One year of COVID-19 pandemic: what we Radiologists have learned about imaging

Ein Jahr COVID-19-Pandemie: Was wir Radiologen über die Bildgebung gelernt haben

Authors
Alexander Gross, Thomas Albrecht

Affiliation
Radiology and Interventional Therapy, Vivantes-Klinikum Neukölln, Berlin, Germany

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Correspondence
Dr. Alexander Gross
Radiology and Interventional Therapy, Vivantes-Klinikum Neukölln, Rudower Straße 48, 12351 Berlin, Germany
Tel.: +49 30 130 14-2046
alexander.gross@vivantes.de

ABSTRACT

Background Since its outbreak in December 2019, Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) has infected more than 151 million people worldwide. More than 3.1 million have died from Coronavirus Disease 2019 (COVID-19), the illness caused by SARS-CoV-2. The virus affects mainly the upper respiratory tract and the lungs causing pneumonias of varying severity. Moreover, via direct and indirect pathogenetic mechanisms, SARS-CoV-2 may lead to a variety of extrapulmonary as well as vascular manifestations.
Methods Based on a systematic literature search via PubMed, original research articles, meta-analyses, reviews, and case reports representing the current scientific knowledge regarding diagnostic imaging of COVID-19 were selected. Focusing on the imaging appearance of pulmonary and extrapulmonary manifestations as well as indications for imaging, these data were summarized in the present review article and correlated with basic pathophysiologic mechanisms.
Results and Conclusion Typical signs of COVID-19 pneumonia are multifocal, mostly bilateral, rounded, polycyclic or geographic ground-glass opacities and/or consolidations with mainly peripheral distribution. In severe cases, peribronchovascular lung zones are affected as well. Other typical signs are the "crazy paving" pattern and the halo and reversed halo (the latter two being less common). Venous thromboembolism (and pulmonary embolism in particular) is the most frequent vascular complication of COVID-19. However, arterial thromboembolic events like ischemic strokes, myocardial infarctions, and systemic arterial emboli also occur at higher rates. The most frequent extrapulmonary organ manifestations of COVID-19 affect the central nervous system, the heart, the hepatobiliary system, and the gastrointestinal tract. Usually, they can be visualized in imaging studies as well. The most important imaging modality for COVID-19 is chest CT. Its main purpose is not to make the primary diagnosis, but to differentiate COVID-19 from other (pulmonary) pathologies, to estimate disease severity, and to detect concomitant diseases and complications.

Key Points:

- Typical signs of COVID-19 pneumonia are multifocal, mostly peripheral ground-glass opacities/consolidations.
- Imaging facilitates differential diagnosis, estimation of disease severity, and detection of complications.
- Venous thromboembolism (especially pulmonary embolism) is the predominant vascular complication of COVID-19.
- Arterial thromboembolism (e. g., ischemic strokes, myocardial infarctions) occurs more frequently as well.
- The most common extrapulmonary manifestations affect the brain, heart, hepatobiliary system, and gastrointestinal system.

Citation Format

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ZUSAMMENFASSUNG

Hintergrund Seit seinem Ausbruch im Dezember 2019 haben sich weltweit mehr als 151 Millionen Menschen mit Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) infiziert. Mehr als 3,1 Millionen Menschen starben an Coronavirus Disease 2019 (COVID-19), der durch das Virus ausgelösten Erkrankung. Hauptmanifestationsort ist neben den oberen Atemwegen die Lunge, wo es zu Pneumonien unterschiedlichen Schweregrades kommt. Darüber hinaus führt SARS-CoV-2 über direkte wie auch indirekte pathogenetische Mechanismen zu verschiedensten extrapulmonalen und vaskulären Manifestationen.

Methode Basierend auf einer systematischen Literaturrecherche mittels PubMed wurden Originalarbeiten, Metaanalysen, Übersichtsartikel und Fallberichte ausgewählt, die den aktuellen Wissensstand zur Bildgebung von COVID-19, insbesondere zum Erscheinungsbild pulmonaler wie extrapulmonaler Manifestationen sowie zur Indikation bildgebender Untersuchungen, wiedergeben. Diese Informationen wurden in der vorliegenden Übersichtsarbeit zusammengefasst und in grundlegende pathophysiologische Zusammenhänge eingeordnet.

