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Spectrum of chest CT manifestations of coronavirus disease (COVID-19): A pictorial essay

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Abstract

Coronavirus disease (COVID-19) is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is an enveloped single-stranded RNA virus belonging to the family of betacoronaviruses. Chest computed tomography (CT) has helped us in understanding this new disease. Typical CT features of COVID-19 pneumonia are ground-glass opacities (GGO), crazy paving pattern and GGO with superimposed consolidation with a basal, posterior and peripheral lung predilection. Less commonly bronchial wall thickening, bronchial dilatation and pleural thickening are seen. Presence of pleural effusion, pericardial effusion and mediastinal lymphadenopathy is seen in severe cases. Reticulations, fibrous stripes, reverse halo sign and perilobular opacities are seen late (>2 weeks) in the course of illness. We aim to present a pictorial review of CT imaging findings in COVID-19 to illustrate the typical and atypical manifestations of this disease in a bid to familiarize radiologists with the myriad imaging manifestations of this disease.

Key words: COVID-19; CT; Ground-glass opacity; SARS-CoV-2; segmental pulmonary vessel enlargement

Introduction

Coronavirus disease (COVID-19) originated in Wuhan, China towards the end of 2019 and swiftly spread across the world infecting an estimated 6.5million people and claiming 382 867 lives till June 06, 2020.[1] COVID-19 is an infectious disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which is an enveloped single-stranded RNA virus belonging to the family of betacoronaviruses.[2] The disease is highly contagious and spreads through the respiratory route with lungs being the primary organs affected. Real-time reverse transcriptase-polymerase chain reaction (RT-PCR) performed on respiratory secretions is considered to be the standard diagnostic test.[3] However, RT-PCR has a reported sensitivity of 60–71% with many false-negative reported cases.[4] Imaging serves as a complementary tool in confirming the diagnosis, especially in RT-PCR negative cases. Chest radiography is the preliminary investigation used for patients with suspected COVID-19. Chest radiographs may be normal in early or mild disease. However, up to 69% of patients with COVID-19 requiring hospitalization have an abnormal chest radiograph at

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the time of admission, and up to 80% show radiographic abnormalities sometime during hospitalization.[5] Chest computed tomography (CT) is sensitive to the detection of COVID-19 pneumonia. It is also useful in monitoring the progress of the disease or in monitoring the response to treatment. Nuclear imaging procedures (^{18}F-FDG PET/CT or ^{131}I SPECT/CT) performed for various standard clinical conditions may incidentally detect signs of COVID-19 pneumonia with increased metabolic activity in the pulmonary lesions and mediastinal lymph nodes.[6] Given the increasing number of COVID-19 cases globally, many radiologists will incidentally encounter chest imaging of COVID-19 patients. So, familiarity with the imaging manifestations of this disease is essential. We performed a literature search of PubMed and Embase databases initially on May 17, 2020, and updated on June 9, 2020. After screening the titles and abstracts, 15 original studies and two review articles reporting CT imaging features of COVID-19 from countries like China, Europe and India were selected. Based on a compendious review of these published studies and our own experience in interpreting COVID-19 imaging in the frontline, we aim to present a pictorial review of CT imaging findings in COVID-19 to illustrate the typical and atypical manifestations of this disease in a bid to familiarize radiologists with the myriad imaging manifestations of this disease. The study was approved by the Institutional Review Board (IRB) and the requirement of informed patient consent was waived off.

Main Observations

Bilateral, peripheral and basal ground-glass opacities with multilobar involvement have been described as the initial CT manifestations of COVID-19 pneumonia.[1] During the intermediate stage of disease, progressive transformation of GGOs into consolidations occurs with the development of interlobular septal thickening producing characteristic crazy paving patterns. The CT findings reach a crescendo around the tenth day of symptom onset. Some patients deteriorate and develop extensive lung opacities leading to acute respiratory distress syndrome (ARDS), which is the main cause of death. In patients with clinical recovery, there is a gradual resolution of consolidative changes with a reduction in both the size and number of these opacities with a new development of reticulations and fibrous stripes, usually observed after 2 weeks. Pleural effusion, pericardial effusion, mediastinal lymphadenopathy, halo sign or reverse halo sign are uncommon but possible CT features of COVID-19 seen with disease progression.[7-15] Table 1 provides a summary of different pulmonary findings in COVID-19 reported across various studies.

