Analysis of Characteristics of Bedside Chest Radiography in Critically Ill COVID-19 Patients

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Objective: To analyze the characteristics of bedside chest radiography in critically ill COVID-19 patients.

Methods: Bedside chest x-ray data of 8 severe cases with COVID-19 during hospitalization were collected consecutively. The disease was divided into three stages, including early stage (1-4 days), progression stage (5-10 days), and recovery stage (≥11 days). Two radiologists individually analyzed the chest radiographs by a double-blind method and compared the changes of the distribution, morphology, and boundary of the pulmonary lesions, as well as mediastinum and heart shadow of different disease stages.

Results: Among these cases, 1 case was in the early stage, 6 cases were in the progressive stage, and 1 case was in the recovery stage. A total of 68 bedside chest radiographs were obtained. In early stage, lesions were mainly in the external zone of both lungs with increased lamellar density. In progression stage, the lesions involved multiple pulmonary segments and lobes with extensive infiltrating changes. The heart shadow was mildly to moderately enlarged. In recovery stage, the broad distribution of striated density increased in both lungs, and the heart shadow remained enlarged.

Conclusions: The pulmonary lesions in critically ill COVID-19 patients were characterized by rapid progression, extensive distribution, varied manifestations, and possible concomitant cardiac dilatation. Bedside chest radiograph examination could provide certain significance in the follow-up of critically ill patients.

Key words: COVID-19; Pneumonia; Critical cases; Bedside chest radiography

A novel human coronavirus causing severe respiratory symptoms was identified late December 2019, and later it was named ‘COVID-19’ by World Health Organization (WHO). As of April 4, 2020, more than 1.1 million COVID-19 cases are confirmed in 113 countries and regions, bring to a total of 1,100,283 infection cases and total death toll to 58,929, which posts a serious public health risk worldwide [1]. The infection mainly causes respiratory symptoms and involves lungs. The lung injury usually presents with diffuse tissue injury, extensive exudation, bleeding, destruction of alveolar epithelium, reactive hyperplasia, macrophages dominated inflammatory response, and fibrosis. While most of the COVID-19 patients had mild clinical symptoms, some patients rapidly developed acute respiratory distress syndrome (ARDS) within a few days, with a mortality rate of up to 15% [2]. Bedside chest radiograph is the modality of choice to diagnose and follow up with severe COVID-19 patients. It could provide useful information for physicians to identify the frequent changes of imaging characteristics during disease course [3]. In this study, we analyzed and elaborated the bedside chest radiographic features of critically ill COVID-19 patients in the designated hospital.

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Material and Methods

Patients

This study was approved by the ethics committee of public health clinical center, Fudan University. All patients or their immediate family member signed the written consent. Inclusion criteria were: (1) Hospitalized critically ill COVID-19 patients, who were confirmed by Centers for Disease Control, Shanghai, China through novel coronavirus nucleic acid antibody test. (2) Patients with complete clinical data and standard quality of the bedside chest radiographs. Exclusion criteria: (1) non-critically ill COVID-19 patients, or bedside chest radiographs were absent or with poor quality. (2) patients with pneumonia caused by bacteria and other viral pathogens. Finally, eight COVID-19 patients in critically ill condition were recruited. Out of 8 patients, 7 were male and 1 was female. Age ranges between 25 to 82 years. General information including age, sex, time of onset, body temperature, heart rate, respiratory rate, laboratory tests, and blood gas analysis were included. Brachial artery systolic and diastolic blood pressure were measured 3 times in a resting state, and the mean value was calculated. In addition, the usage of ventilator, ECMO, AKI stage, and Glasgow score when admitted were also recorded.

Image analysis

Each patient underwent a bedside chest radiography once a day. The digital radiography (DR) system of uDR370i mobile was used, and all images were uploaded to Picture Archiving and Communication Systems (PACS) of the hospital for review. The tube voltage was 40kv-150kv and tube current was 25ma-400ma.

Two radiologists independently read the chest radiographs. A discussion would be carried out to reach a consensus if there were different opinions. The contents of the analysis included the distribution, morphology, and boundary of the lung lesions, as well as mediastinum, heart, and pleura. Chest radiographs were categorized by the clinical course: (1) early stage, 1-4 days after onset; (2) progression stage, 5-10 days after onset; (3) recovery stage, beyond 11 days.