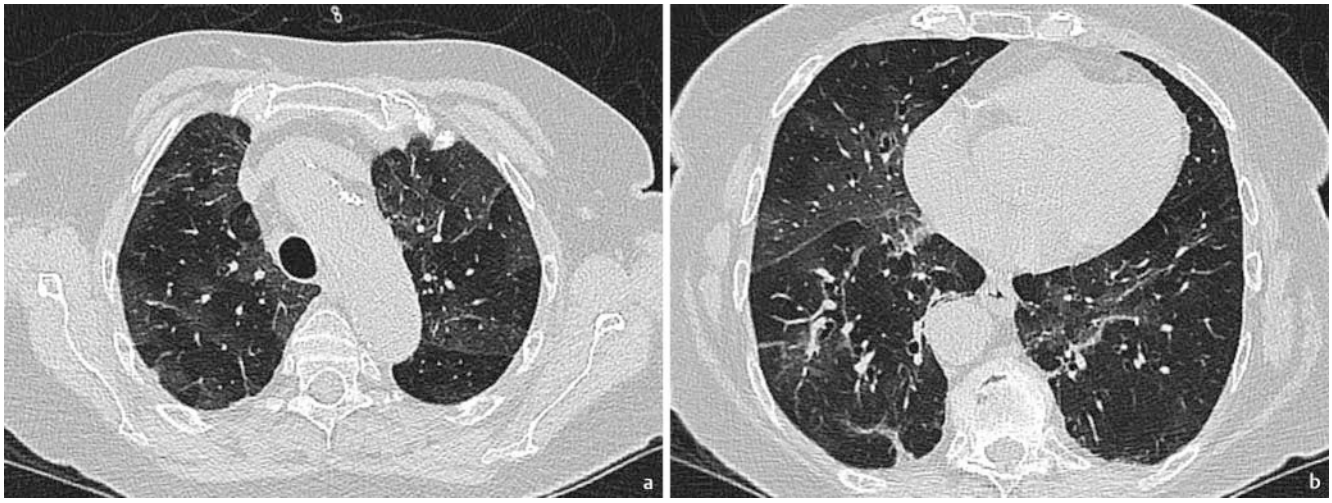
Ergebnisse und Schlussfolgerungen Typische Zeichen einer COVID-19-Pneumonie sind multifokale, meist bilaterale, rundliche bzw. polyzyklische, teilweise auch landkartenartig konfluierende Milchglasareale und/oder Konsolidierungen in vorwiegend peripherer Verteilung; in schwereren Fällen sind zusätzlich auch peribronchovaskuläre Lungenabschnitte betroffen. Weitere typische Zeichen sind ein „Crazy Paving"-Muster, seltener auch ein Halo oder Reversed Halo. Venöse Thromboembolien (u. a. Lungenarterienembolien) sind die häufigsten vaskulären Komplikationen von COVID-19, aber auch arterielle thromboembolische Ereignisse wie ischämische Schlaganfälle, Myokardinfarkte und systemische arterielle Embolien treten vermehrt auf. Die häufigsten extrapulmonalen Organmanifestationen von COVID-19 betreffen das Gehirn, das Herz, das hepatobiliäre System sowie den Gastrointestinaltrakt und sind häufig ebenfalls bildmorphologisch zu erkennen. Die größte Rolle bei der bildgebenden Diagnostik von COVID-19 spielt das Thorax-CT. Sein Wert liegt weniger in der primären Diagnosestellung als in der differenzialdiagnostischen Abgrenzung, Einschätzung des Schweregrades sowie Detektion von Begleiterkrankungen und Komplikationen.

Introduction

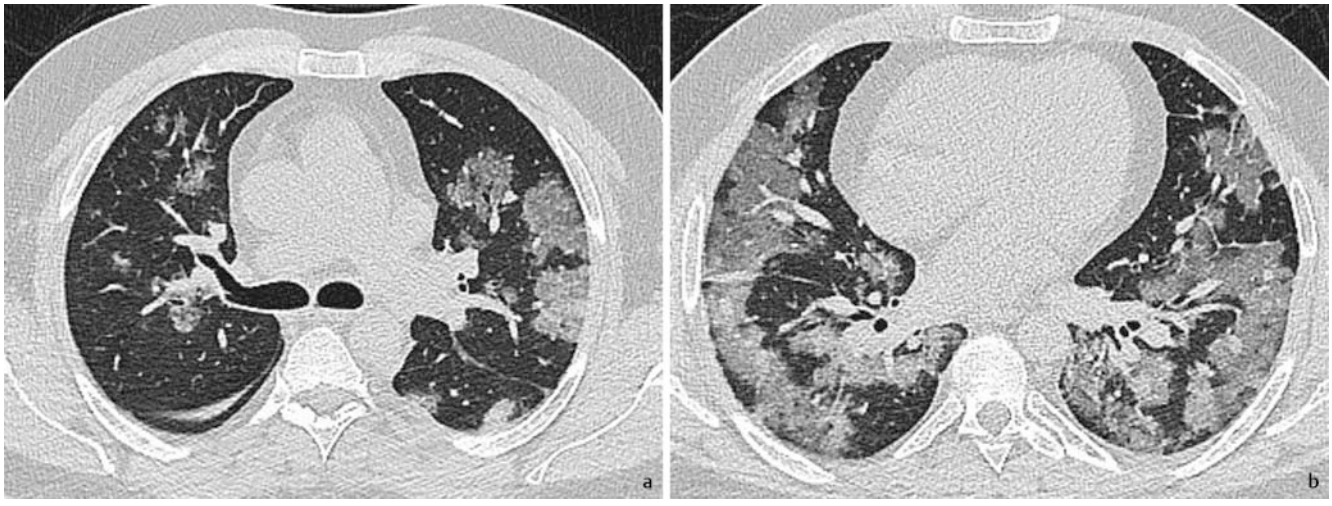
More than one year after the identification of the first case in Germany on 1/28/2020, COVID-19 (coronavirus disease 2019) is more relevant than ever. Since the outbreak of the disease in Wuhan (Hubei province, China) in December 2019, SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus 2), the pathogen causing COVID-19, has infected over 151 million people worldwide (as of 5/2/2021). Over 3.1 million have died of or with the disease [1]. More than 3.4 million infections and over 83 000 deaths have been recorded in Germany (as of 5/2/2021). 88 % of those who died were over the age of 70 [2]. Over 129 000 medical articles on a wide range of aspects of the disease (including radiology), (PubMed search for "COVID-19" on 5/2/2021) have been published. In addition to the dominant pulmonary changes, systemic complications and manifestations in various other organ systems have increasingly become the focus of scientific interest.

