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Computed Tomography of the Chest in COVID-19: A Pictorial Review of Indian Patients

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Abstract

The Coronavirus disease 2019, caused by severe acute respiratory syndrome corona virus 2 (SARS-CoV-2), has evolved into a pandemic and has affected more than 130 million people globally to date and continues to infect more. The disease primarily involves the respiratory system and manifests as fever, dry cough, dyspnea, and myalgia. Nearly half of the infected patients may be asymptomatic. The real-time reverse transcriptase polymerase chain reaction (RT-PCR) performed on the blood or respiratory samples is the diagnostic test with high accuracy. Although imaging with CT is not routinely indicated in this disease, this modality may provide a quick answer and assist in making a diagnosis in certain situations. In addition, imaging with CT also aids in evaluating the progress of the disease and in prognostication. A thorough knowledge of the common findings on the CT scan helps a radiologist in suggesting a diagnosis when it is performed in unsuspected patients. In this review, we describe the common and uncommon chest findings of COVID-19 on the CT scan.

Keywords
- severe acute respiratory syndrome
- coronavirus disease
- COVID-19
- consolidation
- ground glass opacity

Introduction

The novel Coronavirus, causing severe acute respiratory syndrome (SARS)-like disease, is a recently discovered zoonotic virus spread from the bats, which act as natural hosts and reservoirs.[1,2] This virus, now renamed as SARS Coronavirus-2 (SARS-CoV-2), belongs to the subgenus *Sarbecovirus* and family *Coronaviridae* and is a single-stranded RNA virus.[2] The disease began in Wuhan, in China, in late December 2019 and was declared a pandemic by the World Health Organization (WHO), as it has spread to almost every country. To date, (April 04, 2021), the virus has infected over 130 million people worldwide and has resulted in over 2.8 million deaths.[3]

The virus predominantly affects the lungs and airways, and imaging is not routinely necessary for the diagnosis. However, many studies have shown that CT has a role to play in the diagnosis of COVID-19 in specific situations and hence the radiologist may be the first to suggest the diagnosis when it not clinically suspected.

Clinical Features

The SARS-CoV-2 virus primarily affects the respiratory system; particularly the lower respiratory tract.[4] The most common symptom is fever, seen in up to 98% of the patients. Other common symptoms include dry cough, dyspnea, fatigue, and myalgia.[4,5] Sputum production, headache, hemoptysis, and diarrhea are uncommon. The symptoms differ from the other diseases caused by Coronavirus family like SARS and Middle East respiratory syndrome (MERS), in that these infections more commonly affect the upper respiratory tract and have higher incidence of diarrhea.[4] Although the disease affects all

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ages and gender, it is more commonly seen in the middle age population and men. About 37% of the infected patients had associated comorbidities like diabetes mellitus, hypertension, and cardiovascular disease.[5] About 30% of the patients may require admission to intensive care unit (ICU) to correct hypoxemia. Laboratory findings are nonspecific and show elevation of C-reactive protein (CRP), erythrocyte sedimentation rate (ESR), and lactate dehydrogenase (LDH).[5]

Pathology

The pathological changes in the lungs in patients with COVID-19 correlate with the stage of the disease and CT findings.[6,7] The lung changes are found in almost all patients irrespective of whether the patient is symptomatic and are similar to that found in SARS and MERS.[8,9] The primary pulmonary changes on histology are that of diffuse alveolar damage and include hyaline membrane deposition, alveolar epithelial cell injury, accumulation of exudates of fibrin, and diffuse hyperplasia of type II pneumocytes.[10] The initial stage is mild exudative phase, which corresponds to ground-glass opacities (GGO) on CT scan. Histologically, there is alveolar edema, exudates of protein, focal areas of hyperplastic pneumocytes, and patchy infiltration of inflammatory cells. The subsequent stage is proliferative phase, which is represented by consolidation on CT scan and by fibroblast proliferation and deposition of extracellular matrix and fibrin within the alveoli on histology.[10] When there is secondary bacterial infection, the alveoli may show neutrophilic infiltration. The primary reason for the predominant pulmonary involvement in COVID-19 is the selective requirement of angiotensin-converting enzyme 2 (ACE-2) by the virus to infect cells and the high concentration of these receptors in the pneumocytes.[11]

Diagnosis

The disease is extremely contagious and has no specific treatment. These two factors make a timely diagnosis imperative to isolate and manage the infected person.[12] The confirmatory test of COVID-19 is reverse transcriptase polymerase chain reaction (RT-PCR), which identifies the RNA in the respiratory or blood samples. The test has a sensitivity varying from 71% to 97% in different studies.[13-15] The real time RT-PCR requires approximately 5 to 6 hours to produce the final result. In countries where the number of cases are high, the number of the kits for RT-PCR may not be readily available.[16] This sometimes prompts the necessity of performing imaging, particularly CT scan, in clinically suspected patients of SARS-CoV-2 infection. Further, since nearly half of the patients are asymptomatic, incidental detection of findings on the lung bases may be possible when an abdominal scan is performed for an unrelated pathology. Hence, it is critical that the performing radiologist is clearly aware of the various chest CT appearances of COVID-19, so as to raise a suspicion of the disease and suggest proper subsequent steps in the management. The CT scan has a sensitivity for detection of the disease in the range of 86 to 98%, but the specificity is low (25%) as such findings may be seen in other infectious diseases.[12,13]

Safety Measures with CT Scan

COVID-19 is a highly contagious disease, and performing CT scan of patients afflicted with it exposes the staff and the scanner to contamination by the virus. All precautionary measures should be in place to avoid these risks.[17] Prior to performing the CT scan, adequate staff training, properly laid standardized operative procedures like scheduling such patients during later part of the day and, whenever possible, dedicated hallways for these patients help in significantly mitigating the risk of transmission. Entry of personnel into the CT scanner room should be restricted and all, including patients, should wear a mask.

While performing the CT scan, the technologists should wear personal protective equipment (PPE).[18] The recommendation is to have two technologists to perform a CT scan, one to remain in the scanning room to shift and position the patient and the other in the console room for planning and performing the scan.[19]

Once the CT scans are performed, the next step is decontamination of the CT scanner, the room, and room air.[19] The protocol for decontamination is to mop the floor and the wipe the CT scanner, initially with water mixed with detergent, followed by sodium hypochlorite solution. Subsequently, the room is fumigated with formaldehyde for 30 minutes. The high-frequency contact surfaces should be wiped with a cloth soaked in alcohol-based disinfectants. The CT suite should be completely closed for 1 hour and properly ventilated.

