Radiology Perspective of Coronavirus Disease 2019 (COVID-19): Lessons From Severe Acute Respiratory Syndrome and Middle East Respiratory Syndrome

Melina Hosseiny[1]
Soheil Kooraki[2]
Ali Gholamrezanezhad[2,3]
Sravanthi Reddy[2]
Lee Myers[2]

OBJECTIVE. Since the outbreak of the novel coronavirus pulmonary illness coronavirus disease 2019 (COVID-19) in China, more than 79,000 people have contracted the virus worldwide. The virus is rapidly spreading with human-to-human transmission despite imposed precautions. Because similar pulmonary syndromes have been reported from other strains of the coronavirus family, our aim is to review the lessons from imaging studies obtained during severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS) outbreaks.

CONCLUSION. The review of experiences with the MERS and SARS outbreaks will help us better understand the role of the radiologist in combating the outbreak of COVID-19. The known imaging manifestations of the novel coronavirus and the possible unknowns will also be discussed.

In December 2019, a lower respiratory tract febrile illness of unknown origin was reported in a cluster of patients in Wuhan City, Hubei Province, China. A novel strain of coronavirus isolated from the bronchoalveolar lavage of the patients was determined to be responsible for the outbreak [1]. The pulmonary syndrome was later named coronavirus disease 2019 (COVID-19) by the World Health Organization. Despite the imposition of strict quarantine rules and travel restrictions, the virus transmitted rapidly out of China with a number of confirmed cases reported in Europe, the United Kingdom, and the United States [2]. The global number of confirmed cases has surpassed 79,000, with more than 2600 virus-related deaths as of February 24, 2020 [3].

Similar pulmonary syndromes have been recognized as being caused by other strains of the coronavirus family. The most notable examples are the severe acute respiratory syndrome (SARS) and the Middle East respiratory syndrome (MERS). The SARS outbreak has been contained, with no human infection reported since 2003; small outbreaks of MERS continue to be reported. Imaging is a critical component of the diagnostic workup, monitoring of disease progression, and follow-up in coronavirus-related pulmonary syndromes [4]. Imaging features in the acute and chronic phases of SARS and MERS are variable and nonspecific [5–8]. The first accounts of the imaging findings of COVID-19 have also reported nonspecific findings [9–11]. Investigators are making every effort to further characterize the imaging features of this novel coronavirus syndrome, but information is still limited.

Radiologists should be prepared for the incidence of COVID-19 to escalate. Because the etiologic and clinical features of the syndrome are similar to those of SARS and MERS, the experience from those pulmonary syndromes can be helpful for managing the emerging COVID-19 outbreak. The aim of this review is to familiarize radiologists with the imaging spectrum of coronavirus syndromes and to discuss the reported imaging features of COVID-19.

Lessons From SARS and MERS

In 2003, a coronavirus was identified as the cause of the first pandemic of the new millennium in Guangdong Province, China, with the clinical presentation of rapidly progressive pneumonia [12]. The clinical syndrome, SARS, infected 8422 individuals and claimed 916 lives. The outbreak was contained, and no instance of SARS has been reported since 2003 [13]. In contrast, the coronavirus causing MERS was first identified in the sputum of a Saudi Arabian patient presenting with pneumonia and acute kidney injury in 2012 [14]. The disease has infected 2492

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[1]Department of Radiological Sciences, David Geffen School of Medicine, University of California at Los Angeles, Los Angeles, CA.

[2]Department of Radiological Sciences, Keck School of Medicine, University of Southern California, Los Angeles, CA.

[3]Department of Radiological Sciences, Division of Emergency Radiology, Keck School of Medicine, University of Southern California, 1500 San Pablo St, Los Angeles, CA 90033. Address correspondence to A. Gholamrezanezhad (ali.gholamrezanezhad@med.usc.edu).

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TABLE 1: Comparison of Clinical and Radiologic Features of SARS, MERS, and COVID-19

