The COVID-19 pandemic has had devastating medical and economic consequences globally. The severity of COVID-19 is related, in a large measure, to the extent of pulmonary involvement. The role of chest CT imaging in the management of patients with COVID-19 has evolved since the onset of the pandemic. Specifically, the description of CT scan findings, use of chest CT imaging in various acute and subacute settings, and its usefulness in predicting chronic disease have been defined better. We performed a review of published data on CT scans in patients with COVID-19. A summary of the range of imaging findings, from typical to less common abnormalities, is provided. Familiarity with these findings may facilitate the diagnosis and management of this disease. A comparison of sensitivity and specificity of chest CT imaging with reverse-transcriptase polymerase chain reaction testing highlights the potential role of CT imaging in difficult-to-diagnose cases of COVID-19. The usefulness of CT imaging to assess prognosis, to guide management, and to identify acute pulmonary complications associated with SARS-CoV-2 infection is highlighted. Beyond the acute stage, it is important for clinicians to recognize pulmonary parenchymal abnormalities, progressive fibrotic lung disease, and vascular changes that may be responsible for persistent respiratory symptoms. A large collection of multi-institutional images were included to elucidate the CT scan findings described.

KEY WORDS: chest CT scans; COVID-19; COVID-19 pneumonia; SARS-COV-2

The year 2020 will be remembered for the devastation caused by the COVID-19 pandemic. Intensive global efforts took place to mitigate its spread, to produce vaccines, to develop rapid and accurate diagnostics, and to identify effective treatments. The key role of chest imaging also has evolved with the pandemic. Early on, when molecular and
antigenic testing were not as widely available, CT scanning provided results more rapidly, and in some circumstances, with greater sensitivity than reverse-transcription polymerase chain reaction (RT-PCR) for diagnosis of COVID-19.1-4

In April 2020, the Fleischner Society released a multinational expert consensus statement that offered guidance to physicians on the use of thoracic imaging in various health care environments.5 The Society of Thoracic Radiology, the American College of Radiology, and the Radiological Society of North America offered additional guidance for the use of both plain chest radiography and CT imaging for patients suspected to have COVID-19.6 These guidelines recommend against the routine use of chest CT imaging to diagnose COVID-19 because findings were considered nonspecific, and normal CT imaging results fail to rule out the infection. Additional concerns included the potential risk of aerosol dispersion of the virus during performance of the study, the time required to clean suites between patients, and the need for personal protective equipment, placing additional strain on limited resources.2

These recommendations are pragmatic and are based on valid clinical reasoning. In consonance with these guidelines, we do not recommend chest CT imaging for routine diagnostic purposes or as a screening method in asymptomatic individuals. Chest CT imaging may be useful in moderate to severe disease in patients who demonstrate worsening gas exchange or show lack of improvement in respiratory status with time. This may apply to patients with negative RT-PCR results, but with a high index of clinical suspicion for COVID-19.

The purpose of this article is to review the data on COVID-19 published over the past year and to put it in the context of the published guidelines. We focus on the role of CT scans in the diagnosis and management of patients with COVID-19 pneumonia. We reiterate the importance of standardizing descriptors of typical and atypical CT scan findings in COVID-19 pneumonia and discuss the role of chest CT imaging in assessing the severity of the disease and triaging the patient accordingly. Finally, we discuss the radiographic and clinical features that identify patients likely to demonstrate progressive fibrotic lung disease.

Methods
We performed a systematic literature search using Embase, Medline, and World Health Organization COVID-19 databases for articles published through December 31, 2020. We made an exception by referencing an ahead-of-print article with an accompanying editorial that was published in January 2021 and provides valuable information on long-term follow-up (6 months) of pulmonary lesions. Tables of contents from specific radiology and cardiothoracic journals not included in these databases were searched separately. Key search terms included corona, coronavirus, COVID-19, SARS-CoV-2, 2019nCoV, or Wuhan virus AND computed tomography, computerized tomography, CAT, CT, or HRCT. Study selection criteria included only articles in English, with patients with COVID-19 confirmed by RT-PCR or gene sequencing. Studies were included only if a detailed description of chest CT imaging was included. Particular emphasis was given to meta-analyses. Conference abstracts, editorials, and case series with fewer than 10 patients were excluded. Duplicate studies—patients reported from the same hospital, during the same time frame, in different journals—also were excluded. Each of the 458 articles retrieved was graded from 1 through 6, using a grading system by two members of the writing committee (either a pulmonologist or radiologist). Articles were assessed for number of patients studied, methodology, reproducibility, primary and secondary outcomes studied, and clinical usefulness of recommendations made. A minimum cumulative average score of 60% had to be achieved to include the article. Any reviewer rejecting an article was asked to comment on the reasons for rejection. When significant disagreement occurred between reviewers, a third senior member of the writing committee made the final decision.