Technique of Computed Tomography

The technique of performing a CT scan of the chest in a patient of COVID-19 is not different from the standard technique. The scan is performed with patient in supine position from thoracic inlet to costophrenic angles, with breath held in end-expiration.[6] Intravenous (IV) contrast is usually not necessary.[20] Both lung and mediastinal windows should be evaluated along with multiplanar reconstructions.

Spectrum of Findings on Computed Tomography

Various findings have been described on the CT scan of the chest in patients of COVID-19, which aid in the diagnosis. The spectrum of findings in the chest are broadly classified into four categories: pulmonary parenchymal, airway, pleural, and other organ changes.[6,12,21,22] A schematic representation of the chest findings are shown in ►**Fig. 1**.

Pulmonary Parenchymal Changes

Pulmonary alveoli are the most common site of involvement in the chest. A variety of alterations in the alveoli and the interstitium have been described in patients with COVID-19 pneumonia.

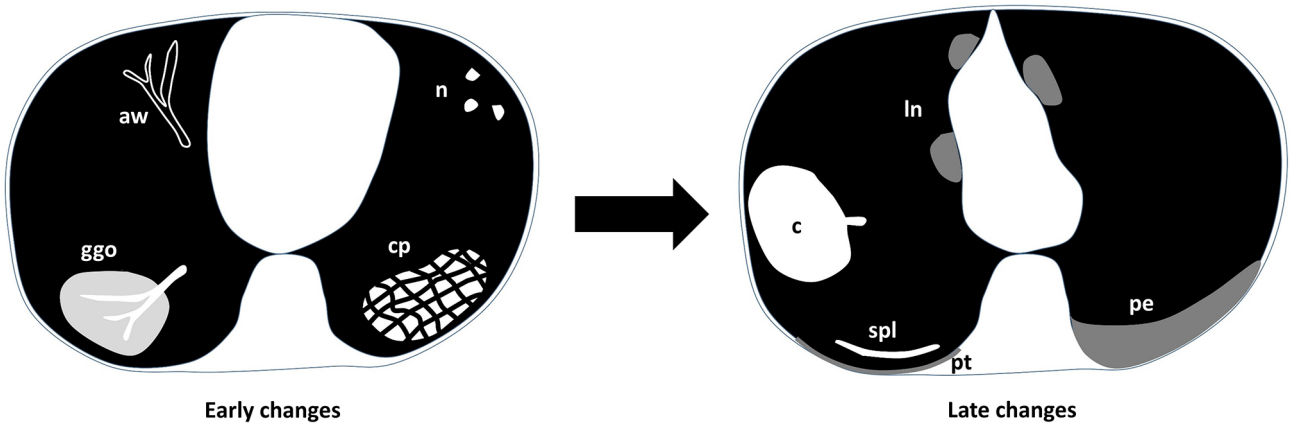

Fig. 1 Schematic diagram of the changes in the lungs in COVID-19 pneumonia. aw—airway (bronchial wall thickening, bronchiectasis); c—consolidation (obscured vessels); cp—crazy paving (alveolar with interstitial exudates); ggo—ground-glass opacity (vasculature seen); ln—mediastinal lymphadenopathy; n—nodules; pe—pleural effusion; pt—pleural thickening; spl—subpleural line.

Ground-Glass Opacity

Ground glass opacity (GGO) is the most common manifestation of COVID-19 pneumonia. The GGO occurs due to partial filling of the alveoli with the inflammatory exudates, fluid, and hyaline membrane.[6,23] On CT scan, the GGO appear as an area of increased density in the lungs, without obscuration of vascular and bronchial markings (►**Fig. 2**).

It is considered as one of the earliest CT signs and is found in 98 to 100% of the patients.[22,24,25] However, Pan et al suggested that the extent of the GGO and lung findings depends on the time of scan from the symptom onset, with GGO seen in small sizes and in subpleural regions in the early stage of the disease (►**Fig. 3**).[26] Subsequently, these progress to consolidation and interstitial thickening.[27]

Consolidation

Consolidation, the second most common finding in COVID-19 pneumonia, is seen as an area of increased density in the lungs, with obscuration of vascular and bronchial markings on the CT scan (►**Fig. 4**). Consolidation occurs when there is alveolar infiltration with fluid and inflammatory cells, as described in the previous section.[10,21,23] This appearance is found in up to 63% of the patients and may be patchy, segmental, and multifocal.[25,28] The consolidation may be found de novo or may develop in an area of previous GGO, indicating that this is seen more commonly as the disease progresses.[6,24] Further, many of the patients during the course of the disease, particularly during 1 to 3 weeks, have a combination of GGO and consolidation.[7] It may be associated with an air-bronchogram.

In a study by Song et al, the authors showed that consolidation is more common in the late stage of the disease and in patients aged more than 50 years.[27] Hence, consolidation may be a warning of a severe disease course.

Interstitial Changes

Along with alveolar infiltration, there may be an associated infiltration of the intralobular and interlobular septae by lymphocytes, resulting in their thickening.[6] This finding is seen in up to 49% of patients and constitutes the third most common finding.[22] On the CT scan, the interstitial thickening is seen as reticular densities, which may have smooth or nodular outline (►**Fig. 5**).[6,21,22]

A finding described along with interstitial tissue involvement is crazy paving pattern. This occurs due to coexisting GGO and interlobular septal thickening, giving the appearance of a

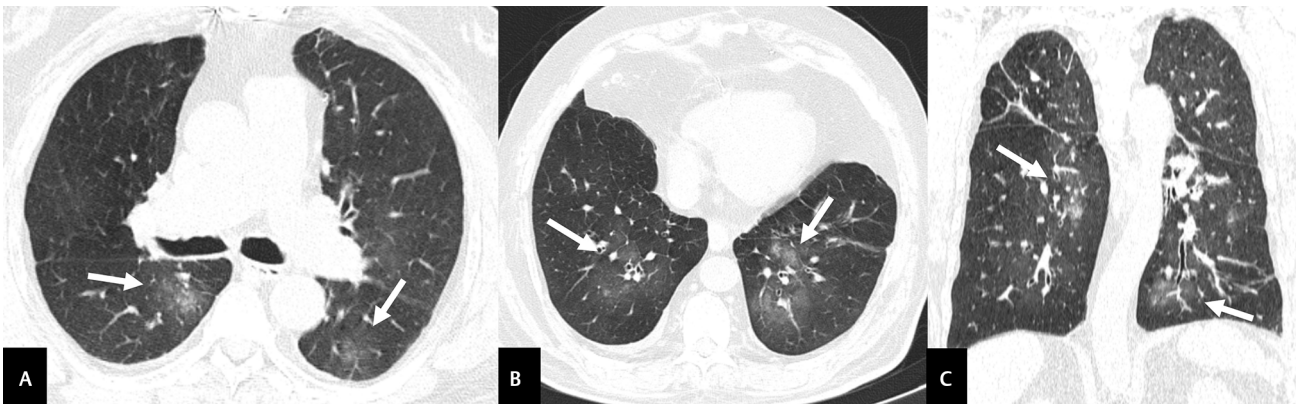

Fig. 2 Axial (**A, B**) and coronal (**C**) CT images in lung window of a 72-year-old male COVID-19 patient show multifocal ground-glass opacities (GGOs) in bilateral lungs, predominantly in the lower lobes (arrows).