Pathophysiology and symptoms

SARS-CoV-2 is an enveloped single-stranded (positive-sense) RNA virus that is primarily transmitted on an airborne-basis by inhaling viral particles emitted during breathing, coughing, and speaking; to a lesser degree it is transmitted by direct contact [3, 4]. The most common symptoms are fever (80.4 %), cough (63.1 %), fatigue (46 %), expectoration (41.8 %), anorexia (38.8 %), tightness in the chest (35.7 %), shortness of breath (35 %), dyspnea (33.9 %), and muscle soreness (33 %) [5]. Loss of taste and smell has also been frequently described [6]. In addition to the upper respiratory tract, the virus mainly affects the lungs, with pneumonia requiring inpatient care being seen in approximately 2–3 % of those infected [7, 8]. This organotropism can be explained by the high expression of the angiotensin-converting enzyme 2 (ACE2) receptor on the alveolar epithelial cells: The cellular serine protease TMPRSS and other proteases prime the spike protein of SARS-CoV-2, which binds to the ACE2 receptor and enters the host cells [9]. In addition to the lung, other organ systems are affected to varying degrees of frequency and severity, including the vascular system, the heart, the nervous system, the gastrointestinal tract, the hepatobiliary system, and the kidneys [9]. Some of these disease manifestations can be attributed to direct viral toxicity: Viral RNA as well as a co-expression of ACE2 and TMPRSS2 were detected in the indicated organs [9]. Damage to endothelial cells with resulting inflammation and formation of a prothrombotic milieu seems to be another important component in the pathogenesis of COVID-19. The expression of ACE2 has been detected in arterial and venous endothelial cells of various organs, and histopathological studies have shown microthrombi in small vessels of the lung among other organs [9, 10]. Dysregulation of the immune response with a cytokine storm is a further pathophysiological characteristic of severe COVID-19 [9]. Not least, a disruption of the renin-angiotensin-aldosterone system plays a pathogenetic role [9]. The role of these individual mechanisms in the overall pathophysiology of COVID-19 has not yet been sufficiently clarified. In severe cases, general pathophysiological processes of systemic infection and inflammation including changes in the coagulation system are also seen [9].



▶ **Fig. 1** Mild COVID-19 pneumonia. 83-year-old female, approx. 24 hours after onset of symptoms: dry cough, weakness, shivering. Peripheral oxygen saturation in room air 87 %, respiratory rate 15/min. SARS-CoV-2 RT-PCR from nasal swab performed the same day was positive. CT shows discreet, patchy and geographic, peripheral and perifissural ground-glass opacities bilaterally in all lobes – typical image of mild COVID-19 pneumonia.

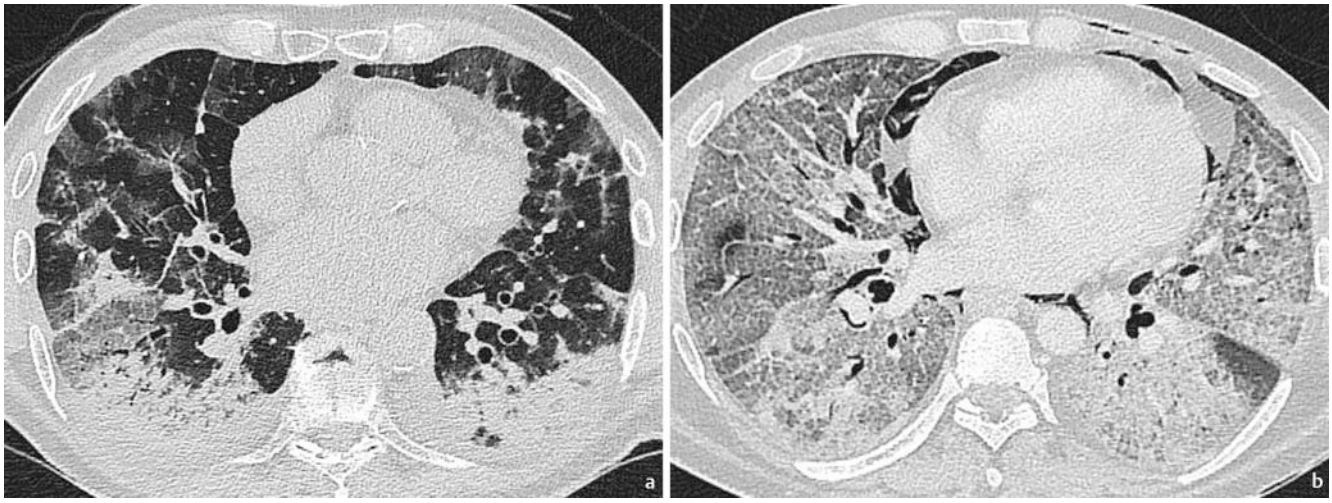


▶ **Fig. 2** Moderate COVID-19 pneumonia. 36-year-old male with laboratory-proven SARS-CoV-2 infection, 5 days after symptom onset: progressive cough and intermittent fever. Peripheral oxygen saturation in room air 94 %, respiratory rate 22/min. CT shows extensive, multifocal, bilateral, rounded and geographic ground-glass opacities predominantly in lower lung zones. Note immediate subpleural sparing in both lower lobes.

