Chapter

Chest Imaging in Coronavirus Disease-19 (COVID-19)

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Abstract

Coronavirus disease-19 (COVID-19), a highly contagious viral disease caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) affects many organ systems causing a vast range of clinical manifestations. However, involvement of lungs is the most common manifestation and is the main cause of mortality. Detection of viral nucleic acid in the respiratory secretions is the corner stone of the diagnosis of COVID-19 infection; however, imaging plays a critical role in clinching diagnosis of reverse transcriptase polymerase chain reaction (RT-PCR) negative cases and those with atypical presentation. More importantly imaging has a pivotal role in the detection of complications and their appropriate management. Chest radiography, computed tomography (CT) and magnetic resonance imaging (MRI) all have a role in the diagnosis of COVID-19 pneumonia and detection of various thoracic complications related to this disease. This chapter comprehensively discusses the thoracic manifestations of COVID-19 and the role of imaging in their diagnosis and effective management.

Keywords: COVID-19, chest manifestations, CXR, CT, MRI, CT perfusion, PET-CT

1. Introduction

Coronavirus disease 2019 (COVID-19) first emerged in Wuhan, China in late 2019 and spread rapidly across the world. COVID-19 has touched vast swathes of land affecting 220 countries across the world. The disease has infected an estimated 57.7 million people and claimed 1.37 million lives as on 23 November, 2020. The World Health Organization (WHO) declared COVID-19 a pandemic on 11 March, 2020 [1].

COVID-19 is a viral disease. The causative agent is a novel enveloped single-stranded RNA virus belonging to betacoronavirus group and is referred to as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [2]. SARS-CoV-2 is believed to have originated from bats which act as the natural reservoir. The disease spreads through human-to-human contact via respiratory route [3]. Coronaviruses (CoVs) are classified into three genera of alphacoronavirus, betacoronavirus, and gammacoronavirus [4]. CoVs infect animals and humans and cause respiratory, gastrointestinal and neurological diseases of various degrees of severity. CoVs exhibit the genetic characteristics of mutation and recombination which confers them the ability to adapt to new hosts and ecological niches [5].

Respiratory system is the primary target organ of SARS-CoV-2 [6]. However, the virus also affects other organ systems including gastrointestinal system, neurological system, cardiac and vascular systems [7–11]. Many infected patients do not

develop any symptoms. 19–50% patients have been reported to have an asymptomatic infection [12]. Asymptomatic patients act as covert transmitters and constitute a potential contagious source of SARS-CoV-2 as they unknowingly transmit the virus to others [13–17]. However, many patients who are asymptomatic at the time of initial diagnosis become symptomatic later and are referred to as pre-symptomatic cases [16].

Detection of viral nucleic acid in the respiratory secretions by reverse transcriptase polymerase chain reaction (RT-PCR) is the mainstay of diagnosis [13, 15]. RT-PCR has a reported sensitivity of 60–71 percent with a very high specificity [17]. However, the performance of RT-PCR is limited by various factors including specimen collection, type of specimen, transportation of specimen and the processing time which results in many false negative results [18, 19].

Imaging plays a key role in the diagnosis of various manifestations of COVID-19 and detection of its associated complications. An effective utilization of imaging would require a comprehensive understanding and appropriate interpretation of the typical and atypical imaging features of the disease. In this chapter we first elaborate chest manifestations of COVID-19 and subsequently we discuss the role of various chest imaging modalities in their management.

2. Chest manifestations of COVID-19

SARS-CoV-2 which is acquired through the inhalation route primarily targets the respiratory system. The symptoms attributable to respiratory system include cough, breathlessness, expectoration, sore throat, chest discomfort or pain and hemoptysis. Non-specific symptoms include fever, fatigue, and myalgia [20].

SARS-CoV-2 expresses various spike proteins on its outer surface which avidly binds to angiotensin converting enzyme-2 (ACE-2). ACE-2 is expressed in alveolar pneumocytes and vascular endothelium in abundance. The virus binds to ACE-2 and enters into the cell where it replicates and causes cell death with consequent release of inflammatory cytokines in profusion which cause damage to the host [21, 22].

The primary manifestation of COVID-19 is pneumonia. The pneumonia is usually bilateral and peripheral with a predilection for lung bases. Mild to moderate disease constitutes the bulk of cases (80%) and is characterized by constitutional symptoms and development of mild pneumonia, whereas severe disease occurs in approximately 15% and is generally characterized by more than 50% lung involvement and presents with dyspnea and hypoxia [21]. Critically ill patients constitute a small portion (5%) of infections and present with respiratory failure, shock and multiorgan dysfunction. Apart from affliction of lungs the bronchial tree is also affected by this disease leading to inflammation of bronchial walls [23, 24].

Pulmonary vascular involvement is commonly reported in COVID-19. Frequent involvement of pulmonary vessels is a unique feature of COVID-19 which makes it different from other viral and bacterial causes of pneumonia [18]. Pulmonary embolism frequently occurs in severely ill COVID-19 cases. The underlying mechanisms include the triad of Virchow including hypercoagulability induced by infection and hypoxia, immobility and vascular endothelial injury [25, 26]. However, besides involvement of major pulmonary vessels affection of small pulmonary vessels has been described as a unique distinguishing feature of COVID-19 pneumonia [27].

In various autopsy studies of COVID-19 patients small vessel involvement has been reported to be the hallmark of COVID-19 pneumonia [28]. Small pulmonary vessel thrombosis is commonly found in COVID-19 pneumonia. The putative mechanism put forth to explain this includes immunothrombosis [29]. Vascular

endothelial injury caused by SARS-CoV-2 upon binding with ACE-2, which is expressed abundantly on endothelial cells, leads to severe endothelialitis and thrombosis of these small vessels [28–30].

Cardiac manifestations in COVID-19 include arrhythmias, myocarditis, cardiomyopathy, carcinogenic shock and cardiac arrest and sudden death. Myocarditis and cardiomyopathy has been reported in 7% and 7–33% of severely ill COVID-19 cases, respectively [31, 32]. Myocardial dysfunction evidenced by elevated serum troponin levels is associated with poor clinical outcome. Various mechanisms have been put forth to explain cardiac injury in COVID-19. COVID-19 can cause direct injury to myocardium leading to myocarditis which is a dreaded complication with high mortality [32]. Severe infection can induce plaque rupture and coronary artery thrombosis leading to myocardial ischemia. Infection associated hypoxia and vasoconstriction can affect coronary vessels leading to critical myocardial ischemia and cardiac dysfunction [33]. Alternately, disseminated intravascular coagulation (DIC) induced by severe SARS-CoV-2 infection can precipitate coronary artery thrombosis and cause myocardial infarction [33]. Lastly, stress induced cardiomyopathy can also explain myocardial dysfunction in COVID-19 [34].