We performed non-contrast chest CT in 179 non-consecutive RT-PCR confirmed SARS-CoV-2 infected patients. Among the total study population, 152 (84.9%) patients were symptomatic and 27 (15.1%) patients were asymptomatic. Among the symptomatic patients, the most common symptoms reported were fever (73%), cough (49%), myalgia (61%), fatigue (66%), sore throat (23%), breathlessness (9%), hyposmia/anosmia (4%) and dysguesia (3%).The CT findings of our study cohort are summarized in Table 2.

Ground-glass opacity (GGO)

GGO is a descriptive term that denotes an area of increased lung attenuation on CT through which vascular and bronchial structures can be seen [Figure 1]. It results from the partial filling of alveoli with fluid, blood or cells or due to the thickening of pulmonary interstitium. COVID-19 has been typically described to present with multifocal GGOs with a basal, peripheral and posterior distribution. The GGOs can be patchy or confluent, rounded or elongated. Salehi *et al*.[7] in a systematic review of 22 studies found GGO as the commonest CT manifestation in COVID-19 with a cumulative prevalence of 88%. Parry *et al*.[8] reported GGO with a cumulative prevalence of 100%. Bernheim *et al*.[9] reported the presence of pure GGOs in 34% and GGOs mixed with consolidation in 41%. Caruso D *et al*.[16] reported GGOs in 100% of their patients.

Crazy-paving pattern

It refers to GGO with superimposed interlobular thickening producing a crazy pavement like pattern thus earning it the moniker of the crazy-paving pattern [Figure 2]. Crazy-paving pattern has been variably reported from 5% to 40% in COVID-19 pneumonia.[9,13,17] Its incidence

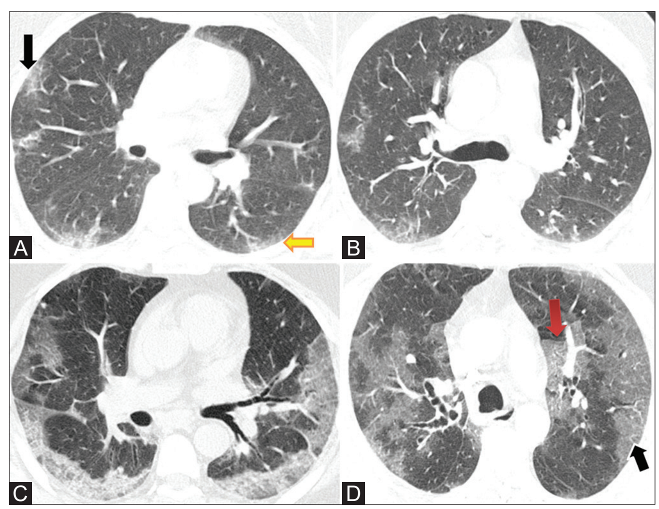

Figure 1 (A-D): 42-year-old man presenting with fever and cough with RT-PCR confirmed COVID-19 (A and B). Non-contrast axial chest CT images (A and B) performed 5 days after symptom onset reveal multiple small peripheral patchy wedge shaped GGOs (black arrow in A) with posterior distribution (yellow arrow in A) in both lungs. 65-year-old (C) and 62-year-old (D) male patients presenting with fever, cough and dyspnea with RT-PCR confirmed COVID-19. Axial CT images performed 7 days after symptom onset in both patients showing extensive bilateral, confluent and elongated GGOs in both lungs with posterior and peripheral predominance

Table 1: Rate of occurrence of chest CT manifestations of COVID-19 pneumonia (according to 8 published studies with a sample size of more than 100 patients)

