Cardiothoracic Imaging

CT imaging features of 34 patients infected with COVID-19

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ABSTRACT

Objective: To retrospectively analyze the CT findings in patients infected with Coronavirus disease 2019 (COVID-19).

Materials and methods: The thirty-four cases, 15 females and 19 males, with an age ranging from 7 to 88 years old, confirmed by real-time reverse-transcriptase-polymerase chain reaction (RT-PCR), were used for our study. All thin-section CT scans of the lungs were performed in all of patients. The clinical, laboratory and CT imaging were available to evaluate in all patients.

Results: The patients present with fever (85.29%, n = 29), cough (67.65%, n = 23), fatigue or myalgia (26.47%, n = 9), and pharyngalgia (8.82%, n = 3). The 4 patients (11.76%) with no symptoms were identified during screening for close contacts, who had typical CT findings. On initial CT scans, the bilateral lung involved was shown in 24 cases (70.59%), while 29 (82.35%) cases were distributed in peripheral. The pure ground glass opacity (GGO) was shown in 18 cases (52.94%), the GGO with consolidation was in 12 cases (35.29%), and full consolidation only in 3 cases. The lesion with air bronchogram was seen in 14 (41.18%) cases, with enlarged blood vessel in 17 (50.00%) cases, with crazy-paving pattern in 8 (23.53%) cases, with fine reticular pattern in 4 (11.77%) cases, and with intralesional vacuole sign in 6 (17.65%) cases. The pleural effusion was seen in one patient. Follow-up imaging in 19 patients during the study time window demonstrated mild, moderate or severe progression of disease, as manifested by increasing extent and density of lung opacities.

Conclusions: The bilateral GGO with air bronchogram, enlarged blood vessel, fine reticular pattern, and peripheral distribution are the early CT findings of COVID-19. The crazy-paving pattern and intralesional vacuole sign are the features of progressive stage.

1. Introduction

On December 31, 2019, the World Health Organization (WHO) learned of several cases of a respiratory illness clinically resembling viral pneumonia and manifesting as fever, cough, and shortness of breath. The newly discovered virus emerging from Wuhan City, Hubei Province of China, has been temporarily named "novel coronavirus" (2019-nCoV) [1]. This new coronavirus belongs to the seventh member of the family of coronaviruses that infect humans being different from severe Acute Respiratory Syndrome (SARS) and Middle East

Respiratory Syndrome (MERS) [2,3]. Coronavirus disease 2019 (COVID-19) is defined as illness caused by a novel coronavirus now called severe acute respiratory syndrome coronavirus 2 [4].

The outbreak is escalating quickly, with thousands of confirmed COVID-19 cases reported globally. On January 30, the China reported the first confirmed instance of person-to-person spread of the virus [5]. And then, infections have been identified in other Chinese cities., besides, several exported cases have been confirmed in other countries in Thailand, Japan, South Korea, and the USA [6]. Now, the COVID-19 has led to a world-wide pandemia, which has affected also Europe,

Australia, New Zealand, Africa etc. [7].

Proven cases of COVID-19 have been acquired both in the community and hospital setting. The source of COVID-19 is not yet clear, but the origin of the infection has been associated with bat [8]. COVID-19 has been detected in healthy patients with or without known co-morbidities before, with a larger proportion of reported cases in this group. Patients with diabetes, hypertension, chronic renal failure, cardiomyopathy, decreased immunity and malignancy seem to be at a higher risk for developing severe disease [6]. The current symptoms include cough, fever, dyspnea, nausea, and myalgia [9]. Severe cases of COVID-19 may be admitted to intensive care and mechanical ventilation. As we all know, no specific antiviral agents are available against COVID-19 at present.

Therefore, early disease recognition is important not only for prompt implementation of treatment, but also for patient isolation and effective public health surveillance, containment and response. However, limited information exists regarding chest imaging findings of COVID-19 pneumonia. A recent cohort study of 41 patients with confirmed COVID-19 infection included limited analysis of chest radiographs [6]. The aim of this study was to review and better describe the chest CT findings in patients with COVID-19.

