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Imaging of COVID-19

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The novel coronavirus disease 2019 (COVID-19) emerged as the source of a global pandemic in late 2019 and early 2020 and quickly spread throughout the world becoming one of the worst pandemics in recent history. This chapter reviews the most up to date radiological literature and outlines the utility of thoracic imaging in COVID-19, defining both the common and the less typical imaging appearances during the acute and subacute phases of COVID-19. The short term complications and the long term sequela will also be discussed in the context of radiology, including pulmonary emboli, acute respiratory distress syndrome, superimposed infections, barotrauma, cardiac manifestations, pulmonary parenchymal scarring and fibrosis.

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Introduction

In late 2019 and early 2020, the World Health Organization (WHO) recognized a new respiratory virus that would emerge as the source of a global pandemic, SARS-CoV-2, the virus that causes novel coronavirus disease 2019 (COVID-19). As of the end of 2021, there have been hundreds of millions of reported COVID-19 cases around the world, almost five million deaths, and many patients with long term morbidity.[1] Despite one of the fastest vaccine development and deployment programs in history with over five billion vaccines administered across the globe, COVID-19 is unlikely to be eradicated.[2] Imaging plays a critical role in initial diagnosis, management of symptoms, prognostication of outcomes, and evaluation of long-term complications.[3] This chapter reviews the current literature, outlines the utility of thoracic radiological imaging in COVID-19, and defines the strengths and weaknesses of each modality in acute, subacute, and chronic stages of COVID-19.

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Historical perspective

Prior to the recognition of COVID-19, the world had only experienced a few respiratory coronavirus outbreaks. For example, severe acute respiratory syndrome (SARS) had 8000 documented cases in 2003, mostly in China, fewer than 1000 deaths, and has never resurfaced since the year it emerged.[4] A related coronavirus, middle east respiratory distress syndrome (MERS), surfaced in Saudi Arabia in 2012 and has had a relatively low incidence, with only intermittent outbreaks.[5] However, with increasing globalization, localized outbreaks become harder to contain, and by the time COVID-19 reached the United States, there were other outbreaks throughout the world.

Radiologists gathered initial data from China to describe the imaging characteristics of COVID-19. An early landmark study in *Radiology* described the computed tomography (CT) imaging features with typical findings characterized by bilateral multifocal pulmonary parenchymal ground-glass or consolidative opacities, sometimes with a rounded morphology and a lower and peripheral lung distribution.[6] Another study described the CT imaging features in relation to duration of infection with an increasing burden of disease correlating with time from symptom onset.[7]

Radiologists and researchers noticed that imaging findings in COVID-19 were similar to those seen during the SARS epidemic in 2003, with studies on SARS demonstrating predominantly ground glass opacities with a lower and peripheral lung distribution.[8] While SARS was relatively limited in scale, studies showed that late-stage disease led to acute respiratory distress syndrome (ARDS), which appears similar to ARDS of any cause, whether or not patients were

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on mechanical ventilation.[9] Another study on SARS demonstrated that at 7 year follow-up, some patients had persistent interlobular septal thickening and traction bronchiectasis, although ground-glass opacification had resolved.[10] As in COVID-19, patients with SARS have a variable progression of disease. A study by Antonio et al. demonstrated that 70% of patients had radiologic progression of disease followed by improvement, 17% had a fluctuating course, 7% had static radiologic findings with no peak, and 5% had progressive radiologic progression.[11] Additionally, during the SARS epidemic, many studies described the initial chest radiography features, particularly noting that more extensive disease on radiography portended a poorer prognosis.[12–18]

Imaging in early/acute COVID-19

Early in the global pandemic, real-time reverse transcription-polymerase chain reaction (RT-PCR) testing was limited in availability, often with results delayed by several days. Therefore, imaging played a more significant role in triage and diagnosis; however, as the epidemic evolved, nucleic acid amplification testing became more widely available with faster turnaround times, and so imaging became less valuable as a screening or diagnostic test. The utility of imaging studies is also affected by changes in pre-test probability, such as disease prevalence in a geographic location at a given time.

Indications

In April 2020, the Fleischner Society published a consensus statement categorizing imaging indications by both laboratory testing results (positive/negative) and disease severity (mild/moderate/severe). The panel discouraged imaging in COVID-19 patients who had mild disease (unless there was risk of progression), but recommended chest radiography for those with worsening clinical disease, daily routine chest radiography for intubated patients, and CT for both positive patients in resource-constrained environments with moderate to severe clinical symptoms at presentation and for

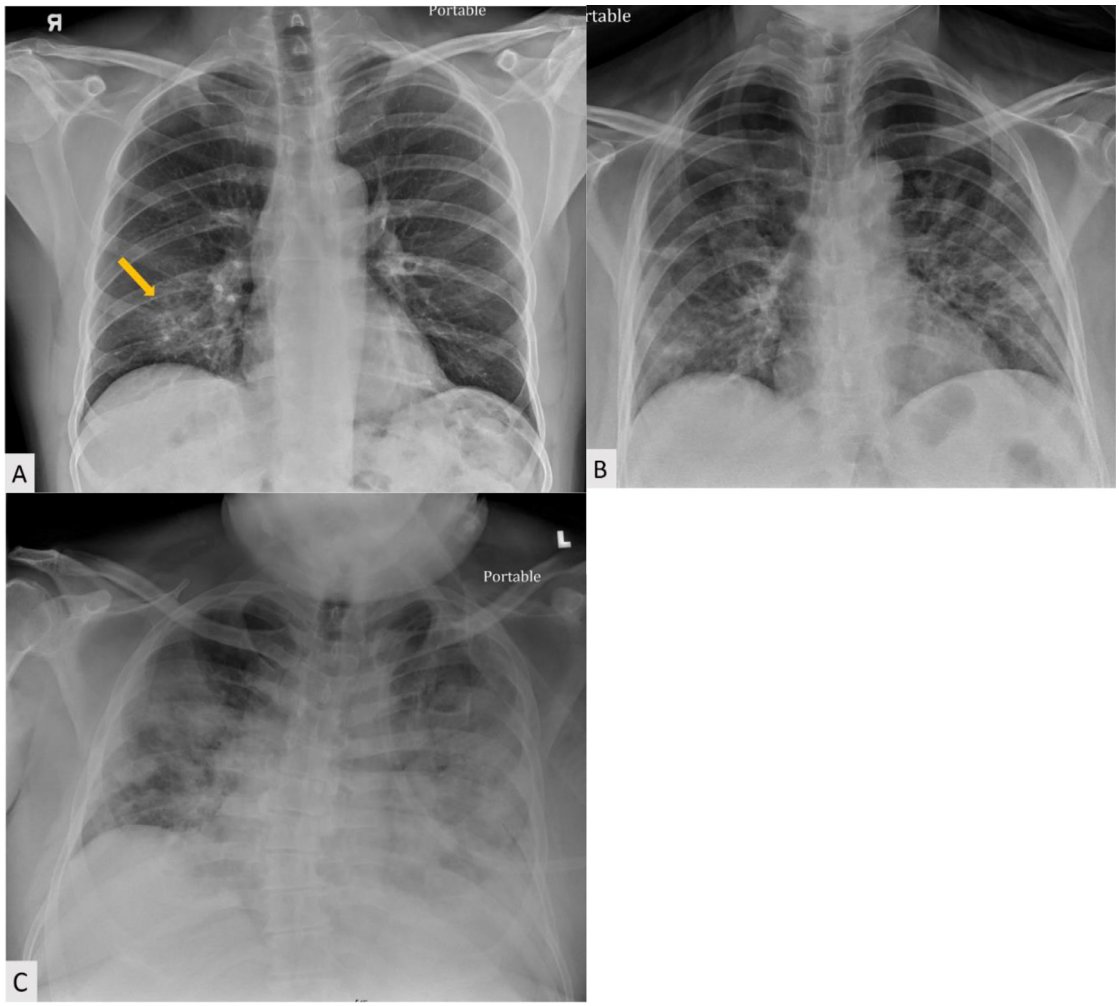

Figure 1 (A) Frontal chest radiograph in a patient with mild COVID-19 demonstrates hazy, patchy opacity with a rounded morphology limited to the right lower lung zone (arrow); (B) Frontal chest radiograph demonstrates moderate acute COVID-19 with bilateral patchy pulmonary opacities with a peripheral and lower lung distribution; (C) Frontal chest radiograph demonstrates severe bilateral diffuse pulmonary consolidation, similar to findings in diffuse acute lung injury of any etiology.

