

Three-Month Pulmonary Function and Radiological Outcomes in COVID-19 Survivors: A Longitudinal Patient Cohort Study

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Background. This study aimed to investigate pulmonary function and radiological outcomes in a group of coronavirus disease 2019 (COVID-19) survivors.

Methods. One hundred seventy-two COVID-19 survivors in a follow-up clinic in a referral hospital underwent high-resolution computed tomography (CT) of the thorax and pulmonary function at 3 months after hospital discharge.

Results. The median duration from hospital discharge to radiological and pulmonary function test (interquartile range) was 90 (88–95) days. Abnormal pulmonary function was found in 11 (6.40%) patients, and abnormal small airway function (FEF_{25-75%}) in 12 (6.98%). Six (3.49%) patients had obstructive ventilation impairment, and 6 (3.49%) had restrictive ventilatory impairment. No significant differences in lung function parameters were observed between the nonsevere and severe groups. Of 142 COVID-19 patients who underwent CT scan, 122 (85.91%) showed residual CT abnormalities and 52 (36.62%) showed chronic and fibrotic changes. The ground-glass opacities absorption in the lungs of severe cases was less satisfactory than that of nonsevere patients. The severe patients had higher CT scores than the nonsevere cases (2.00 vs 0.00; $P < .001$).

Conclusions. Of the COVID-19 survivors in our study, 6.40% still presented pulmonary function abnormality 3 months after discharge, which did not vary by disease severity during hospitalization; 85.91% of patients had abnormalities on chest CT, with fibrous stripes and ground-glass opacities being the most common patterns.

Keywords: COVID-19; pulmonary function assessment; SARS-CoV-2.

Coronavirus disease 2019 (COVID-19) is new respiratory illness that can cause serious pneumonia and lung failure [1]. The World Health Organization (WHO) declared COVID-19 a public health emergency of international concern on January 30, 2020, and this pandemic quickly spread globally to more than 200 countries. This novel disease has triggered enormous human casualties and serious economic loss around the globe [2]. Due to its highly contagious nature, there are few data describing pulmonary function in the acute phase of the disease. Evaluation of lung function in recovered patients will enable better understanding of the prognostic characteristics of COVID-19 [3].

As of July 7, 2020, we found 3 studies describing the pulmonary function of COVID-19 patients at or after hospital discharge [4–6]. One study of 110 COVID-19 patients showed that at discharge the abnormal spirometry parameters ranged from 4.5% to 47.2% [4]. Another study including 18 COVID-19 patients showed that 39% suffered from pulmonary impairments 1 month after rehabilitation and discharge [5]. Another study reported clinical manifestation of lung function and chest radiology in 2 critically ill patients with COVID-19 3 months after onset [6], with the younger patient (aged 20 years) showing complete recovery on both radiology and pulmonary function tests, whereas the older patient showed residual radiological changes and impaired lung function.

As the above 2 studies with follow-up for >1 month after discharge were small in size (ie, only 2 and 18 patients included), we evaluated the radiology and pulmonary function of a larger sample of COVID-19 patients with longer follow-up. Our study aims at, first, describing the characteristics of radiology and pulmonary function in a larger sample of COVID-19 patients with a longer follow-up and, second, evaluating the results of chest CT and pulmonary function by baseline disease severity. All patients were recruited from the only referral hospital in one of the largest cities in China, Shenzhen. Awareness

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of the characteristics of radiology and pulmonary function at 3 months after discharge may enable a better understanding of the prognosis of COVID-19 patients.

METHODS

Study Design and Participant Criteria

Our study consisted of 172 patients consecutively hospitalized from January 11, 2020, to February 21, 2020, at the Third People's Hospital of Shenzhen. The Third People's Hospital of Shenzhen is the only referral hospital authorized by the government in Shenzhen to care for and treat patients with COVID-19. COVID-19 was diagnosed according to the WHO interim guidance [7]. All patients were followed until June 13, 2020. Data obtained from electronic medical records included epidemiological, clinical, laboratory, and radiological information as well as the treatment and progression of the disease. Information of confirmed COVID-19 patients was collected by nurses, physicians, or other medical staff at the hospital.

