The Clinical and Chest CT Features Associated With Severe and Critical COVID-19 Pneumonia

Kunhua Li, MS, † Jiong Wu, MS, ‡ Faqi Wu, MS, ‡ Dajing Guo, MD, † Linli Chen, MS, * Zheng Fang, MS, * and Chuanming Li, MD*

Objective: The aim of this study was to investigate the clinical and computed tomography (CT) features associated with severe and critical coronavirus disease 2019 (COVID-19) pneumonia.

Materials and Methods: Eighty-three patients with COVID-19 pneumonia including 25 severe/critical cases and 58 ordinary cases were enrolled. The chest CT images and clinical data of them were reviewed and compared. The risk factors associated with disease severity were analyzed.

Results: Compared with the ordinary patients, the severe/critical patients had older ages, higher incidence of comorbidities, cough, expectoration, chest pain, and dyspnea. The incidences of consolidation, linear opacities, crazy-paving pattern, bronchial wall thickening, and bronchial wall thickening in severe/critical patients were significantly higher than those of the ordinary patients. Besides, severe/critical patients showed higher incidences of lymph node enlargement, pericardial effusion, and pleural effusion than the ordinary patients. The CT scores of severe/critical patients were significantly higher than those of the ordinary patients (P < 0.001). Receiver operating characteristic curve showed that the sensitivity and specificity of CT score were 80.0% and 82.8%, respectively, for the discrimination of the 2 types. The clinical factors of age older than 50 years, comorbidities, dyspnea, chest pain, cough, expectoration, decreased lymphocytes, and increased inflammation indicators were risk factors for severe/critical COVID-19 pneumonia. Computed tomography findings of consolidation, linear opacities, crazy-paving pattern, bronchial wall thickening, high CT scores, and extrapulmonary lesions were features of severe/critical COVID-19 pneumonia.

Conclusions: There are significant differences in clinical symptoms, laboratory examinations, and CT manifestations between the ordinary patients and the severe/critical patients. Many factors are related to the severity of the disease, which can help clinicians to judge the severity of the patient and evaluate the prognosis.

Key Words: COVID-19, SARS-CoV-2, acute respiratory disease, pneumonia, severity, risk factor

MATERIALS AND METHODS

Our institutional review board approved this retrospective study, and the requirement for informed consent was waived.

Study Population

Ninety patients were diagnosed as COVID-19 according to the Diagnosis and Treatment of Novel Coronavirus Pneumonia (Fifth Trial Version) of China in our hospitals from January 2020 to February 2020 in this study. The inclusion criteria were as follows: (1) having an epidemiological history; (2) having one of the following etiological evidences—(a) real-time reverse-transcriptase polymerase-chain-reaction detection of SARS-CoV-2 nucleic acid positive in throat swabs or lower respiratory tract, and (b) the virus gene sequencing of respiratory or blood samples was highly homologous with SARS-CoV-2; and (3) having undergone thin-section CT at least one time. The ordinary patients all had fever or other respiratory symptoms with CT manifestations of pneumonia. The severe/critical patients met any of the following conditions: (1) respiratory rate of 30 breaths per minute or greater; (2) finger tip oxygen saturation of 93% or less in a resting state; (3) arterial oxygen tension (PaO2)/inspiratory oxygen fraction (FiO2) of 300 mm Hg or less; (4) shock occurred; and (6) patients with other organ failure, or even death. The successful treatment of severe and critical COVID-19 pneumonia. Therefore, in this study, we compared the clinical and computed tomography (CT) features of 80 ordinary COVID-19 cases and 25 severe/critical cases to explore the related factors of severe/critical patients.

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From the *Department of Radiology, the Second Affiliated Hospital of Chongqing Medical University; †Department of Radiology, Chongqing Three Gorges Central Hospital, Chongqing; and ‡Department of Medical Service, Yanzhong Central Hospital of Gangcheng District, Jinan, China.

Kunhua Li and Jiong Wu contributed equally to this work.

Correspondence to: Chuanming Li, MD, Department of Radiology, The Second Affiliated Hospital of Chongqing Medical University, No. 74 Linjiang Rd, Yuzhong District, Chongqing 400010, China. E-mail: lichuanming@hospital.cqmu.edu.cn.

