Relation Between Chest CT Findings and Clinical Conditions of Coronavirus Disease (COVID-19) Pneumonia: A Multicenter Study

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OBJECTIVE. The increasing number of cases of confirmed coronavirus disease (COVID-19) in China is striking. The purpose of this study was to investigate the relation between chest CT findings and the clinical conditions of COVID-19 pneumonia.

MATERIALS AND METHODS. Data on 101 cases of COVID-19 pneumonia were retrospectively collected from four institutions in Hunan, China. Basic clinical characteristics and detailed imaging features were evaluated and compared between two groups on the basis of clinical status: nonemergency (mild or common disease) and emergency (severe or fatal disease).

RESULTS. Patients 21–50 years old accounted for most (70.2%) of the cohort, and five (5.0%) patients had disease associated with a family outbreak. Most patients (78.2%) had fever as the onset symptom. Most patients with COVID-19 pneumonia had typical imaging features, such as ground-glass opacities (GGO) (87 [86.1%]) or mixed GGO and consolidation (65 [64.4%]), vascular enlargement in the lesion (72 [71.3%]), and traction bronchiectasis (53 [52.5%]). Lesions present on CT images were more likely to have a peripheral distribution (88 [87.1%]) and bilateral involvement (83 [82.2%]) and be lower lung predominant (55 [54.5%]) and multifocal (55 [54.5%]). Patients in the emergency group were older than those in the nonemergency group. Architectural distortion, traction bronchiectasis, and CT involvement score aided in evaluation of the severity and extent of the disease.

CONCLUSION. Patients with confirmed COVID-19 pneumonia have typical imaging features that can be helpful in early screening of highly suspected cases and in evaluation of the severity and extent of disease. Most patients with COVID-19 pneumonia have GGO or mixed GGO and consolidation and vascular enlargement in the lesion. Lesions are more likely to have peripheral distribution and bilateral involvement and be lower lung predominant and multifocal. CT involvement score can help in evaluation of the severity and extent of the disease.

Keywords: coronavirus disease, COVID-19, CT, pneumonia, SARS-CoV-2

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In December 2019, a series of cases of pneumonia of unknown causation emerged in Wuhan, Hubei, China, and quickly raised intense attention around the world [1]. A novel bat-origin coronavirus, 2019 novel coronavirus, was identified by means of deep sequencing analysis [2]. The virus, named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [3], is phylogenetically closest to bat SARS-like coronavirus but in a separate clade, which means that a novel coronavirus is spreading [2]. As of February 17, 2020, 72,436 laboratory-confirmed cases were consecutively reported in 31 provinces (municipalities and regions) in China, including 11,741 severe cases, 1868 fatal cases, and 6242 suspected cases [4]. After the first reported case in Wuhan, several exported cases were confirmed in Thailand, Japan, South Korea, and the United States [5–8]. On January 31, 2020, the World Health Organization [9] declared the outbreak of coronavirus disease (COVID-19) a Public Health Emergency of International Concern. Given the striking speed of virus transmission, the ongoing COVID-19 outbreak has undoubtedly been linked to panicked memories of two previous betacoronavirus outbreaks in the 21st century: SARS-CoV [10, 11] and Middle East respiratory syndrome coronavirus (MERS-CoV) [12, 13].

SARS-CoV-2 proved to have the ability for efficient human-to-human transmission [14–16]. The explosion of confirmed cases of COVID-19 has been overwhelming, even though the mortality of COVID-19 is lower than that of SARS-CoV and MERS-CoV infections [17]. A curative vaccine has not yet been developed. Early detection and efficient control of the route of transmission (i.e., isolation of suspected cases, disinfection) are still the most effective way to fight the COVID-19 outbreak. The epidemiologic, laboratory, and clinical features of COVID-19 pneumonia have been described [2, 14, 17, 18]. A specific epidemiologic history (e.g., exposure to the Huanan seafood market in Wuhan) and a prodrome of fever and dry cough are highly indicative of infection with SARS-CoV-2 [18]. However, infections by other viruses, such as influenza A and influenza B, can cause the same clinical symptoms as COVID-19, which makes the clinical diagnosis of COVID-19 pneumonia difficult, especially during flu season. For the large number of cases of suspected COVID-19, laboratory detection is time-consuming and may not be available for all people with suspected infection owing to the shortage of test kits for SARS-CoV-2. These challenges increase the risk of spread by free movement of people with highly suspected disease. In addition, the laboratory test can have false-negative results.