Patient Consent Statement

This study was approved by the ethics committee of the Third People's Hospital of Shenzhen (IRB No. 2020 108). All participants signed informed consent. It was not appropriate or possible to involve patients or the public in the design or conduct of our research.

Confirmation of COVID-19

The real-time reverse transcription polymerase chain reaction method was applied to detect severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [8]. Two pairs of primers targeting the open reading frame 1ab (ORF1ab) and nucleocapsid protein (N) were amplified and examined. The corresponding sequences for ORF1ab were 5'-CCCTGTGGGTTTACACTTAA-3' (F), 5'-ACGATTGTGCATCAGCTGA-3' (R), and 5'-CY3-CCGTCTGCGGTATGTGAAAGGTTATGG-BHQ1-3' (probe), and those for N were 5'-GGGGAACCTCTCCTGCTAGAAT-3' (F), 5'-CAGACATTTTGCTCTCAAGCTG-3' (R), and 5'-FAM-TTGCTGCTGCTTGACAGATT-TAMRA-3' (probe). Each sample was run in triplicate with both positive and negative control sets. The identification process strictly complied the diagnostic criteria recommended by the National Centers for Disease Control and Prevention of China (China CDC). The key laboratory of the Shenzhen CDC reconfirmed the samples with positive results for COVID-19.

Severity of COVID-19 Patients

According to the national guidelines for community-acquired pneumonia and the diagnosis and treatment plan for COVID-19 in China [9, 10], patients were assigned to the severe or mild group based on the results from chest radiography, clinical examination, and symptoms. Those with mild symptoms, such as fever, cough, expectoration, and other upper respiratory tract

symptoms but with normal radiological images or with mild changes on chest radiography were identified as nonsevere cases [11]. The degree of radiological change was differentiated by multiple small patchy shadows and interstitial changes, mainly in the outer zone of the lung and under the pleura. Severe pneumonia was diagnosed by any of the following conditions: (1) significantly increased respiratory rate (RR): $RR \geq 30$ times/min; (2) hypoxia: oxygen saturation (resting state) $\leq 93\%$; (3) blood gas analysis: partial pressure of oxygen/fraction of inspired oxygen (PaO_2/FiO_2) ≤ 300 mmHg; or (4) the occurrence of respiratory or other organ failure that requires intensive care unit (ICU) monitoring and treatment or shock.

Follow-up Examination for Radiology and Pulmonary Function Assessment

Of the patients who returned for follow-up examination 3 months after discharge, all were invited to have chest computerized tomography (CT) scan. Results of the CT scans were evaluated by radiology experts, with the severity status marked. In addition, these patients had a normal oxygen saturation, and the results of the 6-minute walking test were normal. Their lung function was evaluated using spirometry to obtain relevant indices including first second exhalation volume (FEV_1), forced vital capacity (FVC), $FEV_1/FVC\%$, forced expiratory flow rate at 50% and 75% of FVC ($FEF_{50\%}$, $FEF_{75\%}$), forced expired flow at 25–75% of FVC ($FEF_{25-75\%}$), inspiratory reserve volume (IRV), tidal volume (TV), and expiratory reserve volume (ERV).

Statistical Analysis

All data were analyzed using R, version 4.0.2 (R Core Team, Vienna, Austria). The qualitative variables were described as frequency and percentages, and the quantitative variables as mean and SD, or median and interquartile range (IQR) if they did not follow a normal distribution. For quantitative data that were normally distributed, independent group *t* tests were performed to compare the means; otherwise, the Mann-Whitney test was used. Qualitative data were compared using the χ^2 test or the Fisher exact test if the counts were small. A 2-sided α of $<.05$ was considered statistically significant.