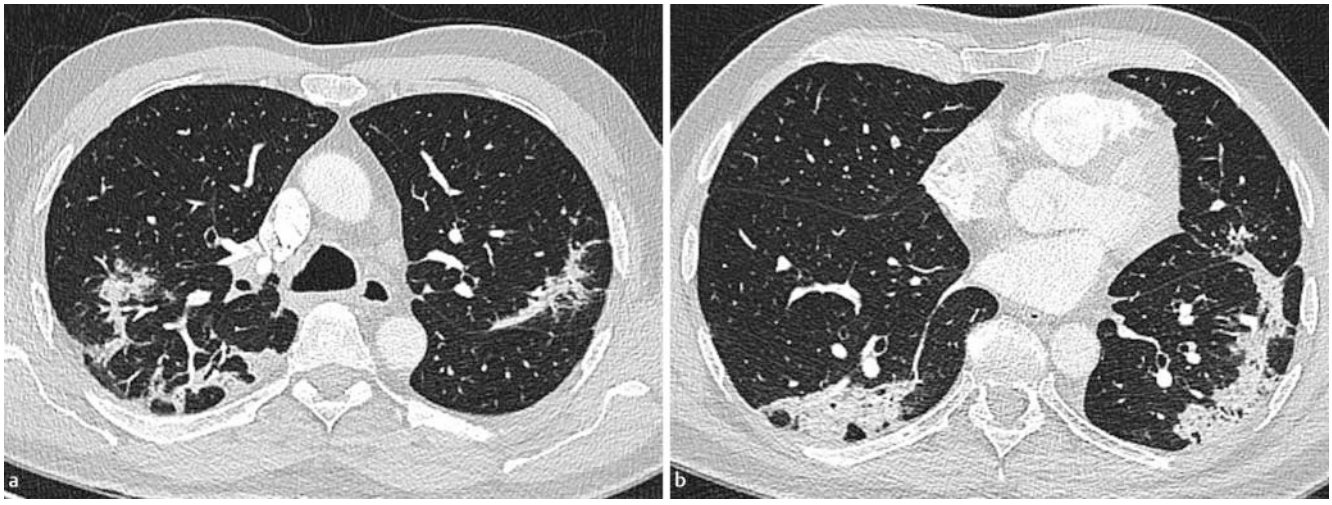
Pulmonary manifestations

COVID-19 pneumonia on CT

Typical signs of COVID-19 pneumonia are rounded, polycyclic, or geographic confluent ground-glass opacities and/or consolidations with peripheral (subpleural and perifissural) or both peripheral and peribronchovascular distribution. The immediate subpleural space can be spared (▶ **Fig. 1–4**) [11–13]. The ratio between ground-glass opacities and consolidations varies and ranges from presentations with only ground-glass opacities to presentations with only consolidations [11–13]. At the onset of pneumonia, ground-glass opacities usually dominate, while consolidations increase as the disease progresses [14–18]. In later stages of the disease, consolidations frequently show a band-like or irregular configuration (▶ **Fig. 4**). In the recovery phase, ground-glass opacities prevail again [14–18]. COVID-19 pneumonia typically has a multifocal appearance with bilateral lesions in all lobes. Predominant occurrence of changes in the dorsal and basal pulmonary segments is frequently, but not necessarily, seen [11–13]. Further, less common, but highly typical changes include reticular consolidations that – in combination with ground-glass opacities – result in a "crazy paving" pattern (▶ **Fig. 3**). Moreover, the halo sign and the reversed halo sign (ground glass opacity surrounded by a ring-shaped consolidation) as well as slight dilatation of the vessels in the affected lung areas have been reported [11–13, 19]. In rare cases, the "ring of fire sign" (peripheral ring-shaped opacification consisting of consolidation and ground-glass opacity surrounding lung parenchyma with normal transparency) and the "target sign" (ring-shaped



▶ **Fig. 3** Severe COVID-19 pneumonia. **a** Critically ill 80-year-old male receiving high-flow nasal oxygen, 13 days after onset of symptoms. Combination of confluent multifocal, bilateral, peripheral ground-glass opacities with subtle crazy paving and consolidations, predominantly affecting posterior zones of both lower lobes. Bronchiectasis in both lower lobes and minimal pleural effusion on the left as secondary findings. **b** Critically ill 33-year-old male receiving high-flow nasal oxygen, 10 days after onset of symptoms. Peripheral oxygen saturation on 10 l O2/min 83 %, respiratory rate 28 /min. Extensive peripheral and central ground-glass opacities with crazy paving in all lobes bilaterally, most pronounced in lower lung zones. In addition, moderate consolidations in both lower lobes. Pneumomediastinum.



▶ **Fig. 4** Residual changes following COVID-19 pneumonia. 65-year-old male, 3 weeks after recovering from moderate COVID-19 pneumonia without hospitalization. Multifocal bilateral curvilinear parenchymal bands and irregular consolidations, predominantly in posterior lung zones.

opacity around lung parenchyma with normal transparency containing a central hyperdensity reminiscent of a target) have been described as specific imaging findings [20–22].

Solitary lesions, exclusively peribronchovascular distribution of changes, and nodules or cavitations are not typical for COVID-19 pneumonia [11–13]. Pleural effusions accompanied by lymphadenopathy are rare. However, in the case of protracted severe courses, they are slightly more common and may indicate a possible concomitant pathology or complication (see below) [11–13].

Disease severity correlates to a certain degree with the extent of the pulmonary changes on CT [23]. In 10.6 % of symptomatic COVID-19 patients, however, chest CT imaging findings are normal, particularly in the first days of the disease [11, 15]. On the other hand, typical pulmonary changes can be seen on CT in 54 % of asymptomatic SARS-CoV-2-positive patients [24].