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CT Examinations and Imaging Evaluation

All scans were obtained using a 16-row multidetector scanner (Siemens Sensation 16, Erlangen, Germany) with the following parameters:
120 kVp, 150 mA, 1.5 mm collimation, 1.35:1 pitch, sharp kernel (B80f), reconstruction matrix of 512 × 512, slice thickness of 1.0 mm, and high spatial resolution algorithm. Two chest radiologists with 10 and 8 years of experience who were blinded to the clinical data evaluated the CT findings in consensus. For each of the 83 patients, the initial chest CT images were evaluated for the following characteristics based on the Fleischner Society Nomenclature recommendations and similar studies: ground glass opacity (GGO), consolidation, nodule, reticulation, interlobular septal thickening, crazy-paving pattern, linear opacities, subpleural curvilinear line, bronchial wall thickening, lymph node enlargement, pleural effusion, and pericardial effusion. The “spider web sign” was defined as a triangular or angular GGO in the subpleural lung with the internal interlobular septa thickened like a net; the adjacent pleura was pulled and formed a spider-web-like shape in the corner. To quantify the extent of lesions, a thin-section CT score was assigned on the basis of all abnormal areas involved. Each lobe was assigned a score that was based on the following: score 0, 0% involvement; score 1, less than 5% involvement; score 2, 5% to 25% involvement; score 3, 26% to 49% involvement; score 4, 50% to 75% involvement; and score 5, greater than 75% involvement. There was a score of 0 to 5 for each lobe, with a total possible score of 0 to 25. The software of the Pulmonary Infection Assistant Diagnosis (V1.7.0.1, Dexin Medical Imaging Technology Co, Ltd, Xian City, Shaanxi Province, China) was applied to acquire the 3D visualization of CT-VRT by automatically segmenting the whole lung and pulmonary lesions, then further precise manual correction was made.

### Statistical Analysis

All statistical analyses were performed using SPSS statistical software (version 20.0, IBM) and MedCalc software (version 15.2.2, MedCalc Software). Categorical variables were described as frequency rates and percentages, and quantitative variables were described using mean (SD) or median (interquartile range) values. The χ² test and Fisher exact test were used for categorical variables. Quantitative variables were tested for normality using Shapiro-Wilk tests. Normally distributed data were analyzed by independent sample t test; otherwise, the Mann-Whitney U test was used. Receiver operating characteristic (ROC) analysis was used to determine the clinical value of CT scores in distinguishing the ordinary and severe/critical types, and find the corresponding cutoff value. For logistic regression analysis, quantitative variables were transformed into categorical variables according to their reference ranges or the cutoff values provided by ROC analysis. Then a univariate logistic regression analysis was performed to identify the clinical and CT features associated with severe/critical COVID-19 pneumonia cases. P values less than 0.05 were considered as statistically significant.

### RESULTS

#### Characteristics and Clinical Manifestations

The most common symptoms in 83 patients with COVID-19 pneumonia were fever, cough, expectoration, and myalgia. Less common symptoms were headache, dyspnea, abdominal pain/diarrhea, pharyngeal discomfort, and chest pain (Table 1). Twenty-five (30.1%) of them were severe/critical cases, and 58 (69.9%) of them were ordinary cases. Compared with the ordinary group, the severe/critical patients were significantly older (mean age, 53.7 years [SD, 12.3] vs 41.9 years [SD, 10.6]; P < 0.001) and had more comorbidities of diabetes mellitus and chronic obstructive pulmonary disease. No