Usefulness of Chest CT Imaging for Diagnosis
A variety of diagnostic tests are available for COVID-19, with RT-PCR being the reference standard. Rapid assay screening is only approximately 56% sensitive, but 99.5% specific, with results available immediately.7 The sensitivity and specificity of RT-PCR depends on the site of swab collection and method of collection (Table 1).5,9 Accuracy of these tests varies by disease stage and the degree of viral replication. Abnormal chest CT scan findings can precede positivity on RT-PCR testing, because the latter may take up to 4 days to convert in a patient with COVID-19.6 The reported sensitivities and specificities of CT imaging for COVID-19 vary widely because of the lack of strict diagnostic criteria for imaging in earlier studies.10 However, the use of a standardized chest CT scan grading system can improve the diagnostic performance of CT chest imaging, as discussed later in this article.

Patients referred for chest CT imaging should undergo non-contrast-enhanced imaging because most of the findings in noncomplicated COVID-19 pneumonia are
confined to the lungs, without involvement of the mediastinum or pleura.\textsuperscript{11} Chest CT scanning should be performed with an inspiratory breath hold from the lung apices to the bases. Low-radiation-dose chest CT imaging is preferred to minimize radiation burden.\textsuperscript{2,12} Thin-section axial images with a lung reconstruction algorithm should be produced. IV contrast may be administered if CT scan pulmonary angiography is required to detect pulmonary embolism or if a concern arises for necrotizing pneumonia.\textsuperscript{2,11}

COVID-19 lung disease may present with both typical and atypical CT scan findings. The Radiological Society of North America (RSNA) has provided guidance to standardize CT scan reporting in patients with COVID-19 pneumonia. The RSNA proposed four categories for reporting CT scan findings: typical, indeterminate, atypical, and negative (Table 2).

Typical features are the most specific for COVID-19 pneumonia and most characteristically include peripheral, bilateral, or multifocal rounded foci of ground-glass opacity (GGO). Additional findings include airspace consolidation, with or without an associated crazy-paving pattern and a reverse halo abnormality (Fig 1A-C). Indeterminate features include multifocal, diffuse, perihilar, or unilateral GGO, with or without consolidation. The GGO often lacks a rounded

### Table 2: Radiological Society of North America Consensus Statement Proposed Reporting Language for CT Scan Findings Related to COVID-19, Including Rationale and CT Scan Findings

<table>
<thead>
<tr>
<th>COVID-19 Pneumonia Imaging Classification</th>
<th>Rationale</th>
<th>CT Scan Findings</th>
</tr>
</thead>
</table>
| **Typical appearance**                  | Commonly reported imaging features of greater specificity for COVID-19 pneumonia | - Peripheral, bilateral, GGO with or without consolidation or crazy paving  
- Multifocal GGO of rounded morphologic features with or without consolidation or crazy paving  
- Reverse halo sign or other findings of organizing pneumonia |
| **Indeterminate appearance**           | Nonspecific imaging features of COVID-19 pneumonia | Absence of typical features and presence of:  
- Multifocal, diffuse, perihilar, or unilateral GGO with or without consolidation lacking a specific distribution and that are nonrounded and nonperipheral  
- Few very small GGO with a nonrounded and nonperipheral distribution |
| **Atypical appearance**                | Uncommonly or not reported features of COVID-19 pneumonia | Absence of typical or indeterminate features and presence of:  
- Isolated lobar or segmental consolidation w/o GGO  
- “Tree-in-bud”  
- Lung cavitation  
- Smooth interlobular septal thickening w/ pleural effusion |
| **Negative findings for pneumonia**   | No features of pneumonia | No CT scan features to suggest pneumonia |

Data are presented as percentage. NAAT = nucleic acid amplification test\textsuperscript{7-9}; RT-PCR = reverse-transcriptase polymerase chain reaction.