2.1 Chest X-ray radiography (CXR)

Chest X-ray radiography (CXR) is the preliminary imaging modality employed in the initial workup of suspected COVID-19 pneumonia cases [35]. CXR has a multitude of unique advantages and limitations. CXR is widely available in almost all health facilities including emergency rooms (ER), intensive care units (ICU) and wards. Due to the small size of equipment it has the advantage of portability which circumvents the transfer of patients away from ICU or wards for performance of imaging thereby minimizing the requirements of staff and chances of spread of infection [35, 36]. CXR equipment is easy to disinfect. CXR entails a small radiation dose to the patient which makes it preferable for children and pregnant patients. Owing to these advantages major medical societies across the world have advocated the use of CXR in the workup of individuals suspected of having COVID-19. American College of Radiology supported the use of CXR for the evaluation of suspected individuals to facilitate triage and monitoring the course of illness [36, 37].

However, CXR has some major limitations. It has a low sensitivity and specificity in the detection of COVID-19 pneumonia. The sensitivity of CXR has been reported in the range of 33–69% [38–40]. CXR is insensitive especially in mild cases and during the early stages of disease [40]. To address the issue of low sensitivity and specificity attempts have been made to take advantage of artificial intelligence by developing deep learning algorithms [41, 42]. Deep learning algorithms have been found to improve the accuracy of CXR in the detection of COVID-19 pneumonia. Most of the patients have a normal CXR during the initial stages of infection, however, with the passage of time the positivity rate of CXR increases. It has been reported that approximately 80% patients will have a positive CXR at some point during the course of hospitalization [43, 44].

A postero-anterior or an antero-posterior CXR is obtained. A slight modification of conventional technique has been made by interposing a glass door between the patient and film to reduce exposure of radiographer to infection [44]. This technique has been found to produce optimal image quality and at the same time minimizing the exposure of radiographer to infection.

The typical findings at CXR include consolidations and ground glass opacification (GGO) with a peripheral and basal predilection (**Figure 1**). Peripheral distribution of pulmonary opacities is one of the specific features of COVID-19 pneumonia [45]. Diffuse lung opacification may be seen in patients with severe disease or acute

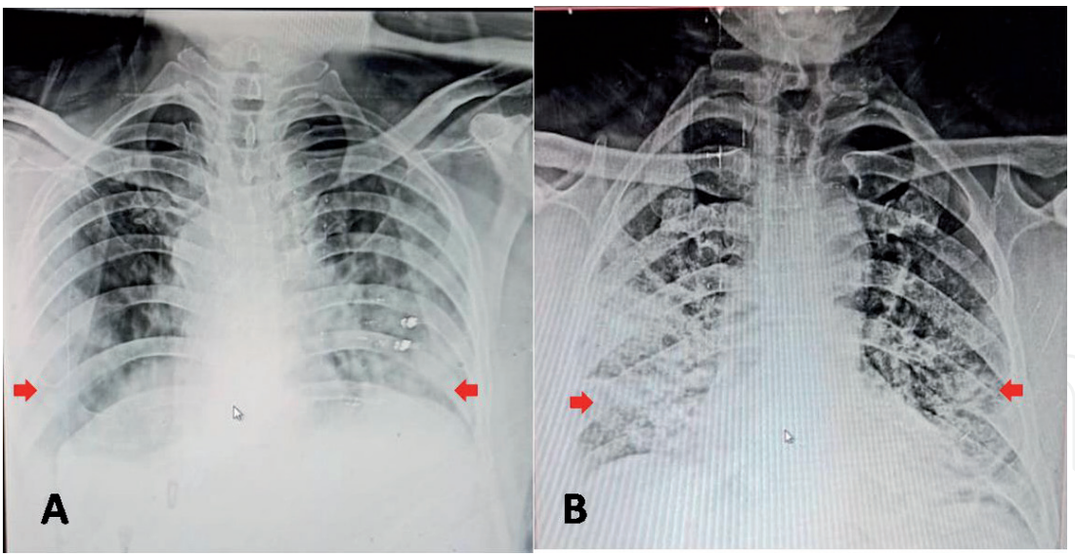

Figure 1.
CXR in two different RT-PCR confirmed COVID-19 cases showing bilateral ground glass opacification (red arrows in A) and multifocal consolidations (red arrows in B) with lower zone predominance.

respiratory distress syndrome (ARDS) [46, 47]. Initially the CXR may be normal; however, lung opacities may evolve rapidly reaching a peak at around 6–12 days [48, 49]. Pleural effusion, pericardial effusion and mediastinal lymphadenopathy is seen infrequently in severe cases [44]. The degree of pulmonary opacification on CXR has been reported to predict the need for hospitalization or intubation with patients having GGO in two lung zones more likely to require hospitalization and those with opacification of three or more zones likely to undergo intubation [46]. Bilateral lung involvement is seen commonly (73%) whereas, a unilateral lung involvement is seen less frequently (<25%) [43, 44]. It is a good clinical practice to look beyond lungs when assessing a CXR. Position of tubes (endotracheal tube and nasogastric tube) and lines (central venous line) must be assessed on CXR [46].

The two most common radio-opacities of GGO and consolidation are not specific to COVID-19 and are seen in many other infectious and non-infectious pulmonary pathologies [47, 48]. Non-COVID-19 viral pneumonias like influenza, Middle East Respiratory Syndrome (MERS) and other viral pneumonias must be included in the differential diagnosis in cases of bilateral pulmonary affection [49]. Bacterial pneumonia must be considered in the differential diagnosis particularly in cases of unilateral lung involvement [50]. Non-infectious causes of pulmonary opacities like pulmonary edema, aspiration, pulmonary hemorrhage, inflammation (like pulmonary eosinophilia) and pulmonary vasculitides should be considered in the differential diagnosis in appropriate clinical setting [43, 48].

The British Society of Thoracic Imaging (BSTI) guidelines recommend performance of CXR in all patients with a oxygen saturation of less than 94% and those who do not meet this criterion, CXR should be performed in them when "clinically required" [45]. COVID-19 survivors who recover from acute illness require clinico-radiological follow-up. BSTI guidelines recommend that patients who required ICU or high dependency unit (HDU) admission or were managed as in-ward patients with severe pneumonia should be assessed virtually at 4-6 weeks post-discharge and then face-to-face if needed and subsequently a face-to-face clinical assessment along with a CXR must be undertaken at 12 weeks. Patients who did not require ICU or HDU admission and were managed as mild–moderate pneumonia should undergo a follow-up CXR at 12 weeks [45]. Follow-up CXR are essential to pick any residual lung abnormalities sufficiently early to ensure their management to avert any long-term fibrotic pulmonary sequelae.

2.2 Lung ultrasound (LUS)

Due to its rapidity, easy availability, portability, repeatability and lack of ionizing radiation there has been a resurgent use of LUS in COVID-19 pandemic. It has been used mostly as a complementary and sometimes as an alternative modality in the detection of pulmonary involvement in COVID-19 cases. LUS usage has been particularly rewarding in critically ill patients who need a bedside modality which could circumvent their transfer out of the intensive care unit (ICU) room [46, 47].

The most common imaging features of LUS in pulmonary involvement in COVID-19 include B-lines, thick irregular pleura and subpleural consolidations [46]. B-lines are an imaging surrogate of subpleural interlobular septal thickening which occurs due to accumulation of fluid in pulmonary interstitium and alveolar spaces [48]. B-lines are hyperechoic linear lines, oriented vertically from pleural surface into the depths of lung. These lines spread like rays down the ultrasound screen and maintain their brightness throughout without fading. B-lines may be separate or coalescent. When multiple lines coalesce together they produce what is referred to as shining white lung. B-lines should move or slide with respiratory excursions [49]. Lack of this sliding movement should alert one to consider the possibility of underlying pneumothorax [49].