Feature	SARS	MERS	COVID-19
Clinical sign or symptom			
Fever or chills	Yes	Yes	Yes
Dyspnea	Yes	Yes	Yes
Malaise	Yes	Yes	Yes
Myalgia	Yes	Yes	Yes
Headache	Yes	Yes	Yes
Cough	Dry	Dry or productive	Dry
Diarrhea	Yes	Yes	Uncommon
Nausea or vomiting	Yes	Yes	Uncommon
Sore throat	Yes	Uncommon	Uncommon
Arthralgia	Yes	Uncommon	
Imaging finding			
Acute phase			
Initial imaging			
Normal	15–20% of patients	17% of patients	15–20% of patients
Abnormalities			
Common	Peripheral multifocal airspace opacities (GGO, consolidation, or both) on chest radiography and CT	Peripheral multifocal airspace opacities (GGO, consolidation, or both) on chest radiography and CT	Peripheral multifocal airspace opacities (GGO, consolidation, or both) on chest radiography and CT
Rare	Pneumothorax	Pneumothorax	Pneumothorax
Not seen	Cavitation or lymphadenopathy	Cavitation or lymphadenopathy	Cavitation or lymphadenopathy
Appearance	Unilateral, focal (50%); multifocal (40%); diffuse (10%)	Bilateral, multifocal basal airspace on chest radiography or CT (80%); isolated unilateral (20%)	Bilateral, multifocal, basal airspace; normal chest radiography findings (15%)
Follow-up imaging appearance	Unilateral, focal (25%); progressive (most common, can be unilateral and multifocal or bilateral with multifocal consolidation)	Extension into upper lobes or perihilar areas, pleural effusion (33%), interlobular septal thickening (26%)	Persistent or progressive airspace opacities
Indications of poor prognosis	Bilateral (like ARDS), four or more lung zones, progressive involvement after 12 d	Greater involvement of the lungs, pleural effusion, pneumothorax	Consolidation (vs GGO)
Chronic phase			Unknown, but pleural effusion and interlobar septal thickening have not yet been reported
Transient reticular opacities[a]	Yes	Yes	
Airtrapping	Common (usually persistent)		
Fibrosis	Rare	One-third of patients	Not yet reported

Note—SARS = severe acute respiratory syndrome, MERS = Middle East respiratory syndrome, COVID-19 = coronavirus disease 2019, GGO = ground-glass opacity, ARDS = acute respiratory distress syndrome.
[a]Over a period of weeks or months.

individuals worldwide and has claimed 858 human lives; new cases have been reported as recently as December 2019 [15]. Although SARS and MERS share similarities in virulence factors, clinical symptoms, and imaging features, they have a number of important differences. A brief review of the imaging spectrum of these syndromes in the acute and chronic disease phases may help predict the imaging manifestations of COVID-19.

Imaging of Acute Infection

The imaging features of SARS and MERS overlap, but differences exist as well (Table 1). The initial chest radiograph will be abnormal in up to 80% of patients with SARS [16]. The initial imaging in SARS frequently shows unilateral disease, with peripheral distribution and ill-defined areas of airspace opacity in lower lung zones. The initial involvement is focal in approximately half of patients and multifocal in the remainder, with less than 10% showing early diffuse involvement [17]. Follow-up imaging in the majority of patients will show progressive multifocal consolidation over a course of 6–12 days involving one or both lungs; however, in one-quarter of patients, the opacity will remain focal and unilateral [16]. CT frequently shows patchy areas of ground-glass opacity and consolidation. Centrilobular nodules and tree-in-bud opacities are not characteristic and likely indicate other atypical or opportunistic causes of pneumonia [5]. Radiologic improvement after recovery is expected in most patients. The presence of bilateral confluent diffuse airspace opacities, similar to the findings of acute respiratory distress syndrome, involvement of four or more lung zones, bilateral lung involvement, and progressive worsening of airspace consolidation on chest imaging more than 12 days after symptom onset despite treatment are associated with unfavorable outcomes [8, 16, 18].

Similarly, in 83% of patients with MERS, the findings on initial chest radiography will be abnormal; multifocal airspace opacities in the lower lung zones are the most common finding [19]. The radiographic abnormalities will extend into the perihilar and upper lobes as the disease progresses. Likewise, CT will show bilateral and predominantly ground-glass opacities with a predilection to the basilar and peripheral lung zones; however, isolated consolidation, interlobular septal thickening, and pleural effusion are not rare in MERS and might be observed in 20–33% of affected individuals [6]. Tree-in-bud opacities and cavitation rarely occur, and lymphadenopathy is not characteristic of this type of virus [20]. Pleural effusion, pneumothorax, and greater involvement of the lungs are associated with poorer prognosis [19].

Long-Term Follow-Up Imaging

After a patient has recovered from SARS, CT shows transient interlobular septal thickening and reticulation over a course of several weeks to months. The reticulation appears after the 2nd week and peaks around the 4th week [21]. One-third of patients with persistent respiratory symptoms will have imaging findings of fibrosis, including interlobular and intralobular reticulation, traction bronchiectasis, and, rarely, honeycombing [5]. Areas of airtrapping, caused by damage to ciliated respiratory epithelium, have been reported in 92% of patients who have recovered from pneumonia and are less likely to resolve completely [22].

Likewise, in patients with MERS, although the majority fully recover, 33% show evidence of lung fibrosis on follow-up imaging. These patients were commonly older, had prolonged ICU admission, and had greater lung involvement in the acute phase of the disease [7].