### Table 1. Baseline Characteristics Between Severe/Critical Group and Ordinary Group

| Parameter                        | Total (n = 83) | Severe/Critical Group (n = 25) | Ordinary Group (n = 58) | P       |
|----------------------------------|---------------|--------------------------------|-------------------------|---------|
| Age, y                           | 45.5 (12.3)   | 53.7 (12.3)                     | 41.9 (10.6)             | <0.001  |
| Onset of symptoms to hospital, d | 7.00 (4.75–9.00) | 8.00 (6.00–12.00)            | 6.00 (3.00–8.50)       | 0.006   |
| Sex                              |               |                                |                         |         |
| Male                             | 44 (53.0%)    | 15 (60%)                       | 29 (50.0%)              | 0.402   |
| Female                           | 39 (47.0%)    | 10 (40%)                       | 29 (50.0%)              |         |
| Comorbidities                    |               |                                |                         |         |
| Diabetes mellitus                | 15 (18.1%)    | 11 (44.0%)                     | 4 (6.9%)                | <0.001  |
| Hypertension                     | 5 (6.0%)      | 2 (8.0%)                       | 3 (5.2%)                | 0.635   |
| COPD                             | 7 (8.7%)      | 7 (28.0%)                      | 0 (0.0%)                | <0.001  |
| Heart disease                    | 5 (6.0%)      | 4 (16.0%)                      | 1 (1.7%)                | 0.027   |
| Fever                            | 72 (86.7%)    | 22 (88.0%)                     | 50 (86.2%)              | 1.000   |
| Cough                            | 65 (78.3%)    | 24 (96.0%)                     | 41 (70.7%)              | 0.010   |
| Expectoration                    | 15 (18.1%)    | 9 (36.0%)                      | 6 (10.3%)               | 0.013   |
| Myalgia                          | 15 (18.1%)    | 5 (20.0%)                      | 10 (17.2%)              | 1.000   |
| Headache                         | 9 (10.8%)     | 3 (12.0%)                      | 6 (10.3%)               | 1.000   |
| Dyspnea                          | 9 (10.8%)     | 7 (28.0%)                      | 2 (3.4%)                | 0.004   |
| Abdominal pain/diarrhea          | 7 (8.4%)      | 2 (8.0%)                       | 5 (8.6%)                | 1.000   |
| Pharyngeal discomfort            | 6 (7.2%)      | 2 (8.0%)                       | 4 (6.9%)                | 1.000   |
| Chest pain                       | 5 (6.0%)      | 4 (16.0%)                      | 1 (1.7%)                | 0.027   |
| Temperature, °C                  | 37.5 (0.7)    | 38.0 (0.9)                     | 37.6 (0.6)              | 0.048   |
| Heart rate, beats per minute     | 90 (12)       | 92 (14)                        | 89 (11)                 | 0.437   |
| Respiratory rate                 | 20 (20–22)    | 21 (19.5–24.5)                 | 20 (20–22)              | 0.165   |
| Median arterial pressure, mm Hg  | 93.3 (86.0–101.0) | 91.0 (84.3–100.5)          | 93.3 (87.2–103.3)       | 0.204   |

Data are n (%), mean (SD), or median (interquartile range). *One patient who came to the hospital for health examination without symptom was not included in statistics. COPD, chronic obstructive pulmonary disease.
difference was observed in the proportion of men and women between the 2 groups. The median time from illness onset to hospital admission in severe/critical patients (8 days [6–12]) was significantly longer than those of the ordinary patients (6 days [3–8.5]) (P = 0.006). Compared with the ordinary patients, severe/critical patients had higher body temperature and higher incidences of cough, expectoration, dyspnea, and chest pain (Table 1). No significant differences of heart rate, respiratory rate, and arterial pressure were found between the 2 groups.

**Laboratory Parameters**

Compared with the ordinary patients, the severe/critical patients had increased neutrophil ratio, C-reactive protein, and procalcitonin, whereas decreased lymphocyte ratio and lymphocyte count (Table 2). White blood cell count and neutrophil count were numerically increased whereas decreased lymphocyte ratio and lymphocyte count (Table 2).

**Chest CT Findings**

The common chest CT features of both groups included GGO (81/83, 97.6%), linear opacities (54/83, 65.1%), consolidation (53/83, 63.9%), interlobular septal thickening (52/83, 62.7%), and crazy-paving (81/83, 97.6%), linear opacities (54/83, 65.1%), consolidation (53/83, 63.9%), and crazy-paving (81/83, 97.6%). The CT scores of the severe/critical patients were significantly higher than those of the ordinary patients (P < 0.001). The number of lung lobes involvement for severe/critical group was significantly higher than that of the ordinary group. For ROC analysis, the area under the ROC curve (AUC) of CT score was 0.87 (95% confidence interval, 0.78–0.94; P < 0.001) for the ordinary and severe/critical patients discrimination. When the cutoff value of CT score was 7, the sensitivity and specificity were 80.0% and 82.8%, respectively.

**Factors Associated With Severe/Critical COVID-19 Pneumonia**

Table 4 showed the results of univariate logistic regression analyses in relationship to severe/critical COVID-19 pneumonia. The clinical factors of age older than 50 years, comorbidities, dyspnea, chest pain, cough, expectoration, decreased lymphocytes, and increased inflammation indicators were risk factors for severe/critical COVID-19 pneumonia. Computed tomography findings of consolidation, linear opacities, crazy-paving pattern, bronchial wall thickening, high CT scores (>7), and extrapulmonary lesions were imaging features of severe/critical COVID-19 pneumonia.