2. Methods and materials

2.1. Patient population

From Jan 24, 2020 to Mar 5, 2020, we reviewed a case series of chest CT scan from 34 patients infected with COVID-19 to identify and characterize the most common findings. All these cases consisted of 15 (44.12%) female and 19 (55.88%) male, with an age ranging from 7 to 88 years old (median age, 49.21 years, interquartile range [IQR] = 32–64 years). 11 patients (32.35%) had an exposure to individuals from Wuhan, China, the remaining patients had an history of contact with the person who had been exposed to individuals from Wuhan proven COVID-19. The patients were admitted to five hospitals in four Cities of Shandong province. All were positive for COVID-19 via laboratory testing of respiratory secretions.

Nineteen patients underwent a second CT examination within 3 to 5 days as their symptoms worsened. The median age of 19 patients was 50.00 years (interquartile range [IQR] = 41–59 years).

Written informed consent was waived by our institutional review board for these retrospective cases. Approval for this study was obtained from the local ethics committees of five hospitals. No link between the researchers and the patients was available [3].

2.2. CT techniques

All scans were performed in supine position during end-inspiration without intravenous contrast. At the time of entry into the study, each patient fulfilled the diagnostic criteria for COVID-19 used in each unit by respiratory samples tested by real-time reverse-transcriptase-polymerase chain reaction (rRT-PCR). The clinical, laboratory and CT imaging were available to evaluate in all patients. Thin-section CT was performed from the lung apices to the diaphragm using a low-radiation dose technique (50–80 mAs). Scanning was performed on MDCT units (128-MDCT, iCT 256, Philips Healthcare; 64-MDCT, EVO, GE Healthcare; 64-MDCT, Somatom Definition AS+, Siemens Healthcare) using a high-spatial-frequency reconstruction algorithm with a 1.0 mm section thickness and 5-mm gap. The subjects were scanned in a supine position during breath-holding at full inspiration and at maximal expiration. The images were photographed at conventional lung window settings (window level, −600 Hu; window width, 1000–1500 Hu).

2.3. Analysis of CT images

Two fellowship-trained radiologists independently and blindly reviewed all CT images with approximately over 4 years of experience each in thoracic CT. Images were reviewed retrospectively and final decisions were reached by consensus. Cases of disagreement about CT findings between initial radiologist interpretations were reviewed by a third thoracic radiologist with 10 years of experience. The decision radiologist determined a final decision for the patients by discussing and reviewing cases in the relevant literatures. No negative control cases were set.

CT images were evaluated for the presence and distribution of parenchymal abnormalities, including (1) pure ground-glass opacity (GGO), which was defined as increased lung density with no obscuration of the underlying lung marks; (2) fine reticular pattern, which meant GGO with reticulation or intralobular networks which was regular, more uniform than crazy-paving pattern, and of the same size; (3) GGO with consolidation, which was defined as increased lung density with obscuration of the underlying lung marks; (4) consolidation; (5) air bronchogram(s); (6) crazy-paving pattern, which consisted of scattered or diffuse ground-glass attenuation with superimposed interlobular septal thickening and intralobular lines, irregular and higher density than fine reticular pattern; (7) intralesional vacuole sign, it was defined as lower-density shadow or air chamber in the pulmonary GGO or crazy-paving pattern; and (8) pleural effusion [10].

2.4. Data analysis and interpretation

Data were expressed as frequency (except where otherwise indicated).

3. Results

3.1. Clinical data

The main symptoms were fever (29/34, 85.29%), cough (23/34, 67.65%), fatigue or myalgia (9/31, 26.47%), and pharyngalgia (3/34, 0.82%). The 4 patients with no symptoms were identified during screening for close contacts, and also following up for two weeks. 13 patients had one or more of the following comorbidities: hypertension (9/34, 26.47%), diabetes (9/34, 26.47%), chronic liver or renal disease (3/34, 8.82%) and cardiac disease (7/34, 20.59%; Table 1). All patients were transferred to the airborne infection isolation rooms from the emergency department. An 88-year-old woman was placed in the ICU room after developing respiratory failure and died 14 days later.

