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1. Clinical manifestation

The incubation period from exposure to symptoms is generally 7–14 days; the shortest is 1 day, the longest is up to 20 days. Fever, fatigue, and dry cough appear to be the most common symptoms at illness onset, but these symptoms, which also present in influenza and other respiratory infections, are nonspecific. Upper respiratory tract symptoms like nasal obstruction and rhinorrhea are relatively rare. In general, the majority of patients have a satisfactory prognosis with a few patients being critically ill. Fatal cases are commonly seen in the elderly and those with chronic underlying diseases, such as diabetes and heart disease.

COVID-19 has several clinical characteristics. (1) It mainly attacks the lungs, but it also frequently involves other organs and systems. (2) Some patients show mild onset symptoms without fever and recover 1 week later. (3) About half of the patients developed dyspnea 1 week after onset, and the symptoms and imaging findings of one-third of sufferers were asynchronous. Some patients initially showed no fever or no obvious coughing or dyspnea, but their chest imaging manifestations continued to progress, and their condition strikingly exacerbated within a week. In severe cases, some quickly deteriorated into acute respiratory distress syndrome (ARDS), septic shock, and metabolic acidosis hard to correct, coagulopathy, and multiple organ failure. (4) Severe or critical patients might present low to moderate fever or even no obvious fever in the course of their illness, which impedes the prevention and control of this epidemic. Therefore, it is pivotal for all hospital departments to screen patients with fever and pneumonia in order to prevent nosocomial infections. (5) Among the patients with symptoms,
the incidence rate of severe cases is approximately 20%. As for confirmed cases of COVID-19, it is necessary to analyze and evaluate the severity of the disease, observe closely, and instruct the patients themselves to report any progression in a timely manner. Respiratory failure, a very important indicator of exacerbation, is characterized by symptoms like chest tightness and shortness of breath, and by objective indicators, such as blood oxygen saturation. Time of onset, fever, and chest tightness and shortness of breath are important factors in evaluating the condition. The condition of patients with an onset time of 7–10 days or more and symptoms of chest tightness, shortness of breath, and high fever, is more likely to become aggravated. Persistent high fever and chest tightness are likely to indicate the stage of the peak period. Intervention prior to the peak period in severe patients to prevent the development of severe respiratory failure is vital in treating critically ill patients, because most of these patients will gradually recover if they survive this 2–3-week peak period.

2. Abnormal findings of laboratory tests

The abnormality of COVID-19 in laboratory examination is reflected in several aspects. In the early stages, the white blood cell count is normal or decreased, and the lymphocyte count, an indicator negatively correlated with severity of illness, is reduced. Severe lymphoid depletion (0.3–0.4 × 10⁹/L) could be observed in critically ill patients. If the patient’s lymphocyte count can gradually recover to more than 1.0 × 10⁹/L, the overall condition will improve accordingly; however, if it fails to rise to 1.0 × 10⁹/L, the state of illness will usually be at a deadlock: although the patient’s vital signs can remain stable, it is difficult to achieve the condition of extubation. In addition, the C-reactive protein and erythrocyte sedimentation rate are increased, and procalcitonin (PCT) is normal in most patients. It is necessary to be alert to whether the patient has a bacterial infection in cases with elevated PCT. Often accompanied by circulatory dysfunction or poor distal limb perfusion, a number of severe patients have coagulation dysfunction: in some ICU patients, D-dimers increased substantially, even up to 50 mg/L. Some patients have increased liver enzymes, troponin, and myoglobin, with myoglobin levels above 10,000 μg/L. In addition to D-dimer, liver, and kidney function, we must pay attention to the changes of peripheral blood lymphocytes, especially CD4+ T lymphocytes and NK cells in lymphocyte subsets, the diminishment of which figure is a significant indicator of poor prognosis in sufferers of SARS. If the lymphocyte count of
patients with COVID-19 is extremely low—as low as 400/$\mu$L or even 200/$\mu$L—the chance of a patient’s survival will plunge. Given that the attack of the virus on the immune system and the intensity of the body’s own excessive immune storms vary, there is a sharp difference in clinical performance of different patients even if there is no change in the virus genotype.