Modified with permission from Radiology: Cardiothoracic Imaging.\textsuperscript{7} GGO = ground-glass opacity.
configuration. These opacities may lack a peripheral distribution (Fig 2).

An atypical appearance is uncommonly associated with COVID-19 pneumonia and is more indicative of an alternate diagnoses, including bacterial pneumonia with or without cavitation, and tree-in-bud branching centrilobular nodules. The indeterminate pattern is observed mainly in elderly patients and is the most challenging. In this category, the detection of subsegmental vascular enlargement (defined as more than 3 mm in diameter), involving both arteries and veins, is observed most frequently ($P < .001$) and could be an ancillary sign to guide diagnosis.

Inui et al. used chest CT scan patterns described in the RSNA expert consensus statement and other CT
scan grading systems to calculate their sensitivity, specificity, positive predictive value (PPV), and negative predictive value for the diagnosis of COVID-19 (Table 3). The presence of a typical appearance on chest CT scanning has a sensitivity and specificity of 73.5% and 82.8%, respectively. The presence of either a typical appearance or indeterminate appearance on chest CT imaging has a sensitivity and specificity of 92.0% and 41.0%, respectively. Ciccarese et al\(^{13}\) reported that the application of the four standardized categories for CT scan reporting proposed by RSNA could support a faster triage of patients in the backdrop of high community disease burden and is highly predictive of RT-PCR results. In their series of 560 CT scans from 460 patients, the typical pattern provided a high PPV for COVID-19 (87.8%), whereas atypical and negative patterns provided a high PPV for non-COVID-19 disease (89.6% and 86.2%, respectively).\(^{13}\)

A separate COVID-19 Reporting and Data System (CO-RADS) score was proposed by the Dutch Radiological Society and also can be used for triaging suspected patients with COVID-19 with moderate to severe symptoms. A CO-RADS score of 1 to 6 is useful for identifying the likelihood of pulmonary involvement secondary to COVID-19 (Table 4, Fig 3A-E).\(^{15}\) A CO-RADS score of ≥ 4 can be used to predict positive and negative RT-PCR results in high-prevalence settings, with a sensitivity of 89.4%, specificity of 87.2%, negative predictive value of 94.6%, and PPV of 76.4%, respectively.\(^{16}\) It should be pointed out that these reporting and scoring systems have been used mainly as research tools and are used less commonly in clinical practice. Their value in clinical settings remains to be established.

### Usefulness of Chest CT Imaging in Acute Settings

**Prognosis and Management of COVID-19 Based on Chest CT Scan Findings**

Chest CT imaging may be used to stratify the severity of lung involvement and to predict outcomes in COVID-19, which in turn may assist physicians with proper triaging of patients and allocation of resources. Studies have described five patterns of lung parenchymal involvement on CT scanning that may correlate with no involvement to progression and severe disease.\(^{4}\) These

### TABLE 3 | Diagnostic Accuracy of Chest CT Scan Grading Systems for COVID-19 Pneumonia

<table>
<thead>
<tr>
<th>CT Scan Grading System</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSNA expert consensus statement</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical appearance</td>
<td>73.5</td>
<td>82.8</td>
<td>81.0</td>
<td>75.7</td>
</tr>
<tr>
<td>Typical appearance or indeterminate appearance</td>
<td>92.0</td>
<td>41.0</td>
<td>60.9</td>
<td>83.7</td>
</tr>
<tr>
<td>CO-RADS score</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>64.5</td>
<td>89.0</td>
<td>85.4</td>
<td>71.5</td>
</tr>
<tr>
<td>4 or 5</td>
<td>85.5</td>
<td>68.3</td>
<td>72.9</td>
<td>82.5</td>
</tr>
<tr>
<td>3, 4, or 5</td>
<td>91.0</td>
<td>53.8</td>
<td>66.3</td>
<td>85.7</td>
</tr>
</tbody>
</table>

Data are presented as percentage. Modified with permission from *Radiology: Cardiothoracic Imaging*.\(^{14}\) CO-RADS = COVID-19 Reporting and Data System; NPV = negative predictive value; PPV = positive predictive value; RSNA = Radiological Society of North America.