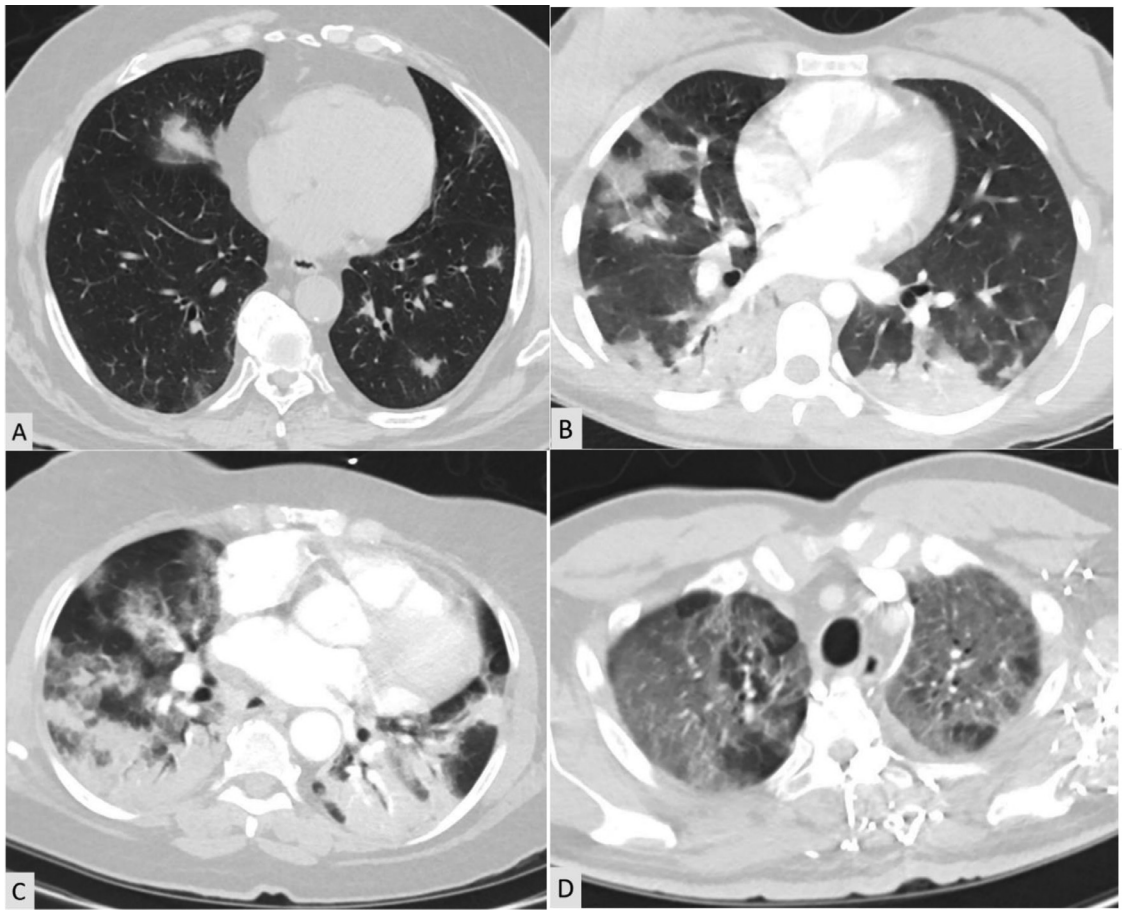

Figure 2 (A) Axial CT demonstrates mild acute COVID-19 with mild severity of peripheral-predominant ground-glass opacities and consolidation, with a rounded morphology in both lower lobes. (B) Axial CT demonstrates moderate acute COVID-19 with a moderate amount of ground-glass and dense consolidation in a perilobular distribution; (C) Axial CT demonstrates severe acute COVID-19 with bilateral confluent consolidative opacities in a patient with cardiomegaly; (D) Axial CT demonstrates diffuse ground-glass opacities extending to the lung apices, seen in more severe disease and portending a poorer prognosis.

patients with a negative laboratory test.[19] Chest radiography was insensitive in early or mild disease, while CT had much higher sensitivity for detecting COVID-19 in early stages, suggesting some utility of CT in diagnosis when laboratory testing is difficult to obtain.[20] Furthermore, asymptomatic positive patients under 60 years of age with imaging findings rarely required inpatient or intensive care unit (ICU) care, suggesting limited utility in screening asymptomatic patients with chest radiography or CT. Conversely, some patients incidentally found to have typical pulmonary findings of COVID-19 on CT performed for other reasons should be screened with laboratory testing.[21] Imaging may still be indicated for older patients with more comorbidities at presentation, regardless of presenting symptoms.[22] Ultimately, clinical team members are responsible for deciding whether chest radiography or CT is needed at any point as the disease progresses.

Risk factors

Risk factors for more severe disease at presentation include older age, male gender, non-white race, a history of current daily tobacco use, and many comorbid medical conditions (particularly cardiovascular diseases).[23] Physical examination and laboratory findings associated with more severe disease include obesity, dyspnea, elevated c-reactive protein (CRP), elevated D-dimer, elevated neutrophil-lymphocyte ratio, and decreased lymphocyte count. In addition, socioeconomic status, diet, lifestyle, geographical differences, and quality of health care have been reported to influence outcomes.[24–28]

Chest radiography findings and their significance

Chest radiography features are not pathognomonic for COVID-19, but often resemble features of other infectious and inflammatory processes, including other viral or bacterial pneumonias, organizing or eosinophilic pneumonias, or acute lung injury.[29] The distribution of findings of COVID-19 on chest radiography is typically lower lobe and peripheral predominant; however, in later and more severe cases, disease can more diffusely affect all lobes, with features similar to ARDS of any cause (Fig. 1).[30]

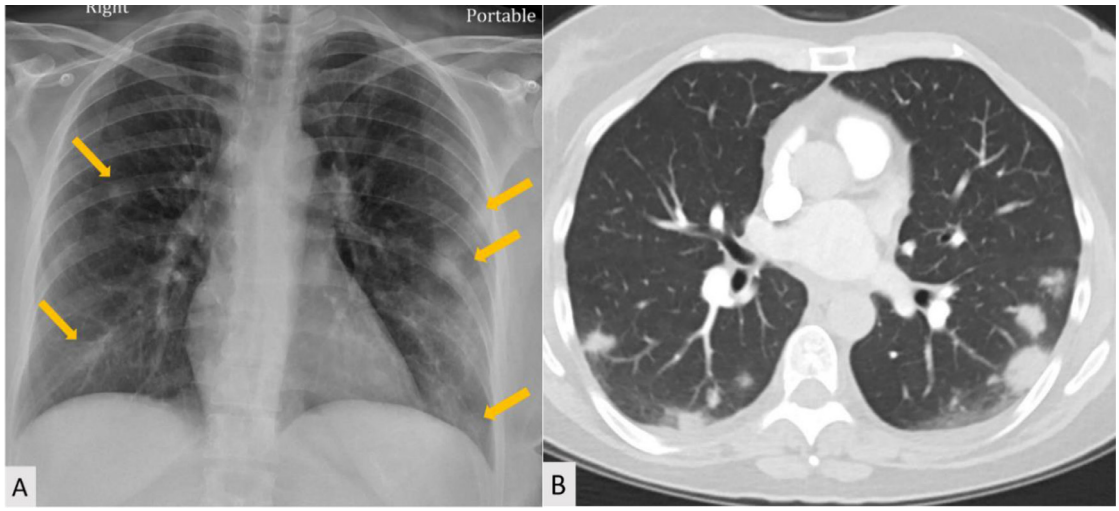

Figure 3 Patient (A) chest radiography and (B) axial CT demonstrating the classic rounded morphology (arrows) of pulmonary opacities associated with COVID-19 pneumonia.