LUS can be used in emergency room (ER) for prompt detection of pulmonary involvement in symptomatic patients suspected of COVID-19 as soon as they arrive in the ER. LUS features typical of pulmonary involvement will ensure rapid detection, prompt isolation and timely treatment of these patients before RT-PCR results are available [50].

LUS can prove handy in monitoring the course of illness in inward patients by demonstrating the degree of lung involvement. The presence of a few widely separated B-lines in limited areas of chest suggests a mild disease whereas multiple clumped lines spread in multiple chest areas is indicative of a more severe form of disease [50, 51]. Similarly, in ICU setting LUS can help in monitoring the progression of disease and additionally help in detection of complications like pleural or pericardial effusion [51]. LUS can also be used in detection of complications of mechanical ventilation like pneumothorax. Ultrasound can also be used in the diagnosis of arterial and venous thrombosis, a complication which is frequently seen in severe COVID-19 cases [52].

Echocardiography, a specialized form of ultrasound, can aid in detection of cardiac complications of COVID-19 like myocarditis, cardiomyopathy, cardiac failure, intracardiac thrombosis and major pulmonary artery embolism [53]. Echocardiography can be used in this specific disease for the detection of major pulmonary embolism and its prognostication [54]. Detection of thrombus in right heart, right ventricular outflow tract or main pulmonary artery, akinesis of free wall of right ventricle (McConnell's sign), hypercontractility of right ventricular apical wall, dilatation of right ventricle (ventricular diameter of >42 mm at base and > 35 mm at mid-cavitary level) and paradoxical motion of interventricular septum are specific echocardiographic signs of pulmonary embolism [55, 56]. Echocardiography can also detect cardiac dysfunction in myocarditis, myocardial ischemia and cardiac failure [56].

2.3 Computed tomography (CT)

CT is a cross-sectional imaging modality which uses x-rays projected through multiple angles at the patient to generate an image [22]. The use of CT for the diagnosis and screening of COVID-19 has been universally discouraged by various radiological societies across the world citing reasons such as lack of specificity of CT

for precise diagnosis with overlap seen between COVID-19 pneumonia and other viral infections on CT [16, 19]. Secondly, CT entails transfer of patients from wards or ICU to CT suite. Finally there is a possibility that CT suites may act as a vector of cross infection. The consensus guidelines of American College of Radiology (ACR) and European Society of Radiology (ESR) and the European Society of Thoracic Imaging (ESTI) do not recommend performance of CT for the diagnosis or screening of COVID-19 [16, 22, 31]. CT has thus been reserved for a small subset of patients with severe disease, those showing respiratory worsening during illness or to monitor the course of disease. However, in some selected circumstances CT may also be helpful in patients with milder symptoms who have pre-existing co-morbidities, such as diabetes mellitus, chronic respiratory disease, obesity, chronic kidney disease etc. [57]. Performance of repeat CTs is not routinely indicated during recovery. However, a repeat CT may be warranted in cases with suspicion of complications likely superadded infection and pulmonary embolism [57].

Notwithstanding the recommendations, CT has been widely performed in COVID-19 cases and has been used to support the diagnosis, assess severity, detect complications, choose appropriate treatment and monitor response to therapy [41]. CT has greatly helped in understanding the natural course of the disease. While CXR is considered the first line tool in the initial screening or assessment of COVID-19 cases, CT is still employed widely owing to its high sensitivity in the detection of pneumonia [43]. In many cases subtle imaging findings which are difficult to detect on CXR are readily identifiable on CT.

Typical CT findings include multifocal and bilateral GGOs and or consolidations with peripheral and lower lobe predominance (**Figures 2** and **3**) [34, 36, 38]. Unilateral lung involvement is less common [43]. On CT, GGO is defined as increased lung attenuation with preservation of underlying vascular and bronchial structures [58]. Consolidation is defined as increased lung attenuation with obscuration of underlying bronchial and vascular structures [58]. Other additional features seen on CT include crazy paving pattern which is a GGO with superimposed interlobular septal thickening producing a pavement like appearance [59, 60]. The relative frequency of type and distribution of lung lesions varies across different studies. A systematic analysis of 34 published studies including 4121 patients revealed bilateral lung involvement in 73% [61]. Multilobar lung involvement was seen in 67% patients. GGOs were seen in 68%, consolidation in 32% and crazy-paving pattern in 35% patients [61]. Additional findings reported were air bronchogram sign (44%), pleural thickening (27%), pleural effusion (5%) and lymphadenopathy (5%) [61]. Some

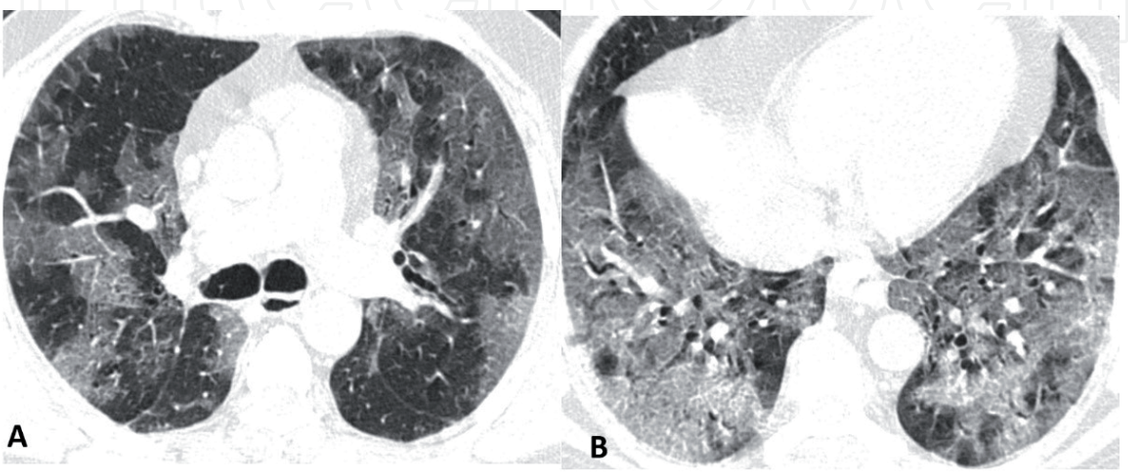

Figure 2.
Axial chest CT images at slightly different levels (A, B) in lung window settings of a 56-year-old COVID-19 patient showing diffuse ground glass opacification in both lungs with a peripheral distribution.