Imaging plays an important role in the diagnosis and management of COVID-19 pneumonia. CT is considered the first-line imaging modality in highly suspected cases and is helpful for monitoring imaging changes during treatment. Therefore, CT has been identified as an efficient clinical diagnostic tool for people with suspected COVID-19 [19]. It has potential for identifying people with negative results of a reverse transcription–polymerase chain reaction (RT-PCR) assay but in whom COVID-19 is highly suspected [20, 21]. COVID-19 pneumonia is the most common clinical presentation of COVID-19. The findings on CT images may reflect the severity of disease. Previous studies [18, 22–24] have shown imaging features in small sample sizes. The detailed imaging features and differences in imaging features between the four clinical types (mild, common, severe, fatal) [19] have not been well studied for this disease.

The purpose of this study was to clarify the chest CT features in laboratory-confirmed cases of COVID-19 to further help clinicians screen for suspected COVID-19 cases and evaluate the confirmed cases.

Materials and Methods

This study received medical ethical committee approval, and the requirement for patient informed consent was waived in accordance with Council for International Organizations of Medical Sciences guidelines.

Patients

We retrospectively collected the records of patients with laboratory-confirmed COVID-19 in the database of the Radiology Quality Control Center, Hunan. The diagnosis of COVID-19 was determined with following methods: isolation of SARS-CoV-2 or at least two positive results of real-time RT-PCR assay for SARS-CoV-2 or a genetic sequence matched with SARS-CoV-2. A total of 101 patients with consecutively laboratory-confirmed COVID-19 (45 women, 56 men; mean age, 44.44 ± 12.32 [SD] years; median, 43 years; range, 17–75 years) who underwent CT in four cities in Hunan, China, were included in this study. The numbers of confirmed cases were as follows: 74 in Changsha, seven in YueYang, 10 in ChangDe, and 10 in XiangTan. All available clinical, laboratory, and epidemiologic data were collected for all patients. According to the guideline on COVID-19 (trial version 5) [19] issued by the China National Health Commission, patients were divided into four groups: those with mild-type, common-type, severe-type, and fatal-type disease. Because treatment regimens vary by disease type, we regrouped patients into nonemergency (mild and common types) and emergency (severe and fatal types) groups. All patients underwent CT after admission. The mean interval between admission and CT examination was 1 day (range, 0–7 days; median, 1 day).

Imaging Technique

All patients underwent scanning with the following four scanners: Anatom 16HD (Anke Medical Solutions), HiSpeed-Dual (GE Healthcare), 64-MDCT LightSpeed VCT (GE Healthcare), and Somatom Emotion (Siemens Healthcare). The acquisition parameters were set at 120 kVp; 100–200 mAs; pitch, 0.75–1.5; and collimation, 0.625–5 mm. All imaging data were reconstructed by use of a medium sharp reconstruction algorithm with a slice thickness of 0.625–5 mm. CT images were acquired at full inspiration with the patient in the supine position.

Imaging Interpretation

Two radiologists (5 and 15 years of experience) reviewed chest CT scans blindly and independently in consensus. All images were viewed with both lung (width, 1500 HU; level, –700 HU) and mediastinal (width, 350 HU; level, 40 HU) settings. We evaluated 14 imaging features defined in a previous study [25]: ground-glass opacities (GGO), consolidation, mixed GGO and consolidation, centrilobular nodules, architectural distortion, cavitation, tree-in-bud, bronchial wall thickening, reticulation, subpleural bands, traction bronchiectasis, intrathoracic lymph node enlargement, vascular enlargement in the lesion, and pleural effusions. We described four distributions: craniocaudal, transverse, lung region, and scattered. A CT score system was used to evaluate the extent of disease. The details of the imaging interpretation were described in our previous study [21].

Statistical Analysis

Continuous variables were presented as medians and compared by Mann-Whitney *U* test. Categoric variables were presented as numbers and percentages and were compared by chi-square or Fisher exact test between emergency and nonemergency groups. Two-sided $p < 0.05$ was considered statistically significant. All statistical analyses were performed with SPSS software (version 24.0, IBM).