Imaging of Coronavirus Disease 2019

Although the diagnosis of COVID-19 is suspected on the basis of symptoms of pneumonia (e.g., dry cough, fatigue, myalgia, fever, and dyspnea) as well as history of recent travel to China or exposure to a known patient, chest imaging plays an important role in both assessment of disease extent and follow-up. Chest radiography typically shows patchy or diffuse asymmetric airspace opacities, similar to other causes of coronavirus pneumonias [23]. The first report of patients with COVID-19 described bilateral lung involvement on initial chest CT in 40 of 41 patients, with a consolidative pattern seen in patients in the ICU and a predominantly ground-glass pattern in patients who were not in the ICU [24]. An investigation of initial chest CT findings in 21 individuals with confirmed COVID-19 reported abnormal findings in 86% of patients, with a majority (16/18) having bilateral lung involvement [9]. Multifocal ground-glass opacities and consolidation were reported in 57% and 29%, respectively, with a peripheral lung predilection (Figs. 1 and 2). Likewise, the chest imaging in a family cluster of seven people with confirmed COVID-19 showed bilateral patchy ground-glass opacities with greater involvement of the lungs in the older family members [10]. Although the imaging features closely resemble those of MERS and SARS, involvement of both lungs on initial imaging is more likely to be seen with COVID-19; initial chest imaging abnormalities in SARS and MERS are more frequently unilateral (Table 1). Pleural effusion, cavitation, pulmonary nodules, and lymphadenopathy have not been reported in patients with COVID-19 to our knowledge. Pneumothorax was reported in 1 of 99 patients with confirmed COVID-19 [23], but it was unknown if the pneumothorax was a direct complication of the coronavirus infection.

A report of five patients with confirmed COVID-19 who initially had negative results from a swab test for the virus highlighted the value of early CT findings for diagnosis of the disease. This report showed that the presence of typical CT findings could be helpful for initial screening in individuals who are suspected to be have the virus [25]. However, early reports have stated that initial imaging might show normal findings in 15% of individuals, so a normal chest imaging examination does not exclude the infection.

Because chest imaging is an important component of patient management in individuals with COVID-19, further investigations are required to expand understanding of the imaging findings throughout the disease course. The experiences with SARS and MERS show that follow-up imaging should be performed in individuals recovering from COVID-19 to look for evidence of chronic involvement of the lungs (i.e., interlobular thickening, airtrapping, or fibrosis).

Precautions taken to prevent nosocomial human-to-human transmission may play a critical role in decreasing the spread of the disease. The radiology team should be aware of all precautions and strategies to minimize the risk of infection among staff and patients [26].

Conclusion

The reported imaging features in COVID-19 are variable and nonspecific and have significant overlap with those of SARS and MERS. Early evidence suggests that initial chest imaging will show abnormality in at least 85% of patients, with 75% of patients having bilateral lung involvement initially that most often manifests as subpleural and peripheral areas of ground-glass opacity and consolidation. Older age and progressive consolidation might suggest poorer prognosis. Besides the acute phase, CT is recommended for follow-up in individuals who are recovering from COVID-19 to evaluate long-term or permanent lung damage including fibrosis, as is seen with SARS and MERS infections.

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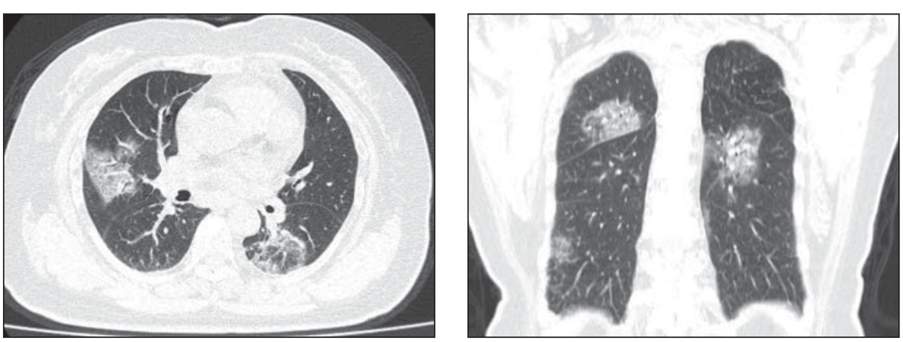
A B

Fig. 1—79-year-old woman who presented with fever, dry cough, and chest pain for 3 days. Her husband and daughter-in-law had been recently diagnosed with coronavirus disease 2019 (COVID-19). Patient expired 11 days after admission (Courtesy of Song F, Shanghai Public Health Clinical Center, Shanghai, China)
A and **B,** Axial (**A**) and coronal (**B**) CT images show multiple patchy, peripheral, bilateral areas of ground-glass opacity.

