severity was associated with anemia, which persisted and increased in prevalence six months post-infection. Baseline anemia, Hb, and MCH levels emerged as crucial predictors for post-COVID anemia, emphasizing the need for continuous hematological monitoring in COVID-19 survivors.

Key words: COVID-19; anemia; disease severity; post-COVID.

Introduction

The emergence of the COVID-19 pandemic has led to a global public health emergency not witnessed since the Spanish flu pandemic of 1918 [(1)]. This has had significant implications for patients and healthcare workers [(2).] The manifestations of this disease span from asymptomatic cases to devastating conditions such as acute respiratory distress syndrome and fatalities [(3).] In some patients, COVID-19 infection can trigger a broad disruption in the body's response to the virus, involving excessive production of inflammatory cytokines, disturbances in the coagulation process, and abnormal activation of endothelial cells [(4).]

Despite the significant advances in our knowledge of COVID-19 within a relatively short time frame [(5-8),] the connection between anemia and COVID-19- remains uncertain. The link between COVID-19 and anemia is intricate. Both of them can lead to dysregulated immune system, making patients susceptible to similar autoimmune complications, and this relationship is bidirectional [(9,10).] Individuals with COVID-19 may develop anemia, and those who are already anemic are at an increased risk of experiencing severe COVID-19 infection [(11,12).]

Post-acute COVID-19- often referred to as "post-COVID conditions or long COVID"- is a syndrome defined by the continuation of clinical symptoms that extend beyond four weeks from the initial onset of acute symptoms. The Center for Disease Control (CDC) has adopted these terms to describe health problems that endure for more than four weeks following a COVID-19 infection [(13).]

The objective of this research is to assess the relationship between COVID-19 and hematological variations on hospital admission and six months after discharge.

Patients and methods

This is a prospective observational study in which we enrolled patients who presented to Kafr-Shokr Specialized Hospital with COVID-19 during the period from September 2021 to September 2022. The study was initiated after achieving Research Ethics Committee approval (No. 20-2021/18). The study was conducted in adherence to the Declaration of Helsinki.

Adult patients with polymerase chain reaction (PCR)-proved COVID-19, were eligible for the study. Patients who required hospitalization and completed the follow-up until 180 days after discharge from the hospital- were included in the hospitalized group. Patients with mild disease who did not require hospitalization and were matched to the hospitalized group in the demographic criteria and baseline comorbidities- were selected as the non-hospitalized group for comparison. Patients with a history of chronic anemia, autoimmune or connective tissue disease, endocrinopathies, chronic liver disease, malignancy, or any systemic debilitating diseases were excluded. Pregnant and lactating females were also excluded.

A written informed consent was obtained from each included patient.

The study patients received a thorough clinical evaluation, including dedicated history-taking, a complete physical

examination, routine laboratory and radiological investigations. For the assessment of the complete blood count (CBC), two milliliters of venous blood were withdrawn under aseptic conditions in an EDTA vacationer. CBC assessment was done using SysmexKX-21N, Sysmex Corporation, New York, USA.

The COVID severity and the decision to hospitalize adhered to the Egyptian protocol for diagnosis and treatment version 1.4 [(14)]. The diagnosis of anemia was based on the criteria proposed by the World Health Organization (WHO), with Hb levels of less than 13.0 g/dL in males and 12.0 g/dL in females denoting anemia [(15)].

The statistical analytic processes were implemented using IBM SPSS Statistics version 27 (IBM Inc., Armonk, NY, USA). For comparison of the numerical and categorical data of the two groups, the independent t test and the chi-square test- were used, respectively. Continuity correction (Yates' correction) was employed to correct for the overestimation of the chi-square value. For the paired comparison of the hospitalized group, a paired t-test and McNemar statistic- were used for the numerical and categorical data, respectively. Binary logistic regression analysis was conducted to assess the predictors of post-Covid anemia, where the odds ratios (ORs) and their confidence intervals (CIs) were calculated. The differences between groups were judged as statistically significant if p-values were less than 0.05.