3.2. CT findings

3.2.1. Initial chest CT findings

All but one of the 34 patients presented as GGO and consolidation,

Table 1
Demographics and baseline characteristics of patients infected with COVID-19.

Characteristics	No. (%) or range (median) (n = 34)
Age, years	7–88 (median, 49.21)
Sex	
Male	19 (55.88%)
Female	15 (44.12%)
Exposure to individuals from Wuhan	11 (32.35%)
Any comorbidity	
Diabetes	9 (26.47%)
Hypertension	9 (26.47%)
Chronic liver or renal disease	3 (8.82%)
Cardiac disease	7 (20.59%)
Signs and symptoms	
Fever	29 (85.29%)
Cough	23 (67.65%)
Pharyngalgia	3 (8.82%)
Fatigue or myalgia	9 (26.47%)
No symptoms	4 (11.76%)

Table 2
CT features in 34 patients infected with COVID-19.

Main CT findings	No. of patients (%)
GGO	30/34 (88.24%)
Pure GGO	18/34 (52.94%)
GGO with consolidation	12/34 (35.29%)
Full consolidation	3/34 (8.82%)
Air bronchogram	14/34 (41.18%)
Enlarged blood vessel	17/34 (50.00%)
Fine reticular pattern	4/34 (11.77%)
Crazy-paving pattern	8/34 (23.53%)
Intralesional vacuole sign	6/34 (17.65%)
Pleural effusion	1/34 (2.94%)
Lung Cavitation	(–)

or both in the first CT scanning (Table 2). There were pure GGO in 18/34 (52.94%) patients, GGO with consolidation in 12/34 (35.29%) patients (Fig. 1), full consolidation in 3/34 (8.82%) patients. The lesions with fine reticular pattern were found in 4/34 (11.77%) patients (Fig. 2), air bronchogram in 14/34 (41.18%) patients (Figs. 1a and 2), 17/34 (50.00%) with enlarged blood vessel (Figs. 1b and 2), 8/34 (23.53%) with crazy-paving pattern (Figs. 3 and 4), and 6/34 (17.65%) with intralesional vacuole sign (Fig. 4). The pleural effusions were seen in one patient. Lung cavitation was absent. One CT scan was normal.

Data of initial chest thin-section CT imaging findings in 34 patients with COVID-19 pneumonia are presented in Tables 3. There were 24/34 (70.59%) patients with a total of 127/166 (76.51%) lesions involving both lungs, and 17/34 (50.00%) patients with 105/166 (63.25%) lesions involving 4 to 5 lobes. 29/34 (85.29%) patients with 149/166 (89.76%) lesions distributed in the lung periphery (Fig. 5).

3.2.2. CT follow up

The 33 cases were cured except one death. All cured patients were performed with CT scanning to confirm that the inflammation had disappeared or significantly decreased when they were cured and allowed to discharge. Nineteen patients underwent a second CT examination within 3 to 5 days as their symptoms worsened. One of the nineteen patients (13%) had normal initial and follow-up chest CT examinations, with no interval change. Five of the 19 patients demonstrated mild progression (Fig. 1, Fig. 3), and 8 patients demonstrated moderate progression and advanced from pure GGO to crazy-paving pattern (Fig. 3) and appeared intralesional vacuole sign (Fig. 4). An 88-year-old woman demonstrated severe progression and was died of respiratory failure 14 days later after being found going worse (Fig. 3). The CT manifestations of 4 asymptomatic patients became worse after one week, but they were also asymptomatic until they were

cured. The qualitative changes at follow-up CT examination in 19 patients were seen in Table 4.