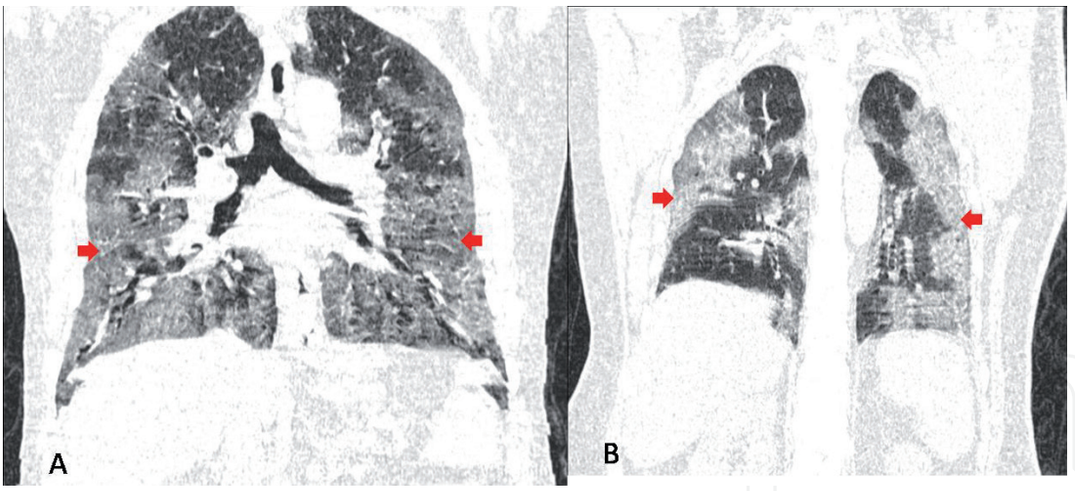

Figure 3.
Coronal chest CT images at slightly different levels (A, B) in lung window settings of a 61-year-old COVID-19 patient showing diffuse ground glass opacification in both lungs with both upper and lower lobe involvement.

symptomatic patients may have a normal CT, especially during the early stages of disease. Similarly, asymptomatic patients may have an abnormal chest CT [62–64].

CT findings evolve rapidly after symptom onset and reach a peak at around 6–13 days of illness [63]. There is increase in the extent of lung involvement and change in the appearance of pulmonary opacities. GGOs may progress into crazy paving pattern or consolidations [64]. Thereafter the findings may remain stable for some time and then gradually resorb [65]. However, in some cases there may be rapid progression into ARDS [66]. The pulmonary opacities during resolution phase start organizing and lead to secondary organizing pneumonia which manifests as reverse halo or atoll sign and perilobular opacities [61]. In one study nearly half of the patients had residual lung abnormalities consisting of fibrosis 3 months after discharge [66]. Other findings observed on CT include segmental or subsegmental vascular enlargement (defined as greater than 3 mm diameter) within the lung opacities. It has been observed in up to 89% COVID-19 pneumonia [28]. This sign of segmental or subsegmental vascular enlargement is a relatively specific sign of COVID-19 pneumonia with a diagnostic significance [41]. Presence of vascular enlargement sign may help confidently diagnose COVID-19 pneumonia. The underlying pathophysiological mechanism for vascular enlargement sign may be related to severe vascular inflammation, vasodilatory effect of proinflammatory cytokines or small vessel thrombosis [65–67].

Other less common findings observed on CT include reverse halo sign or atoll sign, bronchial wall thickening, nodules and halo sign [34]. Reverse halo sign is defined as a relatively lucent GGO surrounded by a dense ring of consolidation [51]. This finding is typically seen in resorptive stage of the disease. Pleural effusion, pericardial effusion and mediastinal lymphadenopathy is seen infrequently particularly in severe disease [18]. Presence of cavitation or tree in bud nodules are not observed in COVID-19 and should arouse suspicion of an alternate diagnosis. CT has been reported to have a high sensitivity of around 94% in detecting COVID-19 [54]. However, the specificity of CT is limited (39%) [68]. The dominant findings of GGO and consolidation observed in COVID-19 are seen in many other infectious and non-infectious diseases of lung [69, 70]. A comprehensive and detailed clinical information and exposure history is essential during interpretation of CT to increase the diagnostic confidence.

To determine the severity of lung inflammation in COVID-19 and help in identifying the patients in need of special care, severity scoring systems have been devised [71]. Anatomically there are five lobes in two lungs. Each lobe is assessed

individually to determine the degree of pulmonary opacification. Each lobe is scored visually from 0 to 5. A score of 0 is assigned if there is no involvement, score of 1 for <5% involvement, score 2 for 5–25% involvement, score 3 for 26–50% involvement, score 4 for 51–75% involvement and score 5 for >75% involvement. The individual scores of all 5 lobes are added to provide a final CT severity score. CT severity scores of 1–5 are categorized as mild disease, 6–14 as moderate disease and 15–25 as severe disease [71, 72]. The disease severity as determined on CT correlates with short-term clinical outcome with higher CT severity scores associated with worse outcomes [73].

CT imaging features of COVID-19 overlap with many other pulmonary infections, predominantly viral infections, but it also exhibits some characteristic imaging features which are seen infrequently in other infections [65]. The Radiological Society of North America (RSNA) Expert Consensus Statement on Reporting proposed a standardized nomenclature and included four categories to determine the chances of a pulmonary opacity being COVID-19 [74]. The four categories are typical appearance, indeterminate appearance, atypical appearance and negative for pneumonia (**Table 1**) [74]. In March, 2020, the Dutch Radiological Society developed a standardized CT based reporting format known as COVID-19 reporting and data system (CO-RADS) to ensure uniformity in reporting and to improve communication between radiologists and physicians [75]. CO-RADS provides a level of suspicion for lung involvement in COVID-19. The degree of suspicion increases from CO-RADS category 1 (very low suspicion) to CO-RADS-5 (very high suspicion). The two peripheral categories of 0 and 6 are invoked when a CT is technically inferior and insufficient for diagnosis or to label a scan in a patient with positive RT-PCR result for SARS-CoV-2, respectively (**Table 2**) [74–76].

2.4 CT pulmonary angiography (CTPA)

CTPA has demonstrated pulmonary embolism in up to 30% of COVID-19 patients [61]. The location of these emboli has been reported in main pulmonary artery (22%), lobar pulmonary artery (34%), segmental pulmonary artery (28%) and subsegmental arteries (16%) [77, 78]. In cases with a severe disease with sudden respiratory worsening or hemodynamic instability, CTPA is indicated to detect pulmonary embolism [77]. Pulmonary embolism is a life-threatening complication of COVID-19. However, if diagnosed early and treated appropriately improved outcomes are observed. CTPA entails administration of a bolus of non-ionic iodinated contrast and performance of CT during passage of contrast through the pulmonary vascular tree. To ensure optimal timing of scanning a bolus tracking technique is used. Pulmonary embolism manifests as a filling defect within a contrast filled pulmonary artery [79]. Besides the direct visualization of embolus some indirect signs in lungs and heart can be seen. Pulmonary infarction can be seen as a wedge shaped peripheral consolidation [80]. Similarly, bowing of interventricular septum, dilatation of right ventricle and reflux of contrast into inferior vena cava or hepatic veins may be seen and indicates increased pulmonary artery pressure [80, 81].