RESULTS

A total of 172 confirmed COVID-19 patients admitted to the Third People's Hospital of Shenzhen from January 11, 2020, to February 16, 2020, and followed until June 13, 2020, were included. The baseline (ie, at hospitalization) characteristics by disease severity are shown in [Supplementary Table 1](#). Patients who were older, smoked, had fever, had chronic obstructive pulmonary disease (COPD), or needed ICU care, invasive ventilatory support, or noninvasive ventilatory support tended to develop severe COVID-19 (*P* from $<.001$ to $.02$). Moreover, the length of hospitalization was significantly longer in the severe group than the nonsevere group (*P* $<.001$). The duration from

discharge to Pulmonary Function Tests was also longer in patients with nonsevere disease than severe patients (40 ± 11.6 vs 34.7 ± 16.5 days).

All patients evaluated pulmonary function by spirometry. The symptom profiles at follow-up are shown in [Supplementary Table 2](#). No significant differences were found between the nonsevere and severe groups. The median (IQR) age of the patients was 47.50 (28–67) years. Of the 172 patients, the median (IQR) FEV₁, FVC, and FEV₁/FVC% were 104.70 (96.78–113.76), 128.49 (119.20–139.49), and 81.39 (77.33–85.09), respectively, with younger patients showing significantly lower FEV₁ % pred and FVC % pred and higher FEV₁/FVC than older age groups ($P = .002$, $.003$, and $<.001$, respectively). Patients who smoked had significantly lower FEV₁ % pred and FVC % pred ($P = .04$ and $.03$, respectively). Underweight patients had lower FVC % pred and higher FEV₁/FVC% than patients with higher BMI ($P = .01$ and $.001$, respectively). Furthermore, FVC % pred was significantly higher in patients with hypertension or headache as initial symptoms (both $P = .03$), but lower in those who had fever as an initial symptom ($P = .04$). Patients who had cough as an initial symptom showed higher FEV₁/FVC% ($P = .03$), but FEV₁/FVC% was lower in those who used lopinavir/ritonavir ($P = .03$) ([Table 1](#)).

At 3 months after discharge, 10 (7.19%) of the nonsevere cases and 1 (3.03%) of the severe cases had abnormal pulmonary function. Of those with anomalies on pulmonary function tests, 6 (3.59%) had abnormal FEV₁ % pred, 4 (2.38%) had abnormal FVC % pred, and 6 (3.55%) had abnormal FEV₁/FVC%. Regarding the FEF, 13 (7.56%) patients were had FEF_{50%}, 2 (1.16%) FEF_{75%} and 12 (6.98%) FEF_{25-75%}. Of the 139 patients with nonsevere COVID-19, 6 (4.79%) had obstructive ventilation impairment and 5 (3.73%) had restrictive ventilatory impairment. Furthermore, 1 (3.12%) patient in the severe group had restrictive ventilatory impairment at 3 months after discharge.

No significant differences in levels of FEV₁ pred, FVC pred, or FEV₁/FVC% were observed between the nonsevere and severe groups ([Table 2](#)). The median (IQR) values of IRV (L), TV (L), and ERV (L) were 1.19 (0.83–1.67), 1.11 (0.91–1.36), and 1.17 (0.79–1.62), respectively, with no significant differences between the nonsevere and severe groups observed ([Table 2](#)).

Of the patients who returned for follow-up examination 3 months after discharge, 142 (82.56%) had chest CT scans. The severe patients had higher CT scores than the nonsevere cases (2.00 vs 0.00; $P < .001$). Of these, 122 (85.91%) had residual CT abnormalities and 52 (36.62%) showed chronic and fibrotic changes. The ground-glass opacities (GGO) in the lung were completely absorbed in 77 (54.23%) patients, partially absorbed in 64 (45.07) patients, and increased in 1 severe case. Severe cases showed higher rates of residual CT abnormalities (ie, GGO) in the lungs than nonsevere cases (76.67% vs 37.50%; $P = .004$) ([Table 3](#)).