4. Discussion

A wide variety of CT findings in COVID-19 were reported in several studies [10,11]. On initial one reported bilateral consolidation with peripheral distribution [2]. A second report showed that bilateral GGO from one patient [12,13]. In two other large studies with 138 and 99 confirmed cases, consolidative airspace opacities and GGO were the most commonly reported imaging features [1,14]. In a prospective case series of 41 admitted patients, CT abnormalities suggestive of GGO showed bilateral lung involvement [6]. A different report mentioned less details on distribution or pattern besides GGO [5]. In another study, Chung et al. characterized the CT manifestations of COVID-19 pneumonia in 21 patients and reported bilateral lung involvement in 76% and peripheral airspace opacities in one-third of the cases at presentation [3]. More than half of their patients showed GGO without consolidative opacities, whereas 29% showed GGO in addition to consolidative opacities at presentation. In another study of 51 patients with confirmed COVID-19, 1324 lung lesions were detected on chest CT. The most common CT findings seen in these patients were isolated GGO, GGO with reticular or interlobular septal thickening, and GGO in combination with consolidative opacities [15]. Air bronchograms were reported in 80% of these patients [16]. In this retrospective case series, we noted each had abnormalities present in their CT scans with the goal of familiarizing radiologists and clinical teams with identifying the radiological features of infected with the COVID-19 of this new outbreak. We found that GGO were typical CT findings with a rounded morphology and a peripheral lung distribution, and GGO were more extensive than consolidation. Some additional features were observed such as air bronchogram and distribution of the changes in the peripheral parts of the lungs. Some patients were characteristically described as crazy-paving pattern, of which the reticular network in it is thought to represent the thickened interlobular septa while the GGO reflect the alveolar filling with periodic acid-Schiff-positive material. The mechanisms thought to be responsible for this pattern include interstitial fibrotic processes, alveolar filling processes, or a combination of both [16]. We also noted the number of lobes of the lungs that were affected with ground glass opacities and consolidation. In the present study, the fine reticular pattern was distinguished from crazy-paving pattern. It is more uniform and of the same size. This manifestation may be due to the dilation of the microvessels in the alveolar septa caused by early inflammation, and further development tends to be a "crazy paving" pattern which means the thickened septa is more irregular, sharper, and denser. Intralesional vacuole sign was observed in 4 cases,
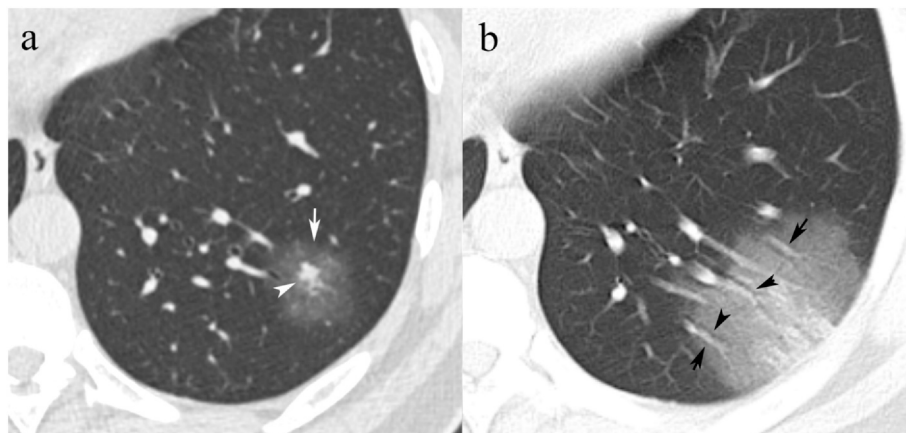

