PULMONARY FUNCTIONS AND IMMUNOLOGICAL RESPONSE AMONG HEALTH CARE WORKERS RECOVERED FROM COVID-19 INFECTION COMPARED TO THEIR COUNTERPARTS WITHOUT PREVIOUS INFECTION

BY

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Abstract

Introduction: COVID-19 infection is the most critical ongoing global health problem with more outstanding effects on health care workers (HCWs) as they are the first line of defense against any disease outbreak. **Aim of Work:** To assess the ventilatory pulmonary functions and the immunological response by detection of SARS-CoV-2 specific immunoglobulins (IgM and IgG) among HCWs recovered from COVID-19 infection and compare the results with those of their counterparts with no previous infection. **Materials and Methods:** The exposed group involved 60 previously infected COVID-19 HCWs confirmed by positive Polymerase Chain Reaction (PCR) tests from March till June 2020. A matched control group was selected to involve 60 PCR-negative HCWs from the same clinical departments and during the same period. Ventilatory pulmonary function tests (PFTs) were carried out together with the detection of specific serum IgM and IgG antibodies. **Results:** All clinical manifestations of COVID-19 infection were significantly prevalent among previously infected HCWs compared to their controls with a significant continuation of dyspnea and fatigue 3 months after infection. Restrictive and obstructive patterns were significantly observed among previously infected HCWs. IgM and IgG were detected in previously infected HCWs 3 months after infection with a significant prevalence of IgG. The study also showed statistically significant negative correlations between all parameters of ventilatory PFTs and PCR conversion duration. **Conclusion:** Previously infected HCWs with COVID-19 are at higher risk to develop complications in the form of continuation of some clinical manifestations (as dyspnea and fatigue) and ventilatory impairment mainly; in the form of restrictive patterns. Serum IgG antibodies could also persist for several months after COVID-19 infection reflecting the development of humoral immunity against the novel virus.

Keywords: COVID-19 infection; Health care workers; Ventilatory pulmonary function tests and Immunological response.

Introduction

Healthcare workers (HCWs) are crucial to any healthcare system. During the ongoing Coronavirus disease 2019 (COVID-19) pandemic, healthcare workers are at a substantially increased risk of becoming infected with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and could come to considerable harm as a result (Bielicki et al., 2020; Ferland et al., 2022).

COVID-19 due to SARS-CoV-2 involves multiple organs, and lung injury is one of the most common clinical manifestations. The route of entry of SARS-CoV-2 into the human cells is mainly facilitated by the angiotensin-converting enzyme 2 (ACE2) receptors, which seem to be expressed by type II pneumocytes (Verdecchia et al., 2020).

The binding of SARS-CoV-2 to the ACE2 receptors could arise into acute systemic inflammatory responses and cytokine storm, consequentially leading to lung resident dendritic cells (rDCs) activation, and T lymphocytes production, and release of antiviral cytokines into the alveolar septa and interstitial compartments (Zhu et al., 2020).

Studies on SARS-CoV-2 have recently described pulmonary function derangements in the early convalescent period after COVID-19 infection and also after months following infection (Guler et al., 2021).

Moreover, detection of specific immunoglobulins (IgM & IgG) against COVID-19 could play a vital role in confirming present or past infection, assessing the development of antibody-mediated protective immunity and investigating immune response and immunopathology in COVID-19 infection (Shah et al., 2021).

Patients appeared to be stabilized in their symptoms, and the disappearance of chest high resolution computed tomography (HRCT) abnormalities usually occurs within three months (Zhao et al., 2020).

Aim of Work

To assess the ventilatory pulmonary functions and the immunological response by detection of SARS-CoV-2 specific immunoglobulins (IgM and IgG) among HCWs recovered from COVID-19 infection and compare the results with those of their counterparts with no previous infection.

Materials and Methods

Study design: It is a comparative cross-sectional analytical study.

Place, and duration of the study The study was carried out among some HCWs (doctors, nurses, technicians, and workers) from different departments in Cairo University Hospitals (various surgical and medical specialties, intensive care units (ICUs), emergency room (ER), outpatient clinics, and laboratories, in addition to radiology, gynecology, pediatrics, and toxicology departments); for 3 months from 1st of July till the end of September 2020(the time of the study was three months from the start of infection of HCWs which is confirmed by the date of the positive PCR test).