Parameter (%)	Zhao (12)	Bai (21)	Bernheim (9)	Ai (11)	Guan (10)	Han (13)	Parry (17)	Akin (19)
Number of patients	101	219	121	1014	1099	108	211	185
Bilateral lung involvement	82	75	60	-	52	-	76.4	86.4
Peripheral distribution	87	80	52	-	-	90	100	87.1
Posterior distribution		-	-	-	-	-	100	46.3
Multilobar involvement	-	-	85	-	-	65	-	-
GGO	86	91	34	46	56	60	100	82.3
GGO and consolidation	64	69	41	50	-	41	47.2	32.7
Crazy-paving pattern	-	5	5	-	-	40	32.6	21.8
Air bronchogram	-	14	-	-	-	48	24.7	23.1
Bronchial dilatation	53	-	1	-	-	-	-	19
Pleural effusion	14	4	1	-	-	-	1.5	2
Pleural thickening	-	15	-	-	-	-	-	12.9
Pericardial effusion	-	-	-	-	-	-	0	0
Lymphadenopathy	1	3	0	-	-	-	0	12.2
Bronchial wall thickening	29	9	12	-	-	-	-	-
Reticular pattern	49	35	7	1	-	-	29.2	-
Sub pleural lines	28	-	-	-	-	-	18	27.9
Reverse halo sign	-	5	2	-	-	-	18	15
Nodules	23	32	0	3	-	-	0	18.4
Vessel enlargement	71	59	-	-	-	80	67.4	34

Figure 2: 59-year-old male presenting with fever, cough and dyspnea with RT-PCR confirmed COVID -19. Non-contrast axial chest CT image performed 8 days after symptom onset showing combined peripheral-central and predominantly posterior ground glass opacities with associated interlobular septal thickening forming the typical crazy paving pattern (red arrows)

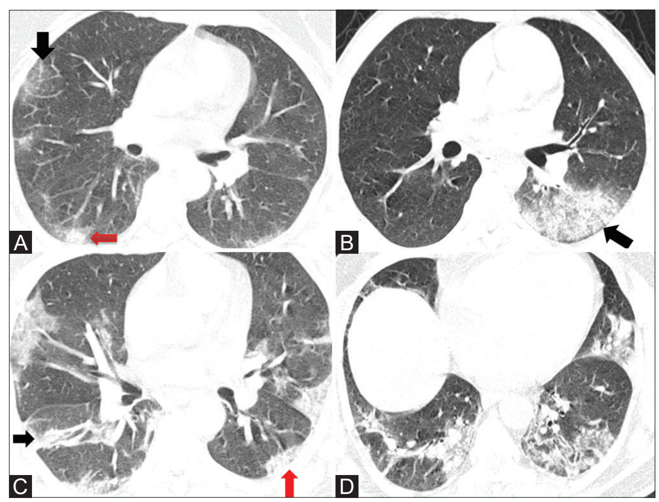

Figure 3 (A-D): 42-year-old (A) and 24-year-old (B) male patients presenting with cough and fever with RT-PCR confirmed COVID -19. Non-contrast axial chest CT images performed on 4th (A) and 6th (B) day of illness respectively, show peripheral GGOs (arrows in A) and large consolidation in superior segment of left lower lobe (black arrow in B). Another 36-year-old male patient presenting with fever and cough with RT-PCR confirmed COVID -19 (C and D). Non-contrast axial chest CT images (C and D) performed 10 days after symptom onset showing multifocal peripheral consolidations in both lungs (red arrow in C). One bronchocentric consolidation (black arrow in C) is also seen

also increases with the progression of disease and is seen predominantly around the eighth day of infection.

Consolidation

Consolidation connotes an increase in pulmonary attenuation with obscuration of underlying vascular and bronchial structures and pathologically represents flooding of air-filled alveolar spaces with fluid, blood or inflammatory cells [Figure 3]. Consolidations are seen increasingly in COVID-19 as the infection progresses with a peak incidence at 13–16 days. Consolidations are found more commonly superimposed on GGOs whereas pure consolidations are less common.[7,8] Consolidations also have a peripheral and bilateral distribution akin to

Table 2: CT findings in RT-PCR confirmed SARS-CoV-2 infected patients in our study