[Supplementary Figure 1](#) shows the CT scans of a patient with nonsevere COVID-19. The GGO in the right upper lobe of the lung at admission had begun to disappear at discharge, were further absorbed 1 month after discharge, and had been completely absorbed 3 months after discharge. [Supplementary Figure 2](#) shows the CT scans of a severe COVID-19 patient. Lung consolidation in the inferior lobes could be seen at admission. The right lower lobe consolidation was large, and air bronchogram was found. The lesion was completely absorbed before discharge with mild GGO remaining. The GGO in the lungs were completely absorbed at 1 month and 3 months after discharge, without bronchial dilatation in the bronchial tubes ([Supplementary Figure 2](#)).

DISCUSSION

In this study, we comprehensively described the characteristics of radiology and pulmonary function tests in COVID-19

Table 1. Characteristics of 172 Patients With SARS-CoV-2/COVID-19 by Lung Function at 3-Months Follow-up After Hospital Discharge

Characteristics	Pulmonary Ventilation Function					
	FEV ₁ % pred ^a	P value	FVC% pred ^b	P value	FEV ₁ /FVC% ^c	P value
Median (IQR)	104.70 (96.78–113.76)		128.49 (119.20–139.49)		81.39 (77.33–85.09)	
Age, median (IQR), y						
<10	59.86 (57.37–63.89)		64.48 (60.11–71.39)		90.83 (87.61–94.97)	
10–19	109.7 (109.3–114.1)		123.90 (120.4–127.9)		88.47 (86.21–91.34)	
20–29	101.64 (94.38–114.58)	.002	119.60 (113.9–126.4)	.003	84.11 (76.91–90.06)	<.001
30–49	106.32 (98.26–114.58)		130.46 (121.78–140.36)		82.24 (78.18–86.04)	
≥50	101.38 (95.02–153.82)		128.99 (118.27–140.85)		79.80 (76.18–83.73)	
Gender, Median (IQR)						
Female	106.45 (97.2–114.67)	.26	128.49 (118.84–138.93)	.98	81.79 (78.28–86.31)	.34
Male	102.23 (96.33–111.77)		128.32 (119.4–140.51)		81.05 (76.88–85.88)	
BMI, kg/m ² , Median (IQR)						
Underweight	101.01 (70.46–106.34)		116.50 (76.55–120.79)		88.08 (87.3–93.5)	
Normal	106.51 (97.13–114.18)	.32	128.97 (122.1–139.78)	.01	81.45 (77.24–85.13)	.001
Overweight	102.55 (97.22–112.34)		130.50 (119.7–143.1)		79.99 (76.70–84.65)	
Obesity	99.84 (90.19–112.72)		126.76 (108.82–135.28)		83.94 (78.03–86.53)	