stoned pavement with random lines (►**Fig. 6**). This finding is found in 5 to 36% of patients of COVID-19 pneumonia.[29] When this finding is present with GGO and consolidation, it may suggest peak stage or progressive disease.[26]

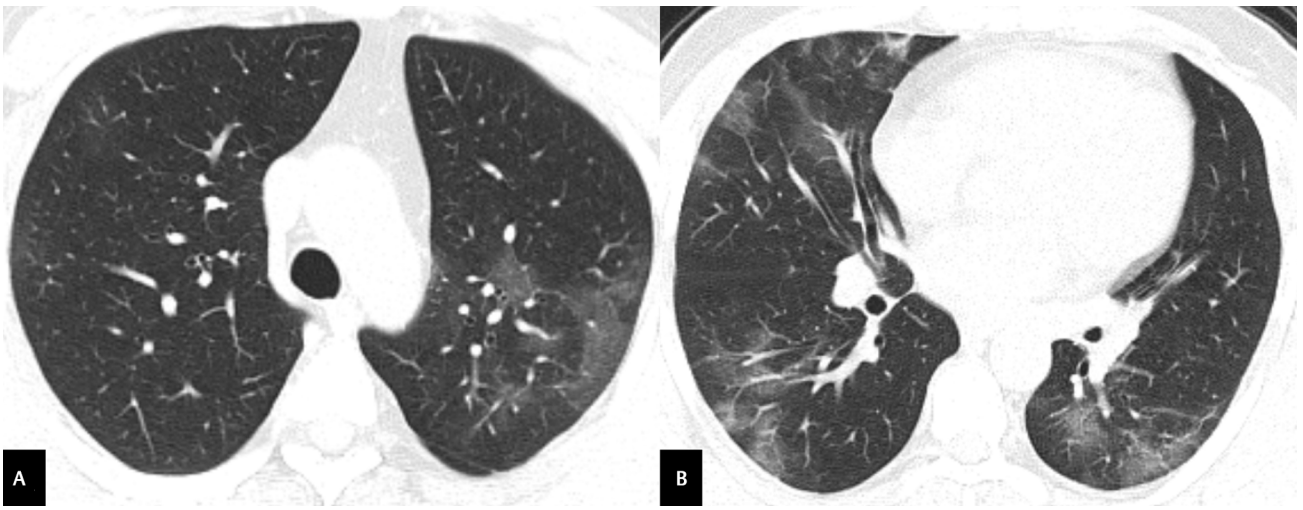

Fig. 3 Axial CT images in lung window (**A, B**) of a 40-year-old male with COVID-19 infection show multifocal ground-glass opacities (GGOs) in the peripheral and subpleural distribution.

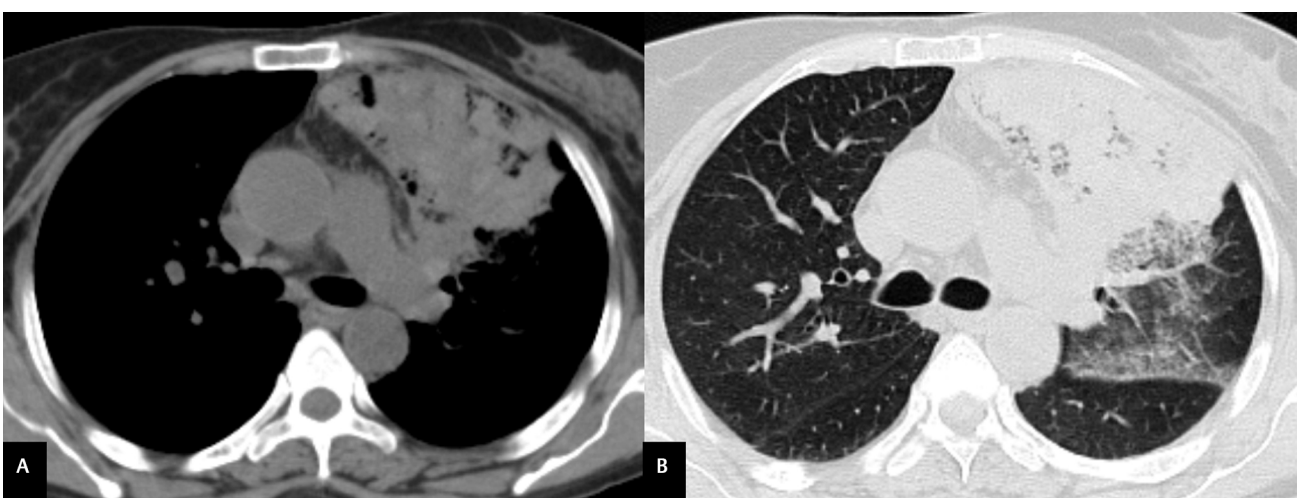

Fig. 4 Axial CT images, mediastinal (**A**) and lung (**B**) windows of a 64-year-old female with COVID-19 pneumonia show an area of segmental consolidation in the left upper lobe. Adjacent ground-glass opacities (GGOs) and interlobular septal thickening are also seen.