2.5 CT perfusion angiography

Besides pulmonary macroembolism, involvement of pulmonary microvasculature is a unique feature of COVID-19. Micro vascular dysfunction of pulmonary and non-pulmonary organ systems has been widely reported in COVID-19 [66]. It is believed that binding of viral spike proteins to ACE-2 on endothelial cells incites severe endothelialitis and precipitates microthrombosis of these small vessels. This microthrombotic phenomenon also referred to as immunothrombosis has been

Category	CT findings
Typical appearance	1. GGOs+/−consolidations or visible intralobular lines (crazy-paving pattern) with a bilateral and peripheral distribution. 2. Multifocal GGOs of rounded morphology +/− consolidation or visible intralobular lines (crazy paving pattern) 3. Reverse halo or atoll sign or other findings of organizing pneumonia (like perilobular opacities)
Indeterminate appearance	Absence of typical CT findings and the presence of either of the following: 1. Multifocal, perihilar, diffuse or unilateral GGOs +/− consolidation which lack a specific distribution and are non-rounded or non-peripheral 2. Few very small GGOs with a non-rounded and non-peripheral distribution
Atypical appearance	Absence of typical or indeterminate findings and the presence of 1. Lobar or segmental consolidation without GGO 2. Discrete small lung nodules (e.g. centrilobular, tree-in-bud appearance) 3. Lung cavitation 4. Smoother interlobular septal thickening with pleural effusion
Negative for pneumonia	No CT features of pneumonia (like absence of GGO and consolidation)

Table 1.
RSNA expert consensus guidelines for reporting CT in patients suspected of COVID-19.

CO-RADS category	Level of suspicion	CT findings
0	Not interpretable	Low quality, technically insufficient scan for assigning a score
1	Very low	Normal or non-infectious pathology (like mass)
2	Low	Typical for other infection but not COVID-19
3	Equivocal/unsure	CT features are ambiguous; compatible with both COVID-19 and non-COVID-19 causes of pneumonia
4	High	Suspicious for COVID-19
5	Very high	Typical for COVID-19
6	RT-PCR proven	CT findings of pneumonia with RT-PCR positive for SARS-CoV-2

Table 2.
COVID-19 reporting and data system (CO-RADS).

confirmed by various autopsy studies [15, 23]. This microthrombotic angiopathy causes obliteration of vascular bed and results in hypoxemia [29]. Non-contrast CT or CTPA cannot detect this condition. The direct visualization of occlusion of micro vascular bed is not possible on CTPA as it is beyond the resolution thresholds of currently available technology [80]. CT perfusion angiography is an advanced CT technology which demonstrates micro vascular thrombosis by detecting pulmonary perfusion defects [81]. However, this technology is limited by its availability. It has been suggested that CT perfusion angiography may also have a role in COVID-19 survivors who demonstrate residual respiratory dysfunction by detecting residual clot burden [82, 83].

2.6 Magnetic resonance imaging (MRI)

MRI is not recommended for the detection of pulmonary involvement in COVID-19. However, in many cases MRI performed for other indications may accidentally pick up pulmonary changes consistent with COVID-19 [84]. On MRI,

pulmonary parenchymal changes of increased signal intensity on both T1-weighted and T2-weighted sequences correspond to GGO and consolidation seen on CXR and CT [84, 85]. MRI has found use in the evaluation of cardiac complications of COVID-19. MRI has the capability to demonstrate changes of myocarditis or ischemia precipitated by COVID-19 infection and also to provide a quantitative measure of various cardiac functional indices [85]. In myocarditis, a diffuse increase in myocardial signal intensity on T2-weighted sequence, increase in T1-relaxation values on T1-mapping can be seen [84]. Post-contrast studies may reveal late gadolinium enhancement in a mid-myocardial or transmural pattern. Cine steady state free precession (SSFE) sequences will reveal regional or global wall motion abnormalities with reduced ejection fraction [86].

2.7 Positron emission tomography/computed tomography (PET-CT)

Although PET-CT is not currently indicated in the management of COVID-19 cases, however, reports of pulmonary findings consistent with COVID-19 have emerged when PET-CT was used for other conditions particularly oncology imaging [87]. The lung opacities of GGO and consolidation demonstrate increased 18-fluorodeoxyglucose (FDG) uptake [88]. Standard uptake values (SUV) of 4.6 to 12.2 have been reported [88]. Increased FDG uptake has also been demonstrated in normal sized mediastinal and hilar nodes in COVID-19. In future, FDG-PET may find use in the monitoring of response to treatment and prediction of recovery as FDG uptake may help determine the degree of residual inflammation [89, 90].

3. Conclusion

Pulmonary and extra-pulmonary thoracic organ involvement lies at the heart of COVID-19 disease manifestation. Chest imaging, although not a substitute for microbiological diagnosis of COVID-19, has helped tremendously in understanding the natural course of disease and its management. Imaging supports the diagnosis, helps in triage, detects complications, guides treatment and is useful in monitoring the response to therapy. A varying combination of CXR, CT, LUS, CTPA and MRI performed individually or in different combinations depending on the clinical presentation has played a pivotal role in the management of COVID-19 disease.

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References

[1] World Health Organization. WHO coronavirus disease (COVID-19) dashboard. https://covid19.who.int/ Accessed 24 November 2020.

[2] Chen Y, Li L. SARS-CoV-2: virus dynamics and host response. The Lancet Infectious Diseases. 2020 Mar 23.

[3] Kong WH, Li Y, Peng MW, Kong DG, Yang XB, Wang L, Liu MQ. SARS-CoV-2 detection in patients with influenza-like illness. Nature Microbiology. 2020 Apr 7:1-4.

[4] Yang Y, Yang M, Shen C, et al. Evaluating the accuracy of different respiratory specimens in the laboratory diagnosis and monitoring the viral shedding of 2019-nCoV infections. 2020. doi:10.1101/2020.02.11.20021493.

[5] Wu A, Peng Y, Huang B, Ding X, Wang X, Niu P, Meng J, Zhu Z, Zhang Z, Wang J, Sheng J. Genome composition and divergence of the novel coronavirus (2019-nCoV) originating in China. Cell host & microbe. 2020 Feb 7.

[6] Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, Liu L, Shan H, Lei CL, Hui DS, Du B. Clinical characteristics of coronavirus disease 2019 in China. New England journal of medicine. 2020 Apr 30;382(18):1708-1720.

[7] Jin X, Lian JS, Hu JH, Gao J, Zheng L, Zhang YM, Hao SR, Jia HY, Cai H, Zhang XL, Yu GD. Epidemiological, clinical and virological characteristics of 74 cases of coronavirus-infected disease 2019 (COVID-19) with gastrointestinal symptoms. Gut. 2020 Jun 1;69(6):1002-1009.

[8] Mao L, Jin H, Wang M, Hu Y, Chen S, He Q, Chang J, Hong C, Zhou Y, Wang D, Miao X. Neurologic manifestations of hospitalized patients with coronavirus disease 2019 in Wuhan, China. JAMA neurology. 2020 Apr 10.

[9] Parry AH, Wani AH, Yaseen M. Acute mesenteric ischemia in severe coronavirus-19 (COVID-19): possible mechanisms and diagnostic pathway. Academic radiology. 2020 Aug 1;27(8):1190.

[10] Parry AH, Wani AH, Yaseen M. Neurological dysfunction in coronavirus disease-19 (COVID-19). Academic Radiology. 2020 Jun 10.

[11] Shafi AM, Shaikh SA, Shirke MM, Iddawela S, Harky A. Cardiac manifestations in COVID-19 patients—A systematic review. Journal of cardiac surgery. 2020 Aug;35(8):1988-2008.