- Study Sample: The exposed group involved 60 healthcare workers. Inclusion criteria included who were previously infected with COVID-19 and were documented as PCR-positive cases during the period from March to June 2020. According to the statistical information obtained from the infection control department in Cairo University Hospitals, there were 148 HCWs documented as PCR-positive cases of COVID-19 infection during the mentioned period. Although the study targeted the whole documented population (148), however, 35 HCWs refused to share in the study and 24 HCWs were excluded because they gave medical history of chronic chest diseases before their COVID-19 infection. Moreover, 29 HCWs could not perform the procedures of pulmonary function testing. Therefore, the final number of the studied exposed group was 60. A matched control group was selected with comparable sex, age, Body Mass Index (BMI), and smoking indices to involve 60 HCWs from the same clinical departments and during the same period whose PCR tests were negative for COVID-19 infection. The control group also had no medical history of previous chest diseases. It is worth mentioning that infected HCWs underwent home or hospital isolation (according to the case severity) when their infection was proven by a positive PCR test and returned to work only with a documented negative PCR test.

Study Methods:

I- Questionnaire: All participants were subjected to a questionnaire including full medical history, detailed occupational history, with special emphasis on general and chest symptoms related to COVID-19 disease.

II- Clinical examination: General and local examinations were performed, focusing on chest examination.

III-Investigations:

a) Basic Ventilatory Pulmonary Function Testing (PFTs) (Spirometry): Subjects were tested for their Forced Vital Capacity (FVC % predicted), Forced Expiratory Volume in the 1st second (FEV1 % predicted), FEV1/FVC ratio as a percent from normal predicted values, Peak Expiratory Flow Rate (PEFR), Vital Capacity (slow VC) and Maximal Voluntary Ventilation (MVV). Normal predicted values were calculated by giving data of the participating subjects (age, gender, weight, height, and BMI) using "Minispir" Handheld, PC-Based Spirometer, a complete spirometer with Electronic Health Records (HER) connectivity and accurate readings, designed for software-based medical solutions. The primary criterion for diagnosis of obstruction is FEV1/FVC ratio < 70% of predicted while a restrictive pattern is defined as a reduced FVC below 80% of the predicted. The test was repeated 3 times and the best reading was recorded.

b) Qualitative detection of serum-specific immunoglobulins (IgM and IgG) against SARS-CoV-2: Five milliliters of venous blood were withdrawn and put into red top blood collection tubes (vacutainers). The tubes were labeled carefully with the participant's full name. Filled vacutainers were left to sit upright at room temperature for about 30 minutes to allow the clot to form. The blood sample was then centrifuged in a low-speed centrifuge for 20 minutes at 3000-3400 rpm at room temperature. After centrifuging, the serum appeared on top of the clot. Using a pipette, the serum was transferred to another sterile tube, and the samples were stored at -20°C for further testing.

Principle of the assay: The QuickZen® COVID-19 IgM/IgG kit (ZenTech, Angleur, Belgium) adopted the immune colloidal gold technique to detect IgM/IgG antibodies against the novel coronavirus (Nishiura et al., 2020).

Consent

An oral informed consent to share in the research work and to withdraw blood samples from each participant was obtained after explaining the aim of the study.

Ethical Approval

The study protocol was approved

by the Ethical Committee of the Occupational and Environmental Medicine Department, Faculty of Medicine, Cairo University.

Data Management

Data were coded and entered using the statistical package for the Social Sciences (SPSS) version 26 (IBM Corp., Armonk, NY, USA). Data were summarized using mean, standard deviation, median, minimum and maximum in quantitative data and using frequency (count) and relative frequency (percentage) for categorical data. Comparisons between quantitative variables were done using the Student's-t-test for the normally distributed data and the non-parametric Mann-Whitney U test for the not normally distributed data. For comparing categorical data, Chi-square ($\chi 2$) test was performed. Exact test was used instead when the expected frequency is less than 5 (in 25% of cells). Correlations between quantitative variables were done using the Spearman correlation coefficient. P-values less than 0.05 were considered statistically significant.

Results

Table (1): General and some occupational characteristics of the studied groups.