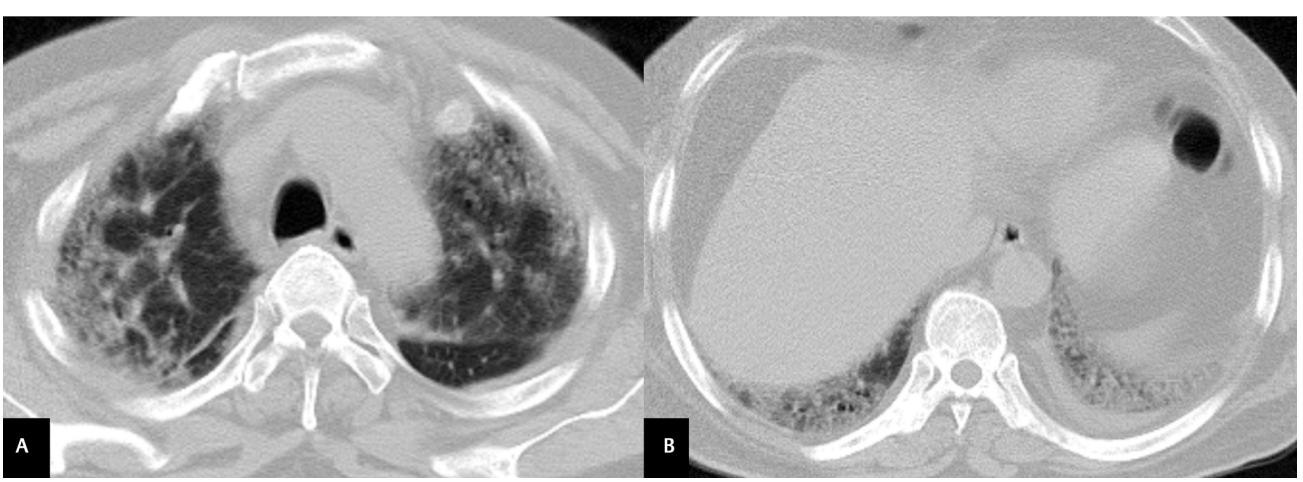

Fig. 5 Axial CT images in lung window (**A, B**) of a 55-year-old male with COVID-19 infection show areas of intralobular and interlobular septal thickening in the bilateral subpleural regions.

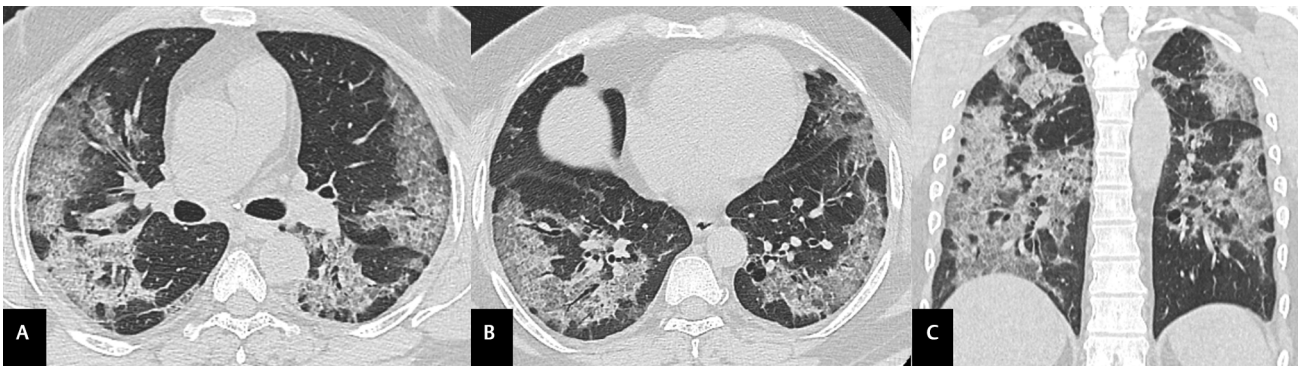

Fig. 6 Axial (**A, B**) and coronal (**C**) CT images of a 30-year-old male with COVID-19 infection show combination of ground-glass opacities (GGOs) and interstitial thickening in bilateral lungs, giving the appearance of crazy paving.

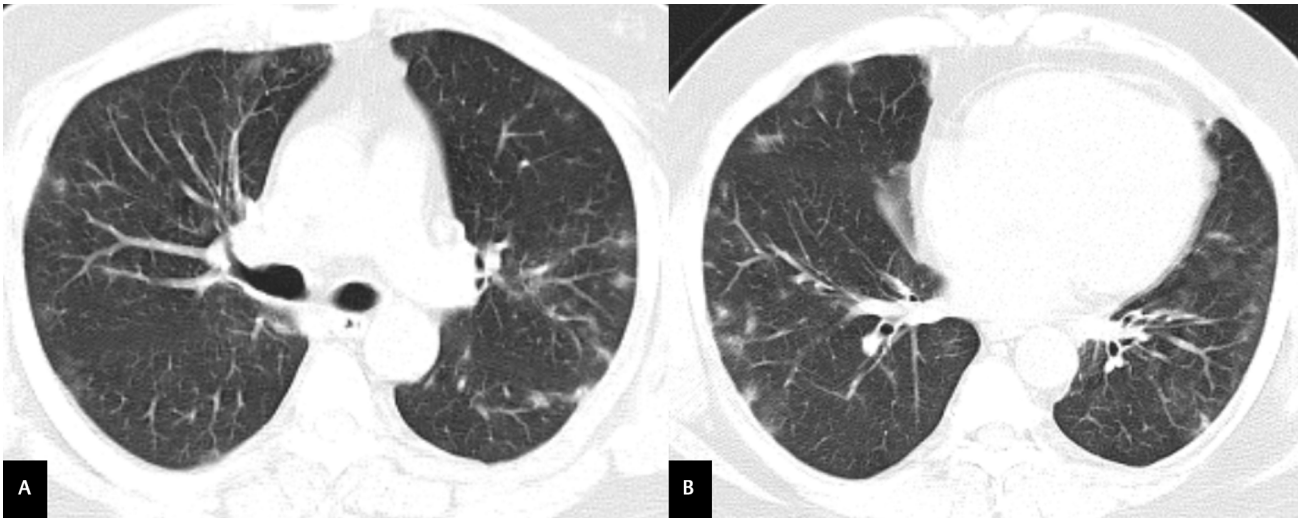

Fig. 7 Axial CT images in lung windows (**A, B**) of a 55-year-old male with COVID-19 infection show ill-defined centrilobular nodules in bilateral lungs, predominantly distributed in the subpleural regions.

Nodules

About 23% of patients with COVID-19 may show centrilobular nodules (size < 3 cm) on CT scan.[22] The nodules may be solitary or, more commonly, multiple and frequently have ill-defined margins (►**Fig. 7**).[21] As the disease progresses, the nodules may increase in size and number.[30] There may be an associated ground glass halo around some of the nodules.

Vascular Enlargement

Enlargement of the pulmonary vasculature is found in approximately 70% of the patients of COVID-19.[22] On CT scan, they are seen as smoothly dilated pulmonary vessels within or around an area of GGO or consolidation (►**Fig. 8**). This finding develops due to the vasodilatation, injury and edema of the vessel wall from acute inflammation.[21,22]

Halo and Reverse Halo Sign

Halo sign is defined as a nodule with surrounding GGO (►**Fig. 9**).[23] This finding is nonspecific and is uncommonly described in COVID-19 pneumonia.[31,32] Although in other diseases, the halo of GGO is due to hemorrhage, its pathogenesis in COVID-19 is currently unclear.