Concomitant pulmonary pathologies like pulmonary emphysema, interstitial lung diseases, fibrotic changes, or pulmonary edema make it difficult to detect typical COVID-19 changes and to discriminate between these and other (e. g., bacterial or viral) forms of pneumonia [11, 25, 26]. Complications of COVID-19 pneumonia like bacterial superinfection (in 10 % of hospitalized patients), acute respiratory distress syndrome (ARDS), pulmonary infarction (due to pulmonary embolism, see below), or cardiac decompensation due to COVID-19 are sometimes difficult to differentiate from pulmonary changes caused directly by SARS-CoV-2 [11, 25, 26].

COVID-19 pneumonia on chest X-ray

The described morphological changes seen on CT can also be identified on chest X-ray [12, 27]. In the early stages of the disease, the sensitivity is lower (55 % in the first two days after symptom onset) than that of CT (88 %, performed on average on day 4 after symptom onset) but improves as the disease progresses to 79 % (more than 11 days after symptom onset) while the specificity decreases (from 83 % to 70 %, p = 0.02). Repeating chest X-ray also increases the sensitivity from 73 % to 83 % but reduces the specificity from 80 % to 73 % [28, 29]. Multifocal (bilateral), primarily peripheral infiltrates should always be considered possible manifestations of COVID-19 pneumonia and a corresponding workup should be initiated, whereas pleural effusions, cavitations, or a pneumothorax make COVID-19 pneumonia less probable. The latter changes in patients with confirmed COVID-19 pneumonia indicate complications [30–32].

COVID-19 pneumonia on thoracic ultrasound

Ultrasound primarily plays a role as a bedside examination of intensive care patients [12, 33, 34]. Based on B-line artifacts, irregular pleural thickening, and subpleural consolidations, conclusions about the presence and extent of pneumonia can be made [33, 35]. B-line artifacts are hyperechoic artifacts that are vertical to the surface of the lung and change dynamically as the lung moves, arise from the pleura or consolidated areas of the lung, and resemble a “beam of light” or a “comet tail” [35, 36]. They correspond to the accumulation of fluid in the pulmonary interstitium and the alveoles and are therefore suitable for identifying even early forms of COVID-19 pneumonia [33, 35]. However, the specificity of these signs is limited [34, 37].

Indications for thoracic imaging

The indications for thoracic imaging (chest X-ray or CT) in COVID-19 continue to be the object of scientific discussion. The gain of diagnostic information with potential therapeutic consequences comes at the cost of radiation exposure for patients, risk of pathogen transmission to medical personnel and other patients during the examination, and the utilization of personnel, space, and diagnostic and material resources (e. g., personal protective equipment) [38]. The knowledge that is gained relates to multiple areas:

1. Diagnosis: Early publications on the diagnostic performance of chest CT show a pooled sensitivity of 94.6 % (95 % CI: 91.9 %, 96.4 %) and a pooled specificity of 46.0 % (95 % CI: 31.9 %, 60.7 %) in the detection of COVID-19. Subsequent studies with up to 4824 patients achieved higher specificities (between 73 % and 94 %) with an approximately equivalent sensitivity (between 86 % and 90 %) in relation to the results of reverse transcriptase-polymerase chain reaction (RT-PCR) as the diagnostic reference standard, usually using structured reporting (see below) [13, 39–43]. When using a reference standard composed of RT-PCR results and clinical evaluation, the sensitivity of chest CT was 94.7 % and the specificity was 91.4 % [44]. A suggestive appearance on CT often results in RT-PCR testing being repeated in initially (false) SARS-CoV-2-negative patients who are ultimately positive [39, 43, 45, 46]. COVID-19 cannot be reliably ruled out – particularly in asymptomatic patients – based on chest CT which makes it unsuitable for screening [11, 41, 47].
2. Differentiation from alternative diagnoses and detection of concomitant pathologies: Thoracic imaging allows quick detection of additional or alternative pulmonary pathologies like bacterial pneumonias, decompensated cardiac insufficiency, pulmonary embolisms, or tuberculosis. These diseases require specific treatment and their swift diagnosis (prior to a negative RT-PCR result) not only accelerates improvement of the patient but also shortens the patient's stay at an emergency department, hospital, or intensive care unit [38, 39].
3. Detecting complications: Thoracic imaging, particularly CT imaging, enables the detection of pulmonary complications (bacterial superinfection, ARDS, pulmonary infarction, cardiac decompensation, see above) as well as vascular and extrapulmonary manifestations of COVID-19, primarily pulmonary embolisms (see below) [25, 38].
4. Evaluation of severity, baseline for follow-up examinations, and prognostic information: Imaging data regarding preexisting and concomitant pulmonary diseases as well as the extent of COVID-19-associated pulmonary changes is useful for the evaluation of COVID-19 severity, facilitates the evaluation of follow-up examinations, and can be used for prognostic classification [25, 38, 48]. Standardized scores make it possible to objectively evaluate disease severity based on imaging but have not yet become established in practice [23, 48, 49]. The use of automated prediction algorithms for diagnosing and determining the prognosis of COVID-19 is currently not recommended in the clinical routine [23, 49, 50].

National and international societies including the Thoracic Imaging Working Group of the German Radiological Society and the Fleischner Society do not recommend thoracic imaging either as a screening test for asymptomatic persons or as routine imaging for patients with minimal COVID-19-typical symptoms (except in the case of an increased risk for rapid disease progression): Given sufficient and quick availability, RT-PCR should be given preference here [34, 38, 51–53]. However, this was not always the case in different phases of the pandemic, and it often took multiple days to obtain RT-PCR results. A typical CT examination in such situations provides an almost immediate preliminary diagnosis and makes it possible to rule out other differential diagnoses with corresponding implications including patient isolation [38, 53].