Results

The present study included 292 patients who fulfilled the eligibility criteria, 133 patients in the non-hospitalized group, and 159 patients in the hospitalized group. The age of the patients ranged from 19 to 73 years, with a mean of 58.31 ± 17.81 in the non-hospitalized group, and from 27 to 86 years, with a mean of 60.27 ± 13.31 in the hospitalized group (p-value = 0.5122). Most patients were females in both groups (n = 81, 60.9% of the non-hospitalized group, and n = 100, 62.9% of the hospitalized group) (p-value = 0.8197). Ten patients (7.5%) and fourteen patients (8.8%) in the two groups, respectively, were smokers (p-value = 0.8535). The patients' comorbidities were: hypertension (n = 42, 31.6% of the non-hospitalized group and n = 56, 35.2% of the hospitalized group) (p-value = 0.5949), diabetes mellitus (n = 39, 29.3% of the non-hospitalized group and n = 55, 34.6% of the hospitalized group) (p-value = 0.4044), cardiac diseases (n = 9, 6.8% of the non-hospitalized group and n = 12, 7.5% of the hospitalized group) (p-value = 0.9764), and bronchial asthma (n = 1, 0.75% of the non-hospitalized group and n = 3, 1.9% of the hospitalized group) (p-value = 0.7448), (**Table 1**).

The CBC assessment of the two study groups revealed that Hb levels were higher in the non-hospitalized group, ranging from 9.9 to 17.2 g/dL, with a mean of 14.13 g/dL ± 1.81, whereas in the hospitalized group, Hb levels showed a range of 7.5 to 15.8 g/dL and a mean of 12.43 g/dL ± 1.68 (p-value < 0.001).

Anemia was less prevalent in the non-hospitalized group, affecting 18.005% of patients, in contrast to the hospitalized group, where anemia was found in 45.3% of patients (p-value < 0.001).

Red blood cell (RBC) counts did not significantly differ between the two groups, with non-hospitalized patients having a mean count of 4.69 million/mm3 ± 0.63 and hospitalized patients having a mean count of 4.597 million/mm3 ± 0.59 (p-value = 0.0850). Similarly, hematocrit (HCT) values showed no significant difference between the groups, with mean values of 37.56% ± 4.18 in the non-hospitalized group and 36.9984% ± 4.41 in the hospitalized group (p-value = 0.2913).

Mean corpuscular volume (MCV) was significantly higher in the non-hospitalized group, ranging from 57.8 fL to 96.00 fL, with a mean of 80.75 fL ± 5.51, compared to the hospitalized group, where MCV ranged from 54.90 fL to 95.00 fL and had a mean of 78.51 fL ± 6.43 (p-value < 0.001). Mean corpuscular hemoglobin (MCH) levels were also significantly higher in the non-hospitalized group, with a mean of 31.11 pg ± 2.45, whereas the hospitalized group had a lower mean of 26.69 pg ± 2.63 (p-value < 0.001).

White blood cell (WBC) counts showed no significant difference, with non-hospitalized patients having a mean count of 6.52 x 10^3/µL ± 2.37 and hospitalized patients having a mean count of 7.03 x 10^3/µL ± 2.54 (p-value = 0.1240). Platelet (PLT) counts were significantly higher in the non-hospitalized group, with a mean of 311.71 x 10^3/µL ± 66.12, compared to the hospitalized group, where PLT counts had a lower mean of 203.64 x 10^3/µL ± 50.77 (p-value < 0.001), (**Table 2**).