A reverse halo or atoll sign has also been described in patients of COVID-19. This sign is defined as a halo of consolidation around a low-density core or GGO (►**Fig. 9**).[33] They occur when a ring of consolidation develops around a GGO core or when there is healing in the center.[25]

Both these signs are uncommonly described in COVID-19 pneumonia. A study by Li et al found halo sign and reverse halo sign in 17.6% and 3.8% of patients, respectively.[31]

Fibrosis and Architectural Distortion

In the late stage of the disease, fibrosis and architectural distortion may be seen. This occurs as a result of the healing process of the GGO, consolidation, and interstitial disease.[30] On CT scan, fibrosis is seen as irregular sharply marginated densities, in the alveolar space or interstitium, or both, leading to distortion of the parenchymal structure, lobar or pulmonary volume loss, and mediastinal shift (►**Fig. 10**).[20] The incidence of fibrosis on CT scan varies from 21 to 53%.[20,22] Although fibrosis indicates healing, its prognosis is still not clear. The reversibility of the fibrosis is not currently known.

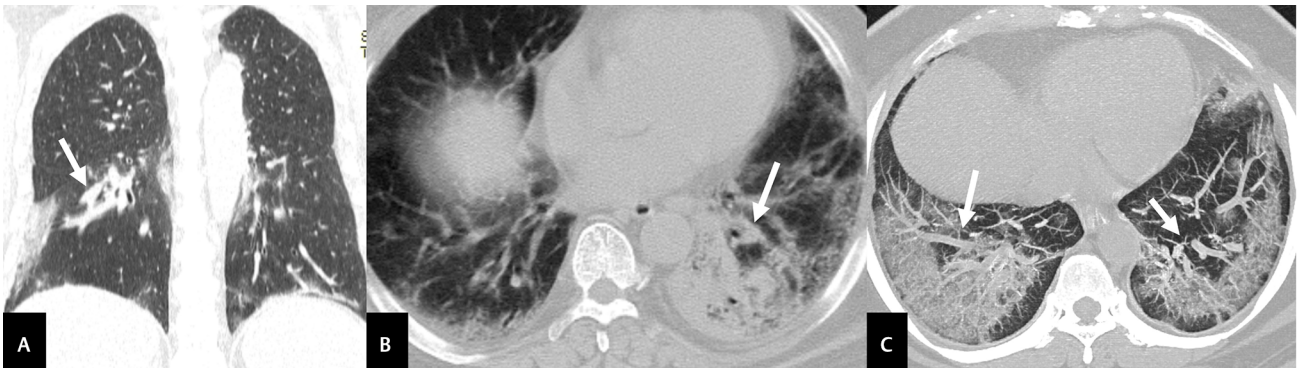

Fig. 8 CT images in lung windows of three different patients of COVID-19 pneumonia showing vascular enlargement in association with ground-glass opacities (GGOs) (arrow in **A**), consolidation (arrow in **B**) and crazy-paving (arrows in **C**).

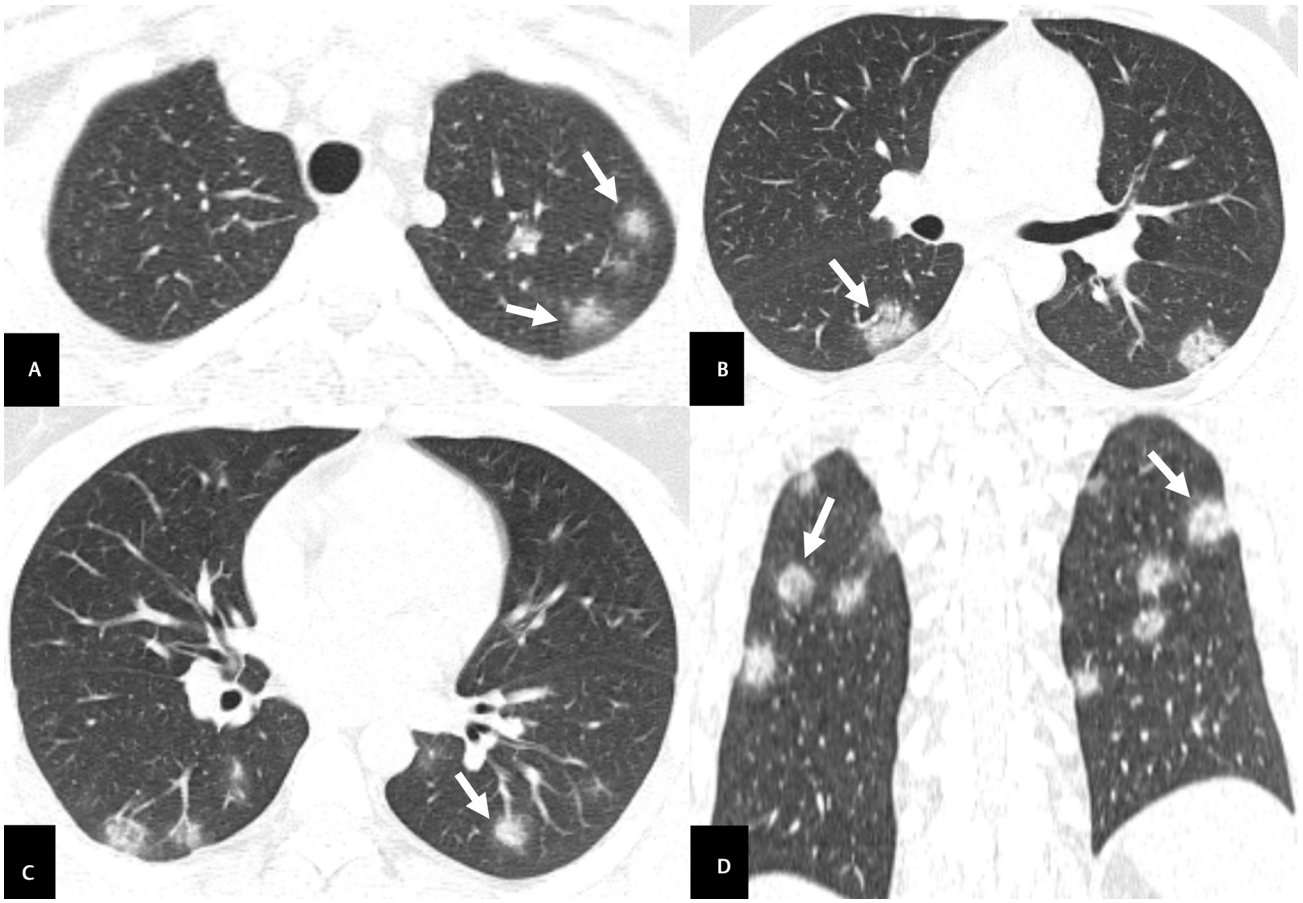

Fig. 9 Axial (**A-C**) and coronal (**D**) CT images in lung window of a 25-year-old male with COVID-19 pneumonia show multiple nodules in bilateral lungs, with halo sign (arrows in **A-C**) and reverse halo sign (arrows in **D**).