Thoracic imaging is recommended in the case of moderate to severe disease with typical COVID-19 symptoms (regardless of the availability of an RT-PCR test result), in the case of worsening of the respiratory situation of SARS-CoV-2-positive patients, and in the case of a discrepancy between a negative RT-PCT test and high clinical suspicion of COVID-19 [38, 51–53].

While the afore-mentioned recommendations of the national societies primarily relate to the use of chest CT, the consensus declaration of the Fleischner Society and the recommendations of the WHO do not specify which modality is to be selected for thoracic imaging [34, 38, 51–53]. Particularly in early stages of the disease, CT has higher sensitivity regarding the detection of

characteristic pulmonary changes. It is also superior with respect to the detection of alternative diagnoses and complications. As a result of earlier and more precise diagnosis, the length of stay of patients in the corresponding functional areas, the emergency department, and in the hospital can potentially be shortened, thereby reducing the risk of transmission of the virus [38]. However, chest X-ray is more quickly available in most cases and is associated with less radiation exposure. Moreover, the use of mobile X-ray units makes it possible to avoid transporting the patient, thereby lowering the infection risk [38]. In the case of repeated examinations and advanced disease stages, the sensitivity of chest X-ray is close to that of CT (see above) [28, 29]. The decision between X-ray and CT as the primary imaging method for COVID-19 patients ultimately depends on the local situation and expertise, individual patient-related factors, and the epidemiological situation [38, 54, 55]. The authors have had success with the early use of chest CT when indicated.

CT examination technique

Non-contrast, low-dose chest CT examinations should be used for diagnosing COVID-19 unless contrast agent is required for differential diagnoses (e. g., pulmonary embolism) [51, 53].

Structured reporting

Structured reporting allows simple and concise communication of findings, thereby facilitating clear diagnosis and treatment planning [56, 57].

The Radiological Society of North America (RSNA) recommends the use of a four-category system (typical, indifferent, atypical, no pneumonia) for interpreting chest CT examinations with respect to COVID-19. The German Radiological Society has adopted a similar system [51, 58]. In two studies, the system showed moderate to significant agreement between different observers. However, a not negligible number of SARS-CoV-2-positive patients were classified as “atypical” and “no pneumonia” [59, 60].

Another system is the CO-RADS (COVID-19 Reporting and Data System), which was developed by the Dutch Radiological Society (Nederlandse Vereniging voor Radiologie). On a 5-point scale based on existing “RADS” like BI-RADS, the probability of COVID-19 pneumonia is rated on a scale of 1 (highly unlikely) to 5 (highly likely). CO-RADS category 6 indicates a SARS-CoV-2 infection already confirmed by RT-PCR, and CO-RADS category 0 is assigned in the case of incomplete or insufficient image quality [13, 61]. Using CO-RADS for the diagnosis of COVID-19, various groups achieved a sensitivity between 86 % and 95 % and a specificity between 73 % and 94 % [13, 39–41, 44].

Based on the authors' experience, CO-RADS is extremely useful in the clinical routine since it uses a clear and intuitive scale with increasing probability for COVID-19 pneumonia and has a high level of acceptance among referring colleagues.

Extrapulmonary manifestations

Vascular (thromboembolic)

COVID-19 patients have a greater risk of thromboembolic complications like deep vein thrombosis (DVT) and pulmonary embolism (PE) as well as arterial events like ischemic stroke, myocardial infarction, and systemic arterial embolism [9, 12, 62].

Data regarding the frequency of DVT and PE are relatively heterogeneous and at times contradictory with respect to whether intensive care patients are affected to a greater degree [62]. In 16 507 COVID-19 patients, a current meta-analysis shows a prevalence of venous thromboembolism of 14.7 % (95 % CI: 12.1–17.6 %): PE occurred in 7.8 % (95 % CI: 6.2–9.4 %) and DVT in 11.2 % (95 % CI: 8.4–14.3 %) of patients [62]. Venous thromboembolisms were significantly more common in patients requiring intensive care compared to those not requiring intensive care (23.2 %, 95 % CI 17.5–29.6 %, versus 9.0 %, 95 % CI 6.9–11.4 %; $p < 0.0001$) and in studies with systematic screening compared to studies in which only symptomatic patients were examined (25.2 % versus 12.7 %, $p = 0.04$) [62].

According to current meta-analyses, ischemic stroke occurred in 1.1–1.6 % of SARS-CoV-2-positive patients. The risk is elevated compared to non-infected control patients [62, 63]. In most cases, these strokes were classified as cryptogenic. However, it must be added as a limitation that a complete diagnostic workup was often not performed [63, 64]. In particular, the possibility of paradoxical embolisms due to a persistent foramen ovale has often not been sufficiently clarified but is of particular interest in light of the increase in venous thromboembolisms seen in COVID-19 [65]. In addition to hypercoagulation, vasculitic processes and SARS-CoV-2-induced cardiomyopathy are also involved in the pathogenesis of COVID-19-associated ischemic stroke [66].

According to a current meta-analysis, acute myocardial infarction or an acute coronary syndrome occurs in 1.1 % of patients with COVID-19 [62]. The risk seems elevated during the disease [67]. An (at least partial) specific pathogenetic relationship with the SARS-CoV-2 infection can be presumed based on experience with other viral diseases like SARS and influenza and based on the systemic prothrombotic and hyperinflammatory changes [67, 68].