[12] Parry AH, Wani AH, Yaseen M, Shah NN, Dar KA. Clinicoradiological course in coronavirus disease-19 (COVID-19) patients who are asymptomatic at admission. BJR|Open. 2020 Jul;2:20200033.

[13] Arons MM, Hatfield KM, Reddy SC, Kimball A, James A, Jacobs JR, Taylor J, Spicer K, Bardossy AC, Oakley LP, Tanwar S. Presymptomatic SARS-CoV-2 infections and transmission in a skilled nursing facility. New England Journal of Medicine. 2020 Apr 24.

[14] Bai Y, Yao L, Wei T, Tian F, Jin DY, Chen L, Wang M. Presumed asymptomatic carrier transmission of COVID-19. Jama. 2020 Apr 14;323(14):1406-1407.

[15] Meng H, Xiong R, He R, Lin W, Hao B, Zhang L, Lu Z, Shen X, Fan T, Jiang W, Yang W. CT imaging and clinical course of asymptomatic cases with COVID-19 pneumonia at admission in Wuhan, China. Journal of Infection. 2020 Apr 12.

[16] Qiu J. Covert coronavirus infections could be seeding new outbreaks. Nature. 2020 Mar 20.

[17] Gandhi M, Yokoe DS, Havlir DV. Asymptomatic transmission, the Achilles' heel of current strategies to control COVID-19.

[18] Yang Y, Yang M, Shen C, et al. Evaluating the accuracy of different respiratory specimens in the laboratory diagnosis and monitoring the viral shedding of 2019-nCoV infections. 2020. doi:10.1101/2020.02.11.20021493.

[19] Fang Y, Zhang H, Xie J, Lin M, Ying L, Pang P, Ji W. Sensitivity of chest CT for COVID-19: comparison to RT-PCR. Radiology. 2020 Feb 19:200432.

[20] Allotey J, Stallings E, Bonet M, Yap M, Chatterjee S, Kew T, Debenham L, Llavall AC, Dixit A, Zhou D, Balaji R. Clinical manifestations, risk factors, and maternal and perinatal outcomes of coronavirus disease 2019 in pregnancy: living systematic review and meta-analysis. bmj. 2020 Sep 1;370.

[21] Ozma MA, Maroufi P, Khodadadi E, Köse Ş, Esposito I, Ganbarov K, Dao S, Esposito S, Dal T, Zeinalzadeh E, Kafil HS. Clinical manifestation, diagnosis, prevention and control of SARS-CoV-2 (COVID-19) during the outbreak period. Infez Med. 2020 Jan 1;28(2):153-165.

[22] Luo W, Yu H, Gou J, Li X, Sun Y, Li J, Liu L. Clinical pathology of critical patient with novel coronavirus pneumonia (COVID-19). Preprints. 2020 Mar;2020:2020020407.

[23] Polak SB, Van Gool IC, Cohen D, Jan H, van Paassen J. A systematic review of pathological findings in COVID-19: a pathophysiological timeline and possible mechanisms of disease progression. Modern Pathology. 2020 Nov;33(11):2128-2138.

[24] Bohn MK, Hall A, Sepiashvili L, Jung B, Steele S, Adeli K. Pathophysiology of COVID-19: mechanisms underlying disease severity and progression. Physiology. 2020 Sep 1;35(5):288-301.

[25] Gąsecka A, Borovac JA, Guerreiro RA, Giustozzi M, Parker W, Caldeira D, Chiva-Blanch G. Thrombotic Complications in Patients with COVID-19: Pathophysiological Mechanisms, Diagnosis, and Treatment. Cardiovascular drugs and therapy. 2020 Oct 19:1-5.

[26] Leonard-Lorant I, Delabranche X, Severac F, Helms J, Pauzet C, Collange O, Schneider F, Labani A, Bilbault P, Moliere S, Leyendecker P. Acute pulmonary embolism in COVID-19 patients on CT angiography and relationship to D-dimer levels. Radiology. 2020 Apr 23.

[27] Parry AH, Wani AH. Segmental Pulmonary Vascular Changes in COVID-19 Pneumonia. American Journal of Roentgenology. 2020 May 8:W1-.

[28] Parry AH, Wani AH, Yaseen M, Dar MI. Demystifying pulmonary vascular complications in severe coronavirus disease-19 pneumonia (COVID-19) in the light of clinico-radiologic-pathologic correlation. Thrombosis Research. 2020 Jun 27.

[29] Wichmann D, Sperhake JP, Lütgehetmann M, Steurer S, Edler C, Heinemann A, Heinrich F, Mushumba H, Kniep I, Schröder AS, Burdelski C. Autopsy findings and venous thromboembolism in patients with COVID-19: a prospective cohort study. Annals of internal medicine. 2020 May 6.

[30] Ackermann M, Verleden SE, Kuehnel M, Haverich A, Welte T, Laenger F, Vanstapel A, Werlein C, Stark H, Tzankov A, Li WW. Pulmonary vascular endothelialitis, thrombosis, and angiogenesis in Covid-19. New England Journal of Medicine. 2020 May 21.

[31] Zeng JH, Wu WB, Qu JX, Wang Y, Dong CF, Luo YF, Zhou D, Feng WX, Feng C. Cardiac manifestations of COVID-19 in Shenzhen, China. Infection. 2020 Dec;48(6): 861-870.

[32] Kochi AN, Tagliari AP, Forleo GB, Fassini GM, Tondo C. Cardiac and arrhythmic complications in patients with COVID-19. Journal of Cardiovascular Electrophysiology. 2020 May;31(5):1003-1008.

[33] Bandyopadhyay D, Akhtar T, Hajra A, Gupta M, Das A, Chakraborty S, Pal I, Patel N, Amgai B, Ghosh RK, Fonarow GC. COVID-19 pandemic: cardiovascular complications and future implications. American Journal of Cardiovascular Drugs. 2020 Jun 23:1-4.

[34] Gavriatopoulou M, Korompoki E, Fotiou D, Ntanasis-Stathopoulos I, Psaltopoulou T, Kastritis E, Terpos E, Dimopoulos MA. Organ-specific manifestations of COVID-19 infection. Clinical and experimental medicine. 2020 Jul 27:1-4.

[35] Toussie D, Voutsinas N, Finkelstein M, Cedillo MA, Manna S, Maron SZ, Jacobi A, Chung M, Bernheim A, Eber C, Concepcion J. Clinical and chest radiography features determine patient outcomes in young and middle age adults with COVID-19. Radiology. 2020 May 14:201754.

[36] Cleverley J, Piper J, Jones MM. The role of chest radiography in confirming covid-19 pneumonia. bmj. 2020 Jul 16;370.

[37] Hui TC, Khoo HW, Young BE, Mohideen SM, Lee YS, Lim CJ, Leo YS, Kaw GJ, Lye DC, Tan CH. Clinical utility of chest radiography for severe COVID-19. Quantitative imaging in medicine and surgery. 2020 Jul;10(7):1540.

[38] Jacobi A, Chung M, Bernheim A, Eber C. Portable chest X-ray in coronavirus disease-19 (COVID-19): A pictorial review. Clinical Imaging. 2020 Apr 8.