Distribution

Many studies describing the distribution of the pulmonary findings have found that the most common site of involvement is the lower lung lobe, seen in 55% of the cases (►**Fig. 11**).[22] Diffuse involvement of upper and lower lobes is the second most common appearance, and in 6%, upper lobes are predominantly involved. Peripheral and subpleural pulmonary areas are more commonly involved (75%) compared to the central regions (►**Fig. 11**).[22,24] In 80%, the disease is bilateral, and in 55%, it is multifocal.

Airway Changes

The airway changes which are described in COVID-19 include bronchial wall thickening and bronchiectasis.[21]

Bronchial Wall Thickening

Bronchial wall thickening, which occurs due to inflammation of the bronchial wall, is found in less than a third of patients of COVID-19.[22,28] On CT scan, it is seen as a smoothly thickened walls of the bronchi (►**Fig. 12**). One study by Li et al

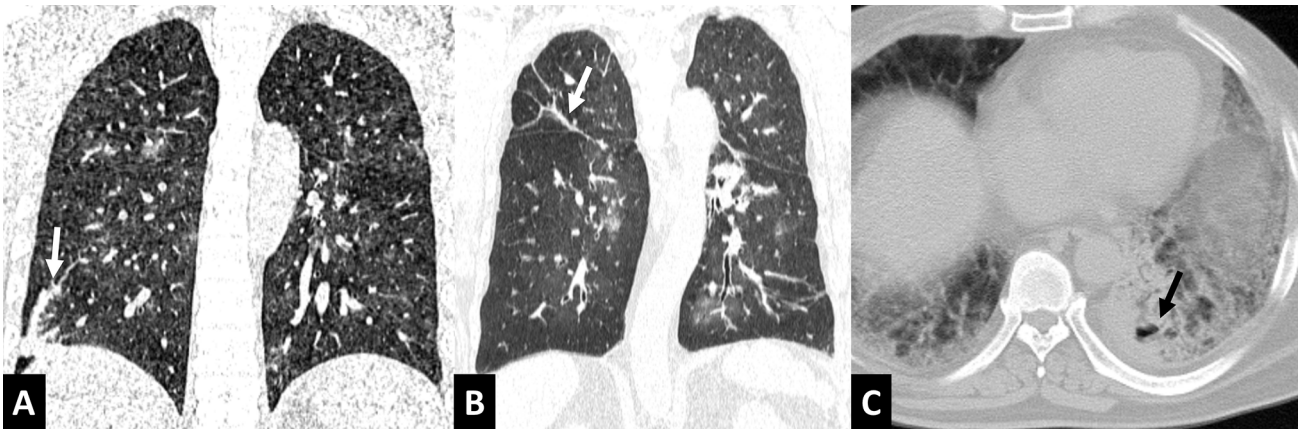

Fig. 10 Coronal (**A, B**) and axial (**C**) CT images in lung window of three different patients of COVID-19 pneumonia in recovery phase show fibrotic bands (arrows in **A** and **B**) and cavitation (arrow in **C**).

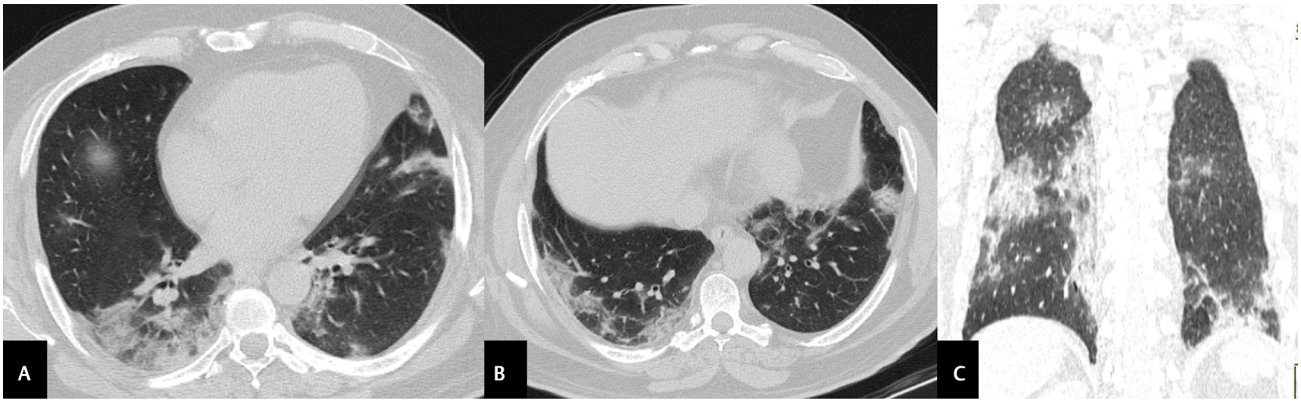

Fig. 11 Axial (**A, B**) and coronal (**C**) CT images in lung window of a 60-year-old male with COVID-19 pneumonia show the distribution of the pulmonary involvement, which is multifocal, peripheral and subpleural with lower lobar predominance.

has shown that this finding was more common in severe and critically ill patients, which may help in predicting disease severity and prognosis.[25]

Bronchiectasis

Bronchiectasis or bronchiolectesis, defined as abnormal irreversible dilatation of the airways, occurs either due to inflammatory weakening of the bronchial wall or due to traction of the bronchi by surrounding fibrosis (tractional bronchiectasis) (►**Fig. 12**).[21] Bronchiectasis is found during the second and third week of the disease and may indicate the beginning of recovery process.[6]

Air bubble sign is a rare finding described in COVID-19 pneumonia.[21] On CT scan, it is seen as a small air-containing space or cyst, which could be due to bronchiolectasis or resorption of an area of consolidation (►**Fig. 12**).

Pleural Changes

Pleural Effusion

Pleural effusion is an infrequent finding in COVID-19 and is seen in approximately 5 to 14% of the patients (►**Fig. 13**).[6,22] This finding is seen late in the course of the disease and may be associated with poor prognosis.[20]

Pleural Thickening

Pleural thickening is more common than pleural effusion and is seen in 32% of patients (►**Fig. 13**).[6,7] This finding is usually associated with pulmonary signs like GGO, consolidation, or interstitial thickening.