3. Abnormalities and features in imaging

Since the majority of patients present as experiencing pneumonia, imaging examination is very important for COVID-19 diagnosis. In brief, chest imaging in the early stage of infection mainly manifests as multiple small patch lesions and interstitial changes, especially in the lung periphery. As the disease progresses, bilateral lungs show ground-glass opacities (GGOs) and infiltration shadows. Consolidation lesions are common in severe patients, but pleural effusion is rare. Most critically ill patients admitted to ICU develop consolidation in gravity-dependent regions, namely consolidation in lower lobes, which is not readily reversible. Therefore, when pulmonary consolidation is detected in imaging, the disease has already deteriorated and the lungs have been damaged by the virus for quite a long time.

Compared with chest X-ray, more details can be observed in CT images. Therefore, chest CT is highly recommended if condition allows. COVID-19 patients presented with various lesions on chest CT, including GGOs (Fig. 3.1), consolidation (Fig. 3.2), nodules (Fig. 3.3), halo and reversed halo sign (Fig. 3.4), airway changes (Fig. 3.5), etc. Multiple lesions could coexist, presenting a mixed pattern.

Chest CT images manifest different features in COVID-19 patients during different courses of the disease. (1) Early stage: ① Unilateral or bilateral, single or multiple, and focal lesions with a peripheral lung and subpleural distribution are commonly encountered. In the early stage of COVID-19, there are single or multiple and focal GGOs, which are more likely to be unilateral rather than bilateral. ② The lesions could also be massive or small patch GGOs, which are caused by vascular enlargement and the increased number of microvascular, consolidation, nodules, and mosaic sign, which is due to the coexistence of GGOs and air trapping. ③ The lesions sometimes manifest as particular slight GGOs and nodules, and it is easy to miss them in the diagnosis. (2) Progressive stage: ① CT images could present bilateral and multiple GGOs or consolidation with air bronchogram sign, nodules with halo sign, reticular patterns (small vascular networks) inside
Fig. 3.1 Ground-glass opacities (GGOs) (A) There were massive GGOs in both lungs accompanying reticular patterns. (B) A single GGO with vascular enlargement was found in the left upper lobe and the margin was obscure. (C) There were particular slight GGOs. (D) CT scans showed small vessels enlargement surrounded by GGOs.

(Continued)
Fig. 3.1, cont'd (E) Multiple GGOs with reticular patterns were observed in both lungs. (F) There were GGOs with “crazy-paving” patterns. (G) There were GGOs with consolidation.
lesions, and reversed halo sign. ② New lesions are mainly located in the middle and lower lobes with subpleural distribution, and most manifest as slight GGOs. ③ Other lesions include subsegmental atelectasis and fibrosis. (3) Severe stage: "White lung" with acute lung injury, the range of lesions increasing by 50% in 48 h, pulmonary fibrosis could be seen in CT images of critically ill patients.

The following content introduces radiological features of COVID-19 via etiologically confirmed cases. (1) Imaging findings in the early stage of COVID-19 (Figs. 3.6–3.13). (2) Imaging findings in the progressive stage

*Consolidation

Fig. 3.2 Consolidation.

Fig. 3.3 Nodules.
*Halo sign

& Day 1 after beginning with fever

# Day 3 after beginning with fever

(A) @ Day 8 after beginning with fever

(B)

(C)

Fig. 3.4 Halo (A) and reversed halo sign (B, C).
of COVID-19 (Figs. 3.14–3.18). (3) Imported cases of COVID-19: some cases showed evident clustering. The clinical characteristics and CT images of three groups of clustered cases are described as follows. The first group (Figs. 3.19–3.22) contains four confirmed cases with slight imaging changes, which were difficult for chest X-ray to detect. Therefore, for clustered cases,