[39] Hui TC, Khoo HW, Young BE, Mohideen SM, Lee YS, Lim CJ, Leo YS, Kaw GJ, Lye DC, Tan CH. Clinical utility of chest radiography for severe COVID-19. Quantitative imaging in medicine and surgery. 2020 Jul;10(7):1540.

[40] Wong HY, Lam HY, Fong AH, Leung ST, Chin TW, Lo CS, Lui MM, Lee JC, Chiu KW, Chung T, Lee EY. Frequency and distribution of chest radiographic findings in COVID-19 positive patients. Radiology. 2020 Mar 27:201160.

[41] Zhang R, Tie X, Qi Z, Bevins NB, Zhang C, Griner D, Song TK, Nadig JD, Schiebler ML, Garrett JW, Li K. Diagnosis of covid-19 pneumonia using chest radiography: Value of artificial intelligence. Radiology. 2020 Sep 24:202944.

[42] Wang L, Lin ZQ, Wong A. Covid-net: A tailored deep convolutional neural network design for detection of covid-19 cases from chest x-ray images. Scientific Reports. 2020 Nov 11;10(1):1-2.

[43] Zhang R, Tie X, Qi Z, Bevins NB, Zhang C, Griner D, Song TK, Nadig JD, Schiebler ML, Garrett JW, Li K. Diagnosis of covid-19 pneumonia using chest radiography: Value of artificial intelligence. Radiology. 2020 Sep 24:202944.

[44] Narin A, Kaya C, Pamuk Z. Automatic detection of coronavirus

disease (covid-19) using x-ray images and deep convolutional neural networks. arXiv preprint arXiv:2003.10849. 2020 Mar 24.

[45] Cleverley J, Piper J, Jones MM. The role of chest radiography in confirming covid-19 pneumonia. bmj. 2020 Jul 16;370.

[46] Denina M, Scolfaro C, Silvestro E, Pruccoli G, Mignone F, Zoppo M, Ramenghi U, Garazzino S. Lung ultrasound in children with COVID-19. Pediatrics. 2020 Jul 1;146(1).

[47] Soldati G, Smargiassi A, Inchingolo R, Buonsenso D, Perrone T, Briganti DF, Perlini S, Torri E, Mariani A, Mossolani EE, Tursi F. Is there a role for lung ultrasound during the COVID-19 pandemic?. Journal of Ultrasound in Medicine. 2020 Mar 20.

[48] Soldati G, Smargiassi A, Inchingolo R, Buonsenso D, Perrone T, Briganti DF, Perlini S, Torri E, Mariani A, Mossolani EE, Tursi F. Proposal for international standardization of the use of lung ultrasound for COVID-19 patients; a simple, quantitative, reproducible method. J ultrasound Med. 2020 Mar 30;10.

[49] Nouvenne A, Zani MD, Milanese G, Parise A, Baciarello M, Bignami EG, Odone A, Sverzellati N, Meschi T, Ticinesi A. Lung ultrasound in COVID-19 pneumonia: Correlations with chest CT on hospital admission. Respiration. 2020;99(7):617-624.

[50] Smith MJ, Hayward SA, Innes SM, Miller AS. Point-of-care lung ultrasound in patients with COVID-19–a narrative review. Anaesthesia. 2020 Apr 10.

[51] Buonsenso D, Pata D, Chiaretti A. COVID-19 outbreak: less stethoscope, more ultrasound. The Lancet Respiratory Medicine. 2020 May 1;8(5):e27.

[52] Parry AH, Wani AH. Pulmonary embolism in coronavirus disease-19 (COVID-19) and use of compression ultrasonography in its optimal management. Thrombosis Research. 2020 May 16.

[53] Vrettou AR, Parissis J, Ikonomidis I. The Dual Role of Echocardiography in the Diagnosis of Acute Cardiac Complications and Treatment Monitoring for Coronavirus Disease 2019 (COVID-19). Frontiers in cardiovascular medicine. 2020;7.

[54] Zhang L, Wang B, Zhou J, Kirkpatrick J, Xie M, Johri AM. Bedside Focused Cardiac Ultrasound in COVID-19 from the Wuhan Epicenter: The Role of Cardiac Point-of-Care Ultrasound, Limited Transthoracic Echocardiography, and Critical Care Echocardiography. Journal of the American Society of Echocardiography. 2020 Jun 1;33(6):676-682.

[55] Dandel M. Cardiac manifestations of COVID-19 infection: the role of echocardiography in patient management. Infection. 2020 Aug 24:1-3.

[56] Zoghbi WA, DiCarli MF, Blankstein R, Choi AD, Dilsizian V, Flachskampf FA, Geske JB, Grayburn PA, Jaffer FA, Kwong RY, Leipsic JA. Multimodality cardiovascular imaging in the midst of the COVID-19 pandemic: ramping up safely to a new normal. JACC: Cardiovascular Imaging. 2020 Jul 1;13(7):1615-1626.

[57] Revel MP, Parkar AP, Prosch H, Silva M, Sverzellati N, Gleeson F, Brady A, European Society of Radiology (ESR). COVID-19 patients and the Radiology department–advice from the European Society of Radiology (ESR) and the European Society of Thoracic Imaging (ESTI). European Radiology. 2020 Apr 20:1.

[58] Yu M, Xu D, Lan L, Tu M, Liao R, Cai S, Cao Y, Xu L, Liao M, Zhang X, Xiao SY. Thin-section Chest CT Imaging of Coronavirus Disease 2019 Pneumonia: Comparison Between Patients with Mild and Severe Disease. Radiology: Cardiothoracic Imaging. 2020 Apr 23;2(2):e200126.

[59] Yang R, Gui X, Xiong Y. Comparison of clinical characteristics of patients with asymptomatic vs symptomatic coronavirus disease 2019 in Wuhan, China. JAMA Network Open. 2020 May 1;3(5):e2010182-.

[60] Salehi S, Abedi A, Balakrishnan S, Gholamrezanezhad A. Coronavirus disease 2019 (COVID-19): a systematic review of imaging findings in 919 patients. American Journal of Roentgenology. 2020 Mar 14:1-7.

[61] Parry AH, Wani AH, Yaseen M, Dar KA, Choh NA, Khan NA, Shah NN, Jehangir M. Spectrum of chest computed tomographic (CT) findings in coronavirus disease-19 (COVID-19) patients in India. European Journal of Radiology. 2020 Aug 1;129:109147.

[62] Zhu J, Zhong Z, Li H, Ji P, Pang J, Li B, Zhang J. CT imaging features of 4121 patients with COVID-19: A meta-analysis. Journal of Medical Virology. 2020 Jul;92(7):891-902.

[63] Wang Y, Dong C, Hu Y, Li C, Ren Q, Zhang X, Shi H, Zhou M. Temporal changes of CT findings in 90 patients with COVID-19 pneumonia: a longitudinal study. Radiology. 2020 Mar 19:200843.

[64] Parry AH, Wani AH, Shah NN, Yaseen M, Jehangir M. Chest CT features of coronavirus disease-19 (COVID-19) pneumonia: which findings on initial CT can predict an adverse short-term outcome?. BJR|Open. 2020 Jun;2:20200016.