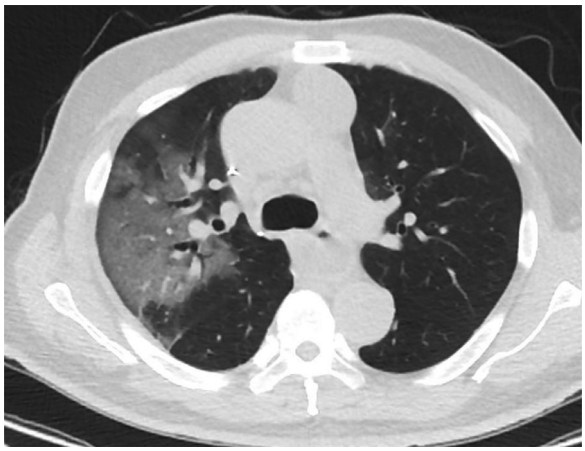

Figure 4 Axial CT demonstrates predominantly ground-glass right upper lobar opacification in the acute phase, without evidence of significant organization or scarring.

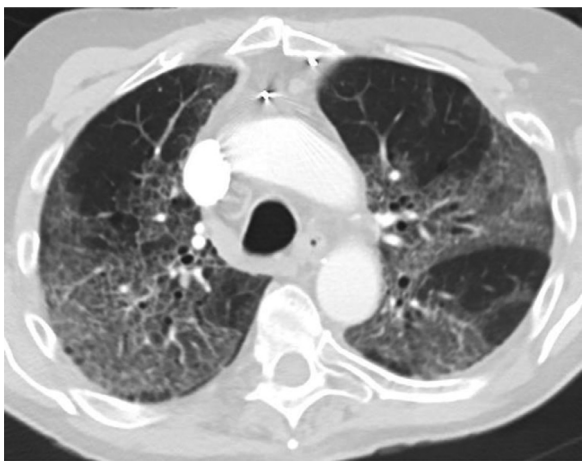

Figure 5 Axial CT demonstrates a pattern of disease characterized by ground-glass opacity and interlobular septal thickening, giving a "crazy paving" appearance in this patient with a background of mild emphysema.

Underlying comorbidities such as congestive heart failure or other chronic lung diseases may confound imaging findings on chest radiography. In addition, early mild disease may not be detectable on chest radiography, which therefore cannot be used as an exclusionary test for diagnosis, though negative radiographs may be helpful in excluding adverse clinical outcomes.[31] Chest radiography is useful during the initial work-up for management, triage, and prognosis, as studies have demonstrated that increasing involvement on chest radiography predicts more severe disease and is correlated with a higher likelihood of inpatient hospitalization, mechanical ventilation, and/or death.[3,32,33]

CT findings and their significance

The CT appearance and distribution of COVID-19 mirrors that of chest radiography, but early and/or mild disease is more easily detectable on CT, with better characterization of

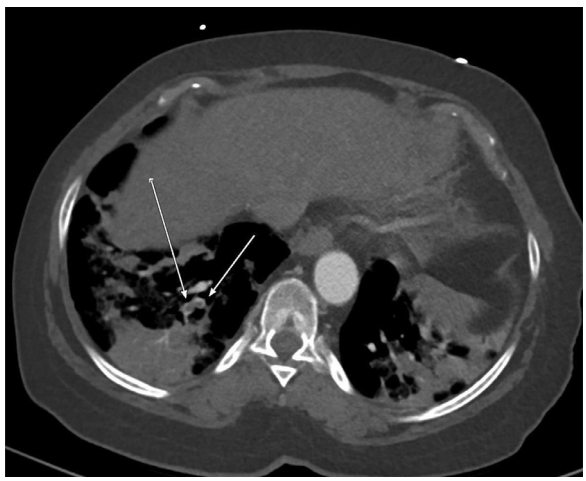

Figure 6 Axial CT of a patient with COVID-19 pneumonia demonstrates filling defects in right lower lobe subsegmental pulmonary artery branches (arrows), consistent with acute pulmonary embolism.

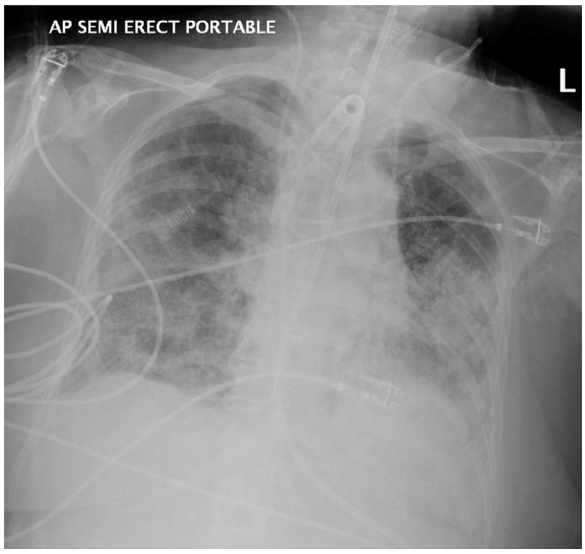

Figure 7 ARDS. (A) Frontal chest radiograph demonstrates diffuse coalescent pulmonary opacities in this patient with a tracheostomy tube in place.

morphologic features. Studies have shown that the sensitivity of CT increases after five days of symptoms.[34] Similar to chest radiography, investigators have demonstrated that more severe parenchymal changes on CT, by either qualitative or quantitative methods, portend a poorer prognosis, including inpatient hospitalization, intubation, and/or death.[35–39] CT severity scores also correlate with clinical and serum markers of disease severity, such has hypoxia or elevations in inflammatory markers.[40] Still, a significant percentage of asymptomatic patients may show parenchymal disease at CT, suggesting that drawing conclusions about disease severity from CT alone has its limitations.[41]

Findings on CT in early COVID-19 can be unilateral or bilateral, often with a ground-glass predominance and a rounded nodular or mass-like morphology (particularly in mild disease) with or without interlobular septal thickening. Confluent multifocal consolidation with a perilobular distribution or a diffuse acute lung injury pattern can also occur (Figs. 2 and 3).[42]

Diffuse ground-glass opacity on CT, which is not as easily identified on chest radiography, has also been reported and can mimic other infections, drug toxicities, and inhalational lung diseases.[43] Less common imaging features reported in acute COVID-19 are lobar consolidation (Fig. 4), superimposed interlobular septal thickening (Fig. 5) sometimes with a "crazy-paving" pattern, and pleural effusions. Patients with severe disease are more likely to present with pleural effusions or superimposed infections.