**DISCUSSION**

Compared with the ordinary patients, the severe/critical patients have poor prognosis and high mortality.11,12 Studying the clinical and imaging characteristics of them is helpful to deepen our understanding of the mechanism of severe/critical conditions and promote its clinical diagnosis and treatment. The objective of this study was to identify clinical and CT features associated with severe/critical COVID-19 pneumonia by comparing severe/critical patients with ordinary patients. In this study, we found that the severe/critical patients were older and had more underlying diseases than the ordinary cases. The people

**TABLE 2. Laboratory Findings Between Severe/Critical Group and Ordinary Group**

| Parameter                  | Total (n = 83) | Severe/Critical Group (n = 25) | Ordinary Group (n = 58) | P     |
|----------------------------|---------------|-------------------------------|-------------------------|-------|
| White blood cell count, ×10⁹/L | 5.30 (4.20–6.80) | 5.50 (4.10–7.70) | 5.27 (4.20–6.30) | 0.634 |
| Increased                  | 9 (10.8%)     | 4 (16.0%)                     | 5 (8.6%)                | 0.544 |
| Decreased                  | 10 (12.0%)    | 4 (16.0%)                     | 6 (10.3%)               | 0.720 |
| Neutrophil ratio, %        | 71.52 (11.31) | 80.08 (9.51)                  | 67.84 (10.00)           | <0.001|
| Increased                  | 25 (30.1%)    | 16 (64.0%)                    | 9 (15.5%)               | <0.001|
| Decreased                  | 1 (1.2%)      | 0 (0.0%)                      | 1 (1.7%)                | 1.000 |
| Lymphocyte ratio, %        | 20.59 (9.39)  | 13.20 (6.27)                  | 23.78 (8.72)            | <0.001|
| Decreased                  | 40 (48.2%)    | 20 (80.0%)                    | 20 (34.5%)              | <0.001|
| Monocyte ratio, %          | 7.17 (2.93)   | 6.16 (4.00)                   | 7.60 (2.23)             | 0.100 |
| Increased                  | 15 (18.1%)    | 6 (24.0%)                     | 9 (15.5%)               | 0.542 |
| Decreased                  | 7 (8.4%)      | 6 (24.0%)                     | 1 (1.7%)                | 0.003 |
| Neutrophil count, ×10⁹/L   | 3.61 (2.67–5.56) | 4.36 (2.87–6.48) | 3.50 (2.64–4.46) | 0.218 |
| Increased                  | 17 (20.5%)    | 7 (28.0%)                     | 10 (17.2%)              | 0.265 |
| Decreased                  | 5 (6.0%)      | 2 (18.0%)                     | 3 (5.2%)                | 0.635 |
| Lymphocyte count, ×10⁹/L   | 1.05 (0.75–1.32) | 0.70 (0.44–0.95) | 1.23 (0.93–1.42) | <0.001|
| Decreased                  | 44 (53.0%)    | 22 (88.0%)                    | 22 (37.9%)              | <0.001|
| Monocyte count, ×10⁹/L     | 0.39 (0.27–0.53) | 0.34 (0.15–0.51) | 0.42 (0.29–0.53) | 0.045 |
| Increased                  | 12 (14.5%)    | 2 (8.0%)                      | 10 (17.2%)              | 0.448 |
| Decreased                  | 2 (2.4%)      | 2 (8.0%)                      | 0 (0.0%)                | 0.088 |
| C-reactive protein, mg/L   | 16.70 (3.58–60.87) | 89.20 (47.88–134.64) | 9.59 (20.27–29.89) | <0.001|
| Increased                  | 50 (60.2%)    | 23 (92.0%)                    | 27 (46.6%)              | <0.001|
| Procalcitonin, ng/mL       | 0.048 (0.032–0.085) | 0.086 (0.054–0.215) | 0.038 (0.028–0.068) | <0.001|
| Increased                  | 44 (53.0%)    | 21 (84.0%)                    | 23 (39.7%)              | <0.001|
| Oxyhemoglobin saturation, %| 97.00 (95.10–98.00) | 95.10 (92.90–97.45) | 97.00 (96.00–98.00) | 0.002 |
| Decreased                  | 16 (19.3%)    | 11 (44.0%)                    | 5 (8.6%)                | 0.001 |

Data are n (%), mean (SD), or median (interquartile range). Increased means over the upper limit of the reference range and decreased means below the lower limit of the reference range.
with higher age or poor state of health suffer from serious diseases, which may be the result of their weakened immune function.\textsuperscript{6} There was no difference in the ratio of men and women between the 2 groups, indicating that sex was not a risk factor for disease severity.\textsuperscript{14} Compared with the ordinary group, the severe/critical group had higher incidences of chest pain and dyspnea. Chest pain may result from the inflammatory affection of the pleura. Dyspnea is related to the severe damage to alveoli in the severe/critical group. The high body temperature may indicate that the immune system of severe/critical patients was highly activated. The occurrence of these symptoms could help clinicians identify the disease severity in clinical practice.