The length of hospital stays (LOS) in the hospitalized patients ranged from 1 to 18 days, with a mean of 7.61 ± 3.02. At the 6-month follow-up of the hospitalized group, Hb levels ranged from 9.6 to 15.0 g/dL (mean: 12.07 g/dL ± 1.29), with anemia diagnosed in 81 patients (50.9%). RBC counts varied from 3.20 to 6.00 million/mm2 (mean: 4.53 million/mm2 ± 0.52). HCT values showed a range from 24.9% to 45.0% (mean: 36.142% ± 3.92), MCV ranged from 55.0 to 90.0 fL (mean: 77.93 fL ± 5.79), MCH levels varied from 20.0 to 32.0 pg (mean: 26.82 pg ± 2.33), WBC counts ranged from 4.2 to 17.7 x 10^3/µL (mean: 10.23 x 10^3/µL ± 1.92), and PLT counts varied from 110 to 470 x 10^3/µL (mean: 216.99 x 10^3/µL ± 42.293). Paired comparison demonstrated that Hb levels, HCT values, and PLT count exhibited a significant decrease (p-value < 0.001, p = 0.003, and p < 0.001, respectively), while WBC counts displayed a significant increase (p-value < 0.001). No significant changes were encountered in the other parameters, (**Table 3**).

Binary logistic regression revealed that the predictors of post-Covid anemia- were only the presence of anemia at the baseline assessment (OR = 10.57, CI = 5.035–22.21, p < 0.001), Hb (OR = 0.451, CI = 0.341–0.596, p < 0.001), and MCH (OR = 0.834, CI = 0.732–0.950, p = 0.006).

Table 1: The patient's demographic characteristics

Characteristic	Non-Hospitalized (n =133)	Hospitalized (n = 159)	p-value
Age (Range, Mean ± SD)	19-73, 58.31 ± 17.81	27-86, 60.27 ± 13.31	0.512
Gender (Female)	81 (60.9%)	100 (62.9%)	0.8197
Smoking	10 (7.5%)	14 (8.8%)	0.854
Hypertension	42 (31.6%)	56 (35.2%)	0.594
Diabetes Mellitus	39 (29.3%)	55 (34.6%)	0.404
Cardiac Diseases	9 (6.8%)	12 (7.5%)	0.977
Bronchial Asthma	1 (0.75%)	3 (1.9%)	0.745

Table 2: The patients' CBC parameters on admission

CBC Parameter	Non-Hospitalized Group (Mean ± SD)	Hospitalized Group (Mean ± SD)	p-value
Hb (g/dL)	14.13 ± 1.81	12.43 ± 1.68	< 0.001*
Anemia (%)	18.005%	45.3%	< 0.001*
RBC (million/mm³)	4.69 ± 0.63	4.597 ± 0.59	0.085
HCT (%)	37.56 ± 4.18	36.9984 ± 4.41	0.291
MCV (fL)	80.75 ± 5.51	78.51 ± 6.43	< 0.001*
MCH (pg)	31.11 ± 2.45	26.69 ± 2.63	< 0.001*
WBC (x 10³/µL)	6.52 ± 2.37	7.03 ± 2.54	0.124
PLT (x 10³/µL)	311.71 ± 66.12	203.64 ± 50.77	< 0.001*

*: statistically significant

Table 3: The hospitalized patients' CBC parameters on-admission and at the 6-month follow-up

CBC Parameter	On-admission (Mean ± SD)	6-Month Follow-Up (Mean ± SD)	p-Value
Hb (g/dL)	12.43 ± 1.68	12.07 ± 1.29	<0.001*
Anemia (%)	45.3%	50.9%	0.231
RBC (million/mm³)	4.597 ± 0.59	4.53 ± 0.52	0.094
HCT (%)	36.9984 ± 4.41	36.142 ± 3.92	0.003*
MCV (fL)	78.51 ± 6.43	77.93 ± 5.79	0.112
MCH (pg)	26.69 ± 2.63	26.82 ± 2.33	0.409
WBC (x 10³/µL)	7.03 ± 2.54	10.23 ± 1.92	<0.001*
PLT (x 10³/µL)	203.64 ± 50.77	216.99 ± 42.293	<0.001*

*: statistically significant Abbreviations; RBC: red blood cells. HCT: Hematocrit, MCV: mean corpuscular volume, WBC: White blood cells.