### TABLE 4 | CO-RADS Categories and Level of Suspicion for Pulmonary Involvement in COVID-19

<table>
<thead>
<tr>
<th>CO-RADS Category</th>
<th>Suspicion of Pulmonary Involvement Resulting from COVID-19</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not interpretable</td>
<td>Poor-quality scan</td>
</tr>
<tr>
<td>1</td>
<td>Very low</td>
<td>Normal or noninfectious</td>
</tr>
<tr>
<td>2</td>
<td>Low</td>
<td>Typical for infections others than COVID-19</td>
</tr>
<tr>
<td>3</td>
<td>Equivocal</td>
<td>Features compatible with COVID, but may be associated with other diseases</td>
</tr>
<tr>
<td>4</td>
<td>High</td>
<td>Suspicious for COVID-19</td>
</tr>
<tr>
<td>5</td>
<td>Very high</td>
<td>Typical for COVID-19</td>
</tr>
<tr>
<td>6</td>
<td>Proven</td>
<td>Positive RT-PCR results for COVID-19</td>
</tr>
</tbody>
</table>

Modified with permission from *Radiology*.\(^{15}\) CO-RADS = COVID-19 Reporting and Data System.
include no involvement, bronchopneumonia (Fig 4A), organizing pneumonia (Fig 4B), progressive organizing pneumonia (Fig 4C), or diffuse alveolar damage patterns (Fig 4D). In a multivariate analysis, crazy paving (Fig 5), bronchial dilatation or bronchiectasis (Fig 6), and severity of parenchymal involvement (diffuse alveolar damage) may indicate a fibroproliferative process and may serve as independent predictors of poor outcome.4,17,18 Specific segmental vascular changes on chest CT imaging, like vascular thinning or enlargement (Fig 7A), vascular wall irregularity (Fig 7B), vascular angulation (Fig 7C), bronchovascular ectasia, and vascular annular contractions, are other predictors of disease severity in patients with COVID-19 pneumonia.19,20

CO-RADS scores of 4 and 5 suggest a high and very high suspicion of pulmonary involvement, respectively, resulting from COVID-19. Hence, a CO-RADS score of ≥ 4 can be used to put a patient in isolation or self-quarantine while awaiting results of RT-PCR testing. CT severity score (CTSS) is based on a subjective visual assessment of the extent of disease in each lobe of the lung. Presence of GGO, crazy paving, or consolidation in each lobe is used for scoring.21 Each lobe has a minimum score of 0 and a maximum score of 5 (Table 5).22,23 The total CTSS is the sum of the individual lobar scores and can range from 0 (no involvement) to 25 (maximum involvement). A CTSS of ≥ 10 and ≥ 15 (Fig 8A-D) have a specificity of ≥ 90% for hospital admission and ICU admission, respectively. A CTSS of ≤ 3 was found to be ≥ 90% sensitive for patient discharge from the ED.16 A CTSS of ≥ 17 is ≥ 90% specific for 30-day mortality, and a score ≤ 5 predicts 30-day survival with a sensitivity of ≥ 90%.
An example of the acute usefulness of chest CT imaging is in patients with a high clinical suspicion of COVID-19 and moderate or severe illness with hypoxemia, but in whom rapid antigen testing results are negative. The typical chest CT scan findings enhance confidence in making the diagnosis and favor prompt initiation of steroids in these patients.

**Chest CT Scan Findings and Ventilatory Strategy**

It has been proposed that modifications of ventilatory strategy can be based on the pattern of lung involvement on CT scan in COVID-19. Patients requiring mechanical ventilation with focal or patchy abnormalities on chest CT imaging may require less positive end expiratory pressure (Fig 9A) than those with diffuse bilateral abnormalities on chest CT imaging (Fig 9B) who may require high levels of positive end expiratory pressure, but little evidence exists to support this hypothesis so far.

**Noninfectious Complications of COVID-19**

COVID-19 predisposes patients to both arterial and venous thrombosis. CT scans of the chest performed in the acute setting can help to identify vascular changes that may be present earlier during the disease process. Pulmonary embolism is a known complication of COVID-19 and can be seen in 17% to 35% of patients, with the highest prevalence in patients who are critically ill (Fig 10A, 10B). CT imaging can be useful to identify pulmonary embolism in patients with COVID-19 who are...
deteriorating acutely, especially if they demonstrate no concomitant increase in lung parenchymal opacities. Interestingly, Espallargas et al. found right upper lobe emboli to be most common among patients with COVID-19. Average time for diagnosis of pulmonary embolism is around 16 days after onset of initial COVID-19-related symptoms. It is worth noting that despite the higher incidence of pulmonary embolism in patients with COVID-19 pneumonia, evidence is lacking to support the usefulness of early CT scan angiography without a clinical indication.