There are a number of case reports regarding acute mesenteric ischemia in COVID-19 [69]. In a study including 412 SARS-CoV-2-positive patients, bowel wall changes (usually bowel wall thickening) were seen in 31 % of performed CTs and pneumatosis intestinalis or gas inclusions in the portal venous system were seen in 20 % of CTs in intensive care patients [70]. Although an arterial occlusion could not be detected on imaging in any of these patients, an ischemic cause was confirmed intraoperatively or histologically in the majority of cases. Occlusions of small vessels, non-occlusive ischemia, and additional direct toxic effects of the virus may have pathophysiological effects [70]. In a further study including 141 SARS-CoV-2-positive patients, abnormalities were seen on abdominal CT in 80 (57 %) patients, including 14 (18 % of the abnormal CT examinations) organ infarctions and vascular occlusions but no clear cases of mesenteric ischemia [71].

Multiple publications report acute limb ischemia in patients with laboratory-confirmed COVID-19 [72]. It is noteworthy that many of these patients did not have preexisting peripheral arterial occlusive disease and limb ischemia occurred in spite of thrombosis prophylaxis [72]. Some authors additionally report a higher incidence or greater severity of acute limb ischemia during the COVID-19 pandemic compared to the corresponding period in the previous year [73, 74].

Extrapulmonary organ manifestations

SARS-CoV-2 can affect a wide range of additional organs and result in changes that are usually nonspecific on imaging. Abnormalities were seen in 34 % to 56 % of patients with acute or subacute COVID-19 who underwent neuroimaging [75, 76]. Ischemic stroke was most common (see above) [76, 77]. Further common imaging findings were 1) signal alterations in the medial temporal lobe as a result of encephalitis; 2) multifocal, non-confluent, hyperintense white matter lesions on fluid-attenuated inversion recovery (FLAIR) images and diffusion-weighted sequences with variable enhancement and possible associated hemorrhagic lesions (similar to acute disseminated encephalomyelitis (▶ **Fig. 5a**) and 3) extensive and isolated white matter microhemorrhages (▶ **Fig. 5b**) [78]. Moreover, leptomeningeal contrast enhancement and extensive and confluent white matter FLAIR hyperintensities without associated hemorrhagic lesions have been described [75, 76, 78].

Myocardial manifestations are seen in severe cases of COVID-19 and contribute to the mortality of the disease, particularly in patients with preexisting cardiac diseases [9, 79, 80]. Ischemic (see above) as well as inflammatory processes seem to play a decisive role [9, 68, 81]. In a meta-analysis including 26 studies with a total of 11 685 patients, the weighted pooled prevalence of myocardial damage was 20 % (95 % CI: 17–23 %). In the individual studies, the prevalence fluctuated between 5 % and 38 % [82]. Multiple case reports show acute myocarditis in patients with active COVID-19 [82]. In the case of hospitalized COVID-19 patients with elevated troponin levels and no other identifiable cause, myocardial damage could be detected on cardiac MRI in 69 % of these patients one month after discharge [83]. In a further study, even unselected patients who had recovered from COVID-19 still showed signs of cardiac involvement (78 %) or active myocardial inflammation (60 %) on MRI approximately 70 days after recovery – regardless of preexisting conditions, disease severity, and time to initial diagnosis [84].

Apart from the lung, the liver is the organ most commonly affected by COVID-19 [85]. However, the changes visible on imaging are usually only subtle and nonspecific. Among other things, periportal edema and heterogeneity of the liver parenchyma indicate SARS-CoV-2-induced hepatitis [70, 71, 85]. A distended gallbladder filled with sludge and enlarged intrahepatic bile ducts are also often observed and indicate impaired bile drainage without a mechanical obstruction. This can result in cholecystitis [70, 71, 85]. Hepatic steatosis is considered an independent risk factor for severe COVID-19 [85].

If not of an ischemic origin (see above), involvement of the gastrointestinal tract is the result of viral gastroenteritis and is seen in the form of typically hypodense thickening of the intestinal wall [70, 85]. It can mostly be attributed to submucosal edema and is sometimes accompanied by hyperenhancement of the mucosa, moderate distension and fluid filling of the affected bowel loops, and inflammatory changes in the surrounding fat tissue [70, 85].

Moreover, in addition to the already mentioned organ infarctions (see above), COVID-19-associated changes have been described in the pancreas (pancreatitis), the kidney (heterogeneity, loss of corticomedullary differentiation), and urinary system (diffuse irregularity and thickening of the wall of the bladder due to interstitial or hemorrhagic cystitis), the spleen (splenomegaly), the musculoskeletal system, the eyes, and the skin [85]. Since providing a detailed description of these changes exceeds the scope of this overview, please refer to the relevant specialized literature.