Fig. 1. A 35-year-old man infected with COVID-19. (a) CT shows a ground-glass opacity lesion with one tiny solid nodule inside it in the left lower lung lobe. (b) The lesion was increased after 5 days, and the enlarged blood vessel sign and bronchogram sign were seen in it (black arrow).
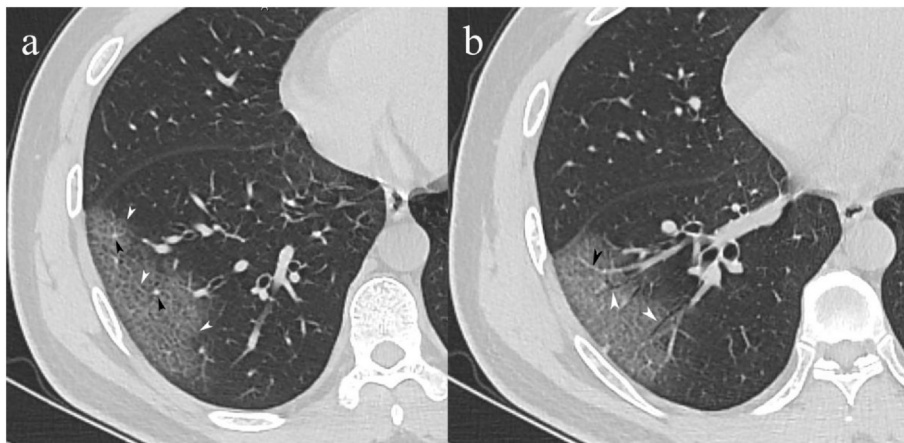
Fig. 2. A 41-year old male with history of travel to Wuhan, presenting with fever. (a) The fine reticular pattern (white arrow heads) was seen in the axial CT image. The center artery of lobular (black arrow heads) was seen in it. (b) The enlarged blood vessel (black arrow head) and bronchograms (white arrow heads) were seen in the CT image.
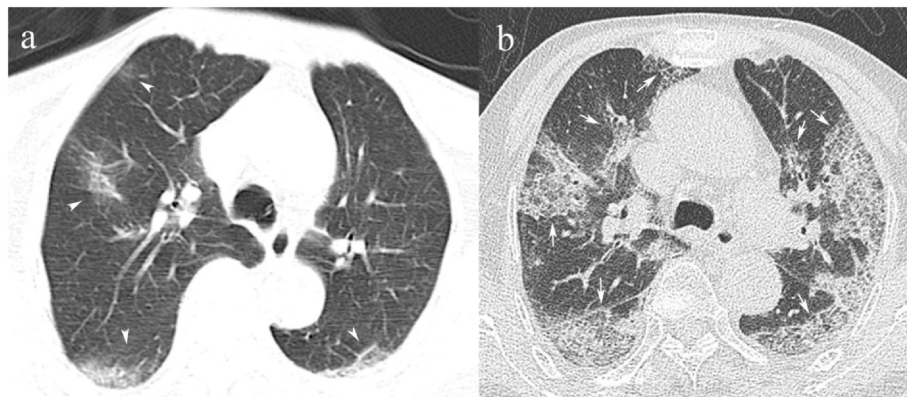
Fig. 3. An 88-year-old female presenting with fever and cough. (a) Ground-glass and consolidative opacities are seen in the bilateral lungs. (b) The lesion was enlarged and increased, and presented as "Crazy-paving" pattern after 3 days follow up.
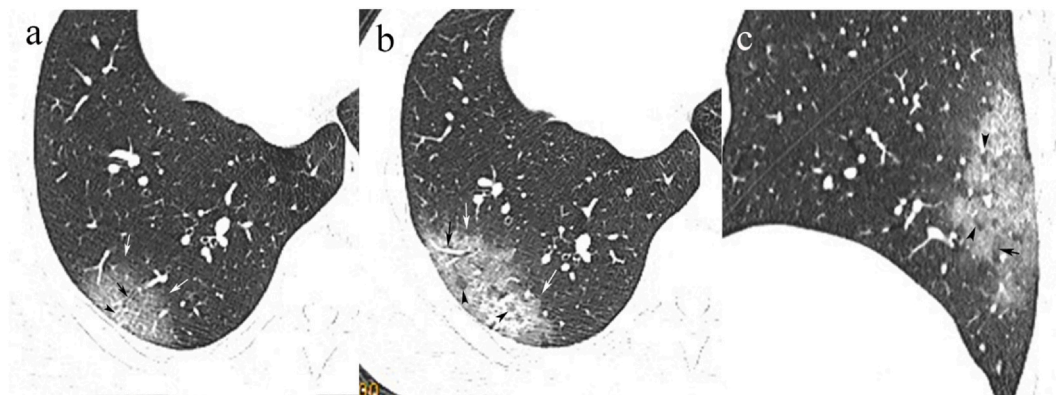
Fig. 4. CT images in a 20-year-old man with a travel history to Wuhan, China. (a) A ground-glass opacity (GGO, white arrows) is shown in right lower lung and the bronchogram (black arrow) and interlobular septal thickening (black arrow head) are seen. (b) The GGO is increased after four days follow up. The "Crazy-paving" pattern (white arrows), enlarged blood vessel (black arrow) and intralesional vacuole sign (black arrow heads) are seen. (c) The intralesional vacuole sign (black arrow heads) and enlarged alveolar ducts (black arrow) are seen in the sagittal CT image.