Results

Clinical Characteristics

Among the 101 included patients, 87 (48 men, 39 women) were in the nonemergency group, and 14 (eight men, six women) were in the emergency group. The age distribution is shown in Table 1; 70.2% of the patients were 21–50 years old. Seventeen (16.8%) patients denied any direct exposure history to Wuhan or to people who had a direct exposure history to Wuhan (i.e., long-term exposure history to Wuhan, traveling in Wuhan before diagnosis). Among the 17 patients, 12 had an exposure history to patients with confirmed disease, and five denied any direct or indirect

TABLE 1: Basic Clinical and Epidemic Features

Feature	All Patients (*n* = 101)
Sex	
Male	56 (55.4)
Female	45 (44.6)
Age (y)	
Mean	44.44
Range	17–75
Age group (y)	
≤ 20	1 (1.0)
21–40	44 (43.6)
41–50	27 (26.6)
51–60	14 (13.9)
61–70	14 (13.9)
≥ 70	1 (1.0)

(Table 1 continues on next page)

TABLE 1: Basic Clinical and Epidemic Features (continued)

Feature	All Patients (*n* = 101)
Epidemiologic history	
Direct exposure	84 (83.2)
Indirect exposure	12 (11.9)
No exposure	5 (4.9)
Onset symptoms	
Fever	79 (78.2)
Cough	63 (62.4)
Myalgia or fatigue	17 (16.8)
Sore throat	12 (11.9)
Dyspnea	1 (1.0)
Diarrhea	3 (3.0)
Nausea and vomiting	2 (2.0)
More than one symptom	67 (66.3)
None	2 (2.0)
Underlying disease[a]	
Cardiovascular and cerebrovascular diseases	16 (15.8)
Surgical history	7 (6.9)
Digestive system disease	6 (5.9)
Respiratory system disease	5 (4.9)
Endocrine system disease	3 (3.0)
None	71 (70.3)

Note—Except for age (mean with SD in parentheses) data are number with percentage in parentheses.
[a]Some patients had more than one underlying disease.