Parameter	All patients (*n*=179)	Symptomatic patients (*n*=152; 84.9%)	Asymptomatic patients (*n*=27; 15.1%)
CT findings			
Present	104 (58.1%)	95 (62.5%)	9 (33.3%)
Absent	75 (41.9%)	57 (37.5%)	18 (66.7%)
Laterality of lung involvement			
Unilateral	19 (18.3%)	13 (13.7%)	6 (66.7%)
Bilateral	85 (81.7%)	82 (86.3%)	3 (33.3%)
Focality			
Unifocal	9 (8.7%)	4 (4.2%)	5 (55.5%)
Multifocal	95 (91.3%)	91 (95.7%)	4 (44.5%)
Axial distribution			
Peripheral predominant	96 (92.3%)	88 (92.6%)	8 (88.9%)
Central and peripheral	8 (7.7%)	7 (7.4%)	1 (11.1%)
Antero-posterior distribution			
Posterior predominant	91 (87.5%)	84 (88.4%)	7 (77.8%)
Anterior and posterior	13 (12.5%)	11 (11.6%)	2 (22.2%)
Type of lung opacity			
Pure GGO	64 (61.5%)	56 (58.9%)	8 (88.9%)
GGO with consolidation	18 (17.3%)	18 (18.9%)	-
Crazy-paving pattern	14 (13.5%)	14 (14.7%)	-
Pure consolidation	6 (5.8%)	6 (6.3%)	-
Nodules	2 (1.9%)	1 (1.1%)	1 (11.1%)
Additional CT findings			
Vessel dilatation sign	71 (68.3%)	71 (74.7%)	-
Reverse Halo sign	17 (16.3%)	15 (15.8%)	2 (22.2%)
Halo sign	1 (0.9%)	1 (1.1%)	-
Bronchial dilatation	5 (4.8%)	5 (5.3%)	-
Bronchial wall thickening	4 (3.8%)	4 (4.2%)	-
Air bubble sign	6 (5.8%)	5 (5.3%)	1 (11.1%)
Reticulations	14 (13.5%)	10 (10.5%)	4 (44.4%)
Subpleural lines	13 (12.5%)	10 (10.5%)	3 (33.3%)
Fibrous stripes	6 (5.8%)	6 (6.3%)	-
Perilobular sign	5 (4.8%)	5 (5.3%)	-
Pleural thickening	4 (3.8%)	4 (4.2%)	-
Pleural effusion	4 (3.8%)	4 (4.2%)	-
Mediastinal lymphadenopathy	3 (2.9%)	3 (3.2%)	-
Important negative findings			
Tree-in-bud appearance	0		
Cavitation	0		
Pneumothorax	0		
Pericardial effusion	0		

GGOs. Unilobar pure consolidation is seldom a feature of COVID-19 and should alert one to consider an alternate diagnosis of bacterial pneumonia.

Reticular pattern

Reticular pattern is characterized by a collection of innumerable interweaving linear or wavy shadows producing a mesh-like pattern on CT and results from a varying combination of interlobular and intralobular septal thickening [Figure 4]. They are found during the resorptive phase of the disease.[8,18]

Subpleural curvilinear lines

On chest CT subpleural lines are represented by thin (1-3mm) curvilinear shadows lying within 1cm of pleural margin and coursing parallel to it [Figure 4]. It is pathologically represented by pulmonary edema or developing fibrosis. It has been reported with an incidence of 17–28% in COVID-19 patients.[8,12]

Air bubble sign

Air bubble sign is the presence of a small air containing lucency within a GGO or consolidation and possibly represents entrapped physiological air space or cross-section of a small dilated bronchus or might represent the early evidence of resorption of consolidation [Figure 5]. It was initially reported in COVID-19 patients by Shi *et al*.[18] who called it round cystic change followed by Kong *et al*.[3] who referred to it as a cavity sign. But a glance through the depicted pictures in these studies led us to conclude that air bubble lucency would be an appropriate term for it.