Imaging of short-term complications of COVID-19

Most patients with COVID-19 recover without short- or long-term complications.[44] Though uncommon, thoracic

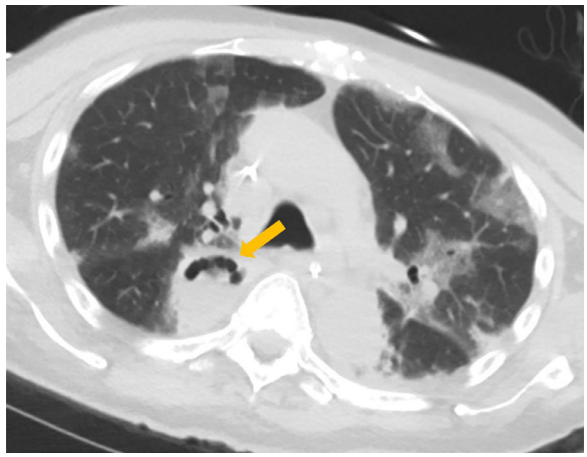

Figure 8 Axial CT demonstrates moderate severity of ground-glass opacities with a perilobular and peripheral lung distribution. In addition, there is a lung abscess (arrow) within the medial right lower lobe, for which a superimposed bacterial infection should be considered.

complications due to COVID-19 pneumonia are similar to complications of other infectious and inflammatory lung conditions, such as pulmonary embolism (PE), lung abscess, empyema, ARDS, and barotrauma (particularly in the setting of mechanical ventilation). Cardiac manifestations of COVID-19 will also be discussed.

Pulmonary embolism (PE)

Many patients with COVID-19, especially those requiring inpatient hospitalization, have an elevated D-dimer level. However, studies have shown that D-dimer levels in COVID-19 patients do not correlate with deep vein thrombosis or

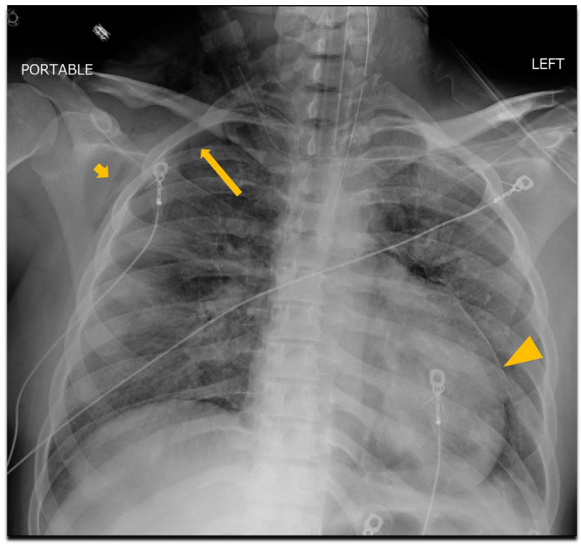

Figure 9 Frontal chest radiograph demonstrates subcutaneous emphysema in the right lower neck and chest wall (short arrow), a small right apical pneumothorax (arrow), and pneumomediastinum (triangle) in this intubated patient with moderate severity of bilateral pulmonary opacities. Also of note, the enteric tube is malpositioned.

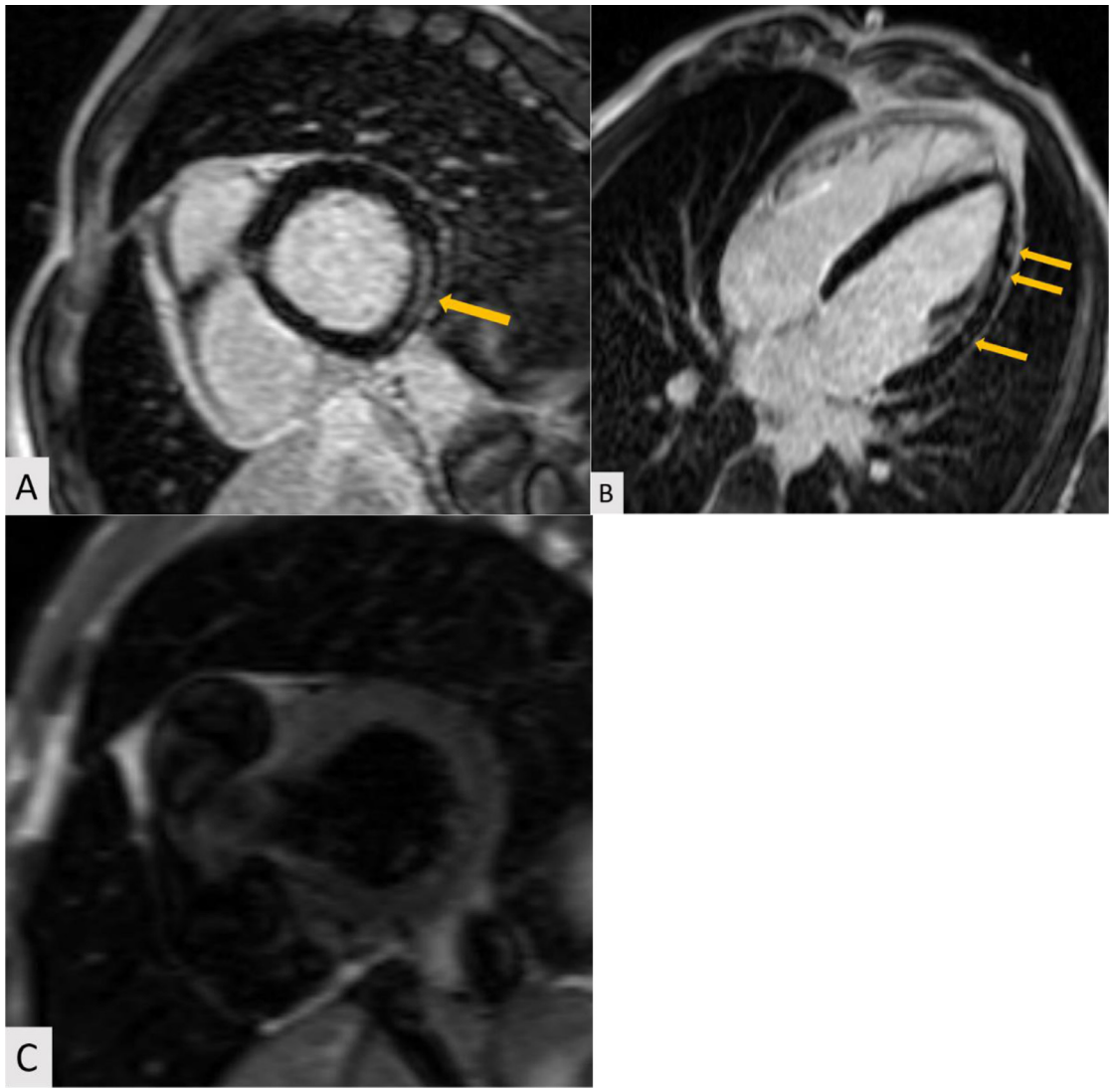

Figure 10 (A) Short axis and (B) 4-chamber late gadolinium enhancement MRI nine months following COVID-19 infection in a 34-year-old patient demonstrates multifocal subepicardial and mesocardial enhancement, predominantly involving the lateral LV wall (arrows), consistent with chronic COVID-induced myocarditis; (C) Note the lack of myocardial edema on short axis T2 imaging, indicating chronicity.