Table 1. Continued

Characteristics	Pulmonary Ventilation Function					
	FEV ₁ % pred ^a	P value	FVC% pred ^b	P value	FEV ₁ /FVC% ^c	P value
Smoke, Median (IQR)^d						
No	106.67 (97.57–117.45)	.04	128.99 (121.92–139.13)	.03	82.07 (78.56–85.98)	.05
Yes	89.90 (87.35–92.44)		97.44 (91.74–103.15)		92.97 (90.10–92.97)	
Personal disease history, Median (IQR)						
Hypertension						
No	103.62 (96.6–113.07)	.20	127.11 (119.17–138.48)	.03	81.79 (77.46–86.02)	.15
Yes	107.55 (101.33–114.89)		137.56 (128.02–148.59)		78.47 (76.17–83.68)	
Cardiovascular disease						
No	104.32 (96.69–113.79)	.56	127.82 (118.68–139.26)	.10	81.88 (77.55–85.95)	.13
Yes	106.69 (97.07–113)		132.40 (127.7–147.53)		77.32 (74.50–84.86)	
Liver disease						
No	104.73 (96.97–113.79)	.91	128.49 (119.26–139.49)	.56	81.30 (77.33–85.95)	.69
Yes	104.70 (94.38–111.29)		127.80 (117.42–138.41)		84.13 (77.58–85.89)	
COPD						
No	104.76 (97.06–113.85)	.30	128.77 (119.22–139.46)	.60	81.61 (77.40–85.93)	.20
Yes	96.61 (88.22–110.23)		122.31 (116.34–138.65)		78.29 (64.91–82.59)	
Initial symptoms, Median (IQR)						
Fever						
No	106.66 (98.38–114.49)	.10	131.72 (121.61–144.20)	.04	81.58 (76.41–84.94)	.52
Yes	102.15 (96.48–112.08)		126.60 (117.08–138.48)		81.28 (77.46–86.17)	
Cough						
No	102.23 (96.58–111.98)	.16	127.82 (119.15–127.97)	.62	80.99 (76.25–85.05)	.03
Yes	107.55 (97.31–114.82)		128.99 (119.51–139.52)		82.81 (78.78–85.97)	
Headache						
No	104.02 (96.61–113.69)	.33	127.87 (118.84–138.99)	.03	81.77 (77.42–85.92)	.07
Yes	111.54 (107.34–113.74)		141.40 (135.4–146.2)		77.05 (70.19–79.03)	
Diarrhea						
No	104.83 (97.00–113.76)	.28	128.67 (119.23–139.49)	.34	81.39 (77.33–85.89)	.77
Yes	96.15 (91.58–102.42)		117.30 (108.10–130.30)		79.70 (77.28–83.28)	
Fatigue						
No	104.32 (96.69–113.79)	.28	127.88 (119.52–139.46)	.52	81.35 (77.33–85.95)	.73
Yes	106.81 (106.45–109.48)		130.60 (128.40–135.20)		81.77 (81.22–82.77)	
Treatment, N (%)						
Lopinavir/ritonavir						
No	108.44 (97.55–116.98)	.03	132.27 (121.49–140.14)	.12	82.53 (77.34–86.52)	.24
Yes	102.15 (96.48–111.10)		126.42 (117.80–139.32)		81.12 (77.39–85.48)	
Favipiravir						
No	104.67 (96.69–113.79)	.70	128.58 (119.18–139.42)	.90	81.30 (77.33–85.90)	.54
Yes	106.18 (103.62–110.08)		122.40 (121.03–148.10)		84.68 (83.68–85.13)	
Need ICU care						
No	105.48 (96.69–113.90)	.22	128.77 (119.25–139.52)	.21	81.35 (77.83–85.95)	.98
Yes	97.23 (97.06–98.46)		116.90 (116.60–127.40)		83.23 (79.92–83.70)	
Invasive ventilatory support						
No	104.76 (96.61–113.85)	.74	128.58 (119.23–139.46)	.51	81.35 (77.32–85.93)	.72
Yes	98.32 (97.69–105.45)		116.90 (116.80–128.90)		83.23 (81.58–83.72)	
Non-invasive ventilatory support						
No	105.48 (96.86–113.85)	.38	128.58 (119.23–139.46)	.43	81.35 (77.34–85.93)	.63
Yes	98.32 (92.17–106.98)		127.38 (110.51–136.13)		83.70 (78.62–85.05)	

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; IQR, interquartile-range; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

^aFive missing values were excluded here only.

^bFour missing values were excluded here only.

^cThree missing values were excluded here only.

^dEighty-eight missing values were excluded here.