Pulmonary nodules

Nodule represents a round or irregular opacity less than 3cm in the longest dimension [Figure 6]. Nodules are uncommonly encountered in COVID-19. It has been variably reported in COVID-19 with an incidence of 3–32% [11,19-21]

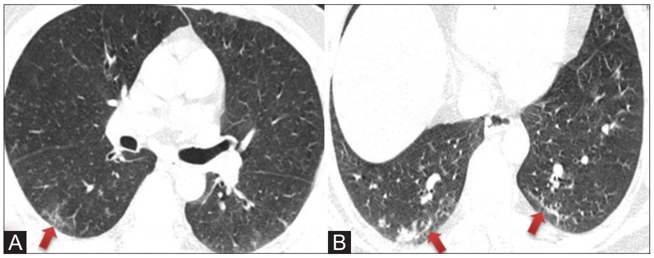

Figure 4 (A and B): 33-year-old asymptomatic patient with RT-PCR confirmed COVID -19 (A). Axial chest CT image (A) shows reticular pattern in superior segment of right lower lobe (red arrow in A). 52-year-old asymptomatic patient with RT-PCR confirmed COVID -19 (B). Axial chest CT image (B) shows curvilinear subpleural lines in lower lobes of both lungs (red arrows in B)

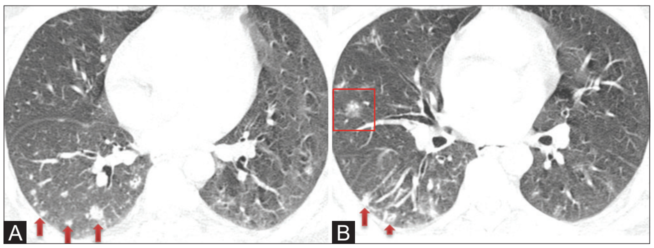

Figure 6 (A and B): 43-year-old male patient presenting with fever and cough with RT-PCR confirmed COVID -19. Non-contrast axial chest CT images obtained 8 days after symptom onset show few ill-defined nodules (red arrows in A & B) with one of the nodules showing surrounding ground glass haze suggestive of halo sign (red frame in B)

Halo sign

It represents a ground-glass haze surrounding a nodule on CT [Figure 6]. Though classically seen in angioinvasive aspergillosis and hypervascular metastasis where it represents the area of perilesional hemorrhage it has been reported in COVID-19 with a frequency of 3–12%[16,18]

Reverse Halo sign or atoll sign

It manifests as a region of ground-glass haze surrounded by a complete or incomplete ring of consolidation [Figure 7]. Thought initially to be specific of cryptogenic organizing pneumonia (COP) it was subsequently reported in other pathologies. It has been seen in progressive or resorptive stages of COVID-19.[14,22] It might represent disease progression with peripheral areas of GGO transforming into consolidation. The converse is also possible where central GGO might be an area of resorption in the midst of a consolidation.

Fibrosis

Fibrous stripes or areas of fibrosis in COVID-19 were reported by Pan *et al*.[14] in 17% of patients. It represents the healing of areas of pneumonia with the formation of fibrosis [Figures 8 and 9].

Airway changes

Bronchial wall thickening and bronchial dilatation may be secondary to bronchial wall inflammation and destruction with surrounding pulmonary parenchymal damage also partly contributing to the bronchial dilatation [Figure 9].[17]

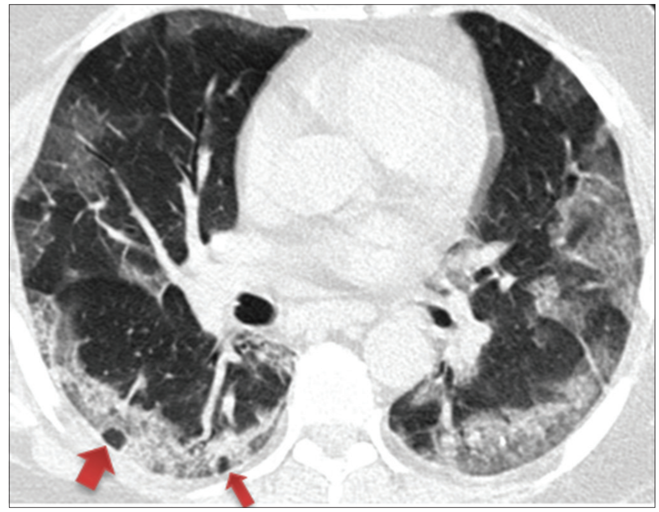

Figure 5: 65-year-old male patient presenting with fever, cough and dyspnea with RT-PCR confirmed COVID -19. Non-contrast axial chest CT image obtained 9 days after symptom onset shows confluent elongated ground glass opacities in both lungs with posterior and peripheral predominance with few rounded lucencies within the GGOs (red arrows) producing air bubble sign