pulmonary embolism; therefore, most COVID-19 patients with an elevated D-dimer do not require CT angiography (CTA).[45] Nevertheless, patients with parenchymal changes inconsistent with clinical symptoms, unexplained worsening of clinical disease, or those with deep venous thrombosis may be evaluated with CTA (Fig. 6). There is a higher incidence of PE on chest CTA in patients with COVID-19 compared to patients evaluated with chest CTA for other reasons.[46,47] While a large study with close to 200,000 patients demonstrated that the incidence of PE in hospitalized patients for any reason was 0.23%, many COVID-19 studies have demonstrated a higher incidence of acute PE (ranging from 8%-30% for hospitalized patients), particularly in ICU patients, with PE diagnosed on average 12 days after symptom onset and 6 days after ICU admission, although the possibility of selection bias is not excluded.[48–51]

Acute respiratory distress syndrome (ARDS)

ARDS, the leading cause of death from COVID-19, is a clinical diagnosis associated with severe acute lung injury, characterized histologically by diffuse alveolar damage (DAD). The imaging features of ARDS due to COVID-19 are similar in appearance to features of ARDS from any cause, including other infectious/inflammatory etiologies, cardiogenic or other systemic illnesses, and inhalational injuries.[52] ARDS is characterized by diffuse and confluent pulmonary opacities on both chest radiography and CT. Opacities may or may not resolve, and in later stages may evolve into a more fibrotic phase manifested by scarring with prolonged ground-glass opacification, pulmonary reticulation, and/or bronchiectasis (Fig. 7).[53]

DAD, the primary histological pattern in COVID-19-induced ARDS, is classified into three categories correlating with chronicity: exudative (acute), organizing (subacute) or

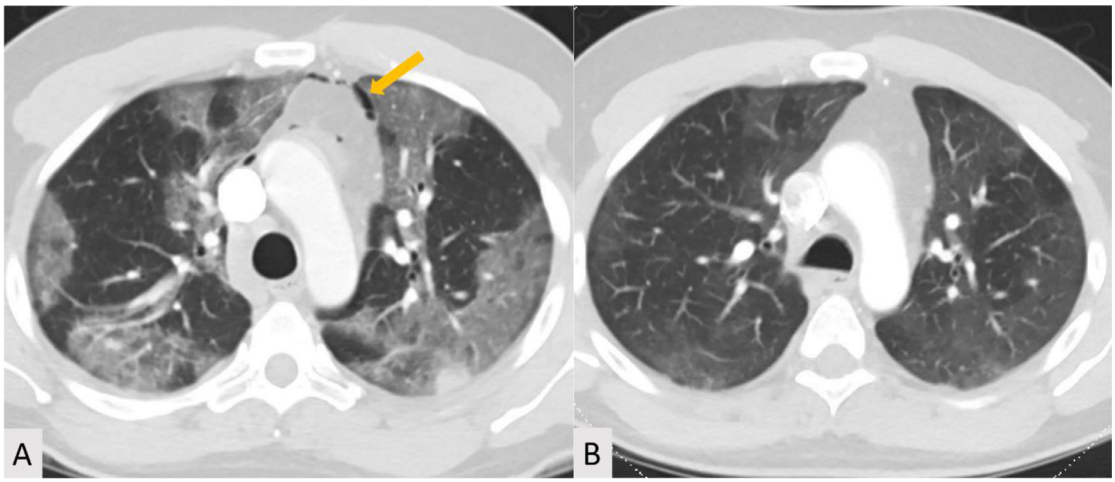

Figure 11 (A) Initial axial chest CT with moderate amount of ground-glass opacity with a peripheral lung distribution (note there is also pneumomediastinum (arrow)) and (B) Axial chest CT 1 month later with much less dense residual ground-glass opacification in a similar distribution.

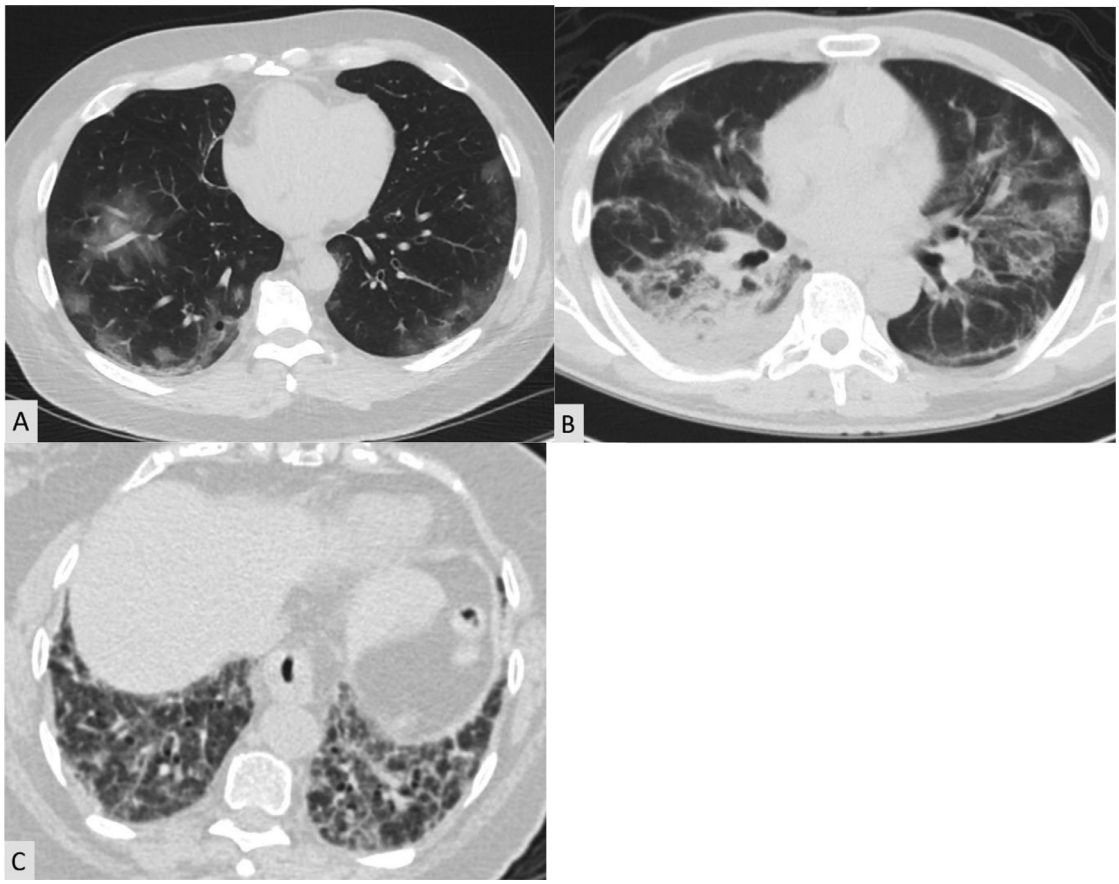

Figure 12 (A) Axial CT demonstrates mild severity of peripheral-predominant ground-glass opacities, some with a rounded morphology. Within the posterior right lower lobe, there is evidence of early organization, with subtle mild peripheral linear opacities paralleling the pleura with 1-2 mm of subpleural sparing; (B) Axial CT demonstrates moderate peripheral-predominant ground-glass and consolidative opacification with a greater degree of organization, as evidenced by progressive perilobular reticulation and linear opacities paralleling the pleural surface. There is also a small right pleural effusion, a less frequent finding in COVID-19 as compared with other pulmonary infections; (C) Axial CT demonstrates severe perilobular reticulation with mild architectural distortion and traction bronchiectasis.