Microvascular thrombi may lead to severe physiologic derangements, but may not be detected by conventional contrast CT scans. COVID-19 may induce a strong inflammatory response with cytokine release, which in turn may culminate in vascular endothelial damage. The net result is a hypercoagulable state and microvascular thrombosis. Autopsy reports have described vascular endothelial injury and widespread capillary microthrombi. Clinically, this may present as profound hypoxemia, very high D-dimer values, preserved lung compliance, and increased physiologic dead space. Most patients will demonstrate multisystem organ dysfunction because this is a widespread phenomenon. This entity is best detected by dual-energy CT imaging (Fig. 11A, 11B). In a study by Remy-Jardin et al., 55 dual-energy CT scans obtained from patients with COVID-19 3 months after hospital discharge showed three interesting findings: (1) unexpected proximal arterial thrombosis in 5.4% of patients, (2) disseminated lung perfusion abnormalities indicating microangiopathy in 65.5% of patients, and (3) areas of increased perfusion corresponding to GGOs resulting from SARS-CoV-2 pneumonia.

Chest CT imaging may be useful in patients with persistent or worsening hypoxia or fever. Multifocal GGOs, airspace consolidation with air bronchograms with or without interlobular septal thickening, or an Atoll sign or reverse halo sign (Fig. 12A, 12B) are patterns suggestive of organizing pneumonia (OP), which is discussed later in the section entitled Usefulness of Chest CT Imaging in Subacute and Chronic Settings. Of note, 40.6% of patients with COVID-19 pneumonia who demonstrate OP may show a more rapid evolution of opacities than are characteristic of OP. These patients may have acute fibrinous and OP. Patients may have nonresolving opacities with BAL confirmation of eosinophilia and may show subsequent resolution of symptoms and
imaging findings with corticosteroid use. This may be suggestive of a chronic eosinophilic pneumonia pattern, which has been reported in a few small case series in the setting of COVID-19 (Fig 13A, 13B). Patients with chest CT scan findings suggestive of OP or chronic eosinophilic pneumonia may need bronchoscopy with BAL along with transbronchial biopsy to establish the diagnosis. These patients will need longer courses of steroids (perhaps months) compared with the usual 7- to 10-day course given for COVID-19 pneumonia.

Figure 7 – A-C. Segmental vascular changes. A, Enhanced thin-section axial image of the lungs from a 72-year-old woman with COVID-19 and worsening shortness of breath showing segmental vascular enlargement (blue arrow) in an area of ground glass opacity (GGO) in the right upper lobe. Note the smaller caliber of the vessels in the normal left upper lobe (red arrow). This finding may be suggestive of disordered vasoregulation in the diseased lung. B, Enhanced axial maximum intensity projection (MIP) image of the right lung in a 54-year-old woman with positive COVID-19 reverse-transcriptase polymerase chain reaction results showing segmental vascular wall irregularity (blue arrow) in an area of GGO in the right lower lobe. Compare this with the smooth vessel contour in the nonaffected portion of the lung (red arrow). C, Enhanced axial MIP image of the right lung in a 48-year-old man with COVID-19 who demonstrated chest pain and shortness of breath showing segmental vascular thinning and angulation (blue arrow) in an area of GGO in the right lower lobe. Compare this with the smooth tapering of the vessels in the nonaffected lung (red arrow).
Barotrauma and Volutrauma

Barotrauma, including pneumothorax (Fig 14A), pneumomediastinum (Fig 14B), and pneumopericardium, have been reported in intubated patients with COVID-19. In a large New York City hospital, a 24% rate of barotrauma was observed in patients with COVID-19 pneumonia who were receiving mechanical ventilation; this was significantly higher than the 11% rate in the comparator group of intubated patients without COVID-19 infection as well as historical control patients. The most common event was pneumomediastinum followed by pneumothorax. Increased barotrauma events did not lead to increased overall mortality. Longer hospital length of stay and younger age were associated with a higher incidence of barotrauma events.