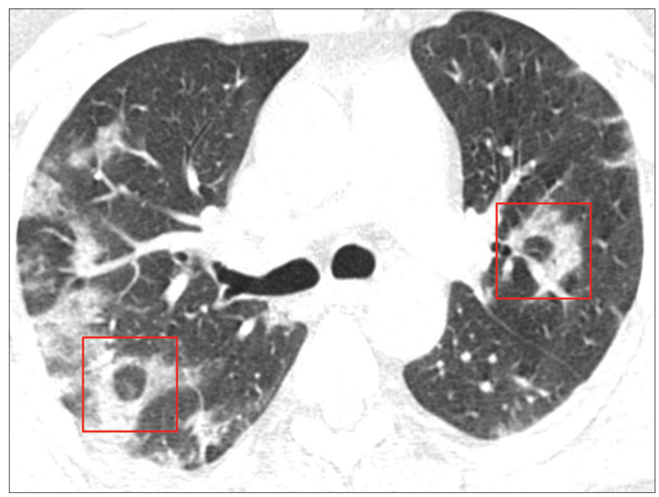

Figure 7: 61-year-old male patient presenting with fever, cough and dyspnea with RT-PCR confirmed COVID -19. Non-contrast axial chest CT image obtained 13 days after symptom onset shows bilateral organizing consolidations with reverse halo (atoll) sign (red frames)

Bronchial wall thickening has been reported in around 9–29% COVID-19 patients whereas bronchial dilatation has been reported in some cases.[12,21]

Vascular changes

Segmental or subsegmental pulmonary vascular enlargement on CT chest seems to be a specific feature associated with COVID-19 [Figure 10]. Parry *et al*.[8] and Caruso D *et al*.[16] reported vascular enlargement in 70% and 89% of COVID-19 pneumonia, respectively. Bai *et al*.[21] described vascular enlargement to be frequently associated with COVID-19 pneumonia compared to non-COVID-19 pneumonia with a significant P value (<0.001). Small pulmonary vessel enlargement has been linked to the in-situ immunothrombosis of small pulmonary vessels in COVID-19 pneumonia.[23]

Pleural changes

Pleural effusion [Figure 11] has been reported uncommonly in COVID-19 patients with a varying incidence of 1–14%.[12,17] Pleural thickening [Figure 8] has been reported in some patients.[19,21]

Pericardial effusion

Pericardial effusion is uncommonly seen in COVID-19 patients. It has been reported to occur in severe or critically ill patients and possibly represents florid inflammation [8,18]

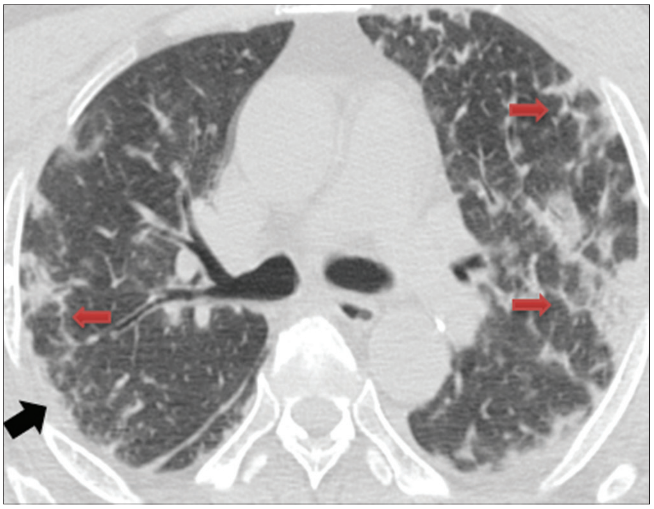

Figure 8: 55-year-old female patient presenting with fever and cough with RT-PCR confirmed COVID -19. Non-contrast axial chest CT image obtained 18 days after symptom onset shows bilateral curvilinear or wavy opacities. The wavy opacities (red arrows) assume arc like shapes and represent perilobular opacities suggesting organizing pneumonia with formation of fibrous stripes. Note is also made of pleural thickening on right side (black arrow)