Definitions

Acute respiratory distress syndrome (ARDS) and shock were defined according to the interim guidance of WHO for novel coronavirus [4]. Acute kidney injury was identified and classified based on the highest serum creatinine level or urine output criteria according to the kidney disease improving global outcomes classification [5]. Hypoxemia was defined as arterial oxygen tension (PaO2) over inspiratory oxygen fraction (FIO2) of less than 300 mm Hg [6].

Statistical analysis

The categorical variable was summarized as n/N (%), where N is the total number of patients with available data, while the continuous variable was summarized as mean with standard deviation (SD) or median with interquartile range (IQR). Statistical analyses were conducted using SPSS version 13 software for Windows (SPSS Inc.).

Results

General information and laboratory inspection

All 8 COVID-19 patients were initially admitted for fever and dry cough. Four patients had a history of hypertension or coronary heart disease. At admission, the mean time of symptomatic onset was 6.5 days (2-14 days). Two patients had tachycardia (heart rate>100 beats/minute) and two patients had respiratory rate >25 breaths/minute. Acute kidney injury (AKI) was observed in 5 patients, and Glasgow coma score was 3 in all 8 patients.

Within 4 days after admission, 7 patients developed ARDS. Among them, 6 patients underwent tracheotomy and ventilator assisted ventilation, and 1 underwent extra-corporeal membrane oxygenation (ECMO) (Table 1).

Laboratory examinations was carried out on admission. The results revealed that 2 cases had increased white blood cell count (> 9.5 x 10^9/L), 6 cases had high neutrophil count percentage (>75%), 7 cases had low lymphocytes percentage (<20%), 2 cases had reduced platelet count (<125 x 10^9/L), 8 cases had increased CD3 ratio (>84%), 7 cases had high CD4 ratio (> 60%), and 2 cases had high CD8 ratio (> 81%). C-reactive protein (CRP) was found to be increased in all 8 cases (> 10.00 mg/L), and B-type natriuretic peptide (B-type natriuretic peptide) increased in 3 cases (>100 pg/ml), and prolonged prothrombin time was found in 6 cases (>13.7 seconds) (Table 2).

Imaging findings

A total of 68 chest radiographs were obtained from 8 patients, including 1 case of early stage, 6 cases of progression stage, and 1 case of recovery stage.

Early stage

The chest radiographs of COVID-19 patient in early stage showed increased lamellar density, which was heterogeneous and mainly distributed in the external of bilateral lungs. Cardiac shadow was found to be enlarged with a cardiothoracic ratio of 0.56, and blunting of the
costophrenic angles was observed. On the second day, the re-check radiograph showed that the lesions in the right lung field was slightly reduced in sized with an increased transmittance, while the lesions in the left lung were not significantly changed. On the 4th day, the third radiograph showed the lesions in the right upper lobe were significantly reduced in size and increased in transmittance with line-like high density, while the lesions in the right lower lobe and left lung were not significantly changed (Fig. 1).

**Progression stage**

A total of 6 cases were in progression stage. All chest radiographs showed extensive infiltration of multiple lung segments and lobes, and patchy and fragmental flocculent high-density shadows were mainly distributed in the bilateral middle and lower lobes. All patients had moderate cardiomegaly with a cardiothoracic ratio of 0.52-0.56. However, there were slightly discrepancies among them. One case showed the densities in the middle and lower lobes were significantly higher than that of the upper lobe, and the densities were heterogeneous. Other 2 cases showed frosted hyaline changes in the right upper lobe. Blunting of the unilateral or bilateral costophrenic angles were shown on all 3 cases.

On the 2nd day, 5 cases underwent the re-check digital radiography (DR). The radiographs showed that the number, size, and the density of lesions in the middle and lower lobe were increased in 2 cases and slightly decreased in other 2 cases. One case did not show obvious changes.

On 4th days, 5 cases underwent the re-check digital radiography. Two cases showed similar findings compared to the previous film; 1 case showed unchanged number and size of lesions but decreased density; 1 cases showed slightly smaller lesions in the right upper lobe with decreased density and increased transparency, and a new blurred high-density patch was found in the left upper lobe; Another 1 case had unchanged number and size of lesions but significant increased density in the left lower lobe (Fig. 2).
Recovery stage

One case was in recovery stage. On the first day, the chest radiograph findings include right upper lobe patchy and slightly high-density fuzzy shadows, bilateral lungs striated and denser shadows with slightly fuzzy edges throughout, blunting of costophrenic angles, and cardiomegaly with a cardiothoracic proportion of 0.55 (Fig. 3A). On the 4th days, the chest radiograph showed the density in the right upper field was significant decreased, while a new high-density line-like shadow and a new patchy high-density shadow were observed in the left lower lobe (Fig. 3B).