Parameters			Groups: Cases (No =60)	Groups: Controls (No =60)	p-value
Age (years)		Mean±SD	42 ± 9.38	43.45 ±10.16	0.382^{c}
		Median	42.5	43	
		Min-Max	(23– 65)	(25-64)	
Work duration (years)		Mean ±SD	13.58 ± 11.51	14.57±11.69	0.537^{d}
		Median	11.5	15	
		Min-Max	(1– 36)	(1-36)	
Smoking index[a] (pack/year)		Mean±SD	13.88 ± 18.23	12.12±9.8	0.738^{d}
		Median	9	10	
		Min-Max	(1– 80)	(2-40)	
BMI (Kg/m²)[b]		Mean ±SD	30.19 ± 4.93	30.03±5.08	0.969^{c}
		Median	29.55	30.08	
		Min-Max	(21.51-46.71)	(17.3-43.7)	
Gender	**Male**	No (%)	26 (43.3%)	30 (50%)	0.464^{e}
	Female	No (%)	34 (56.7%)	30 (50%)	
Smoking habit	**Smoker**	No (%)	11 (18.3%)	12 (20%)	0.817^{e}
	Non-Smoker	No (%)	49 (81.7%)	48 (80%)	0.824^{e}
Diabetic		No (%)	10 (16.7%)	5 (8.3%)	0.168^{e}
Hypertensive		No (%)	5 (8.3%)	9 (15%)	0.255^{e}
Usage of PPE		No (%)	49 (81.7%)	46 (76.7%)	0.716^{e}

BMI: Body mass index, SD: Standard deviation PPE: Personal protective equipment

[a] :Smoking index**:** No of packs/ day × No of years the person had smoked

[b] :BMI (Kg/m^2): weight/ kg ÷ the square of height /m.

c: Student's-t-test, d: Mann-Whitney U test, e: Chi^2 test.

Table (1) showed no statistically significant difference between both studied groups as regards their general and some occupational characteristics.

There was no statistically significant difference as regards the occupational characteristics of both studied groups as regards the nature of their occupations and the type of the departments where they worked (data are not tabulated).

Table (2): Frequency distribution of clinical manifestations among the studied groups.

Clinical Manifestations	Studied Groups				p-value
	Cases (No =60)		Controls (No =60)		
	No	%	No	%	
Dyspnea	35	58.3%	4	6.7%	**< 0.001***
Sore throat	27	45%	1	1.7%	**< 0001***
Cough	31	51.7%	3	5%	**< 0.001***
Expectoration	10	16.7%	0	0%	-
Chest pain	15	25%	0	0%	-
Fever	35	58.3%	1	1.7%	**< 0.001***
Anosmia	34	56.7%	0	0%	-
Rhinitis	15	25%	4	3.3%	**<0.001***
Fatigue	48	80%	11	18.3%	**< 0.001***
Dry mouth	23	38.3%	0	0%	**< 0.001***
Headache	37	61.7%	1	1.7%	**< 0.001***
Loss of appetite	34	56.7%	0	0%	-
Loss of taste	30	50%	0	0%	-

*: Statistically significant $p \leq 0.05$

NB: Chi-square ($\chi 2$) test was performed in this table. Exact test was used instead when the expected frequency is less than 5 (in 25% of cells). In the cells where frequency is 0, there is no need to perform test of significance.

Table (2) showed that there was a statistically significant prevalence of all clinical manifestations of COVID-19 infection among previously infected HCWs when compared with their controls.

However, the continuation of the manifestations till the time of the current study did not show any statistically significant difference between both studied groups (except for dyspnea p-value =0.027 and fatigue p-value =0.027). The latter data is not presented in the table.

Table (3): Comparison between COVID-19 previously infected and non-infected HCWs regarding their chest examination and some investigations.