Subpleural Lines

Subpleural lines or bands, another relatively common finding, are seen in less than a third of patients. On CT scan, these lines are seen within 1 cm of the pleural surface and appear as 1- to 3-mm thick curvilinear densities (►**Fig. 13**).[21] This finding may be related to either pulmonary edema or fibrosis.[25]

Other Changes

Lymphadenopathy

Mediastinal lymphadenopathy is an infrequent finding in COVID-19 and has been reported in 4 to 8% of patients (►**Fig. 14**).[7,28] This finding is associated with severe and critical pneumonia and is considered to be a poor prognostic factor.[25] However, secondary bacterial infection should be considered when this finding is found in association with lung nodules and pleural effusion.[12,13]

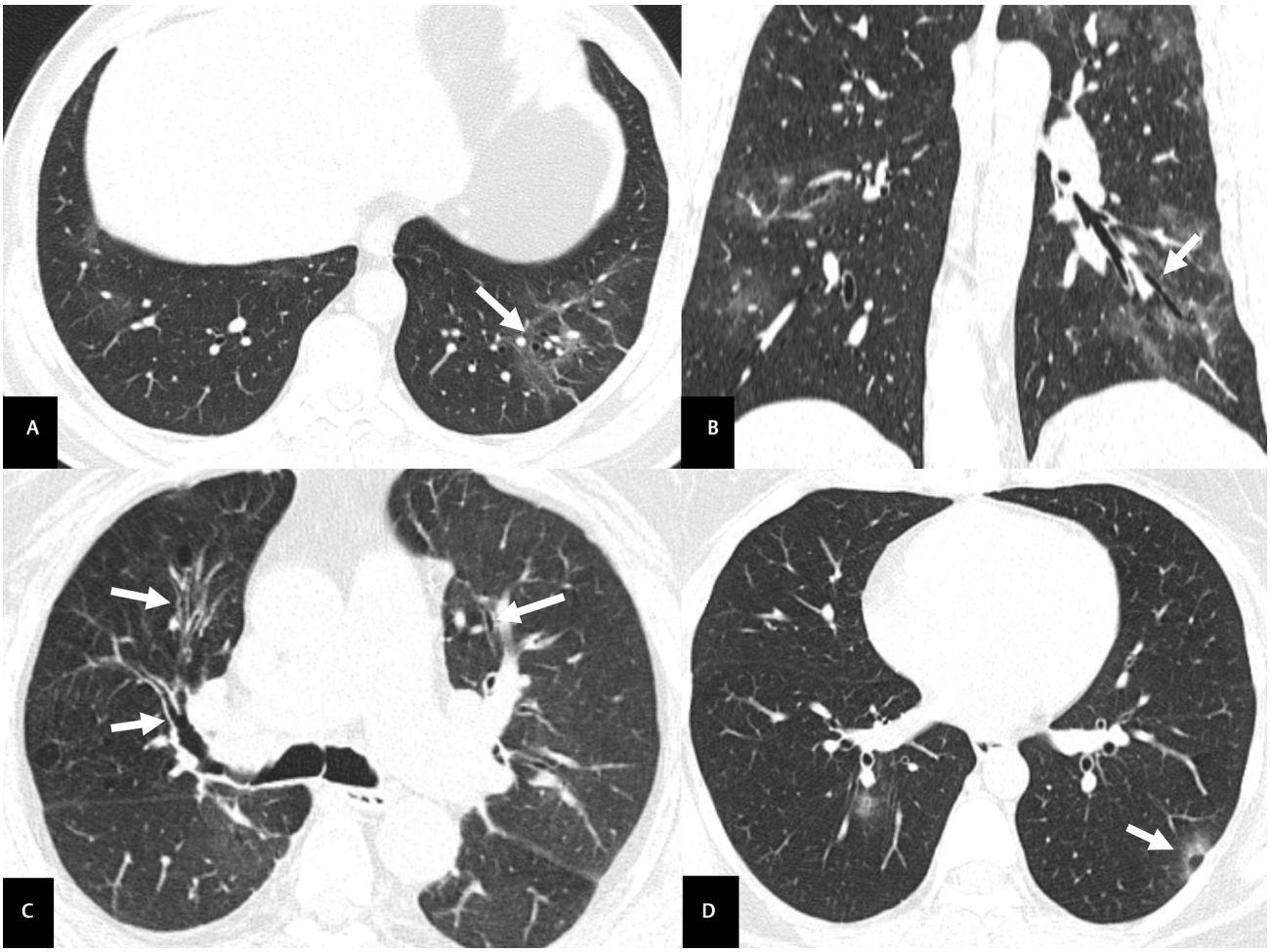

Fig. 12 A, B–Axial (**A**) and coronal (**B**) CT images in lung window of a 40-year-old male with COVID-19 infection show bronchiectasis (arrow) with surrounding ground-glass opacities (GGOs). **C**—Axial CT image in lung window of a 72-year-old male with COVID-19 shows bronchial wall thickening bilaterally (arrows). **D**—Axial CT image in lung window of a 35-year-old female with COVID-19 pneumonia shows the characteristic cyst sign (arrow).

Pericardial Effusion

Pericardial effusion is found in approximately 5% of the patients of COVID-19 and is frequently seen in association with severe and critical disease.[24] Thus, this finding also carries a poorer prognosis.[25]

Pulmonary Embolism

Some reports have suggested the development of pulmonary embolism (PE) in patients of COVID-19 presenting with respiratory failure.[34,35] The current reports have indicated that pulmonary embolism is seen in 22 to 30% patients afflicted with COVID-19.[35] CT pulmonary angiography should be performed whenever PE is clinically suspected.

Recovery Phase of COVID-19

The recovery process typically starts after 14 days of the disease in about three-fourths of the patients.[24] During the recovery phase of the disease, the CT scan shows improvement in the previously documented findings in the form of reduction in the extent of pulmonary or lobar involvement, resorption of GGO and consolidation and disappearance of nodules and crazy paving feature.[26] Subsequently, cavities may develop along with bronchiectasis and other fibrotic changes. The long-term consequences of fibrotic changes are currently not known.

Differential Diagnosis

As mentioned in a previous section, although CT scan has high sensitivity of up to 98%, its specificity is only 25%.[12] This is because the findings seen on CT scan are found in many other diseases caused by adenovirus, influenza and parainfluenza viruses, rhinovirus, and respiratory syncytial virus.[31,36] Although difficult, based on the predominant CT findings, it may be possible to differentiate COVID-19 pneumonia from other viral pneumonias. These findings include asymmetrically distributed centrilobular nodules and consolidation in respiratory syncytial virus; bilateral multifocal, lobar or segmental GGO and consolidation in adenovirus;