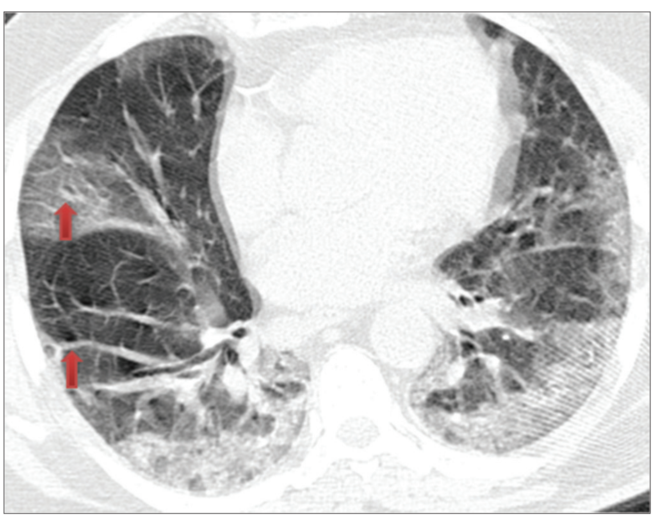

Figure 10: 56-year-old male patient presenting with fever, cough and dyspnea with RT-PCR confirmed COVID -19. Non-contrast axial chest CT image obtained 5 days after symptom onset shows confluent elongated ground glass opacities in both lungs with posterior and peripheral predominance with vascular enlargement (red arrows on right side)

Mediastinal lymphadenopathy

Enlargement of mediastinal nodes (>10mm in short axis) has been infrequently seen in COVID-19 patients especially in critically sick COVID-19 patients and was thus considered as a risk factor of severe or critical disease.[12,19] However, the presence of lymphadenopathy with effusion and numerous pulmonary nodules may suggest bacterial superinfection.

Perilobular opacities and organizing pneumonia

Understandably, there is a paucity of literature regarding the long term pulmonary sequelae of COVID-19. The follow-up imaging late in the course of the disease (>2 weeks) usually shows a reduction in the extent of GGO with development of a mixed pattern of lung abnormalities consisting of arc-like perilobular opacities, subpleural curvilinear lines and subpleural fibrous stripes with architectural distortion of lungs [Figure 12]. The development of perilobular opacities

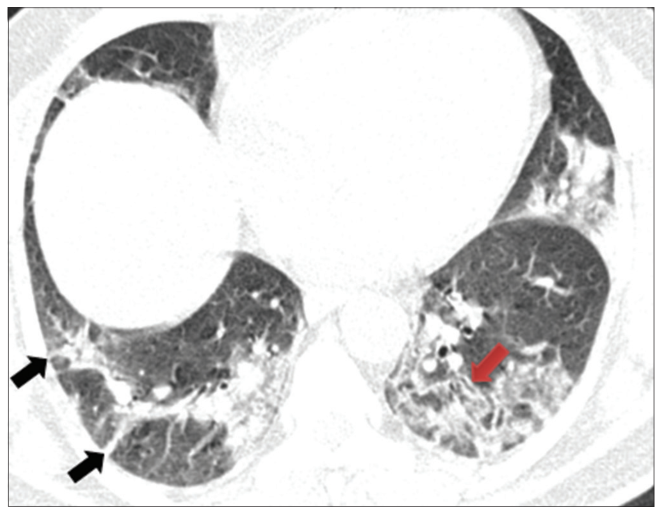

Figure 9: 36-year-old male patient presenting with fever, cough and dyspnea with RT-PCR confirmed COVID -19. Non-contrast axial chest CT image obtained 16 days after symptom onset shows multifocal peripheral consolidations in both lungs with formation of fibrous stripes (black arrows on right side) and segmental bronchial wall thickening (red arrow on left side)