Parameters		Studied Groups				p-value
		Cases (No =60)		Controls (No =60)		
		No	%	No	%	
Chest examination (time of the study)	Normal	43	71.7%	59	98.3%	**< 0.001***
	Wheezes	7	11.7%	1	1.7%	**0.016***
	Decreased air entry	10	16.7%	0	0%	-
D-dimer level (during COVID-19 infection)	Not available or not done	23	38.3%	55	91.7%	-
	Normal	18	30%	5	8.3%	**< 0.001***
	High	19	31.7%	0	0%	-
CT chest findings (during COVID-19 infection)	Not available or not done	14	23.3%	35	58.3%	-
	Normal	21	35%	23	38.3%	0.891
	GGO	24	40%	1	1.7%	**< 0.001***
	Pneumonia (consolidation)	1	1.7%	1	1.7%	-
Severity of infection (Grading by CT chest findings)	Normal	21	35%	23	38.3%	0.891
	Mild	13	21.6%	1	1.7%	**<0.001***
	Moderate	8	13.3%	1	1.7%	**0.031***
	Severe	4	6.7%	0	0%	0.121
Results of rapid test (Immunoglobins) (Qualitative) (time of the study)	Negative	4	6.7%	-	-	-
	IgG	41	68.3%	-	-	
	IgM	5	8.3%	-	-	
	Both	10	16.7%	-	-	
PFTs results (time of the study)	Normal	28	46.7%	53	88.3%	**< 0.001***
	Obstruction	11	18.3%	2	3.3%	**< 0.001***
	Restriction	13	21.7%	5	8.3%	**<0.001***
	Combined	8	13.3%	0	0%	**<0.001***

GGO: Ground glass opacity, PFTs: Pulmonary function tests, CT: Computed Tomography.

*: Statistically significant p ≤0.05.

NB: -Chi-square ($\chi 2$) test was performed in this table. Exact test was used instead when the expected frequency is less than 5 (in 25% of cells).

-The rapid test of qualitative detection of immunoglobulins was not done for the control group.

Table (3) showed statistically significant differences as regards chest examination results and the D-dimer levels (apart from missed data). CT chest findings revealed that 40% of the studied cases showed ground-glass opacities (GGO) in their films with a statistically significant difference when compared to the control group (1.7%).

Although all of the controls have documented negative PCR results, however one CT chest film showed the picture of mild COVID-19 infection and another one matched the criteria of moderate COVID-19 infection. The statistical differences between both studied groups were significant only for mild and moderate grades.

The rapid tests for the qualitative detection of specific immunoglobulins against COVID-19 revealed that the level of IgG showed the highest prevalence (68.3%) compared to IgM (8.3%) or of both immunoglobulins (16.7%) among the exposed group.

As regards PFTs, Table 3 showed statistically significant differences between both studied groups, and the restrictive pattern was the highest (21.7%) compared to the obstructive or combined ones.

Table (4): Comparison between COVID-19 previously infected HCWs and non–infected HCWs as regards the results of the ventilatory pulmonary function tests

	Studied Groups								p-value
	Cases (No=60)				Controls (No =60)				
	Mean	SD	Median	Min-Max	Mean	SD	Median	Min-Max	
FVC%	86.13	15.43	87.5	(48-124)	92.85	13.73	93.5	(52-130)	**0.007***
FEV1%	78.62	17.36	76.5	(43-121)	87.32	13.97	88	(46-126)	**0.003***
FEV1/ FVC%	73.95	13.53	76.55	(39.4-94.4)	79.35	6.59	80.25	(58.7-90.8)	**0.041***
PEF%	49.15	18.82	43.5	(19-95)	59.22	21.75	53	(18-133)	**0.005***
VC%	80.42	16.57	79.5	(46-119)	85.72	15.76	85	(42-134)	**0.037***
MVV	54.66	19.73	49.5	(26-110)	62.90	19.33	62.5	(23-134.6)	**0.005***

FVC: Forced vital capacity, FEV1: Forced expiratory volume in the first second, PEF: Peak expiratory flow, VC: Vital capacity (slow), MVV: Maximal voluntary ventilation.

*: Statistically significant $p \leq 0.05$ NB: Student's-t- test was performed in this table.

Table (4) showed that there was statistically significant decline in the values of all parameters of pulmonary function tests among the previously infected HCWs when compared with their controls.

Table (5): Correlations between ventilatory pulmonary functions means and PCR conversion duration (from positive to negative) among previously infected HCWs with COVID-19

		PCR conversion duration (days)
FVC%	(r)	-0.557
	p-value	**0.022***
FEV1%	(r)	-0.524
	p –value	**0.020***
FEV1/FVC%	(r)	-0.489
	p –value	**0.028***
PEF%	(r)	-0.518
	p –value	**0.018***
VC%	(r)	-0.515
	p –value	**0.018***
MVV	(r)	-0.563
	p –value	**0.024***

FVC: Forced vital capacity, FEV1: Forced expiratory volume in the first second, PEF: Peak expiratory flow, VC: Vital capacity (slow), MVV: Maximal voluntary ventilation , PCR: Polymerase Chain Reaction. (r): Correlation coefficient. *: Statistically significant $p \leq 0.05$

Table (5) showed statistically significant negative correlations between all parameters of ventilatory PFTs and the duration of PCR conversion from positive to negative (in days) among the previously infected HCWs.

