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The Role of Imaging Data from Different Radiologic Modalities During the Previous Global Pandemic

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Abstract

Coronavirus disease 2019 (COVID-19), caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has posed unprecedented challenges to the medical community, particularly in the field of imaging. The multifaceted nature of COVID-19, affecting various organs and systems, necessitates a comprehensive understanding of its imaging characteristics to enhance diagnosis, management, and prognosis. This paper provides an extensive review of the imaging findings associated with COVID-19, focusing on cardiothoracic, neurological, and other system involvements. We delve into the roles of different imaging modalities, including chest radiography, computed tomography (CT), magnetic resonance imaging (MRI), and echocardiography, and highlight the significance of these findings in clinical practice. Furthermore, we discuss the implications of long-term sequelae and the evolving role of imaging in the context of post-acute sequelae of SARS-CoV-2 infection (PASC).

Keywords*:* Covid-19; Radiology; Neurology

Introduction

The global pandemic posed unprecedented challenges to healthcare systems worldwide. Among the critical tools employed to manage and understand the disease were various radiologic modalities. These imaging techniques played a pivotal role in diagnosing, monitoring, and researching disease, providing essential data for clinical and engineering applications. The Coronavirus disease 2019 (COVID-19) has fundamentally altered the landscape of medical imaging, especially within the domains of cardiothoracic and neurological radiology. Imaging plays a pivotal role in diagnosing, managing, and understanding the pathophysiology of COVID-19. The virus's impact on the respiratory system is well-documented, with chest imaging revealing characteristic patterns of lung involvement. Similarly, neurological complications associated with COVID-19 have highlighted the importance of advanced imaging techniques in identifying and managing these manifestations. This paper aims to provide a comprehensive review of the imaging findings associated with COVID-19, with a particular focus on the cardiothoracic system, neurological involvement, and the implications for clinical practice.

We will delve into the role of computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and other radiologic modalities in the context of the pandemic. Additionally, we will discuss how the integration of imaging data with data science techniques has enhanced our ability to diagnose, monitor, and treat COVID-19, ultimately improving patient outcomes. The synergy between radiologic imaging and data science has opened new avenues for precision medicine, particularly in the context of a global health crisis. By analyzing imaging data through advanced computational methods, clinicians can gain deeper insights into disease mechanisms, predict disease progression, and tailor treatments to individual patients. The lessons learned from the COVID-19 pandemic underscore the critical role of imaging and data science in addressing future healthcare challenges, making it imperative to continue advancing these fields.

Methods and Materials

Pathophysiology of COVID-19

SARS-CoV-2 primarily affects the respiratory system but can also impact other organs, including the cardiovascular and neurological systems. The virus gains entry into host cells via the angiotensin-converting enzyme 2 (ACE2) receptor, abundantly expressed in the lungs, heart, and central nervous system (CNS). This receptor-mediated entry triggers a cascade of inflammatory responses, leading to diffuse alveolar damage, thromboembolism, myocarditis, and various neurological manifestations.

Imaging Modalities in COVID-19

Chest Radiography

Chest radiography (CXR) is often the first-line imaging modality due to its widespread availability and rapid turnaround time. Typical radiographic findings in COVID-19 patients include bilateral, peripheral opacities, which can progress to consolidation and coalescence as the disease advances. However, CXR has limited sensitivity, especially in early or mild cases, and can miss subtle parenchymal changes detectable on computed tomography (CT) [1]. A study showed that CXR had a sensitivity of 69% and specificity of 57% for COVID-19 pneumonia [2].
Chest radiography is also used to monitor the progression of the disease and the effectiveness of treatment. In severe cases, radiographic findings can include extensive consolidation and ARDS patterns, which are associated with poor prognosis. Despite its limitations, CXR remains a valuable tool in the initial assessment and follow-up of COVID-19 patients, particularly in resource-limited settings.