*Lesions with vascular enlargement

**Fig. 3.6** Male, 29 years old, with a history of fever for 3 days along with sore throat, but no cough; temperature: 38°C; with epidemic history. Laboratory tests: WBC: 4.62 x 10^9/L, NEUT% 77.7%, LYMPH% 17.1%. CT scans showed scattered exudative patch lesions, GGOs, and consolidation accompanied by vascular enlargement.
**Lesion with vascular enlargement**

**Fig. 3.7** Female, 41 years old, with a history of fever for 3 days, but no cough or expectoration; temperature: 38.8°C; with a history of traveling in Wuhan but no contact with anyone with symptoms of COVID-19. Laboratory tests: $3.74 \times 10^9/L$, NEUT% 59.7%, LYMPH% 26.5%. CT scans showed there were GGOs in the right upper lobe and left lower lobe, and localized consolidation in the left lower lobe with subpleural distribution.

**Fig. 3.8** Male, 55 years old, with a history of fever for 4 days, along with back pain, scalp haphalgesia, occasional cough and white sputum, but no sore throat; temperature: 38°C; with a history of contact with confirmed patients. The personal history is hypertension and diabetes. Laboratory tests: WBC $5.73 \times 10^9/L$, LYMPH% 12%. CT scans showed multiple patch OGGs located in the subpleural area and interlobar fissure in both lungs, and there were also OGGs in the medial segment of the right middle lobe.
especially those with epidemiological history, it is necessary to strengthen identification and screening processes.

The second group (Figs. 3.23 and 3.24) contains two confirmed cases, one of which had clinical symptoms but no abnormal changes in imaging examination initially. But as time passed, lesions gradually appeared in chest imaging. Therefore, pathogen detection and follow-up CT scans are necessary for familial clusters even if CT images find nothing. The third group (Figs. 3.25–3.27) contains three confirmed cases. The parents were diagnosed first, while CT images of the son showed suspicious signs of COVID-19 infection, and during disease deterioration, the area of lesions expanded. His first two nucleic acid tests showed negative results, and the third one showed a positive result. Hence, for patients with epidemiological history, especially those with family clustering history, follow-up and repeated performance of nucleic acid tests are needed, even if nucleic acid tests show negative results. (4) For some patients, lesions could expand rapidly in 3–5 days, and even develop fibrosis on the 7th day from the onset of symptoms (Figs. 3.28 and 3.29).

It is notable that we should not concentrate only on pulmonary infiltration shadows, GGOs, features of pneumonia, features of ARDS, etc. Some slight changes in CT images, such as “SOP–like” changes, suggest causes leading to disease progression. As the disease progresses further, we ought to focus not only on infiltration shadows, but also interstitial changes, “SOP–like” changes, changes of pulmonary embolism, and bacterial or fungal infections (Fig. 3.30).

**Fig. 3.9** Female, 32 years old, without any obvious symptoms. She was residing in Wuhan and went on an errand on January 21. Her husband had symptoms of COVID-19. Laboratory tests: WBC 4.22 × 10⁹/L, LYMPH% 32.9%. CT scans showed multiple subsolid nodules with intrapulmonary and subpleural distribution in both lungs, surrounded by halo sign.
Fig. 3.10 A 22-year-old patient with a history of fever for 1 day, cough and expectoration for 8 days. Temperature: 38.7°C. The patient went to Wuhan on January 10, and left Wuhan on January 21. Laboratory examination: CRP 54.20mg/L, hs-CRP > 5.00mg/L, ESR 19mm/h, D-dimer 2.05mg/L. CT scans showed small patch GGOs with vascular enlargement. Vascular enlargement could be seen in the slight GGOs (A). An increased number of and enlarged lesions with reversed halo sign (B) and halo sign (C) were observed in follow-up CT scans on January 29, 2020. Small pulmonary nodules were found, most of which were located in the subpleural area.
Fig. 3.11 Male, 26 years old, with a history of fever for 1 day, along with dry cough and fatigue; temperature: 37.1°C. He had returned from Wuhan 3 days previously. Laboratory tests: CRP 9.83 mg/L, hs-CRP > 3.00 mg/L, NEUT% 63.2%, LYM 0.75 × 10⁹/L, ESR 29 mm/h, D-dimer + FDP (−). CT scans showed scattered, multiple, and small patch GGOs and micronodular consolidation.