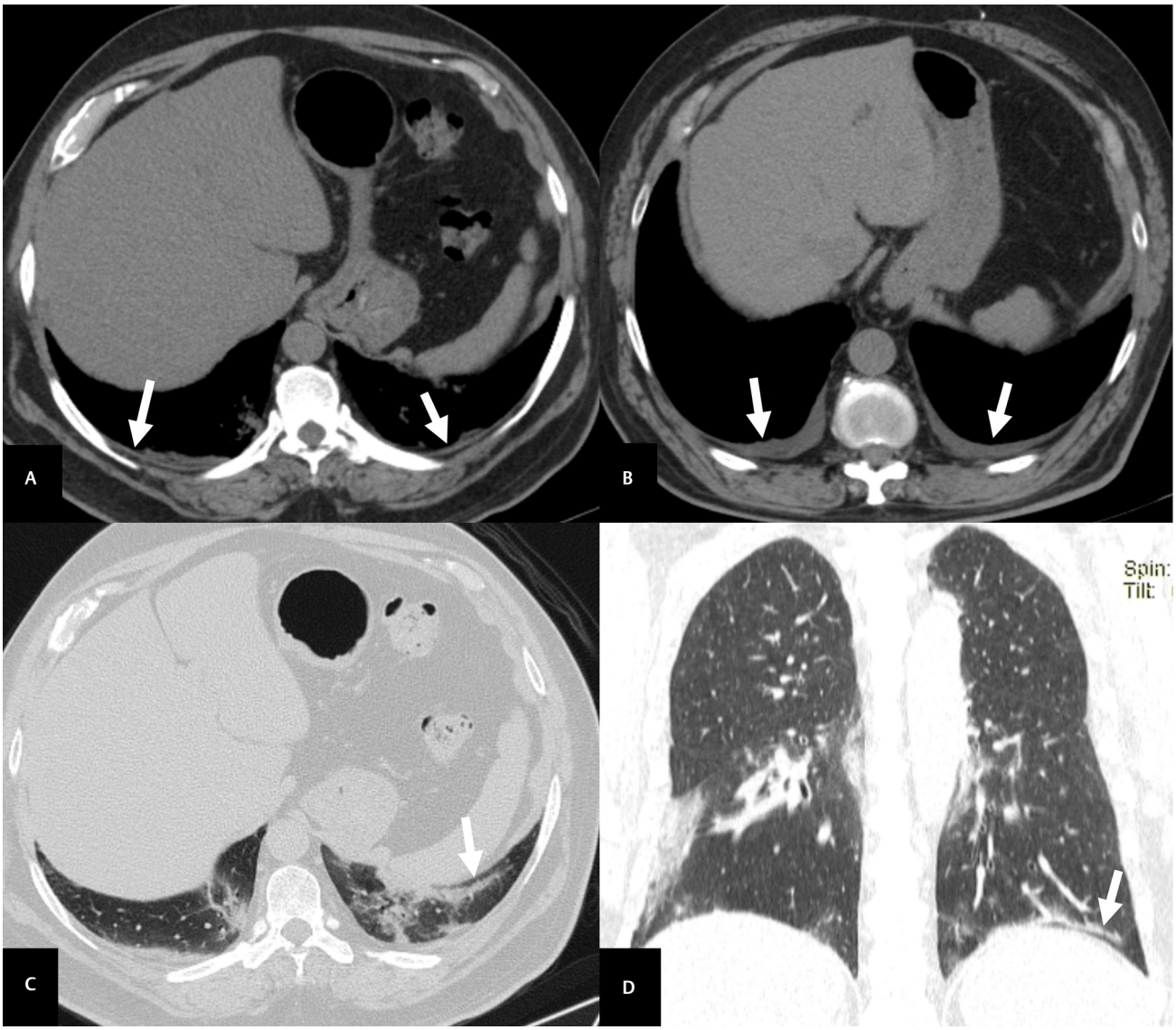

Fig. 13 Axial (**A**, **B**—mediastinal window; **C**—lung window) and coronal (**D**—lung window) CT images of three different patients with COVID-19 pneumonia show pleural involvement in the form of bilateral pleural thickening (arrows in **A**), bilateral pleural effusion (arrows in **B**), and subpleural band (arrow in **C** and **D**).

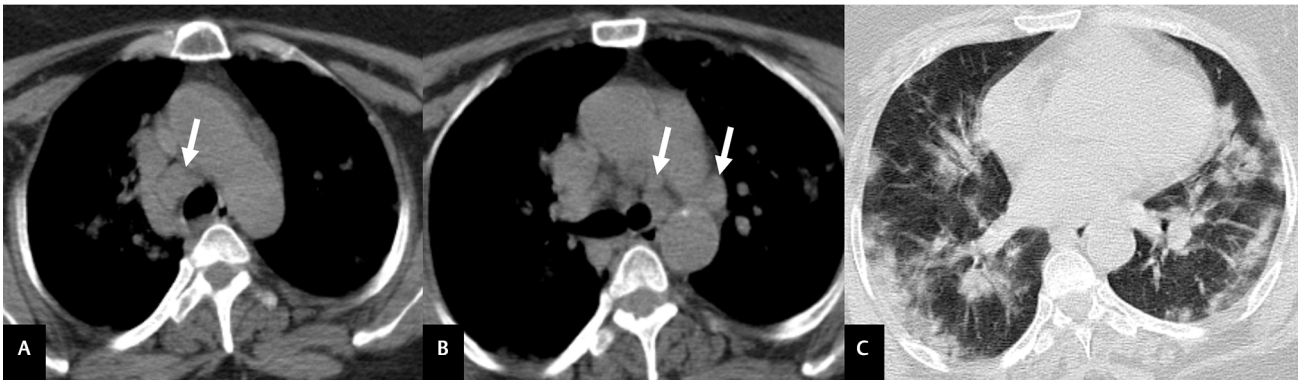

Fig. 14 Axial CT images in mediastinal (**A, B**) and lung (**C**) windows show enlarged mediastinal lymph nodes (arrows in **A** and **B**), with multifocal ground-glass opacities (**GGOs**) in bilateral lungs.

centrilobular nodules and bronchial wall thickening in parainfluenza virus; and bilateral, lower lobar GGO and consolidation in influenza virus pneumonias.[37]

In addition to the above, two other differentials include SARS and MERS, as both these diseases are caused by other Coronaviruses and have similar pathological changes.[21] However, some imaging findings are found to be more common in COVID-19 pneumonia compared to MERS and SARS. These include predominant multifocal involvement, nodules with halo sign and reverse halo sign.[31,38] In addition, some findings like lymphadenopathy, pleural effusion, nodules, and cavitations are uncommon in SARS and MERS.[38]

Conclusion

In conclusion, COVID-19 is a highly contagious viral infection, principally affecting the respiratory system. Although, the real-time RT-PCR is highly accurate in making the diagnosis, CT scan helps in assessing the disease severity and in prognostication. Adequate precautions should be taken while performing CT scan to avoid cross-contamination. Knowledge of the spectrum of findings on the CT scan, as described in this review, is helpful in raising suspicion of the disease in unsuspected cases and differentiating COVID-19 pneumonia from other viral diseases to some extent.

Conflict of Interest
None declared.

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