Computed Tomography

CT is more sensitive and specific than CXR for detecting COVID-19-related lung abnormalities. High-resolution CT (HRCT) of the chest is particularly useful in evaluating the extent and severity of pulmonary involvement. The most common CT findings include ground-glass opacities (GGOs), consolidation, and a "crazy-paving" pattern, characterized by scattered or patchy GGOs with superimposed inter- and intralobular septal thickening [3]. These findings predominantly affect the peripheral and posterior lung regions and are more pronounced in the lower lobes [4]. In a meta-analysis, CT had a sensitivity of 94% and specificity of 37% for COVID-19 diagnosis [5].

CT imaging is crucial not only for initial diagnosis but also for assessing complications such as secondary infections, pneumothorax, and pulmonary embolism. In addition, serial CT scans can be used to monitor disease progression, guide clinical management, and assess the response to therapy. The role of CT in the context of post-acute sequelae of SARS-CoV-2 infection (PASC) is also evolving, with studies reporting persistent GGOs, fibrotic changes, and bronchiectasis in long-term COVID patients [17].

Cardiovascular Imaging in COVID-19

Cardiac Magnetic Resonance Imaging (MRI)

Cardiac MRI is a crucial tool for assessing myocardial involvement in COVID-19. Myocarditis, characterized by myocardial inflammation and damage, is a significant concern in COVID-19 patients and can be detected using MRI. Common MRI findings include increased T2 signal intensity, indicating edema, and late gadolinium enhancement (LGE), which signifies myocardial fibrosis or necrosis [6]. These findings are associated with poor clinical outcomes and can guide therapeutic decisions. A study reported myocardial inflammation in 60% of patients recently recovered from COVID-19 [7]. Cardiac MRI also provides valuable information on cardiac function, chamber sizes, and valvular abnormalities. In the context of COVID-19, MRI can help differentiate between myocarditis, myocardial infarction, and other cardiac pathologies, thereby guiding appropriate treatment strategies. Moreover, the role of cardiac MRI in long-term follow-up of COVID-19 patients is increasingly recognized, with studies highlighting persistent myocardial inflammation and fibrosis in convalescent patients [19].

Echocardiography

Echocardiography is essential for evaluating cardiac function and detecting complications such as myocarditis, pericarditis, and thromboembolism. In COVID-19 patients, echocardiographic findings may include left ventricular dysfunction, right ventricular dilatation, and reduced ejection fraction. The presence of these abnormalities correlates with increased morbidity and mortality [8]. A research study found that 39% of hospitalized COVID-19 patients had echocardiographic abnormalities [9]. Echocardiography is particularly useful in the intensive care unit (ICU) setting, where it can be performed at the bedside and provides real-time assessment of cardiac function. In addition to evaluating systolic and diastolic function, echocardiography can identify thromboembolic complications such as right heart strain and pulmonary embolism, which are common in severe COVID-19 cases [10]. The utility of echocardiography extends beyond the acute phase, as it is also used in the long-term follow-up of COVID-19 survivors to monitor persistent cardiac dysfunction and guide rehabilitation efforts.

Pulmonary Embolism and COVID-19

COVID-19 is associated with a heightened risk of thromboembolic events, including pulmonary embolism (PE). CT pulmonary angiography (CTPA) is the gold standard for diagnosing PE. Studies have shown a significant incidence of PE in hospitalized COVID-19 patients, particularly those with severe disease or prolonged hospitalization [10]. Typical CTPA findings include filling defects in the pulmonary arteries, which can range from segmental to main pulmonary artery involvement. A study reported PE in 23% of COVID-19 patients undergoing CTPA [11]. The pathophysiology of COVID-19-associated PE involves a complex interplay between hypercoagulability, endothelial injury, and stasis, often referred to as the "Virchow's triad." The inflammatory response induced by SARS-CoV-2 infection contributes to a prothrombotic state, increasing the risk of PE and other thromboembolic complications. In addition to CTPA, other imaging modalities such as lower limb ultrasound can be used to detect deep vein thrombosis (DVT), which is often associated with PE in COVID-19 patients. The management of COVID-19-associated PE requires a multidisciplinary approach, combining anticoagulation therapy with supportive care and, in some cases, interventional procedures [12].