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Worsening gas exchange, increasing positive end expiratory pressure, and tidal volume requirements (thus increasing driving pressures) are the most likely causes of ventilator-induced lung injury, but this has not been correlated definitively. Prolonged mechanical ventilation because of COVID-19 or associated conditions also can lead to ventilator-induced lung injury. Notably, increased prevalence of barotrauma was reported previously in Middle East Respiratory Syndrome and Severe Acute Respiratory Syndrome.

TABLE 5 | CTSS of Each Lobe Based on the Extent of Involvement

<table>
<thead>
<tr>
<th>CT Severity Score</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No involvement</td>
</tr>
<tr>
<td>1</td>
<td>&lt; 5% of lobe involvement</td>
</tr>
<tr>
<td>2</td>
<td>5%-25% of lobe involvement</td>
</tr>
<tr>
<td>3</td>
<td>26%-49% of lobe involvement</td>
</tr>
<tr>
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<td>&gt;75% of lobe involvement</td>
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Modified with permission from Radiology. CTSS = CT severity score.

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</tbody>
</table>

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Figure 8 – A-D, Illustration of CT severity score (CTSS). CT scans of the lungs from a 49-year-old male with positive reverse-transcriptase polymerase chain reaction results showing multiple, bilateral ground-glass opacity (GGO) producing an intermediate CTSS of 12: (A) unenhanced thin-section axial and (B) coronal reformatted images. CT scans of the lungs from a 47-year-old man with COVID-19, progressive shortness of breath, and chest pain showing diffuse GGO bilaterally, producing a high CTSS of >15: (C) enhanced thin-section axial and (D) coronal reformatted images.
Cardiac Involvement

CT scans also may provide clues to clinicians about the underlying cardiac injury in hospitalized patients with COVID-19, particularly pericardial effusion that has been reported to occur in up to 5% of patients. Pericardial effusion may be related to the severity of myocardial inflammation and occurs with higher incidence in those with severe illness. Another feature of myocardial injury may be the development of left ventricular failure and pulmonary edema.

Non-COVID-19 Infections

Not infrequently, patients with COVID pneumonia show superimposed bacterial or fungal infections. New or worsening fevers, increases in leukocyte and neutrophil counts, sputum culture analyses, and elevated procalcitonin levels may be helpful in making such a determination, but repeat imaging including chest CT scanning often is helpful. Focal opacities, lobar consolidation, centrilobular tree-in-bud opacities, and pleural effusions are seen more commonly in bacterial pneumonia as compared with COVID-19. In patients who have been treated with immunosuppressants such as steroids or cytokine (IL-1 and IL-6) inhibitors, not only bacterial infections, but also fungal and mycobacterial infections, should be considered. This is especially so if cavitary lung disease is seen (Fig 15). With steroid treatment in patients from endemic areas, helminthic infestations may occur as well.
Usefulness of Chest CT Imaging in Subacute and Chronic Settings

Persistent Lung Parenchymal Disease

Most studies of the temporal course of chest imaging changes occurring after COVID-19 pneumonia have examined short intervals (30 days or so) (Fig 16). In one study, chest CT scan was performed on the day before discharge and 2 weeks and 4 weeks after discharge.38 The authors reported that in 64.7% of these discharged patients, the CT scan changes fully resolved after 4 weeks. Among discharged patients with more than three lobes involved on CT scan and CT scores of > 4 at week 2 after symptom onset, persistent chest imaging abnormalities were more likely.33 As the disease progresses, increases in number, extent, and density of GGO on CT imaging is observed, and these may evolve into consolidation and crazy-paving lesions in days to weeks (Fig 17).39,40