*Small patch GGOs

Fig. 3.12 Female, 44 years old, with a history of hyperpyrexia for 4 days, along with cough and expectoration. She returned to her hometown from Hubei Province on January 22, 2020. Laboratory tests: WBC 4.5 × 10⁹/L, NEUT% 57.4%, LYM 36.1%. CT scans showed small patch GGOs, some of which were accompanied by air bronchogram signs and vascular enlargement.
Fig. 3.13 Male, 49 years old, with a history of fever for 4 days, along with dry cough, fatigue, and chest distress; temperature: 38.2°C. He had worked in Wuhan for a long time. He left Wuhan by train on January 18. Laboratory examination: WBC $5.80 \times 10^9$/L, NEUT% 76.6%, LYMPH% 15.0%, R 22 times per minute, SpO2 98%. (A) CT scans on January 23 showed GGOs with air bronchogram signs and vascular enlargement in the right upper lobe. (B) Follow-up CT scans on January 26 showed an increased number of and enlarged lesions, and emergence of new ones with “crazy-paving” patterns in the left lung.
Fig. 3.14 Male, 47 years old, with a history of fever for 11 days, along with cough and a small amount of white sputum; temperature: 39°C. No travel history to or work in Wuhan, nor contact with anyone who ever stayed in Wuhan. Laboratory tests: WBC 2.92 × 10^9/L, NEUT% 73.0%, LYMPH% 21.8%. CT scans showed multiple, massive, and patch GGOs and consolidation with a small amount of pleural effusion in the right thorax.

1 GGOs with vascular enlargement
2 Bronchovascular bundles thickening
3 a small amount of pleural effusion
4 Lesions with vascular enlargement
5 GGOs
6 Air bronchograms sign
Fig. 3.15 Male, 18 years old, with a history of fever for 1 day, along with fatigue for 6 days and chest distress for 2 days; temperature: 38.5°C. The patient had stayed in Wuhan for 10 days and left on January 22. Laboratory tests: CRP 12.49 mg/L, hs-CRP > 5.00 mg/L, ESR 10 mm/h, D-dimer 1.99 mg/L. (A) CT scans on January 25, 2020 showed massive and mix-pattern consolidation in the right lower lobe, associated with vascular enlargement, air bronchogram, and interlobular septal thickening. In addition, there were GGOs around lesions. (B) Follow-up CT scans on January 29, 2020 showed coexistence of absorption of primary lesions and emergence of enlarged and new ones.
Fig. 3.16 Female, 64 years old, with a history of fever for 6 days, along with cough and pronounced fatigue; temperature: 37.5–38.6°C. The patient was residing in Wuhan on January 14, 2020, and had previous contact with confirmed patients. Laboratory tests: PLT 1.4 × 10^9/L ↓, CRP 7.06 mg/L ↑, EO% 0.2 ↓, EO 0.01 ↓, AST 36.40 ↑, LDH 289 ↑. CT scans showed multiple patch GGOs in both lungs and fibrosis lesions in the lower lobes.

Fig. 3.17 Male, 41 years old, with a history of fever and fatigue for 10 days; temperature: 38.3°C, with a history of contact with confirmed patients in Wuhan 10 days previously. Laboratory tests: WBC 3.71 × 10^9/L, LYMPH 0.88 × 10^9/L, ESR 15 mm/h; CRP 13.50 mg/L, hs-CRP > 3.00 mg/L. HRCT of progressive stage showed multiple, massive, and patch GGOs with vascular enlargement and bronchiolar dilatation in both lungs.
Fig. 3.18  

(A) Bilateral, multiple, and massive patch GGOs
& Thickening oblique fissure of the right lung

(B) GGOs with small vessels enlargement
& Air bronchogram sign
#a small amount of pleural effusion

(C) Air trapping, which is due to the coexistence of exudation lesions and small airway changes, results in mosaic sign.
& GGOs with the increased number of vascular and vascular enlargement
# There is air trapping in the distal area of lesions.