Neurological Imaging in COVID-19

Brain CT and MRI

Neurological manifestations of COVID-19 include anosmia, ageusia, stroke, encephalitis, and acute disseminated encephalomyelitis (ADEM). Brain imaging, particularly CT and MRI, plays a vital role in diagnosing these complications. Common CT findings include infarcts, hemorrhages, and encephalopathic changes. MRI is more sensitive and can detect cortical FLAIR abnormalities, micro hemorrhages, and white matter lesions indicative of encephalitis or ADEM [12]. Another study found that 67% of patients with severe COVID-19 and neurological symptoms had abnormalities on brain MRI [13]. The pathophysiology of neurological complications in COVID-19 is multifactorial, involving direct viral invasion, immune-mediated damage, and secondary effects of systemic illness. MRI is particularly valuable in identifying patterns of brain involvement, such as limbic encephalitis, acute necrotizing encephalopathy, and microvascular injury. In addition to structural imaging, advanced MRI techniques such as diffusion-weighted imaging (DWI) and susceptibility-weighted imaging (SWI) can provide insights into the extent of ischemic and hemorrhagic damage, respectively. Long-term follow-up studies using MRI are crucial to understanding the persistent neurological sequelae of COVID-19 and guiding rehabilitation efforts [20].

Positron Emission Tomography (PET)

PET imaging can be used to assess brain metabolism in COVID-19 patients. Studies have reported hypometabolism in the frontal lobe, temporal lobe, and cerebellum, which correlate with cognitive impairment and other neurological symptoms [14]. In a study PET imaging revealed hypometabolism in 77% of COVID-19 patients with neurological symptoms [15]. The use of PET imaging extends beyond the acute phase, as it can provide valuable information on the long-term effects of COVID-19 on brain function. Hypometabolism detected on PET scans has been associated with persistent cognitive deficits, fatigue, and other symptoms of long COVID. These findings highlight the importance of comprehensive neurological assessment and ongoing monitoring of COVID-19 survivors, particularly those with significant neurocognitive symptoms. Future research should focus on the role of PET imaging in the early detection and management of post-COVID-19 neurological the potential therapeutic interventions to mitigate these effects [21].

Post-COVID-19 Imaging Findings

As the acute phase of COVID-19 resolves, some patients continue to experience lingering symptoms and complications, a condition termed "long COVID" or post-acute sequelae of SARS-

CoV-2 infection (PASC). Imaging plays a vital role in assessing these chronic manifestations.

Lung Imaging

Persistent pulmonary abnormalities are common in post-COVID-19 patients. HRCT may show residual GGOs, fibrotic changes, and bronchiectasis. These findings can correlate with ongoing respiratory symptoms such as dyspnea and cough [16]. A study found fibrotic changes in 35% of severe COVID-19 survivors at six months follow-up [17]. The long-term pulmonary sequelae of COVID-19 are of significant concern, as they can lead to chronic respiratory impairment and reduced quality of life. In addition to HRCT, pulmonary function tests (PFTs) and diffusion capacity of the lung for carbon monoxide (DLCO) measurements are essential for assessing the extent of pulmonary dysfunction. Studies have shown that a substantial proportion of COVID-19 survivors exhibit impaired lung function and reduced DLCO, indicating ongoing alveolar-capillary damage. The management of post-COVID-19 pulmonary sequelae requires a multidisciplinary approach, including respiratory rehabilitation, pharmacological interventions, and regular follow-up with imaging and functional assessments [22].

Cardiac Imaging

Long-term cardiac sequelae of COVID-19 can include persistent myocarditis, myocardial scarring, and pericardial effusion. Cardiac MRI is instrumental in detecting these changes and monitoring their evolution over time [18]. A study reported myocardial inflammation and fibrosis in 58% of patients recovering from COVID-19 [19]. The implications of persistent cardiac involvement in COVID-19 survivors are profound, as they can lead to chronic heart failure, arrhythmias, and other cardiovascular complications. Serial cardiac MRI studies have revealed ongoing myocardial inflammation and fibrosis in a significant proportion of patients, even months after the initial infection. These findings underscore the need for long-term cardiac follow-up and individualized management plans to address the unique cardiovascular risks posed by COVID-19. Additionally, echocardiography and other non-invasive imaging modalities can complement cardiac MRI in monitoring and guiding the treatment of post-COVID-19 cardiac sequelae [23].