it may be the dilation of alveolar ducts and alveolar sac, indicating the alveolar destruction and onset of fibrosis.

Pan et al. reported the temporal course of CT changes in 21 confirmed cases of COVID-19. In early stage, the majority of their patients showed more GGO and a lower number of involved lobes compared with the later follow-up scans. However, intensification of a crazy paving pattern, increase in the number of involved lobes, and appearance of consolidative opacities occurred in most patients over time [17]. Pan et al. assessed the follow-up CT scans of 63 patients that were obtained within 3–14 days after an initial CT study. They found that

more than 85% of the patients showed imaging signs associated with disease progression such as increase in GGO, consolidative opacities, and interstitial septal thickening [18]. In our study, nineteen patients underwent a second CT examination within three to five days as their symptoms worsened. The lesions of 5 patients increased significantly, and 8 patients advanced from pure GGO to crazy-paving pattern and appeared intralesional vacuole sign. Therefore, the crazy-paving pattern and intralesional vacuole sign are the features of progressive stage. Thus, CT examination is very important in evaluating the condition of patients under treatment.

Table 3
Distribution of the lobes and lesions affected with COVID-19 (n = 34).

Main CT findings	No. of patients (%)	No. of lesions (%)
Bilateral	24 (70.59%)	127 (76.51%)
Unilateral	10 (29.41%)	39 (23.49%)
Frequency of lobes involved		
1 lobe	3 (8.82%)	8 (4.82%)
2 lobes	4 (11.76%)	22(13.25%)
3 lobes	7 (20.59%)	31 (18.67%)
4 lobes	14 (41.18%)	76 (45.78)
5 lobes	3 (8.82%)	29 (17.47%)

There are 166 lesions in 34 patients of COVID-19.

Interestingly, not all patients showed any of these CT findings in their initial stages and these radiological findings might be absent. We found that 1 of 34 patients had normal initial chest CT. This shows that CT imaging may lack whole sensitivity and does not show a negative predictive value. Therefore, we can't solely depend on CT to completely exclude presence of COVID-19. The main reason is that COVID-19 infection may take time to demonstrate as a disease prior to visible abnormalities on CT. Lung cavitation, discrete pulmonary nodules, and lymphadenopathy were not observed. Some of the patients also had underlying lung diseases such as fibrosis and emphysema. These features were all recorded for the patients with the coronavirus infections.