Chen et al41 reported that older patients were more likely to demonstrate reticular opacities (a possible sign of microvascular thrombi). In patients remaining symptomatic after COVID-19 pneumonia (as in the patient depicted), detection of vascular changes in the lungs may reflect findings described during the acute phase of the disease, still detectable during the follow-up. Combined analysis of morphologic and perfusion changes in this patient shows us two findings. The first is an increase in iodine (B) (ie, increased perfusion) in corresponding areas of ground glass attenuation in both lungs (A, blue arrow), a combination suggesting that we are dealing with ground-glass opacity (GGO) of vascular origin. In the context of COVID-19 pneumonia, this suggests the possibility of detecting residual neoangiogenesis seen in the acute phase of this viral infection. The second finding is the presence of areas of hyperperfusion (yellow arrows) that are all seen in the vicinity of areas of GGO. These areas cannot be explained by artifacts, nor by the presence of concomitant lung destruction, as shown by the lung image. This is why one can suspect depiction of the second major aspect of COVID-19 vasculopathy, namely, the presence of microthrombi within pulmonary capillaries. Our comments are assumptions based on autopsy reports published at the time of the first wave of the COVID-19 pandemic. Because we can exclude technically related artifacts, we can raise these hypotheses and acknowledge the lack of histopathological confirmation.

Figure 12 – A, B, Organizing pneumonia. Enhanced axial (A) and coronal (B) CT images of the lungs from a 67-year-old man who showed positive results for COVID-19 4 weeks before seeking treatment at the ED with progressive dyspnea, where was found to be hypoxic, with oxygen saturation of 86% on room air. Predominantly peripheral ground glass and consolidative opacities are visible bilaterally (blue arrows). Reverse halo sign present in left lower lobe (red arrow). These findings are suggestive of organizing pneumonia.
of fibrosis) than younger patients. In a retrospective study of COVID-19 with 3 months of follow-up, patients who demonstrated residual pulmonary parenchymal disease on CT scan experienced higher rates of previous ICU admission, longer hospital stays, more extensive disease on initial CT scan, and more underlying comorbidities (Fig 18A, 18B). The most common abnormal radiologic features in patients demonstrating residual disease were GGO (54%), followed by mixed GGO and subparenchymal bands (31.8%) and pure subpleural bands (13.7%) (Fig 19A, 19B). These may represent early fibrotic changes (Fig 20A, 20B).

In a recent prospective study, Han et al reported 114 patients who underwent chest CT imaging during an initial hospital admission and then again 6 months later. A total of 40 of 114 patients (35%) showed evidence of fibrotic-like changes at 6 months included age older than 50 years, severe disease, hospital stay of $\geq 17$ days, total CTSS of $\geq 18$, and development of ARDS or need for noninvasive mechanical ventilation. In an accompanying editorial, George et al suggested that the lung abnormalities that persisted after COVID-19 may reflect twin pathogenic pathways leading to lung damage, one involving diffuse alveolar damage as a result of ARDS and the other involving a viral-induced autoinflammatory process resulting in a fibrotic-like reaction. It is clear that we need further long-term follow-up of these patients to see if these

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**Figure 13** – A, B, Chronic eosinophilic pneumonia pattern. Axial images of the lungs from a 71-year-old man with COVID-19 and persistent shortness of breath from April 2020 (A) and July 2020 (B) showing progression of ground-glass opacity and consolidative opacities bilaterally, with traction bronchiectasis development (arrow). Bronchoscopy with BAL diagnosed eosinophilic pneumonia.

**Figure 14** – A, B, Barotrauma. A, Unenhanced thin-section axial image of the lungs from a 66-year-old man with COVID-19 who underwent scanning because of shortness of breath showing a large right pneumothorax (star), in addition to peripherally located consolidation and ground-glass opacity (GGO) bilaterally. B, Enhanced thin-section axial image of the lungs from a 52-year-old man with COVID-19, elevated D-dimer level, and chest pain showing pneumomediastinum (arrow), in addition to GGO bilaterally.
abnormalities persist and lead to clinically significant fibrotic lung disease or if slow regression of the lung injury occurs.

The optimum management of such chronic lung sequela of COVID-19 infection is unknown. This has raised questions about the role of steroids, other immunosuppressive agents, or even antifibrotic agents in symptomatic patients with residual fibrotic changes after COVID-19 pneumonia. The role of antifibrotic

Figure 15 – Cavitary lung disease. Unenhanced thin-section axial image of the lungs showing a cavity in the right upper lobe (arrow), in addition to diffuse, bilateral ground-glass opacity and consolidation. The patient was found to have methicillin-resistant Staphylococcus aureus. Simultaneously, BAL demonstrated Stenotrophomonas maltophilia.