Discussion

Our case series of chest radiographs showed that critically ill COVID-19 patients had rapidly changing clinical course. In early and progression stages, the numbers, size, and density of the pulmonary lesions were dynamic. In the recovery stage, the chest radiographs showed decreased density and numbers of lesion, along with visible mesh and line-like high-density shadows. Noticeably, all cases in this group also exhibited with mild to moderate cardiomegaly. This may result from cardiac hypertrophy, degeneration, and necrosis, and further lead to enlargement of the cardiac cavity and cardiac dysfunction in COVID-19 patients [7]. Pathological changes of different degrees of lung consolidation are the basic findings of chest imaging, and both chest CT and chest radiograph are useful for the diagnosis of COVID-19 [8]. Although chest radiograph was relatively insensitive to diagnosis the early stage of the disease compared to high-resolution chest CT, bedside chest radiographs are more valuable for the real-time evaluation and follow-up of critically ill cases [9].

The spread of new coronavirus (SARS-Cov-2) follows a different pattern than previous respiratory viruses, posing a serious public health risk worldwide [1]. The studies focusing on pulmonary pathological features of COVID-19 cases have not been well established. Some recent Chinese studies found that COVID-19 pulmonary injuries mainly present with diffuse tissue injury, extensive exudation, bleeding, destruction of alveolar epithelium, reactive hyperplasia, macrophages dominated inflammatory response, and fibrosis [2]. The chest radiographs of the critically ill patients showed multi-lobe and segments of bilateral lungs were involved, especially in peripheral lower lobes. The lesions featured as ground-glass opacities, consolidation, or both. There is a hypothesis that those pathological changes may due to the alveolar macrophages expressing ACE2, which could be regarded as a “target” and further activated by macrophages. The activated macrophages then triggered the secretion of a series of inflammatory factors, causing inflammatory damage and fibrosis of the lungs. Further pathological examination also found serous fluid, fibrin exudate, and transparent membrane in alveolar cavity [10].

| Patient | Age (years) | Gender | Days of onset | Temperature (°C) | HR (bpm) | RR (breaths/min) | SBP (mm Hg) | DBP (mm Hg) | Ventilator (Yes/No) | ECMO (Yes/No) | AKI stage | Glasgow score |
|---------|-------------|--------|---------------|------------------|----------|------------------|-------------|-------------|---------------------|---------------|-----------|----------------|
| 1       | 81          | M      | 2             | 36.6             | 124      | 30               | 135         | 85          | Yes                 | No            | 3         | 3              |
| 2       | 68          | M      | 14            | 36.5             | 79       | 29               | 116         | 70          | Yes                 | No            | 1         | 3              |
| 3       | 80          | M      | 1             | 36               | 79       | 19               | 151         | 80          | Yes                 | No            | 1         | 3              |
| 4       | 71          | M      | 6             | 37.8             | 103      | 20               | 100         | 50          | Yes                 | No            | 2         | 3              |
| 5       | 78          | M      | 7             | 37.5             | 92       | 18               | 126         | 75          | No                  | No            | 0         | 3              |
| 6       | 25          | M      | 8             | 36.7             | 78       | 16               | 125         | 62          | Yes                 | Yes           | 1         | 3              |
| 7       | 75          | M      | 12            | 37.4             | 90       | 17               | 139         | 80          | Yes                 | No            | 0         | 3              |
| 8       | 63          | F      | 2             | 36.5             | 79       | 19               | 125         | 63          | No                  | No            | 0         | 3              |

HR, heart rate; RR, respiratory rate; SBP, systolic blood pressure; DBP, diastolic blood pressure; ECMO, extra-corporeal membrane oxygenation; AKI, acute kidney injury; 1mmHg=0.133kPa
Conclusion
The pulmonary lesions in critically ill COVID-19 patients were characterized by rapid progression, extensive lesion range and various manifestations, and often with the concomitant cardiomegaly. Bedside chest radiograph examination plays a crucial role in the real-time evaluation and follow-up of critically ill patients.

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Conflict of Interest
The authors have no conflict of interest to declare.

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