Discussion

The emergence of the COVID-19 pandemic has posed multifaceted challenges to global healthcare systems and spurred a relentless quest for a deeper understanding of the disease's complexities. Beyond the widely recognized respiratory symptoms, the impact of COVID-19 on various organ systems and physiological processes- has become a subject of intense scrutiny. Hematological changes in COVID-19 patients have garnered increasing attention due to their potential implications for both acute and post-acute disease outcomes.

In this context, the present study conducted a comprehensive examination of hematological parameters in a cohort of adult patients diagnosed with COVID-19. Our approach to patient selection was meticulous. Patients requiring hospitalization during the acute phase of COVID-19, as well as, a carefully matched non-hospitalized group- were included in the study. This distinction enabled us to explore the spectrum of hematological changes from acute disease presentation to the 180-day post-discharge period.

The assessment of hematological parameters in our study yielded intriguing insights into the hematological effects of COVID-19. Notably, we observed significant disparities between non-hospitalized and hospitalized patients. Non-hospitalized patients exhibited higher Hb levels and lower anemia prevalence compared to their hospitalized counterparts. This is a noteworthy finding, as it suggests that the severity of COVID-19 symptoms may be associated with a more substantial decline in Hb levels. Our findings may imply that COVID-19 severity primarily affects the quality of RBCs (as indicated by the MCV and MCH) rather than their quantity. The significantly higher MCV and MCH levels in non-hospitalized patients- suggest that the RBCs in this group are larger and contain more hemoglobin on average, possibly reflecting an adaptive response to COVID-19.

The correlation between the severity of illness and a greater likelihood of developing anemia has been reported in previous studies [16–19]. Several proposed mechanisms could explain our findings. In individuals with confirmed COVID-19, pneumonia can impair lung function, which is essential for consistently oxygenating the blood through the process of breathing [20–22]. As the disease progresses, blood oxygen levels decline, and the oxygen supply to body tissues becomes restricted [23]. It is widely recognized that Hb functions as a carrier of oxygen. It binds with oxygen in the tissues of the lung and releases it in the body’s organs. Simultaneously, hemoglobin plays a critical role in keeping the equilibrium of blood oxygen levels and the PaO2 level [24]. Consequently, a reduction in hemoglobin levels in patients with COVID-19 who have anemia [25] is thought to potentially undermine the ability to deliver oxygen and worsen the severity of the illness.

On the other hand, inflammation triggers distinctive changes in the regulation of iron within the body, characterized by an increase in iron retention and acquisition by macrophages, coupled with a decrease

in the absorption of iron in the intestines [26]. This leads to a decrease in the levels of circulating iron and a reduced supply of this metal for the process of erythropoiesis, which is essential for Hb production. In conjunction with the inhibitory effects of cytokines on erythropoiesis, a shortened lifespan of red blood cells, and a diminished biological effectiveness of the hormone erythropoietin- this cascade of events culminates in the development of what is known as anemia of inflammation (AI) [27,28].

Platelet counts displayed a noteworthy contrast between the two groups. Non-hospitalized patients exhibited significantly higher PLT counts than their hospitalized counterparts. This finding could imply that platelets- which play a crucial role in blood clotting and immune response- may respond differently in patients with varying degrees of COVID-19 severity. The higher PLT counts in non-hospitalized patients may suggest a more effective response to the virus in terms of immune and hemostatic mechanisms. This finding aligns with Boccatonda et al.'s (2022) [29] observation that platelet counts may serve as a valuable prognostic factor in patients admitted with COVID-19, as variations in PLT counts could be correlated with clinical outcomes. They indicated that a reduction in platelet counts may be associated with the disease's severity and clinical outcome.

In the current work, the 6-month follow-up of the hospitalized group provides valuable insights into the hematological changes that persist after COVID-19 infection. Our findings reveal a multifaceted impact on various hematological parameters, shedding light on the long-term consequences of the disease. Hemoglobin levels and HCT values at this stage exhibited a significant decrease in the hospitalized group compared to their initial assessments. This decrease in Hb levels is of particular concern, as it implies a continued hematological impact on patients, even months after recovery from the acute phase of COVID-19. This observation might be attributed to various factors, including the effects of the initial infection, possible treatment-related side effects, or post-viral complications. In this context, easy fatigability has been documented as a notable enduring effect of COVID-19 [30]. While the underlying causes of long COVID are still under study, recent research indicates that certain elements- including iron- may have a significant impact on the seriousness of long COVID [31-33].