Table 2. Pulmonary Function of 172 COVID-19 Patients by Disease Severity at 3-Month Follow-up After Hospital Discharge

Characteristics	Disease Severity		Total	P Value
	Nonsevere	Severe		
No. (%)	139 (80.81)	33 (19.19)	172	
Pulmonary ventilation function				
FEV ₁ % pred, ^a median (IQR) ^a	106.45 (97.18–113.87)	98.47 (94.86–112.11)	104.70 (96.78–113.76)	.18
FEV ₁ % pred, ^a No. (%) <80% ^a	5 (3.73)	1 (3.12)	6 (3.59)	1.00
FEV ₁ % pred, ^b median (IQR) ^b	128.91 (120.02–139.58)	125.83 (114.09–134.28)	128.49 (119.20–139.49)	.08
FVC % pred, ^b No. (%) <80% ^b	4 (2.92)	0 (0.00)	4 (2.38)	.76
FEV ₁ /FVC%, ^c median (IQR) ^c	81.12 (76.45–85.94)	83.45 (79.40–85.85)	81.39 (77.33–85.09)	.14
FEV ₁ /FVC%, ^c No. (%) <70% ^c	6 (4.79)	0 (0.00)	6 (3.55)	.50
Small airway function				
Abnormal FEF _{25-75%} , No. (%)	12 (8.63)	0 (0.00)	12 (6.98)	.17
Abnormal FEF _{50%} , No. (%)	12 (7.10)	1 (3.03)	13 (7.56)	.47
Abnormal FEF _{75%} , No. (%)	2 (1.44)	0 (0.00)	2 (1.16)	1.00
Lung volumes				
IRV, median (IQR), L	1.20 (0.81–1.70)	1.17 (0.99–1.51)	1.19 (0.83–1.67)	.86
TV, median (IQR), L	1.13 (0.91–1.37)	1.06 (0.88–1.28)	1.11 (0.91–1.36)	.69
ERV, median (IQR), L	1.21 (0.79–1.65)	1.02 (0.88–1.42)	1.18 (0.79–1.62)	.22

Abbreviations: BMI, body mass index; COPD, chronic obstructive pulmonary disease; COVID-19, coronavirus disease 2019; ERV, expiratory reserve volume; FEF, forced expiratory flow rate; FEV₁, forced expiratory volume in 1 second; FVC, forced vital capacity; IRV, inspiratory reserve volume; IQR, interquartile-range; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2; TV, tidal volume.

^aFive missing values were excluded here only.

^bFour missing values were excluded here only.

^cThree missing values were excluded here only.

patients 3 months after hospital discharge using data from a designated hospital in Shenzhen, China. Of the 172 COVID-19 patients for whom we evaluated lung function 3 months after discharge, we found that only 6 (3.59%) patients had obstructive ventilation impairment and 6 (3.55%) had restrictive ventilatory impairment. Pulmonary function tests showed no differences between the severe and nonsevere cases. Of 142 COVID-19 patients who had chest CT scans, 122 (85.91%) still had residual CT abnormalities and 52 (36.62%) had chronic and fibrotic changes. Severe cases had higher rates of residual

CT abnormalities than nonsevere patients (presence of GGO was 76.67% vs 37.50%).

The prevalence of pulmonary function abnormality in our study was lower than that in previous studies [5], which may be attributable to different times of measurement, suggesting that lung function might be continuously improved after discharge and that the disease is unlikely to cause lifelong impairment [12, 13]. It has been reported that patients with COVID-19 still suffer from pulmonary dysfunction during the recovery period [14]. One recent study including 18 patients who recovered

Table 3. Radiological Outcome of 142 COVID-19 Patients by Disease Severity at 3-Month Follow-up After Hospital Discharge

Characteristics	Disease Severity		Total	P Value
	Nonsevere	Severe		
No. (%)	112 (78.87)	30 (21.13)	142	
CT score, median (IQR)	0.00 (0.00–2.00)	2.00 (2.00–2.00)	0.00 (0.00–2.00)	<.001
CT changes, No. (%)				
Normal				
Yes	17 (15.18)	3 (10.00)	21 (14.08)	.62
No	95 (84.82)	27 (90.00)	122 (85.91)	
Chronic and fibrotic changes				
Yes	41 (36.61)	12 (40.00)	52 (36.62)	.84
No	71 (63.39)	18 (60.00)	90 (63.38)	
Ground-glass opacity				
Complete absorption	70 (62.50)	7 (23.33)	77 (54.23)	.004
Partial absorption	42 (37.50)	22 (73.33)	64 (45.07)	
Increase	0 (0.00)	1 (3.34)	1 (0.7)	