Neurological Imaging

Neurological sequelae of COVID-19 may persist long after the acute phase. Brain MRI can reveal chronic changes such as atrophy, white matter hyperintensities, and persistent microhemorrhages [20]. In a follow-up study, found 45% of patients with long COVID had abnormal brain MRI findings consistent with post-viral encephalopathy [21]. The long-term neurological impact of COVID-19 is a growing area of concern, as patients continue to report persistent symptoms such as cognitive impairment, fatigue, and mood disturbances. MRI findings of brain atrophy and white matter changes are particularly alarming, as they may indicate progressive neurodegeneration and chronic encephalopathy. Advanced imaging techniques, such as functional MRI (fMRI) and magnetic resonance spectroscopy (MRS), can provide further insights into the underlying mechanisms of these changes and help identify potential therapeutic targets. The management of post-COVID-19 neurological sequelae requires a multidisciplinary approach, including neurorehabilitation, cognitive therapy, and ongoing imaging surveillance to monitor disease progression and response to treatment [24].

Other Imaging Modalities

Ultrasound

Lung ultrasound (LUS) has emerged as a valuable tool for the bedside assessment of COVID-19 patients. LUS findings include B-lines (indicative of interstitial syndrome), subpleural consolidations, and pleural line abnormalities [22]. LUS is particularly useful in resource-limited settings and for monitoring disease progression in critically ill patients [23]. The advantages of LUS include its portability, lack of radiation exposure, and real-time imaging capabilities, making it an ideal tool for use in the ICU and emergency settings. In addition to lung assessment, ultrasound can be used to evaluate cardiac function, detect pleural effusions, and guide procedures such as thoracentesis and central line placement. The role of LUS in the follow-up of COVID-19 patients is also being explored, with studies suggesting its utility in monitoring pulmonary recovery and detecting residual lung abnormalities [25].

Positron Emission Tomography (PET) and CT (PET/CT)

PET/CT imaging can provide valuable insights into the systemic inflammatory response and metabolic changes associated with COVID-19. Studies have reported increased uptake in the lungs, lymph nodes, and myocardium, reflecting the widespread inflammatory process [24]. Additionally, PET/CT can detect unsuspected thromboembolic events and guide therapeutic interventions [25]. The use of PET/CT extends beyond the acute phase, as it can provide valuable information on the long-term effects of COVID-19 on multiple organ systems. Increased metabolic activity in the lungs and myocardium detected on PET/CT scans has been associated with persistent inflammation and ongoing tissue damage, underscoring the need for comprehensive follow-up and targeted therapeutic interventions. Furthermore, PET/CT can help identify occult thromboembolic events and guide the management of post-COVID-19 thrombotic complications, contributing to improved patient outcomes [26].

Conclusion

Imaging has become an indispensable tool in the management of COVID-19, providing critical insights into the disease's pulmonary, cardiovascular, and neurological manifestations. Chest radiography, CT, MRI, echocardiography, and other imaging modalities each play unique roles in diagnosing, monitoring, and understanding COVID-19's impact on various organ systems. Ongoing research and clinical experience will continue to refine our understanding and utilization of these imaging modalities in the context of COVID-19 and its long-term sequelae.

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Conflict of interest
The authors declared no conflict of interest.