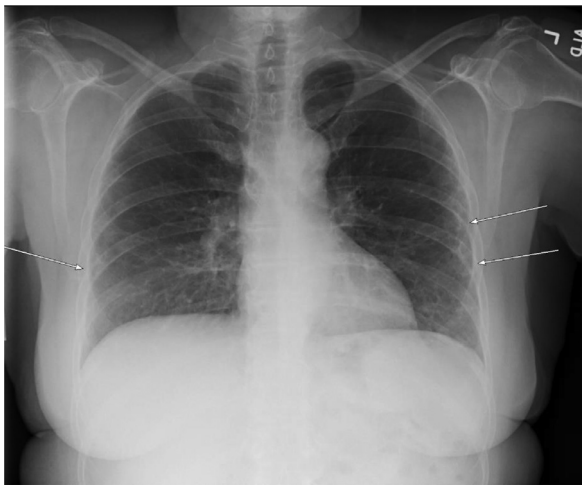

Figure 13 Frontal chest radiograph demonstrates mild opacities with a peripheral and lower lung distribution paralleling the chest wall (arrows), compatible with organization in the setting of known prior COVID-19 infection.

fibroproliferative (chronic).[54] DAD in the acute phase (within one week of initial lung injury) is characterized by intra-alveolar hyaline membranes, edema, and alveolar wall thickening with only mild interstitial inflammation. DAD in the subacute phase (after one week) is characterized by microscopic organization of fibrin, fibroblast migration, secretion of young collagen, presence of hyaline membranes, and changes in type II pneumocytes. While some patients with DAD recover, others may develop fibrosis, which typically resembles usual interstitial pneumonia (UIP) histologically.[55]

As ARDS is a marker of severe disease, patients with imaging and clinical findings consistent with ARDS are more likely to develop both short- and long-term complications, including PE, superimposed infection, prolonged pulmonary parenchymal changes, and pulmonary fibrosis. ARDS is also the most common indication for upgrading COVID-19 patients to the ICU.[56]

Superimposed infections

Lung abscesses, cavitary lesions, and/or empyemas, though rare, can develop in patients with COVID-19, but their presence should suggest the possibility of a superimposed viral, fungal, or more likely bacterial infection (Fig. 8).[57–59]

Barotrauma

Mechanically ventilated patients with COVID-19 have a higher incidence of barotrauma than those intubated for other causes, including the development of subcutaneous emphysema, pneumomediastinum, and pneumothorax (Fig. 9).[60] The radiologist must maintain a high level of suspicion for barotrauma, which is often only diagnosed on routine daily ICU chest radiography, and whose findings can sometimes be subtle when early or mild. Some patients develop subcutaneous emphysema and/or pneumomediastinum in the absence of prior mechanical ventilation, suggesting an underlying element of the disease itself can also result in these complications.[61]

Cardiac manifestations

Cardiac manifestations of COVID-19 are rare, but include myocarditis, pericarditis, and myocardial infarction, all of which may occur during any time in the disease course.[62–65] The most common cause of myocarditis and pericarditis is viral infection, including many other relatively benign upper respiratory tract infectious agents, not just coronaviridae. The exact incidence of cardiac complications in COVID-19 is unknown. In addition, it is unknown whether COVID-19 is more or less likely to cause myocarditis or pericarditis compared to other viral agents. Myocarditis is most often diagnosed on late gadolinium enhancement cardiac magnetic resonance imaging (cMRI) when there are focal or more often multifocal, predominantly subepicardial or mesocardial left ventricular (LV) wall lesions in a non-ischemic pattern (Fig. 10). Myocarditis can also be diagnosed by identifying myocardial edema on T2 inversion recovery, regional or global wall motion abnormalities on cine steady-state free precession MRI (SSFP), and hyperemia on early gadolinium enhancement. Right ventricular wall involvement, though less common, has also been observed. Sites of myocardial fibrosis manifest as abnormality on late gadolinium

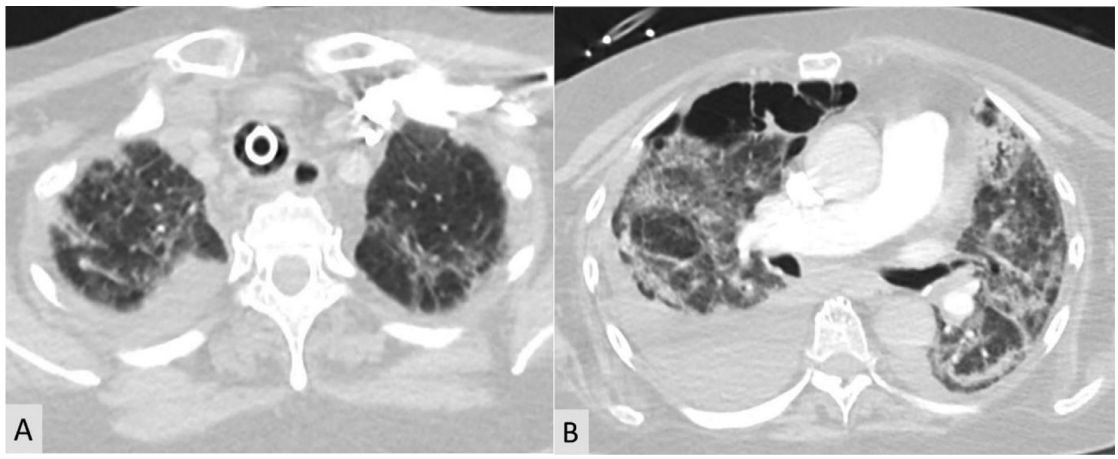

Figure 14 Axial CTs (A & B) demonstrate anterior cystic change in this intubated patient with severe COVID-19. Note is also made of a large right pleural effusion and a small left pleural effusion.