Abbreviations: COVID-19, coronavirus disease 2019; CT, computed tomography; GGO, ground-glass opacity; IQR, interquartile range.

from COVID-19 showed that abnormal pulmonary function at discharge manifested in 5 (41.7%) nonsevere and 2 (33.3%) severe patients [5]. Another study of 2 COVID-19 patients who were discharged from the hospital found that the older case had residual radiological changes and impaired lung function during the 3-month follow-up period [6]. In our study, of the 172 COVID-19 patients for whom we assessed pulmonary function 3 months after discharge, patients aged <10 years had restrictive ventilation impairment, which may be partly due to low compliance during the spirometry test. Moreover, in accordance with previous studies, we showed that abnormal pulmonary function was, as expected, mainly manifested in patients aged >50 years, because pulmonary function naturally declines with aging, as indicated by decreases in elasticity and function of lung tissue as well as muscle strength [15, 16].

Moreover, similar fibrotic changes were observed in patients with SARS, which may not cause lifelong pulmonary damage because recovering patients seem to have the ability of self-rehabilitation, and gradual improvements have been observed over time [3, 17, 18]. Therefore, periodic and regular long-term follow-up studies are warranted to evaluate changes in lung function in COVID-19 patients.

As CT is more sensitive in detecting lung abnormalities than chest x-ray, the abnormality rate was higher than that from pulmonary tests. In COVID-19 survivors after discharge, 85.91% of patients still had residual CT abnormalities, and 36.62% of patients showed chronic and fibrotic changes. A recent study suggested that COVID-19 survivors with residual chest CT abnormalities might progress to pulmonary fibrosis, especially in severe cases [19]. In our study, of the COVID-19 patients discharged from rehabilitation, 54.23% had complete absorption of GGO in the lungs, indicating that with effective antiviral treatment during hospitalization and improvement of self-immunity after discharge, the lesions in both lungs could be improved significantly. Moreover, the GGO progression in 1 severe patient reflected a less satisfactory absorption of GGO in severe COVID-19 patients, which calls for more efficient therapeutic strategies to protect severe patients from long-term lung damage.

This study has several limitations. First, due to the limited number of confirmed COVID-19 patients from cities outside the epidemic center, the sample size of the present study is limited. However, this study has provided the best comprehensive evidence to date showing the results of pulmonary function tests by spirometry and radiology in COVID-19 patients 3 months after hospital discharge. Second, due to the lack of pulmonary function tests at admission or during hospitalization, we did not assess changes in pulmonary function tests or CT scans. In our study, no patients developed chronic lung disease, so it might be reasonable to presume that their basic lung function was normal. However, longer follow-up examinations to evaluate

the longer-term recovery of lung function are necessary. Third, FEV₁ and FVC were lower in younger COVID-19 patients (ie, <10 years old) than adults, which may be due to the difficulties in performing a forceful expiratory manoeuvre to derive reliable spirometry results in young children. Thus the pulmonary function of the young patients could be underestimated.

In conclusion, at 3 months after discharge, of 172 COVID-19 survivors, 11 (6.40%) presented abnormalities on pulmonary function tests, and 85.91% on chest CT scans, with fibrous stripes and ground glass opacities being the most common patterns. Further studies with longer follow-up to evaluate long-term changes in pulmonary function and radiology are warranted.

Supplementary Data

Supplementary materials are available at *Open Forum Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.