[65] Middleton EA, He XY, Denorme F, Campbell RA, Ng D, Salvatore SP, Mostyka M, Baxter-Stoltzfus A, Borczuk AC, Loda M, Cody MJ. Neutrophil extracellular traps contribute to immunothrombosis in COVID-19 acute respiratory distress syndrome. Blood, The Journal of the American Society of Hematology. 2020 Sep 3;136(10):1169-1179.

[66] Nicolai L, Leunig A, Brambs S, Kaiser R, Weinberger T, Weigand M, Muenchhoff M, Hellmuth JC, Ledderose S, Schulz H, Scherer C. Immunothrombotic dysregulation in COVID-19 pneumonia is associated with respiratory failure and coagulopathy. Circulation. 2020 Sep 22;142(12):1176-1189.

[67] Nakazawa D, Ishizu A. Immunothrombosis in severe COVID-19. EBioMedicine. 2020 Sep 1;59.

[68] Fang Y, Zhang H, Xie J, Lin M, Ying L, Pang P, Ji W. Sensitivity of chest CT for COVID-19: comparison to RT-PCR. Radiology. 2020 Feb 19:200432.

[69] Long C, Xu H, Shen Q, Zhang X, Fan B, Wang C, Zeng B, Li Z, Li X, Li H. Diagnosis of the Coronavirus disease (COVID-19): rRT-PCR or CT?. European journal of radiology. 2020 Mar 25:108961.

[70] Raptis CA, Hammer MM, Short RG, Shah A, Bhalla S, Bierhals AJ, Filev PD, Hope MD, Jeudy J, Kligerman SJ, Henry TS. Chest CT and coronavirus disease (COVID-19): a critical review of the literature to date. American Journal of Roentgenology. 2020 Mar 26:1-4.

[71] Yang R, Li X, Liu H, Zhen Y, Zhang X, Xiong Q, Luo Y, Gao C, Zeng W. Chest CT severity score: an imaging tool for assessing severe COVID-19. Radiology: Cardiothoracic Imaging. 2020 Mar 30;2(2):e200047.

[72] Lessmann N, Sánchez CI, Beenen L, Boulogne LH, Brink M, Calli E, Charbonnier JP, Dofferhoff T, van Everdingen WM, Gerke PK, Geurts B. Automated assessment of CO-RADS and chest CT severity scores in patients with suspected COVID-19 using artificial intelligence. Radiology. 2020 Jul 30:202439.

[73] Inui S, Fujikawa A, Jitsu M, Kunishima N, Watanabe S, Suzuki Y, Umeda S, Uwabe Y. Chest CT findings in cases from the cruise ship "Diamond Princess" with coronavirus disease 2019 (COVID-19). Radiology. Cardiothoracic Imaging. 2020 Mar 17;2(2).

[74] Li K, Wu J, Wu F, Guo D, Chen L, Fang Z, Li C. The clinical and chest CT features associated with severe and critical COVID-19 pneumonia. Investigative radiology. 2020.

[75] Prokop M, van Everdingen W, van Rees Vellinga T, Quarles van Ufford J, Stöger L, Beenen L, Geurts B, Gietema H, Krdzalic J, Schaefer-Prokop C, van Ginneken B. CO-RADS–A categorical CT assessment scheme for patients with suspected COVID-19: definition and evaluation. Radiology. 2020 Apr 27:201473.

[76] Fujioka T, Takahashi M, Mori M, Tsuchiya J, Yamaga E, Horii T, Yamada H, Kimura M, Kimura K, Kitazume Y, Kishino M. Evaluation of the usefulness of CO-RADS for chest CT in patients suspected of having COVID-19. Diagnostics. 2020 Sep;10(9):608.

[77] Xie Y, Wang X, Yang P, Zhang S. COVID-19 complicated by acute pulmonary embolism. Radiology: Cardiothoracic Imaging. 2020 Mar 16;2(2):e200067.

[78] Rotzinger DC, Beigelman-Aubry C, Von Garnier C, Qanadli S. Pulmonary embolism in patients with COVID-19: time to change the paradigm of computed tomography. Thrombosis research. 2020 Jun 1;190:58-59.

[79] Leonard-Lorant I, Delabranche X, Severac F, Helms J, Pauzet C, Collange O, Schneider F, Labani A, Bilbault P, Moliere S, Leyendecker P. Acute pulmonary embolism in COVID-19 patients on CT angiography and relationship to D-dimer levels. Radiology. 2020 Apr 23.

[80] Jalaber C, Revel MP, Chassagnon G, Bajeux E, Lapotre T, Croisille P, Lederlin M. Role of upfront CT pulmonary angiography at admission in COVID-19 patients. Thrombosis Research. 2020 Dec 1;196:138-140.

[81] Parry AH, Wani AH, Yaseen M. Pulmonary embolism in coronavirus disease-19 (COVID-19): rational and stepwise use of clinical data and imaging in its diagnosis. Clinical and Translational Imaging. 2020 Oct;8(5):299-301.

[82] Oudkerk M, Kuijpers D, Oudkerk SF, van Beek EJ. The vascular nature of COVID-19. The British journal of radiology. 2020 Sep 1;93(1113): 20200718.

[83] Patel BV, Arachchillage DJ, Ridge CA, Bianchi P, Doyle JF, Garfield B, Ledot S, Morgan C, Passariello M, Price S, Singh S. Pulmonary angiopathy in severe COVID-19: physiologic, imaging, and hematologic observations. American Journal of Respiratory and Critical Care Medicine. 2020 Sep 1;202(5):690-699.

[84] Inciardi RM, Lupi L, Zaccone G, Italia L, Raffo M, Tomasoni D, Cani DS, Cerini M, Farina D, Gavazzi E, Maroldi R. Cardiac involvement in a patient with coronavirus disease 2019 (COVID-19). JAMA cardiology. 2020 Mar 27.

[85] Hameed S, Elbaaly H, Reid CE, Santos RM, Shivamurthy V, Wong J,

Jogeesvaran KH. Spectrum of imaging findings on chest radiographs, US, CT, and MRI images in multisystem inflammatory syndrome in children (MIS-C) associated with COVID-19. Radiology. 2020 Jun 25:202543.

[86] Rudski L, Januzzi JL, Rigolin VH, Bohula EA, Blankstein R, Patel AR, Bucciarelli-Ducci C, Vorovich E, Mukherjee M, Rao SV, Beanlands R. Multimodality Imaging in Evaluation of Cardiovascular complications in Patients with COVID-19. Journal of the American College of Cardiology. 2020 Jul 22.

[87] Zou S, Zhu X. FDG PET/CT of COVID-19. Radiology. 2020 Mar 6:200770.

[88] Deng Y, Lei L, Chen Y, Zhang W. The potential added value of FDG PET/CT for COVID-19 pneumonia. European Journal of Nuclear Medicine and Molecular Imaging. 2020 Mar 21:1-2.

[89] Joob B, Wiwanitkit V. 18F-FDG PET/CT and COVID-19. European Journal of Nuclear Medicine and Molecular Imaging. 2020 Mar 12:1-.

[90] Parry AH, Wani HA, Choh NA, Shah NN, Jehangir M. Spectrum of chest CT manifestations of coronavirus disease (COVID-19): a pictorial essay. The Indian Journal of Radiology & Imaging. 2021 Jan;31(Suppl 1):S170.