Discussion

The current study was done among two groups of HCWs; one was previously infected with COVID-19 and was documented as PCR-positive cases, while the other control group had negative PCR tests for COVID-19 infection. Both groups were matched regarding their sex, age, years of employment, BMI, smoking habits, and socioeconomic status (Table 1). As regards chronic illnesses in the studied groups, the results showed that 16.7% of cases had diabetes mellitus (DM and 8.3% had hypertension (HTN) with no significant difference with the control group. This agreed with Wang et al., (2020) study on COVID-19 and comorbidities.

There was no statistically significant difference as regards the occupational characteristics among the studied groups (Table 1). Lack of use of PPE was noticed among the studied HCWs. A critical shortage of appropriate PPE and a high level of dissatisfaction with the availability and use of PPE were identified in a study among Ethiopian HCWs (Deressa et al., 2021).

The findings of the study demonstrated that there were statistically significant differences between exposed and control groups in the prevalence of general and respiratory manifestations of COVID-19 disease, where about half of cases experienced fever, sore throat, cough, and dyspnea during infection (Table 2). This was in accordance with a large study (No = 1,099) from China, in which Guan et al., (2020) reported that 67.8% of patients with COVID-19 presented with cough, while 33% had sputum production and 18.7% experienced shortness of breath. A relative resemblance was found with Johnson et al., (2020) in Beijing who demonstrated that cough occurred in almost half (45.8%) of 262 patients with COVID-19 infection, whereas dyspnea occurred in nearly 7% of them.

About 80% of HCWs cases were complaining of fatigue during their COVID-19 infection (Table 2); which was higher than the results obtained by Salepci et al., (2020) in Istanbul, Turkey who found that (29.1%) of the studied COVID-19 patients had some general symptoms, including fatigue. Also about one-half of HCWs exposed cases had loss of smell, taste, and appetite during their infection (Table 2). This was similar with several studies which found that these symptoms were the most common among COVID-19 patients. As Speth et al., (2020) in their work on 103 COVID-19 patients found that olfactory dysfunction was highly prevalent occurring early and severely in affected persons often in conjunction with loss of taste. Also, Huang et al., (2020) demonstrated that these symptoms were common in more than a quarter of their studied COVID-19 patients.

The persistence of dyspnea and fatigue among the studied exposed HCWs recovered from COVID-19 were found in 11.7% and 15% respectively (data is not presented). This was in resemblance to Carvalho-Schneider et al., (2021) who found in their study at Tours University Hospital in France; that dyspnea and fatigue are still reported 2 months after the onset of the first COVID-19 symptoms although most symptoms seem to disappear with time. Post-COVID syndrome is frequently associated with continuing respiratory symptoms and debilitating fatigue. Severe forms of the disease may release a great variety of autoantibodies which could play an important role in the extended multi-organ illness persisting for months in previously infected patients (Khamsi, 2021). Another explanation was reported by Bansal et al., (2012) who concluded that impairment of the immune memory can be induced by viruses and could precipitate the symptoms of chronic fatigue syndrome.

The appearance of respiratory tract symptoms, although minimal, among PCR-ve HCWs (control group) may be due to mild infection or subclinical infection, other viral infection, or limited sensitivity of RT-PCR testing in the diagnosis of COVID-19.

There was a statistically significant difference between cases and controls as regards chest examination 3 months after infection where wheezes were found in (11.7%) and decreased air entry in (16.7%) of previously infected HCWs (Table 3). Although the majority of SARS-CoV-2 infected cases could recover completely without any complications, however, amongst COVID-19 survivors, a wide range of pulmonary symptoms including dyspnea on exertion, restrictive pulmonary physiology, as well as fibrotic lung lesions have been documented, all of which have been linked to the severity of the acute illness (Nalbandian et al., 2021).

D-dimer level during previous COVID-19 infection was high in about one-third of the studied HCWs cases (31.7%). It is commonly elevated in patients with COVID-19, correlating with disease severity, and it is a reliable prognostic marker (Yao et al., 2020).