In our study, there were multiple laboratory indicator differences between the ordinary and severe/critical group. The decrease of lymphocytes in the severe/critical patients indicates that a large number of immune cells are consumed and the immune function is inhibited. Damage to lymphocytes may be critical in the exacerbations of patients, and the decreased lymphocytes could be used as an important index in the evaluation of disease severity.\textsuperscript{15} The increased values of neutrophil ratio, C-reactive protein, and procalcitonin in severe/critical group may be related to cytokine storm induced by virus invasion and comorbid with other kinds of infections, which was supported by the recent studies.\textsuperscript{6} Timely prevention of infection may help reduce complication and mortality.

Chest CT can accurately evaluate the type and extent of lung lesions. In this study, we found that the most common CT findings were GGO, consolidation, crazy-paving pattern, and "spider web sign" for both groups of COVID-19 pneumonia. Compared with ordinary groups, consolidation was significantly more frequent in severe/critical patients, which indicates that the alveoli are completely filled by inflammatory exudation. This usually means that the virus diffuses into the respiratory epithelium, leading to necrotizing bronchitis and diffuse alveolar damage.\textsuperscript{16,17}

\begin{table}
\centering
\caption{CT Features Between Severe/Critical Group and Ordinary Group}
\begin{tabular}{lccccc}
\hline
Parameter & Total (n = 83) & Severe/Critical Group (n = 25) & Ordinary Group (n = 58) & \(P\) \\
\hline
CT score & 5 (4–8) & 11 (8–15.5) & 5 (2.5–5) & <0.001 \\
GGO & 81 (97.6\%) & 25 (100.0\%) & 56 (96.6\%) & 1.000 \\
Linear opacities & 54 (65.1\%) & 23 (92.0\%) & 31 (53.4\%) & 0.001 \\
Consolidation & 53 (63.9\%) & 22 (88.0\%) & 31 (53.4\%) & 0.003 \\
Interlobular septal thickening & 52 (62.7\%) & 19 (76.0\%) & 33 (56.9\%) & 0.099 \\
Crazy-paving pattern & 30 (36.1\%) & 14 (56.0\%) & 16 (27.6\%) & 0.013 \\
Spider web sign & 21 (25.3\%) & 4 (16.0\%) & 17 (29.3\%) & 0.201 \\
Bronchial wall thickening & 19 (22.9\%) & 16 (64.0\%) & 3 (5.2\%) & <0.001 \\
Subpleural curvilinear line & 17 (20.5\%) & 8 (32.0\%) & 9 (15.5\%) & 0.088 \\
Nodule & 6 (7.2\%) & 3 (12.0\%) & 3 (5.2\%) & 0.359 \\
Reticulation & 4 (4.8\%) & 3 (12.0\%) & 1 (1.7\%) & 0.079 \\
Lymph node enlargement & 7 (8.4\%) & 7 (28.0\%) & 0 (0.0\%) & <0.001 \\
Pleural effusion & 7 (8.4\%) & 7 (28.0\%) & 0 (0.0\%) & <0.001 \\
Pericardial effusion & 4 (4.8\%) & 4 (16.0\%) & 0 (0.0\%) & 0.007 \\
Frequency of lobe involvement & & & & \\
Right upper lobe & 62 (74.7\%) & 23 (92.0\%) & 39 (67.2\%) & 0.017 \\
Right middle lobe & 61 (73.5\%) & 22 (88.0\%) & 39 (67.2\%) & 0.049 \\
Right lower lobe & 78 (94.0\%) & 25 (100.0\%) & 53 (91.4\%) & 0.316 \\
Left upper lobe & 71 (85.5\%) & 24 (96.0\%) & 47 (81.0\%) & 0.150 \\
Left lower lobe & 80 (96.4\%) & 25 (100.0\%) & 55 (94.8\%) & 0.550 \\
Upper lobe & 74 (89.2\%) & 24 (96.0\%) & 50 (86.2\%) & 0.351 \\
Lower lobe & 80 (96.4\%) & 25 (100.0\%) & 55 (94.8\%) & 0.550 \\
Bilateral lung disease & 79 (95.2\%) & 25 (100.0\%) & 54 (93.1\%) & 0.310 \\
No. lobes involved & 5 (4–5) & 5 (5–5) & 5 (3–5) & 0.003 \\
\hline
\end{tabular}
\label{tab:ct_features}
\end{table}

Data are n (%) and median (interquartile range). CT, computed tomography; GGO, ground glass opacity.