(D) 1 Thickening bronchovascular bundles and air bronchogram sign
2 Localized subsegmental atelectasis
3 Increased number of pulmonary small vascular networks
4 Localized subsegmental atelectasis

(See figure legend on next page)
Male, 46 years old, with a history of fever for 4 days, along with paroxysmal cough; temperature: 37.7°C. He was residing in Wuhan on January 20. Laboratory tests: WBC $2.99 \times 10^9$/L, LYMPH% 16.7%. He had a history of adenocarcinoma in the right upper lobe and was treated with chemoradiotherapy. CT scans on January 25 showed multiple small patch GGOs in both lungs and bronchiolar dilatation in large lesions. There was radiation pneumonia in the right upper lobe, and the tumor was stable.

*Radiation pneumonia

& Small pulmonary nodules

**Fig. 3.19** Male, 46 years old, with a history of fever for 4 days, along with paroxysmal cough; temperature: 37.7°C. He was residing in Wuhan on January 20. Laboratory tests: WBC $2.99 \times 10^9$/L, LYMPH% 16.7%. He had a history of adenocarcinoma in the right upper lobe and was treated with chemoradiotherapy. CT scans on January 25 showed multiple small patch GGOs in both lungs and bronchiolar dilatation in large lesions. There was radiation pneumonia in the right upper lobe, and the tumor was stable.

**Fig. 3.18, cont’d** Male, 50 years old, with a history of fever for 4 days, along with dry cough, fatigue, and chest distress; temperature: 38.2°C. The patient returned from Wuhan by train on January 16, and he was involved in clusters of COVID-19 cases. (Left column) CT scans on January 23 showed GGOs with air bronchogram and vascular enlargement in the right upper lobe. (Right column) Increased number of and enlarged lesions were observed in the right lung on January 26. Meanwhile, new lesions appeared in the left lung.
Female, 45 years old, with a history of fever for 4 days, along with fatigue and paroxysmal cough; temperature: 37.6°C. She and the patient in Fig. 3.19 are a couple. She returned from Wuhan on January 20, 2020. Laboratory tests: WBC 4.24 × 10⁹/L, LYMPH% 26.25%. The patient had positive results on RT-PCR of pharyngeal swab and blood specimens on January 24, 2020. CT scans on January 25, 2020 showed multiple small patch GGOs in the lower lobes and the left upper lobe. All lesions were located in the lung periphery and some were accompanied by vascular enlargement.

Female, 9 years old, with a history of fever for 1 day, along with occasional dry cough but no sputum; temperature: 38°C. She is the daughter of the patients in Figs. 3.19 and 3.20. She returned from Wuhan with her parents in the same car on January 20. Laboratory tests: WBC 5.70 × 10⁹/L, LYMPH% 41.80%, LYMPH 1.87 × 10⁹/L. The patient had positive results on RT-PCR of pharyngeal swab and blood specimens January 24, 2020. CT scans on January 26, 2020 showed multiple, small, and circle GGOs in the lower lobes.
Fig. 3.22 Female, 51 years old, with a history of fever for 2 days and paroxysmal cough for 1 day; temperature: 38°C. She is the sister of the patient in Fig. 3.19 and was residing in Wuhan. Laboratory tests: WBC 3.82 × 10^9/L, LYMPH% 23.3%, NEUT% 81.51%. CT scans on January 26, 2020 showed GGOs with vascular enlargement in the dorsal segment of the right lower lobe.
Fig. 3.23 A 32-year-old female patient was residing in Wuhan and returned to Xi’an on January 21, 2020. She visited hospital without fever on January 27, 2020. Laboratory tests showed she had a positive result on RT-PCR, while WBC and N% were normal. (A) CT scans showed solid nodules of varied size. Some lesions were accompanied by halo signs and others were with smooth margins. (B) There were solid nodules with a subpleural distribution in the posterior segment of the lower lobes. Vascular enlargement was observed in the periphery of the right lower lobe, surrounded by exudative lesions.
COVID-19 nucleic acid test showed the positive result and the initial CT images found nothing.