Similarly, of Hudgins et al. (2023) [34] highlighted the prolonged presence of anemia in post-COVID patients, drawing attention to the large proportion (about one in three) of individuals diagnosed with COVID-19- displaying signs of anemia at both the 180-day and 365-day marks post-infection.

Platelet counts also demonstrated a notable reduction during the follow-up, which is a concerning finding given the critical role platelets play in blood clotting and immune response. A decreased PLT count could indicate a prolonged impairment of these essential functions, potentially impacting the overall health and recovery of COVID-19 patients. Conversely, white blood cell counts displayed a significant increase during the 6-month follow-up. This elevated WBC count suggests a persistent inflammatory response in these

patients. Our results confirm earlier research suggesting that individuals who have been diagnosed with COVID-19 face a risk of experiencing post-COVID complications [35-37].

Our binary logistic regression analysis underscores that on-admission anemia, lower Hb levels, and reduced MCH levels are significant predictors of post-COVID anemia. This agrees with the study of Hudgins et al. (2023)—[34] who demonstrated that anemia on admission was a significant risk factor for the prolonged presence of anemia in post-COVID patients. Identifying individuals at higher risk and implementing appropriate interventions, such as iron supplementation or other treatments- is crucial in managing and reducing the incidence of anemia in individuals recovering from COVID-19.

Overall, our study contributes to the growing body of knowledge on the complex interplay between COVID-19 and hematological parameters. The results of the 6-month follow-up in the hospitalized group underline the intricate and prolonged impact of COVID-19 on hematological parameters. The significant changes observed in Hb levels, HCT values, PLT counts, and WBC counts highlight the importance of continuous monitoring of these parameters in post-COVID-19 patients. These findings, also, point to the necessity of developing appropriate post-recovery interventions and healthcare strategies to address the persistent hematological consequences of the disease.

We acknowledge that, although this study provides valuable insights, it has some limitations. Being performed at a single center could limit the generalizability of our findings. Second, the study is limited by the relatively small sample size. Additionally, the study did not account for post-Covid treatment and vaccinations, which might affect the obtained results. Further research is needed to elucidate the mechanisms underlying these changes and their implications for long-term patient health and recovery.

Conclusion

This work emphasized the intricate relationship between anemia and COVID-19 severity. The study also highlighted the long-term hematological consequences of COVID-19. On-admission anemia, lower Hb levels, and reduced MCH levels- are significant risk factors for post-COVID anemia.

References

1. COVID-19 Map. Johns Hopkins Coronavirus Resource Center. Accessed February 25, 2022. https://coronavirus.jhu.edu/map.html

2. Alfonsi V, Scarpelli S, Gorgoni M, Couyoumdjian A, Rosiello F, Sandroni C, et al. Healthcare Workers after Two Years of COVID-19: The Consequences of the Pandemic on Psychological Health and Sleep among Nurses and Physicians. Int J Environ Res Public Health. 2023 Jan 12;20(2):1410.

3. Di Gennaro F, Petrosillo N. New endemic and pandemic pathologies with interhuman airborne transmission through ear, nose and throat anatomical sites. Acta Otorhinolaryngol Ital. 2022 Apr;42(Suppl. 1):S5-S13.

4. Osuchowski MF, Winkler MS, Skirecki T, Cajander S, Shankar-Hari M, Lachmann G, et al. The COVID-19 puzzle: deciphering pathophysiology and phenotypes of a new

disease entity. Lancet Respir Med. 2021 Jun;9(6):622-642.

5. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. Lancet. 2020 Mar 28;395(10229):1054-1062.

6. Wang M, Cao R, Zhang L, Yang X, Liu J, Xu M, et al. Remdesivir and chloroquine effectively inhibit the recently emerged novel coronavirus (2019-nCoV) in vitro. Cell Res. 2020 Mar;30(3):269-271.