Ground-glass opacities in CT chest during COVID-19 infection were found among (40%) of HCWs cases; (21.6%) were mildly infected, (13.3%) were moderately infected, and (6.7%) were severely infected (Table 3). A cohort study of Shi et al., (2020) in their study on radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China, they detected that most COVID-19 patients showed bilateral lung involvement, with lesions mainly located peripherally and subpleural with a diffuse distribution. The predominant pattern was ground-glass opacity, with ill-defined margins, air bronchograms, smooth or irregular inter-lobular or septal thickening, and thickening of the adjacent pleura.

The study results demonstrated that serum immunoglobulins IgM and IgG antibodies were detected 3 months after infection with COVID-19 among the studied HCWs cases; 8.3% and 68.3% respectively, whereas both were found in 16.7% of affected workers (Table 3). Several studies reported that most patients with positive PCR were associated with higher SARS-CoV-2-specific serum-IgG antibodies (Marklund et al., 2020; Theel et al., 2020; Cervia et al., 2021). Hou et al., (2020), in their longitudinal study, reported that IgM levels decreased rapidly in recovered patients whereas IgG levels persist for several months after recovery. Detection of IgM in the current study might denote a repeated subclinical infection.

In the present study, the findings of pulmonary function tests performed 3 months after infection, demonstrated that 18.3% of previously infected HCWs had obstructive airways, 21.7% had a restrictive pattern and 13.3% had both pulmonary function abnormalities (Table 3). Similar results were detected by Eksombatchai et al., (2021) in their study from a medical school hospital in Thailand, they observed altered pulmonary function tests results in 17.2% of 87 COVID-19 survivors with both obstructive and restrictive defects. Moreover, Talman et al., (2021) stated that the majority of studied COVID-19 pneumonia survivors from Amphia Hospital (Breda, the Netherlands) had abnormal diffusion capacity six weeks after discharge. Also, Torres - Castro et al., (2021), in their systematic review and meta-analysis that involved 380 post-infection COVID-19 patients in France and China showed impaired lung function with obstructive, restrictive patterns and altered diffusion capacity. Fumagalli et al., (2020) mentioned that patients surviving COVID-19 pneumonia may present with a restrictive pulmonary pattern, which is known to be associated with an increased risk of life-threatening comorbidities.

Furthermore, there was a statistically significant decline in all parameters of ventilatory pulmonary function tests measured 3 months after infection among previously infected HCWs when compared with non-infected controls (Table 4). These results were in relative resemblance to Guler et al., (2021) in their national prospective observational Swiss COVID-19 lung study on 113 COVID-19 survivors, they concluded that total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in 1s (FEV1), and DLCO were significantly lower in patients after severe/critical COVID-19.

Also, Salem et al., (2021) noted a significant reduction in total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume (FEV1), FEV1/FEV% in 20 post-COVID-19 pneumonia patients. Other follow-up studies of COVID-19 survivors showed persistent impairment in spirometric parameters and gas transfer indices (Ahmed et al., 2020; Liang et al., 2020; Compagnone et al., 2022).

The study of correlation analysis of the results of the current work showed statistically significant negative correlations between all parameters of ventilatory PFTs and PCR conversion duration (from positive to negative PCR) (Table 5). This was in harmony with a study that compared pulmonary function between severe COVID-19 survivors with longer duration in illness and those with previous shorter duration mild and moderate illness, and they concluded that total lung capacity (TLC), forced vital capacity (FVC), forced expiratory volume in 1st second (FEV1), and DLCO were significantly negatively correlated with duration of previous illness (conversion of PCR from positive to negative) (Guler et al., 2021).

Conclusion and Recommendations: The current work revealed that COVID-19 had a great effect on HCWs where impairment of pulmonary functions may persist for months even after apparent recovery from infection. Serum immunoglobulin particularly IgG antibodies could also persist for several months after COVID-19 infection reflecting the development of humoral immunity against the novel virus. Further studies should be conducted to involve objective measurements of the functional status of the lungs (such as the diffusion capacity test of the lung for carbon monoxide, exercise pulmonary function test, or 6-minute walk test), CT radiological evaluation of the lungs months after infection, and quantitative measurements of immunoglobulins to assess immunity acquired by previous COVID-19 infection.

Conflict of Interest

The authors declared that there is no conflict of interest regarding authorship, and/or publication of this article.

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