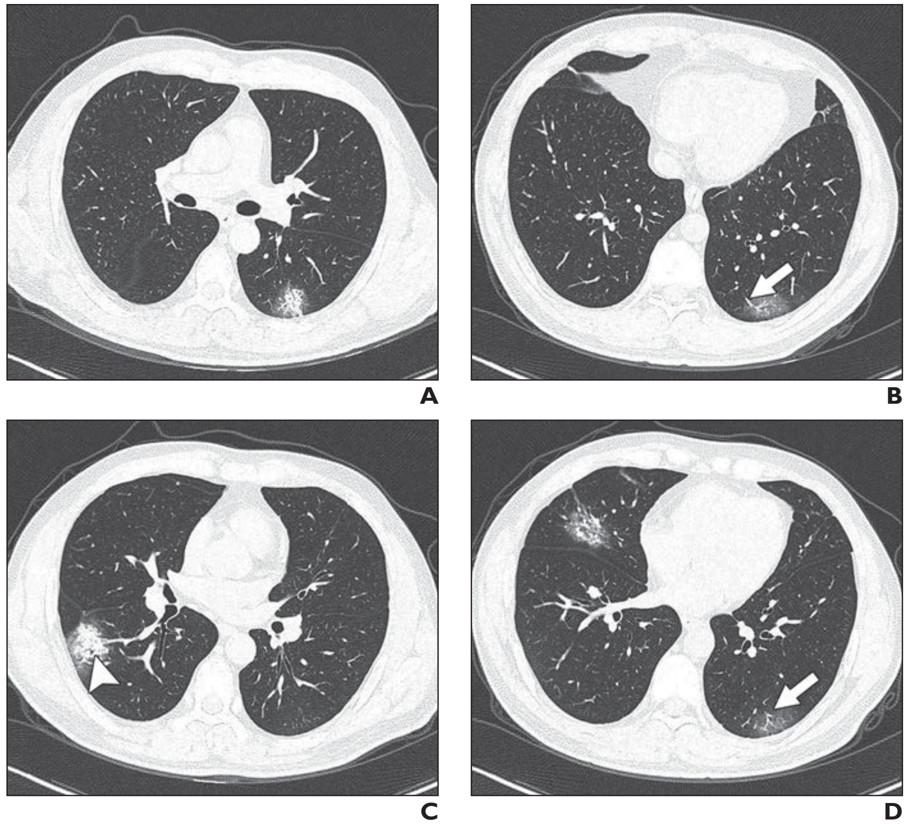

Fig. 1—37-year-old man with confirmed coronavirus disease (COVID-19), common type. Patient had short-term exposure history to Wuhan and onset symptoms of fever (38°C) and cough. CT was performed on day of admission.
A–D, CT images show bilateral multifocal ground-glass opacities (GGO) and mixed GGO and consolidation lesions. Traction bronchiectasis (*arrowhead*, **C**) and vascular enlargement (*arrow*, **B** and **D**) are also present. CT involvement score is 5.

exposure to patients with confirmed disease. Five (5.0%) patients had disease associated with a family outbreak (more than two cases confirmed in one family). Fever was the onset symptom for 78.2% of patients. The rates of other onset symptoms—cough, myalgia or fatigue, sore throat, dyspnea, diarrhea, and nausea and vomiting—are shown in Table 1. Two patients had no onset symptoms.

CT Findings

Most patients with COVID-19 had typical imaging features, such as GGO (87 [86.1%]), mixed GGO and consolidation (65 [64.4%]), vascular enlargement in the lesion (72 [71.3%]), and traction bronchiectasis (53 [52.5%]) (Figs. 1 and 2). Several lesion distribution patterns were identified (Table 2). Lesions present on CT images of patients with COVID-19 were more likely to have a peripheral distribution (88 [87.1%]), have bilateral involvement (83 [82.2%]), be lower lung predominant (55 [54.5%]), and be multifocal (55 [54.5%]). Other evaluated imaging features are shown in Table 2. The mean lung involvement score was 6.39. Cavitation and tree-in-bud were not present on the images in our study. Eight patients had no obvious abnormality on CT images.

Comparison of Basic Clinical Characteristics and CT Findings in Nonemergency and Emergency Groups

Patients in the emergency group were older than those in the nonemergency group; nine (64.3%) patients in the emergency group were older than 50 years. Regarding underlying disease, no significant difference was found between the two groups. Four of the 14 imaging features—architectural distortion, traction bronchiectasis, intrathoracic lymph node enlargement, and pleural effusions—were more likely to be found in the emergency group ($p < 0.05$) (Table 2). The craniocaudal, transverse, and lung region distributions were not significantly different between the two groups, but diffuse lesions were more common (78.6%) in the emergency group. The result was indirectly proved in the extent score analysis, which showed that the extent score was higher in the emergency group than in the nonemergency group ($p = 0.000$).

Discussion

We comprehensively evaluated and analyzed the radiographic characteristics of 101 patients with COVID-19 pneumonia from the Radiology Quality Control Center, Hunan. The basic epidemiologic and clinical features were reported. Patients with disease associated with human-to-human transmission or a family outbreak need medical attention. Typical CT findings can help in early screening of patients with suspected disease and efficiently evaluate the extent of COVID-19 acute respiratory disease.

The increasing frequency of confirmed COVID-19 cases is striking, and the number of cases has risen over the number of SARS cases [17]. Because the origin and biologic characteristics of COVID-19 have not been