7. Hoffmann M, Kleine-Weber H, Schroeder S, Krüger N, Herrler T, Erichsen S, et al. SARS-CoV-2 Cell Entry Depends on ACE2 and TMPRSS2 and Is Blocked by a Clinically Proven Protease Inhibitor. Cell. 2020 Apr 16;181(2):271-280.e8.

8. Gao J, Tian Z, Yang X. Breakthrough: Chloroquine phosphate has shown apparent efficacy in treatment of COVID-19 associated pneumonia in clinical studies. Biosci Trends. 2020 Mar 16;14(1):72-73.

9. Gracia-Ramos AE, Martin-Nares E, Hernández-Molina G. New onset of autoimmune diseases following COVID-19 diagnosis. Cells. 2021;10(12):3592.

10. Kroll MH, Rojas-Hernandez C, Yee C. Hematologic complications of immune checkpoint inhibitors. Blood. 2022;139(25):3594–3604.

11. Fletcher-Sandersjöö A, Bellander BM. Is COVID-19 associated thrombosis caused by overactivation of the complement cascade? A literature review. Thromb Res. 2020;194:36–41.

12. Giannis D, Ziogas IA, Gianni P. Coagulation disorders in coronavirus infected patients: COVID-19, SARS-CoV-1, MERS-CoV and lessons from the past. J Clin Virol. 2020;127:104362.

13. Center for Disease Control. Long COVID or Post-COVID Conditions. Updated July 20, 2023. [cited in October 2023]. Available from: https://www.cdc.gov/coronavirus/2019-ncov/long-term-effects/index.html Date of accession: in October 2023

14. Masoud H, Elassal G, Zaky S, Baki A, Ibrahem H, Amin W, et al. Management Protocol for COVID-19 Patients Version 1.4/30th May 2020. Ministry of Health and Population (MOHP), Egypt. 2020.

15. Blanc B, Finch CA, Hallberg L, Herbert V, Lawkowicz W, Layrisse M. Nutritional anaemias. Report of a WHO Scientific Group. WHO Tech Rep Ser. 1968:1-40.

16. Oh SM, Skendelas JP, Macdonald E, Bergamini M, Goel S, Choi J, et al. On-admission anemia predicts mortality in COVID-19 patients: A single center, retrospective cohort study. Am J Emerg Med. 2021 Oct; 48:140-147.

17. Faghih Dinevari M, Somi MH, Sadeghi Majd E, Abbasalizad Farhangi M, Nikniaz Z. Anemia predicts poor outcomes of COVID-19 in hospitalized patients: a prospective study in Iran. BMC Infect Dis. 2021 Feb 10;21(1):170.

18. Jha M, Tak ML, Gupta R, Sharma P, Rajpurohit V, Mathur P, et al. Relationship of anemia with COVID-19 deaths: A retrospective cross-sectional study. J Anaesthesiol Clin Pharmacol. 2022 Jul;38(Suppl 1): S115-S119.

19. Veronese N, Segala FV, Carruba L, La Carrubba A, Pollicino F, Di Franco Get al. Anemia as a risk factor for disease progression in patients admitted for COVID-19: data from a large, multicenter cohort study. Sci Rep. 2023; 13:9035.

20. Huang Y, Tan C, Wu J, Chen M, Wang Z, Luo L, et al. Impact of coronavirus disease 2019 on pulmonary function in early convalescence phase. Respir Res. 2020 Jun 29;21(1):163.

21. You J, Zhang L, Ni-Jia-Ti MY, Zhang J, Hu F, Chen L, et al. Anormal pulmonary function and residual CT abnormalities in rehabilitating COVID-19 patients after discharge. J Infect. 2020 Aug;81(2): e150-e152.

22. Ksiazek TG, Erdman D, Goldsmith CS, Zaki SR, Peret T, Emery S, et al; SARS Working Group. A novel coronavirus associated with

severe acute respiratory syndrome. N Engl J Med. 2003 May 15;348(20):1953-66.