COVID-19 in children

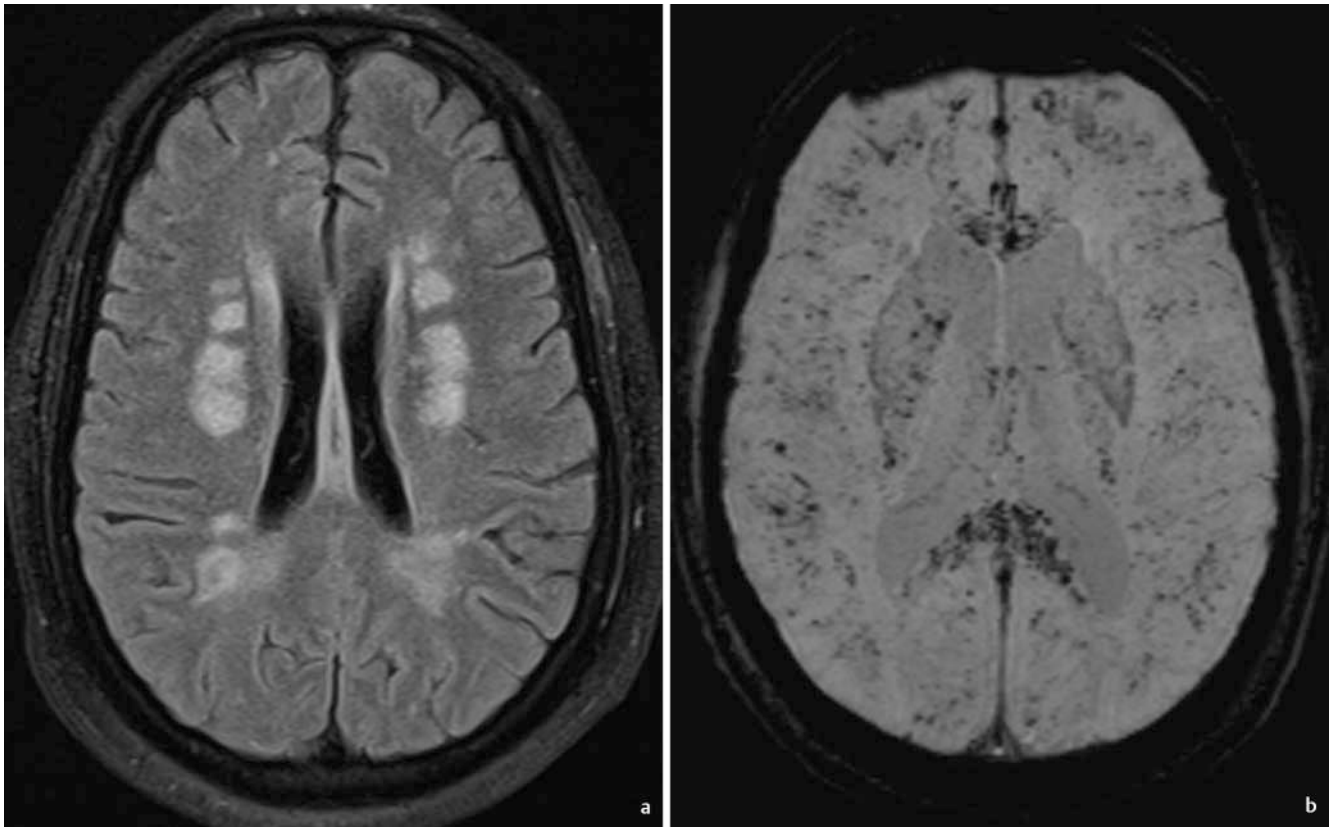
Children contract COVID-19 significantly less frequently and generally experience a milder disease course compared to adults [85, 86]. Nevertheless, approximately one third of children hospitalized with COVID-19 require intensive care and individual cases have been fatal, particularly in children with preexisting conditions [85, 86]. In addition, pediatric multisystem inflammatory syndrome (PIMS), a presumably autoimmune-mediated hyperinflammatory response with parallels to atypical Kawasaki disease, occurs in rare cases in children after acute COVID-19 disease [85, 87]. Since providing a detailed description of the pediatric aspects of COVID-19 is beyond the scope of this study, please refer to the specialized literature for more information.

Long-term effects of COVID-19 (long COVID)

To date, only minimal data regarding the long-term effects of COVID-19 is available. Abnormalities, usually ground-glass opacities followed by irregular lines, were seen on chest CT 6 months after discharge in approximately half of 353 patients hospitalized due to COVID-19 [88]. Another publication describes fibrosis-like changes in 35 % of cases and residual ground glass opacity or interstitial consolidations in 27 % of 114 patients 6 months after severe COVID-19 pneumonia [89]. Further studies with larger patient numbers and longer observation periods are needed to better evaluate the possible long-term effects of COVID-19.

Risk of COVID-19 for personnel in radiology

Employees in radiology departments are at an increased risk of SARS-CoV-2 infection, similar to those working in intensive care units and dedicated COVID-19 units [90]. Due to the limited scope of this overview, please refer to the relevant specialized literature for more detailed information regarding these risks and possible protective measures.



▶ **Fig. 5** Cerebral manifestations of COVID-19. **a** Transverse FLAIR (Fluid Attenuated Inversion Recovery). Patchy, non-confluent, T2-hyperintense white matter lesions, corresponding to inflammatory demyelinating changes (similar to acute disseminated encephalomyelitis – ADEM). **b** Transversal SWI (Susceptibility-Weighted Imaging). Pronounced disseminated white matter microhemorrhages involving the corpus callosum. Both figures (**a**, **b**): courtesy of Prof. Dr. H. Rolf Jäger, Neuroradiological Academic Unit, UCL Queen Square Institute of Neurology, London, UK.

Conclusion

COVID-19 results in typical findings in the lung that can be visualized most effectively with CT. In the case of quickly available RT-PCR test results, the purpose of radiological imaging is not primary diagnosis but rather differentiation from other diseases, investigation of unclear cases with discrepancies between clinical suspicion and RT-PCR test results, evaluation of severity, and detection of comorbidities and complications. Thromboembolic events, particularly venous thromboembolisms as well as arterial vascular occlusions with resulting infarctions in the corresponding target organs, are the most common extrapulmonary complications of COVID-19. Knowledge of additional extrapulmonary organ manifestations is helpful for management particularly of critically ill patients with a protracted course who require intensive care. The possible long-term effects of COVID-19 are only known to a minimal extent and require longer and more detailed observation.

Conflict of Interest

The authors declare that they have no conflict of interest.

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