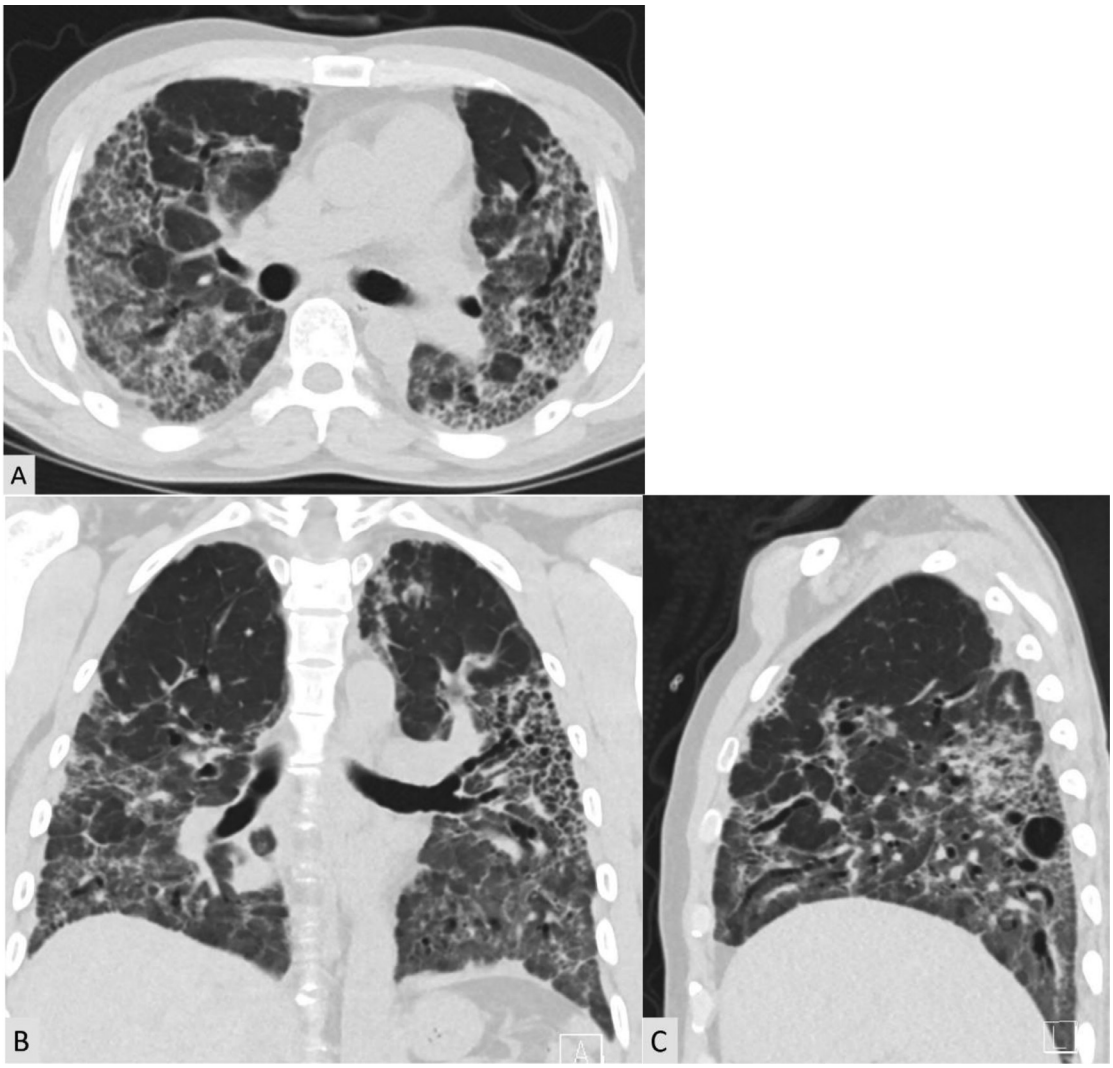

Figure 15 (A) Axial, (B) Coronal, and (C) Sagittal chest CT demonstrates classic severe fibrosis as manifested by lower lobe predominant pulmonary reticulation, architectural distortion, and traction bronchiectasis. Note the absence of honeycombing.

enhancement sequences. Conversely, myocardial infarction is diagnosed when the enhancement is localized to a specific coronary artery territory with a subendocardial or transmural distribution. Both myocarditis and myocardial infarction can present with transmural scarring. Edema on fluid-weighted imaging in areas of scar is indicative of acuity. Pericarditis is diagnosed on cMRI when there is pericardial thickening and/or enhancement. Pericarditis may also be diagnosed on contrast-enhanced CT or echocardiography.

Surveillance imaging in subacute COVID-19

Indications

COVID-19 patients in the subacute phase, similar to patients with other lower respiratory tract infections who are managed in the inpatient setting, do not require routine monitoring with chest radiography or CT. The primary clinical indication for additional CT imaging is an acute change in clinical status, suspicion for a complication such as abscess or empyema, or lack of improvement in symptoms despite treatment.[66,67] Furthermore, a 2013 Cochrane review suggested that routine chest radiography for inpatients with lower respiratory tract infections and/or pneumonias obtained after initial diagnosis had no effect on outcomes and is likely unnecessary.[68]

Imaging findings and their significance

The early acute phase of COVID-19 typically manifests as ground-glass opacities, often unilateral and with a peripheral lung distribution, but then progresses to more diffuse and confluent ground-glass opacity and consolidation bilaterally. Patients with mild to moderate symptoms often have progression with a peak occurring at 9 to 13 days.[42,43] Furthermore, studies have shown that imaging findings often peak

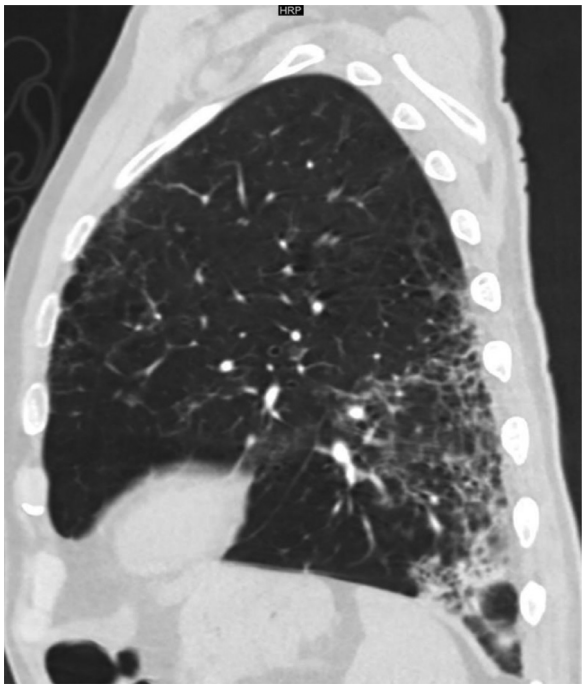

Figure 16 Sagittal reconstruction CT demonstrates mild to moderate lower lobe predominant fibrosis as manifested by pulmonary reticulation, volume loss, architectural distortion, and traction bronchiectasis.

in parallel with clinical symptoms at 10-12 days.[20] After this period, for patients with mild to moderate disease, the lungs typically begin to heal, and large dense opacities become smaller and less dense and may eventually resolve completely (Fig. 11).[69] However, some patients with more moderate disease develop an organizing pattern of lung injury, best evaluated with CT, as defined by a perilobular or peribronchovascular pattern, with or without a "reverse-halo sign", linear reticular opacities often paralleling the chest wall, and, if more severe, early scarring with mild traction bronchiectasis and architectural distortion (Fig. 12).[70] These linear opacities and subpleural parenchymal bands can, to a lesser extent, also be discerned on chest radiography (Fig. 13).

Some patients, particularly those with ARDS on mechanical ventilation, develop intrapulmonary cystic change with an anterior lung distribution, although this is not necessarily specific to COVID-19, as it can be seen in ARDS of any etiology (Fig. 14).[53] There were reports of anterior cystic change in patients with SARS who had either late-stage ARDS on mechanical ventilation or in the absence of mechanical ventilation, suggesting the pneumonia itself may be the cause.[9]

Surveillance imaging in chronic and/or long term COVID-19

The evolution of COVID-19 imaging findings on CT is variable. While most patients' symptoms and pulmonary parenchymal changes resolve without long-term sequelae, risk factors for the development of fibrosis on long-term follow-up CT include greater severity of parenchymal changes on initial imaging, longer length of inpatient hospitalization, development of ARDS, need for noninvasive or invasive mechanical ventilation, older age, and presence of comorbidities. Essentially, a more severe initial presentation with a higher degree of acute lung injury correlates with risk for development of fibrosis, with up to 35% of patients with severe COVID-19 developing fibrosis about three to six months after the acute illness. Patients with fibrosis on follow-up CT were also more likely to have diffusion abnormalities on pulmonary function testing (PFTs).[71] Whether or not this causes permanent lung injury remains an area of active investigation.

Pathologic studies on acute lung injury or ARDS of any cause, not just COVID-19 pneumonia, demonstrate that nearly all patients who survive beyond two weeks have some degree of pulmonary fibrosis, as evidenced by an increase in the amount of total lung collagen.[72] Furthermore, a 1999 study on the imaging findings of ARDS at six month follow-up CT demonstrated that the degree of coarse reticulation correlated strongly with both the degree of ground-glass opacification and the time spent on mechanical ventilation, particularly if the ventilator settings were set such with high tidal volumes, high positive end expiratory pressure (PEEP), or an inspiratory and/or expiratory ratio of >1.[73] In that sense, the severity of acute lung injury and/or the degree of oxygen supportive therapy correlates with the presence or absence of fibrosis at long-term follow-up. Likewise, pulmonary fibrosis in COVID-19 may be related to the disease itself or to ventilator-induced lung injury.