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References

1. Ahn DG, Shin HJ, Kim MH, et al. Current status of epidemiology, diagnosis, therapeutics, and vaccines for novel coronavirus disease 2019 (COVID-19). *J Microbiol Biotechnol* **2020**; 30:313–24.
2. Zhai P, Ding Y, Wu X, et al. The epidemiology, diagnosis and treatment of COVID-19. *Int J Antimicrob Agents* **2020**; 55:105955.
3. Xie L, Liu Y, Xiao Y, et al. Follow-up study on pulmonary function and lung radiographic changes in rehabilitating severe acute respiratory syndrome patients after discharge. *Chest* **2005**; 127:2119–24.
4. Mo X, Jian W, Su Z, et al. Abnormal pulmonary function in COVID-19 patients at time of hospital discharge. *Eur Respir J* **2020**; 55:2001217.
5. You J, Zhang L, Ni-Jia-Ti MY, et al. Anormal pulmonary function and residual CT abnormalities in rehabilitating COVID-19 patients after discharge. *J Infect*. **In press**.
6. Zha L, Shen Y, Pan L, et al. Follow-up study on pulmonary function and radiological changes in critically ill patients with COVID-19. *J Infect*. **In press**.
7. World Health Organization. Clinical management of severe acute respiratory infection when novel coronavirus (nCoV) infection is suspected: interim guidance. Available at: [https://www.who.int/publications-detail/clinical-management-of-severe-acute-respiratory-infection-when-novel-coronavirus-\(ncov\)-infection-is-suspected](https://www.who.int/publications-detail/clinical-management-of-severe-acute-respiratory-infection-when-novel-coronavirus-(ncov)-infection-is-suspected). Accessed 2 July 2020.
8. Bai Y, Yao L, Wei T, et al. Presumed asymptomatic carrier transmission of COVID-19. *JAMA* **2020**; 323:1406–7.

9. Metlay JP, Waterer GW, Long AC, et al. Diagnosis and treatment of adults with community-acquired pneumonia. an official clinical practice guideline of the American Thoracic Society and Infectious Diseases Society of America. *Am J Respir Crit Care Med* **2019**; 200:e45–67.
10. National Health Commission of the People's Republic of China. Handbook of prevention and treatment of the pneumonia caused by the novel coronavirus (2019-nCoV) (in Chinese). Updated 6 February 6 **2020**. Available at: <http://en.nhc.gov.cn/index.html>. Accessed 2 July 2020.
11. Chen N, Zhou M, Dong X, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *Lancet* **2020**; 395:507–13.
12. Antonio GE, Wong KT, Hui DS, et al. Thin-section CT in patients with severe acute respiratory syndrome following hospital discharge: preliminary experience. *Radiology* **2003**; 228:810–5.
13. Shichijo S, Keicho N, Long HT, et al. Assessment of synthetic peptides of severe acute respiratory syndrome coronavirus recognized by long-lasting immunity. *Tissue Antigens* **2004**; 64:600–7.
14. Pan F, Ye T, Sun P, et al. Time course of lung changes at chest CT during recovery from coronavirus disease 2019 (COVID-19). *Radiology* **2020**; 295:715–21.
15. Güder G, Brenner S, Angermann CE, et al. GOLD or lower limit of normal definition? A comparison with expert-based diagnosis of chronic obstructive pulmonary disease in a prospective cohort-study. *Respir Res* **2012**; 13:13.
16. Thomas ET, Guppy M, Straus SE, et al. Rate of normal lung function decline in ageing adults: a systematic review of prospective cohort studies. *BMJ Open* **2019**; 9:e028150.
17. Liu YX, Ye YP, Zhang P, et al. Changes in pulmonary function in SARS patients during the three-year convalescent period [in Chinese]. *Zhongguo Wei Zhong Bing Ji Jiu Yi Xue* **2007**; 19:536–8.
18. Xie L, Liu Y, Fan B, et al. Dynamic changes of serum SARS-coronavirus IgG, pulmonary function and radiography in patients recovering from SARS after hospital discharge. *Respir Res* **2005**; 6:5.
19. Sun D, Li X, Guo D, et al. CT Quantitative analysis and its relationship with clinical features for assessing the severity of patients with COVID-19. *Korean J Radiol* **2020**; 21:859–68.