The second CT scans showed emergence of slight nodules in the left lower lobe.

**Fig. 3.24** A 44-year-old male patient who was residing in Xi’an and had contact with the patient in Fig. 3.23. He developed fever and cough on January 26, 2020, and visited hospital the next day. Laboratory tests showed he had a positive result on RT-PCR, while WBC and N% were normal. (Left column) Initial CT scans showed there were no evident exudative lesions or consolidation. (Right column) Follow-up CT scans on January 31 showed emergence of new slight nodules in the left lower lobe.
Fig. 3.25 A 47-year-old man who developed fever, cough, expectoration, abdominal distention, and poor appetite on January 23, 2020. He visited hospital on January 27, 2020. Laboratory tests showed he had a positive result on RT-PCR, while WBC and N% were normal. CT scans showed multiple and mix GGOs of varied size with obscure margins in the subpleural area. The majority of lesions were quite small, but the lesions in the medial segment of the right middle lobe were massive.

Fig. 3.26 A 47-year-old female patient, who is the wife of the patient in Fig. 3.25, developed fever, cough, expectoration, abdominal distention, and poor appetite on January 27, 2020. She visited to hospital on January 29, 2020. Laboratory tests showed she had a positive result on RT-PCR, while WBC and N% were normal. CT scans showed a small amount of GGOs in the left lower lobe and along the bronchovascular bundles.
The first COVID-19 nucleic acid test showed a negative result. The second COVID-19 nucleic acid test also showed a negative result.

*Fig. 3.27* A 22-year-old man, who is the son of the patients in Figs. 3.25 and 3.26, developed fever on January 27, 2020. Nucleic acid detection was performed twice and had negative results. Laboratory tests showed WBC 11.75, NEUT 9.38, N% 79.8%, LYM 1.13, LYM% 9.6%. CT scans showed patch GGOs with obscure margins and air bronchogram signs in the left lower lobe. Follow-up CT scans showed enlarged lesions in the left lower lobe and emergence of new exudation lesions.
Female, 22 years old, with a history of fever for 3 days, but no cough, expectoration, sore throat, or other symptoms; temperature: 38.1°C. She drove to Wuhan and stayed there for 9h on January 18. Laboratory tests: WBC $6.5 \times 10^9$/L, LYMPH% 18.6%. (A) CT scans on January 27, 2020 showed massive mix-pattern consolidation surrounded by GGOs in the right lower lobe. (B) Follow-up CT scans showed new, multiple, and small patch exudative lesions in the right lower lobe. Additionally, coexistence of absorption of primary lesions and emergence of enlarged ones were observed in the right lower lobe.
Fig. 3.29 Male, 60 years old, with a history of fever for 1 day and fatigue for 5 days; temperature: 38.5°C. He had returned home from Wuhan 5 days previously. Laboratory tests: CRP 43.15 mg/L, hs-CRP > 5.00 mg/L, ESR 15 mm/h. (A) CT scans on January 23, 2020 showed multiple, bilateral, and patch consolidation lesions of varied size surrounded by GGOs. There were reticular patterns and air bronchogram signs inside lesions. (B) Follow-up CT scans on January 28, 2020 showed lesions in the right lower lobe were partially absorbed and changed into fibrosis. There were new, bilateral, and patch GGOs and consolidation lesions with a peripheral lung and subpleural distribution. Compared with the CT images of 5 days before, we found the location of horizontal fissure was different.
Fig. 3.30  Female, 64 years old, with a history of fever for 6 days, along with cough. She lived in Wuhan and was a community medical worker. Initial CT images indicated slightly thickening lung markings. She was treated for upper respiratory tract virus infection without improvement. The temperature fluctuated between 37.5°C and 38.6°C and she felt pronounced fatigue. She developed a more severe cough and occasional dyspnea 3 days later. Follow-up CT scans on day 6 after beginning with fever showed that the shape and range of lesions changed greatly. In addition, fibrosis lesions were observed in the subpleural area of bilateral lower lobes.