FIGURE 1. Chest CT of a 44-year-old man with ordinary COVID-19 pneumonia (CT score = 5). A, An axial CT image showed multiple small regions of subpleural GGO with superimposed interlobular and intralobular septal thickening. B, 3D visualization of CT-VRT showed the extent of GGO with scattered pattern.
Severe/critical patients showed more lymph node enlargement, pericardial effusion, and pleural effusion. These extrapulmonary lesions may indicate the occurrence of severe inflammation. Although GGO is the most common CT feature of COVID-19 pneumonia, no statistical incidence difference was observed between our 2 groups. The CT scores of the severe/critical group were significantly higher than those of the ordinary group. It can accurately distinguish the severe/critical patients from the ordinary patients (AUC > 0.87), which is helpful for the judgment of clinical condition and has important clinical value. To sum up, CT can evaluate the severity of the disease, which is of great significance for the diagnosis and follow-up of COVID-19 pneumonia.

This study has several limitations. First, the data of the 2 groups were not balanced, and the sample size of the severe/critical group was relatively small. Further studies with more patients, especially severe/critical patients, are warranted. Second, because most patients remain in the hospital at the time of submission, it is difficult to assess the risk factors for poor outcomes. Finally, none of the patients had a lung biopsy or autopsy to reflect the histopathological changes.

### TABLE 4. Univariate Logistic Analysis of Clinical and CT Features for Severe/Critical COVID-19 Pneumonia

| Parameter                           | Odds Ratio | P     |
|-------------------------------------|------------|-------|
| Age > 50 y                          | 7.596      | <0.001|
| Comorbidities                       | 10.607     | <0.001|
| Dyspnea                             | 10.899     | 0.005 |
| Chest pain                          | 10.857     | 0.038 |
| Cough                               | 9.951      | 0.030 |
| Expectoration                       | 4.875      | 0.008 |
| Neutrophil ratio increased          | 9.679      | <0.001|
| Lymphocyte ratio decreased          | 7.600      | <0.001|
| Monocyte ratio decreased            | 18.000     | 0.009 |
| Lymphocyte count decreased          | 12.000     | <0.001|
| C-reactive protein increased        | 13.204     | 0.001 |
| Procalcitonin increased             | 7.989      | 0.001 |
| Oxyhemoglobin saturation decreased  | 8.329      | <0.001|
| CT score > 7                        | 19.200     | <0.001|
| Consolidation                       | 6.387      | 0.006 |
| Crazy-paving pattern                | 3.341      | 0.016 |
| Linear opacities                    | 10.016     | 0.003 |
| Bronchial wall thickening           | 32.593     | <0.001|
| Right upper lobe                    | 5.603      | 0.029 |
| Right middle lobe                   | 3.573      | 0.060 |

Data in parentheses are 95% confidence intervals. CT, computed tomography; COVID-19, coronavirus disease 2019.

**FIGURE 2.** Chest CT findings of severe/critical COVID-19 pneumonia (CT score = 18), a 60-year-old man with dyspnea and pleural effusion. A, An axial CT image showed diffuse large regions of crazy-paving pattern (GGO with superimposed interlobular and intralobular septal thickening) with partial consolidation and bronchial wall thickening. B, 3D visualization of CT-VRT showed the diffuse extent of GGO and consolidation.

In conclusion, in this study, we found that the clinical factors of age older than 50 years, comorbidities, dyspnea, chest pain, cough, expectoration, decreased lymphocytes, and increased inflammation indicators may be risk factors for severe/critical COVID-19 pneumonia. Computed tomography findings of consolidation, linear opacities, crazy-paving pattern, bronchial wall thickening, high CT scores, and extrapulmonary lesions may be features of severe/critical COVID-19 pneumonia. Computed tomography plays an important role in the diagnosis and disease severity evaluation of this disease.

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