Figure 16 – Evolution of CT scan findings over time, from ground-glass opacity (GGO) and small consolidation on day 4 after symptom onset (A) to enlarging GGO with crazy paving on day 10 (B), to improvement on day 14 (C), and near resolution on day 22 (D).

Figure 17 – Crazy-paving pattern. Enhanced thin-section axial image of the lungs from a 61-year-old man with chest pain 19 days after receiving a diagnosis of COVID-19 showing diffuse, bilateral ground-glass opacity with a crazy-paving pattern evident in the left upper lobe.
agents and lung transplantation in this group of patients remains to be studied.

**Organizing Pneumonia**

Four to 10% patients with COVID pneumonia may demonstrate an atoll or reverse halo sign suggesting histopathologic OP. Consistent with other forms of acute lung injury, patients may show linear opacities, worsening reticulation, subpleural curvilinear bands, and bronchial dilatation suggesting histopathologic fibrosis (Fig 21).

**Pre-existing Interstitial Lung Disease**

Pre-existing interstitial lung disease is a risk factor for poor outcomes from COVID-19. In one study, patients with interstitial lung disease who contracted COVID-19 showed a more than fourfold increase in the adjusted odds of death and were more likely to require

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**Figure 18** - A, B. Residual pulmonary parenchymal disease. Enhanced thin-section axial image of the lungs from April 2020 (A) and unenhanced thin-section axial image of the lungs from July 2020 (B) showing extensive ground-glass opacity (GGO) and consolidation at the time of presentation with residual pulmonary parenchymal disease consisting of GGO, intralobular lines, and traction bronchiectasis at 3 months after diagnosis.

**Figure 19** - A, B. Residual disease. Unenhanced thin-section axial images of the lungs from a 65-year-old man with persistent shortness of breath 7 months after receiving a COVID-19 diagnosis showing residual disease, as evidenced by perilobular scarring (blue arrow) and band-like opacities (red arrow), consistent with organization and fibrotic-like changes.
ICU admission. Over the years, appreciation of the role of viruses in acute exacerbations of underlying interstitial lung disease has increased (Fig 22A-D). The optimum management of such chronic lung sequela of COVID-19 infection is unknown. The role of corticosteroids, other immunosuppressive agents, or antifibrotic agents in symptomatic patients with residual fibrotic changes after COVID-19 pneumonia remains to be studied formally.

Lung Transplantation

Anecdotal reports exist of successful lung transplantation for nonresolving ARDS after COVID-19. Pathologic findings from the explanted lung were similar to irreversible end-stage pulmonary fibrosis (Fig 23). Lung transplantation is a consideration in patients surviving COVID-19 pneumonia who demonstrate severe pulmonary fibrosis and are appropriate candidates.

Conclusions

Since the onset of the pandemic, the role of chest imaging has evolved considerably. The purpose of this review, therefore, has been to examine all available, pertinent reports from 2020, assessing both current and potential indications for CT imaging. In particular, this includes evaluating the sensitivity and specificity of CT imaging compared with other testing methods, as well as in the specific settings of acute vs subacute and chronic disease.

Importantly, use of a standardized chest CT scan reporting system based on consensus appearances of typical and atypical findings has been shown to aid in the triage of ED patients. In the acute setting, chest CT imaging also may be used to stratify the severity of lung involvement; to assist in the determination of the need for hospitalization, ICU admission, or both; and to predict outcomes in COVID-19. Chest CT imaging also may be useful in patients with persistent or worsening hypoxia, with the ability to differentiate non-COVID-19 lung abnormalities, in particular, OP, chronic eosinophilic pneumonia, and barotrauma. In the appropriate clinical setting, CT scan angiography also is valuable to diagnose pulmonary embolism. In the subacute and chronic settings, CT scan potentially can help to predict which patients are likely to have residual pulmonary involvement, including the development of pulmonary fibrosis-like abnormalities.
Future directions for research include the need for continued validation of standardized reporting systems for patients suspected of having COVID-19 and determination of the range of interobserver and intraobserver variability that will require larger studies. Similarly, continued evaluation of the diagnostic accuracy of CT imaging also is necessary. The role of CT imaging will need to be reassessed as different strains of COVID-19 emerge, with different rates of infectivity and morbidity and mortality. Finally, it is to be expected that artificial intelligence likely will play an ever larger role in CT imaging assessment of a range of COVID-19-related issues.

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References