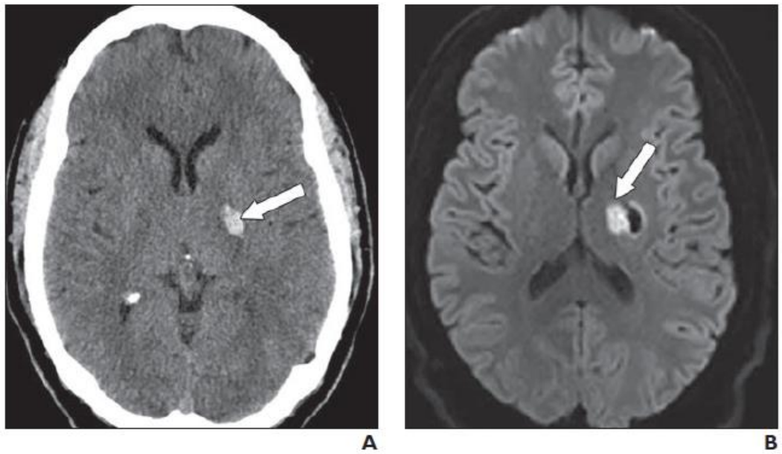

Figure 1Acute small vessel hemorrhagic infarction. A 30-year-old man presented with acute right hemiparesis and slurred speech in the setting of normal blood pressure. A, Axial CT through basal ganglia shows 2-cm acute hemorrhage (arrow) in posterior globus pallidus. B, Concurrent DWI shows restricted diffusion (arrow) medial to the region of hemorrhage, suggesting hemorrhagic conversion of basal ganglia infarct. CTA was negative for large vessel occlusion (not shown). However, a reverse transcriptase polymerase chain reaction test was performed because of incidental findings suggestive of COVID-19 pneumonia at lung apices on CTA performed for stroke and was positive for SARS-CoV-2. [27]

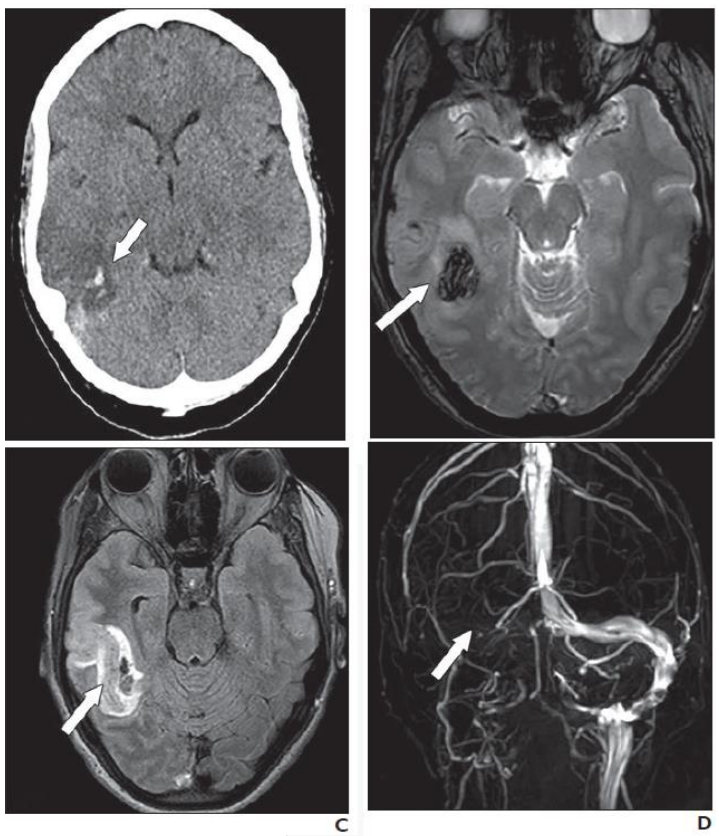

Figure 2 Venous sinus thrombosis and venous infarct. A 35-year-old woman, who tested positive for SARS-CoV-2 on reverse transcriptase polymerase chain reaction test, presented with increasing right temporooccipital headache for 1 week. A, Unenhanced CT shows low attenuation and hemorrhage (arrow) in the right temporal lobe. B–D, Brain MR images (B and C) show hemorrhagic lesion (arrow, B) on gradient-recalled echo image; predominant T2-weighted prolongation (arrow, C) on FLAIR, and no reduced diffusivity on DWI (not shown), consistent with acute venous infarct secondary to thrombosis of the right transverse and sigmoid sinus, as also shown on MR venogram (arrow, D). [27]

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