23. Roberts CM, Levi M, McKee M, Schilling R, Lim WS, Grocott MPW. COVID-19: a complex multisystem disorder. Br J Anaesth. 2020 Sep;125(3):238-242.

24. Baldwin JM. Structure and function of haemoglobin. Prog Biophys Mol Biol. 1975;29(3):225-320.

25. Sullivan KM, Mei Z, Grummer-Strawn L, Parvanta I. Haemoglobin adjustments to define anaemia. Trop Med Int Health. 2008 Oct;13(10):1267-71.

26. Lanser L, Fuchs D, Kurz K, Weiss G. Physiology and Inflammation Driven Pathophysiology of Iron Homeostasis-Mechanistic Insights into Anemia of Inflammation and Its Treatment. Nutrients. 2021 Oct 22;13(11):3732.

27. Weiss G, Ganz T, Goodnough LT. Anemia of inflammation. Blood. 2019 Jan 3;133(1):40-50.

28. Bellmann-Weiler R, Lanser L, Barket R, Rangger L, Schapfl A, Schaber M, Fritsche G, Wöll E, Weiss G. Prevalence and Predictive Value of Anemia and Dysregulated Iron Homeostasis in Patients with COVID-19 Infection. J Clin Med. 2020 Jul 29;9(8):2429.

29. Boccatonda A, D'Ardes D, Rossi I, Grignaschi A, Lanotte A, Cipollone F, et al. Platelet Count in Patients with SARS-CoV-2 Infection: A Prognostic Factor in COVID-19. J Clin Med. 2022 Jul 15;11(14):4112.

30. Cutler DM. The costs of long COVID. JAMA Health Forum. 2022. American Medical Association.

31. Yadav D, Pvsn KK, Tomo S, Sankanagoudar S, Charan J, Purohit A, et al. Association of iron-related biomarkers with severity and mortality in COVID-19 patients. J Trace Elem Med Biol. 2022 Dec; 74:127075.

32. Pvsn KK, Tomo S, Purohit P, Sankanagoudar S, Charan J, Purohit A, et al. Comparative Analysis of Serum Zinc, Copper and Magnesium Level and Their Relations in Association with Severity and Mortality in SARS-CoV-2 Patients. Biol Trace Elem Res. 2023 Jan;201(1):23-30.

33. Dharmalingam K, Birdi A, Tomo S, Sreenivasulu K, Charan J, Yadav D, et al. Trace Elements as Immunoregulators in SARS-CoV-2 and Other Viral Infections. Indian J Clin Biochem. 2021 Oct;36(4):416-426.

34. Hudgins AF, McDonald B, Bush PA et al. Assessing the Prevalence of Anemia Post-COVID-19 Infection in Adult Members of a Southeastern U.S. Integrated Healthcare System, 06 July 2023, PREPRINT (Version 1) available at Research Square [https://doi.org/10.21203/rs.3.rs-3074292/v1]

35. Crook H, Raza S, Nowell J, Young M, Edison P. Long covid-mechanisms, risk factors, and management. BMJ. 2021 Jul 26;374: n1648.

36. Tomasoni D, Bai F, Castoldi R, Barbanotti D, Falcinella C, Mulè G, et al. Anxiety and depression symptoms after virological clearance of COVID-19: A cross-sectional study in Milan, Italy. J Med Virol. 2021 Feb;93(2):1175-1179.

37. Zerbo O, Lewis N, Fireman B, Goddard K, Skarbinski J, Sejvar JJ, et al. Population-based assessment of risks for severe COVID-19 disease outcomes. Influenza Other Respir Viruses. 2022 Jan;16(1):159-165.

To cite this article: Taher Abdel-Aziz, Ghada N. Abd El Aziz, Mai Fawzy, Nagwa I. EL Dosoky, Hanaa I. Hegab, Ismail Dahshan. Hematological Impact of COVID-19: Anemia in Post-COVID. BMFJ 2024;41(2):118-127.