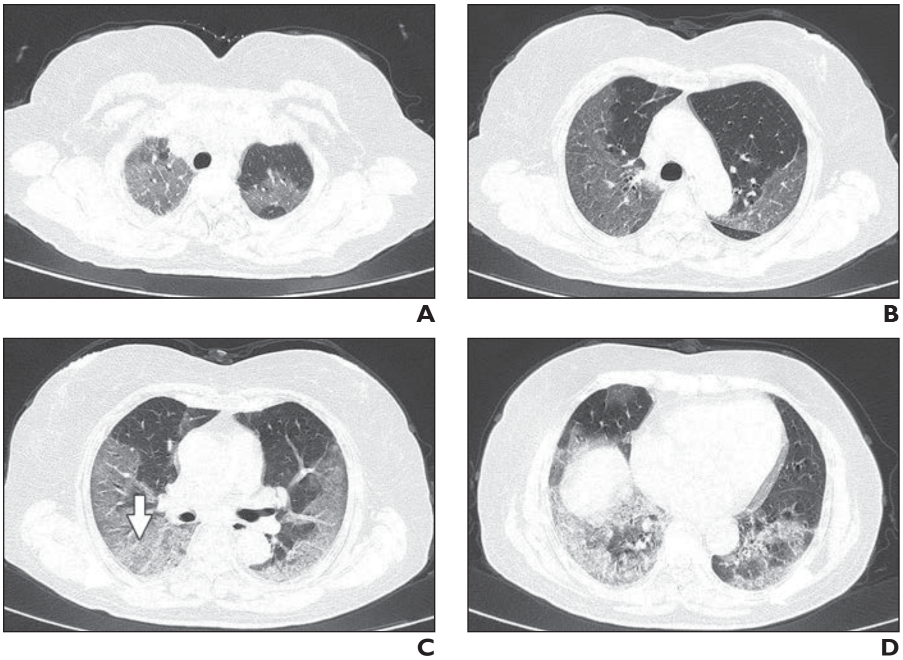

Fig. 2—63-year-old woman with confirmed coronavirus disease (COVID-19), severe type. Patient had long-term exposure history to Wuhan and onset symptoms of fever and cough. CT was performed 1 day after admission. **A–D,** CT images show bilateral diffuse ground-glass opacities and reticulation (*arrow*, **C**). CT involvement score is 18.

well investigated to date, no medicine can effectively treat the disease, but this is not the worst circumstance. The continually increasing number of confirmed and suspected cases is overwhelming medical staff. Laboratory testing has become the standard for the diagnosis of COVID-19 pneumonia, but the supply of laboratory kits cannot meet the demand of the increasing number of suspected cases. At the same time, the problem of false-negative results of the laboratory test has been discussed by clinicians in China. As of February 17, 2020, 6242 suspected cases of COVID-19 were waiting for final diagnosis [4]. The patients with these suspected cases may indirectly promote virus transmission and cross-infection. In our cohort, 12 (11.9%) patients denied any direct exposure history to Wuhan. Five (4.9%) patients denied any direct or indirect exposure history. Five (4.9%) other cases were associated with a family outbreak. These results indicate the importance of early identification of patients with disease and separating the patients without disease from those with suspected disease to reduce human-to-human transmission.

CT is considered the routine imaging modality for diagnosis and for monitoring the care of patients with COVID-19 pneumonia. It may help in early detection of lung abnormalities for screening out patients with highly suspected disease, especially patients with an initial negative RT-PCR screening result [21]. In our study, typical imaging features, such as GGO (86.1%), mixed GGO and consolidation (64.4%), and reticulation (48.5%) were present. These results are similar to those of the CT features of other viral infections of the lung, such as SARS and MERS [26, 27]. Interestingly, we found that most patients had vascular enlargement of the lesion (71.3%) that might have been caused by an acute inflammatory response. However, the vascular change did not resemble the changes of malignant lesions, such as lung adenocarcinoma, which presented distorted or irregular vascular dilatation and vascular convergence, which can be caused by chronic progression and infiltration of the tumor [27]. Regarding lesion distribution, patients with COVID-19 were more likely to have peripheral distribution (87.1%), bilateral involvement (82.2%), lower lung predominance (54.5%), and multifocal distribution (54.5%), which are consistent with results of previous studies [18].

The differences between the nonemergency and emergency groups regarding basic clinical and radiographic features were also analyzed. The patients in the emergency group were older than the patients in the nonemergency group. However, the rate of underlying disease was not significantly different in the two groups, indicating that other factors (e.g., viral load) may be more of a reflection of the severity and extent of COVID-19 pneumonia. Architectural distortion, traction bronchiectasis, and pleural effusions, which may reflect the viral load and virulence of COVID-19, were statistically different between the two groups and may help us to identify the emergency type disease. The performance of intrathoracic lymph node enlargement, a rare feature that had a significant difference in our cohort (only one patient), requires further validation. Moreover, we found that the incidence of diffuse lesions in the patients in the emergency group was greater than the incidence in the nonemergency group (78.6% vs 24.1%). Not surprisingly, the extent score was also higher in the emergency group than in the nonemergency group ($p = 0.000$).