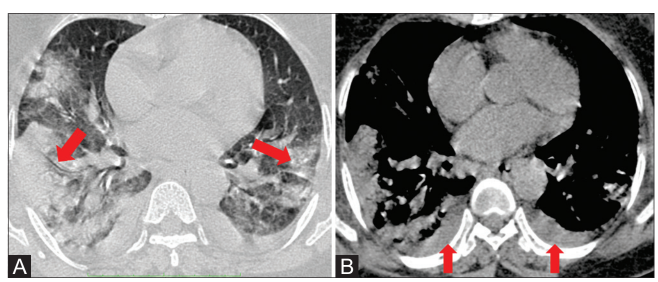

Figure 11 (A and B): Axial CT images in lung window (A) and mediastinal window (B) of a 62-year-old COVID-19 female patient with severe illness obtained on 8th day of illness show bilateral consolidations with air bronchogram (red arrow in A). Bilateral pleural effusion is also noted (red arrows in B)

Table 3: Differential diagnosis of COVID-19 pneumonia on CT

Parameter	COVID-19 Pneumonia	Other Viral pneumonias (Influenza)	Bacterial pneumonia	Pneumocystis jiroveci pneumonia	Pulmonary edema	Alveolar hemorrhage	Drug-induced pneumonitis
Distribution	Bilateral posterior peripheral basal	Diffuse	Confined to a lobe or segment	Central with subpleural sparing	Central predominance	Diffuse	Diffuse
Dominant opacity	GGO	GGO	Air-space consolidation	GGO	GGO	GGO	GGO or organizing pneumonia
Peculiarity (imaging or clinical)	Segmental vessel enlargement	Pleural effusion (30%) Bronchial wall thickening (45%)	Centrilobular nodules, mucoid impaction of bronchi, lymphadenopathy, effusion	Underlying immunodeficiency	Interlobular septal thickening and effusion	Small cavitatory nodules/ hemoptysis/ renal failure	History of drug intake

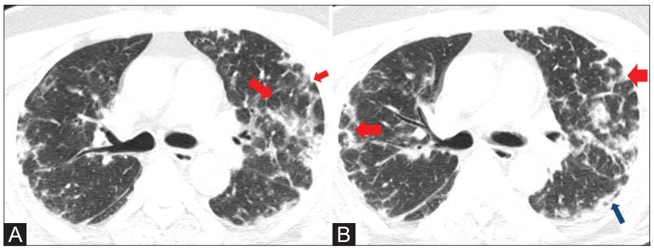

Figure 12 (A and B): 60-year-old male patient presenting with fever and cough with RT-PCR confirmed COVID -19. Non-contrast axial chest CT images acquired on 26th day of illness show multiple arc like perilobular opacities referred to "perilobular sign" which is a typical feature of organizing pneumonia (red arrows in A and B). Curvilinear subpleural lines are also seen (blue arrow in B)

suggests organizing pneumonia.[22] Viral pneumonias like severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS) and influenza are known to produce secondary organizing pneumonia. The currently available evidence also points to the development of secondary organizing pneumonia in the survivors of COVID-19.

Organizing pneumonia is the precursor to the development of lung fibrosis. However, given the fact that corticosteroid therapy has been previously shown effective in the treatment of organizing pneumonia, use of follow-up CT scans to detect the development of organizing pneumonia in COVID-19 patients and early institution of corticosteroid therapy may reduce the possibility of development of lung fibrosis in the survivors.[22]

Conclusion

In conclusion, although bilateral peripheral GGOs and consolidation are the predominant imaging manifestations of COVID-19 pneumonia, imaging findings can vary in different stages and patients. Familiarity with the myriad CT manifestations of COVID-19 pneumonia is essential to clinch an appropriate diagnosis.

Implications

In the current epidemic context, the presence of respiratory symptoms with imaging evidence of pulmonary opacities (GGO or consolidation) immediately brings the diagnosis of COVID-19 to mind. However, there are numerous infectious and noninfectious diseases that mimic COVID-19 on CT [Table 3]. Viral pneumonia of other etiologies (like influenza A and B, SARS, MERS), bacterial pneumonia (typical and atypical) and pneumocystis jiroveci pneumonia are infectious mimics of COVID-19 pneumonia. Among noninfectious causes, pulmonary edema, alveolar hemorrhage and drug-induced pneumonitis are the most notable mimics.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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