The 4 patients with no symptoms had typical CT findings of COVID-19 in our study. This suggests that CT examination is also important for those with an epidemiological history, although there are no clinical symptoms. The WHO suggested contact precautions when resolving suspected cases being infected with COVID-19 [17]. Timely identification of patients is needed for those patients who may present with unusual or mild symptoms, or carry COVID-19 not being recognized, rRT-PCR testing yielding false-negative results [19]. Thus, patients who were exposure or travel to areas of COVID-19 outbreak and were with suggestive imaging findings may aid in early isolation. Generally, the CT outcomes reported for COVID-19 are resembling to those reported with MERS-CoV [20,21] and SARS-CoV [22,23], not surprised because the responsible virus is also coronavirus. Although we managed to radiologically observe the COVID-19 infected individuals, there are still many questions to be answered and further study is required to understand how patients fare after treatment.

Table 4
Qualitative change at follow-up CT examination in 19 patients.

Finding		No. of patients (n = 19)
No change		1 (5.26%)
Disease improvement		0 (0)
Disease progression	Mild	5 (26.32%)
	Moderate	8 (42.11%)
	Severe	5 (26.32%)

5. Conclusions

In summary, this work represents an early investigation of CT findings in COVID-19. The bilateral GGO with air bronchogram, enlarged blood vessel, fine reticular pattern, and peripheral distribution are the early CT findings of COVID-19. The crazy-paving pattern and intralesional vacuole sign are the features of progressive stage. This is important for early diagnosis and assessment of disease progression. Furthermore, normal finding of CT imaging does not exclude the potential infection of COVID-19. CT examination is necessary to detect asymptomatic pneumonia, especially in those with an epidemiological history.
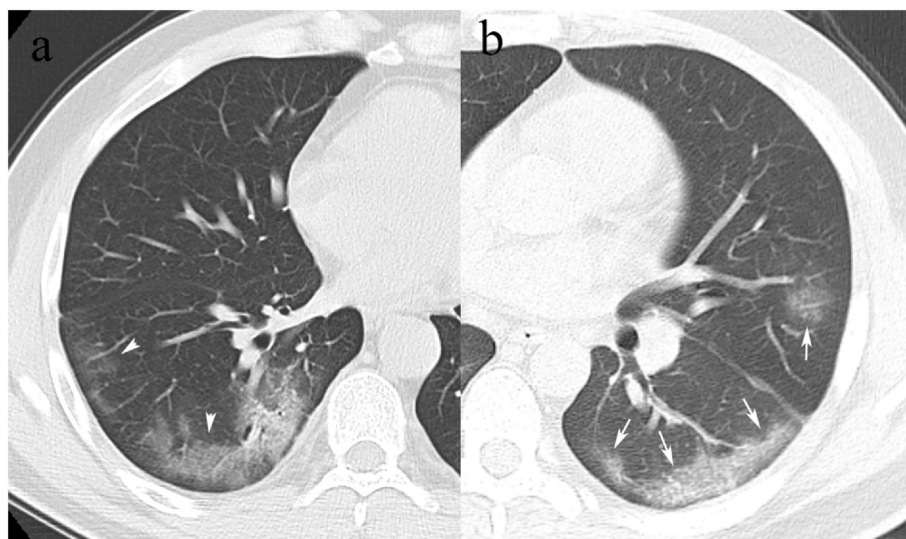
Declaration of competing interest

All authors declare no competing interests.

Author contributions

1. Guarantor of integrity of the entire study: Yuan Zhong Xie, Li Tao Zhang
2. Study concepts and design: Yuan Zhong Xie, Li Tao Zhang
3. Literature research: Xue Kong, Wei Wei Li
4. Clinical studies: Jian Zhong Zhu, Shan Ping Liu, Chun Lin Xu, Li Tao

Fig. 5. The lesions are distributed in the lung periphery. (a) At the right lower lung in a 44 years old male, (b) at the left lower lung in a 49 years old female.

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5. Experimental studies/data analysis: N/A
6. Statistical analysis: Xiu Juan Li, Huan Wang Du
7. Manuscript preparation: Li Tao Zhang, Hui Jing, Jiahuan Xu, Tongtong Shi
8. Manuscript editing: Yuan Zhong Xie.

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