Two patients had no symptoms or any abnormal CT findings at onset, and eight patients had no abnormal CT findings. Among the eight patients, three patients had a history of exposure to people with confirmed cases,

TABLE 2: Imaging Findings

Characteristic or Finding	All Patients ($n = 101$)	Nonemergency Group ($n = 87$)	Emergency Group ($n = 14$)	p
Age (y)	44.44 (12.3)[a]	42.94 (11.7)[a]	53.71 (12.6)[a]	0.003
Sex				0.890
Male	56 (55.4)	48 (55.2)	8 (57.1)	
Female	45 (44.6)	39 (44.8)	6 (42.9)	
Underlying disease	30 (29.7)	23 (26.4)	7 (50)	0.073

(Table 2 continues on next page)

TABLE 2: Imaging Findings (continued)

Characteristic or Finding	All Patients ($n = 101$)	Nonemergency Group ($n = 87$)	Emergency Group ($n = 14$)	p
Imaging finding				
Ground-glass opacities	87 (86.1)	73 (83.9)	14 (100)	0.106
Consolidation	44 (43.6)	36 (41.4)	8 (57.1)	0.270
Mixed ground-glass opacities and consolidation	65 (64.4)	56 (64.4)	9 (64.3)	0.995
Centrilobular nodules	23 (22.8)	20 (23.0)	3 (21.4)	0.897
Architectural distortion	22 (21.8)	16 (18.4)	6 (42.8)	0.040
Bronchial wall thickening	29 (28.7)	22 (25.3)	6 (42.8)	0.173
Reticulation	49 (48.5)	39 (44.8)	9 (64.3)	0.176
Subpleural bands	28 (27.7)	23 (26.4)	4 (28.6)	0.867
Traction bronchiectasis	53 (52.5)	41 (47.1)	12 (85.7)	0.007
Intrathoracic lymph node enlargement	1 (1.0)	0 (0)	1 (7.1)	0.012
Vascular enlargement	72 (71.3)	59 (67.8)	13 (92.9)	0.109
Pleural effusions	14 (13.9)	9 (10.3)	5 (35.7)	0.011
Craniocaudal distribution				0.258
Upper lung predominant	6 (5.9)	6 (6.9)	0 (0)	
Lower lung predominant	55 (54.5)	48 (55.2)	7 (50)	
No craniocaudal distribution	32 (31.7)	25 (28.7)	7 (50)	
Transverse distribution				0.493
Central	1 (1.0)	1 (1.1)	0 (0)	
Peripheral	88 (87.1)	74 (85.1)	14 (100)	
No transverse distribution	4 (4.0)	4 (4.6)	0 (0)	
Lung region distribution				0.172
Unilateral	10 (9.9)	10 (11.5)	0 (0)	
Bilateral	83 (82.2)	69 (79.3)	14 (100)	
Scattered distribution				0.001
Focal	6 (5.9)	6 (6.9)	0 (0)	
Multifocal	55 (54.5)	52 (59.8)	3 (21.4)	
Diffuse	32 (31.7)	21 (24.1)	11 (78.6)	
Extent of lesion	6.39 (0–20)[b]	5.34 (3.84)[a]	12.86 (4.59)[a]	0.000
No. without CT findings	8 (7.9)	8 (9.2)	0 (0)	NA

Note—Except where otherwise indicated, data are number with percentage in parentheses. NA = not applicable.
[a]Mean (SD).
[b]Mean (range).

and five patients had a specific epidemic history in Wuhan. It once again reminded physicians of the importance of inquiring about details of epidemic exposure history when seeing patients in an outpatient clinic. Therefore, the combination of chest CT and PCR screening is necessary for early diagnosis. One of the eight patients had abnormal follow-up CT findings that necessitated additional scanning.

The study had several limitations. First, only 101 patients with confirmed COVID-19 were included; negative results and infections with other viruses were not included in the analyses. Comprehensive investigation of the imaging features of patients with negative results and other virus infections may help us to differentiate COVID-19 pneumonia from other lung infections and then to screen patients with highly suspected cases. Second, we did not evaluate follow-up CT findings in our study. Exploring the CT changes and comparing them with the clinical parameters may help us monitor and predict outcome [28] and support clinical decision making.

Conclusion

Patients with confirmed COVID-19 pneumonia have typical imaging features that may be helpful in early screening of highly suspected cases and in evaluating the severity and extent of the disease.

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