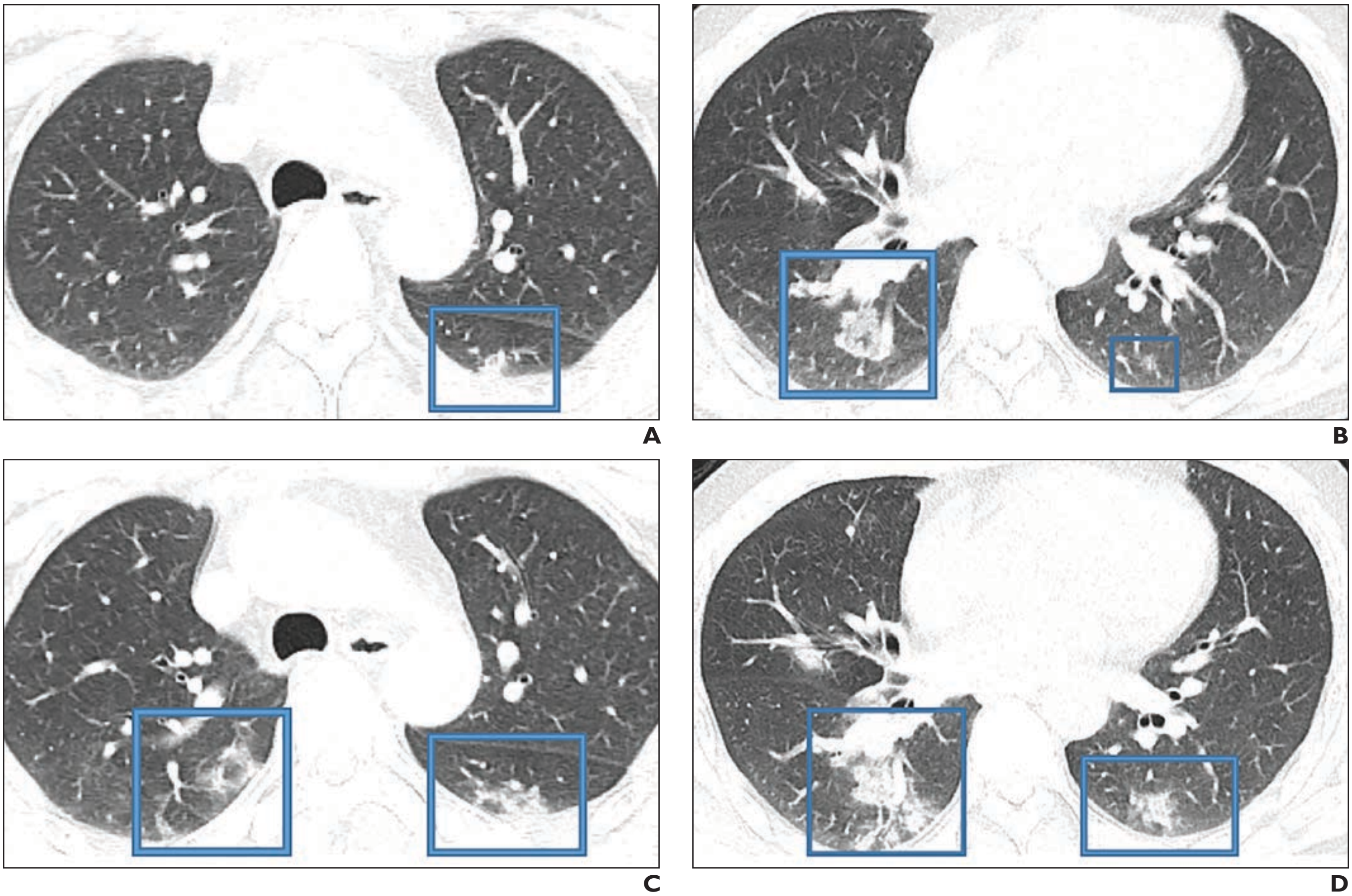

Fig. 2—47-year-old Chinese man with 2-day history of fever, chills, productive cough, sneezing, and fatigue who presented to emergency department. (Courtesy of Liu M, China-Japan Friendship Hospital, Beijing, China)

A and **B,** Initial CT images obtained show small round areas of mixed ground-glass opacity and consolidation (*rectangles*) at level of aortic arch (**A**) and ventricles (**B**) in right and left lower lobe posterior zones.

C and **D,** Follow-up CT images obtained 2 days later show progression of abnormalities (*rectangles*) at level of aortic arch (**C**) and ventricles (**D**), which now involve right upper and right and left lower lobe posterior zones.