Patients with COVID-19-induced ARDS are more likely to develop pulmonary fibrosis compared to patients with ARDS from other causes. Furthermore, all patients with fibrosis have or had an organizing pattern of lung disease.[70] This indicates that COVID-19 pneumonia may be more likely to result in a transition from acute inflammation to an organizing process and eventual fibrosis compared to other types of pneumonia. Paralleling beneficial effects on mortality in the setting of acute moderate to severe COVID-19 pneumonia, steroids may help prevent inflammation from progressing to organization and fibrosis in the subacute to chronic setting, but precise efficacy is yet to be determined.

CT imaging findings

Long-term fibrotic sequelae of COVID-19 pneumonia are best visualized on CT (Fig. 15). The imaging findings of fibrosis are similar in distribution to usual interstitial pneumonia (UIP) and non-specific interstitial pneumonia (NSIP), with a lower lobe and peripheral predominance, which parallels the initial acute lung injury in both location and severity (Fig. 16). However, unlike UIP, which is differentiated by the presence of true honeycombing (stacks of subpleural cysts), COVID-19 pneumonia patients typically do not demonstrate significant honeycombing. Instead, COVID-19-induced fibrosis is characterized by peripheral and basilar predominant reticular opacities with parenchymal bands, traction bronchiectasis, volume loss, and architectural distortion.[71] In milder cases, the progression to frank fibrosis is less apparent, with the predominant CT findings being subpleural

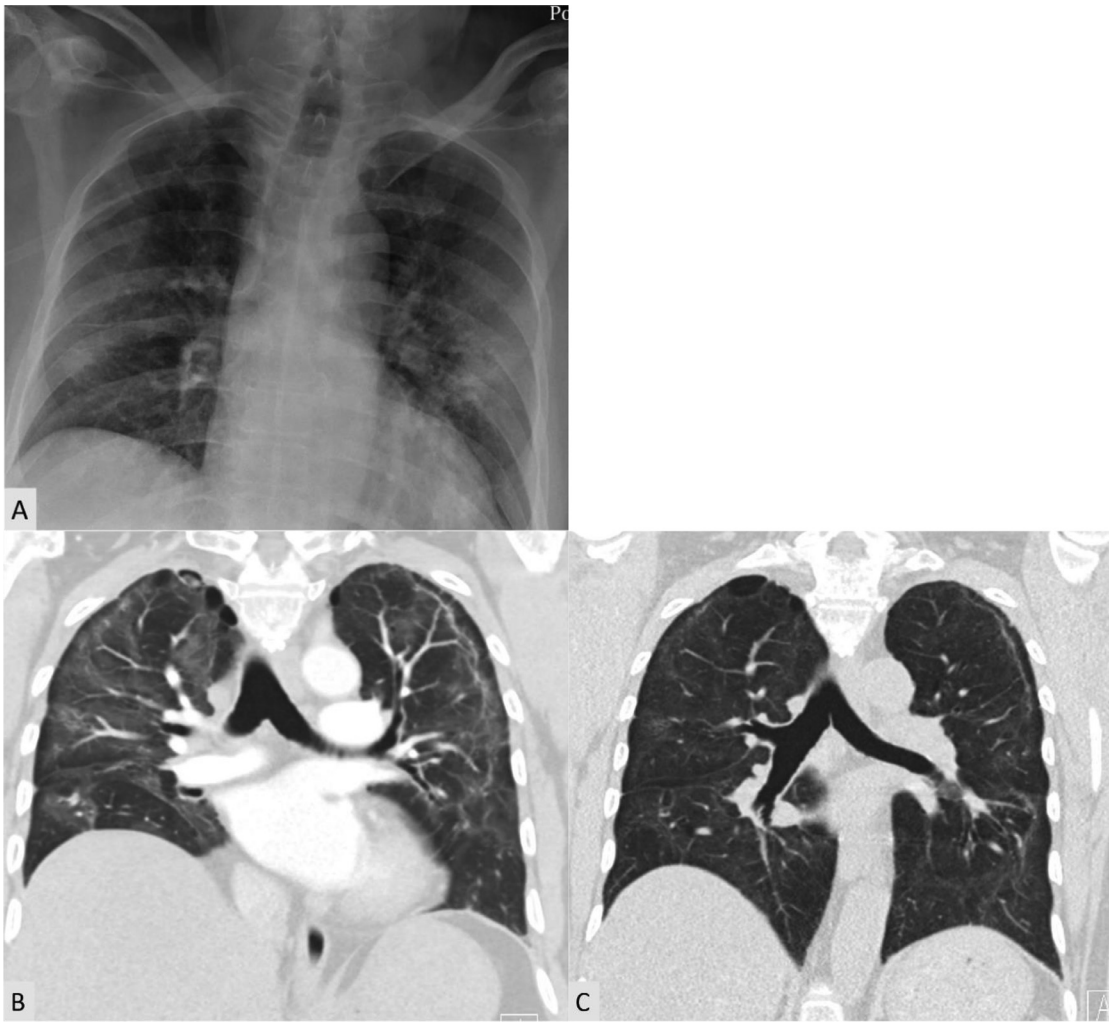

Figure 17 (A) Initial chest radiograph demonstrates mild to moderate acute COVID-19; (B) Two months later, coronal reformatted CT demonstrates moderate amount of bilateral ground-glass opacity with reticular opacities paralleling the pleura, indicating an element of organization; (C) Coronal reformatted CT at nine months demonstrates improvement in ground-glass opacity with persistent more reticular opacification, indicating organization with residual fibrosis.

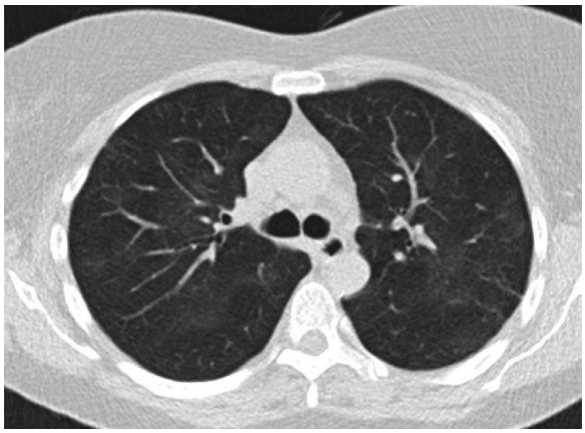

Figure 18 Axial CT demonstrates mild residual diffuse hazy ground-glass opacification in a patient with residual dyspnea four months after infection.

parenchymal bands that parallel the pleura with much less extensive traction bronchiectasis and architectural distortion (Fig. 17). In both cases, ground-glass opacities may also be present.

In some patients, the predominant finding at long-term follow-up is persistent faint ground-glass opacification without frank organization or fibrosis (Fig. 18).

Future of COVID-19

As COVID-19 wanes in many parts of the world and scientific data continues to accrue, physicians are better equipped to provide optimal care. Although imaging patterns have been well described, many questions remain. For example, it remains unknown whether patients with pulmonary fibrosis on imaging will recover or progress, whether COVID-19 patients will be at higher risk of lung cancer or be more susceptible to future pulmonary infections. Furthermore, it is

unclear if emerging variants will have similar or novel imaging appearances. It also remains unknown whether some patients with COVID-19 pneumonia should be monitored with serial CT, as long-term consequences are still being studied.

COVID-19 remains a global pandemic. It is imperative that the radiologist be familiar with imaging findings and complications of COVID-19 and function as a crucial member of the clinical team in managing these patients.

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