1. Introduction

The outbreak of highly infectious novel coronavirus, known as coronavirus disease 2019 (COVID-19), has caused an emerging global health threat with more than 29,737,453 confirmed cases worldwide based on world health organization daily report as of September 17th, 2020 [1]. With continued surge in COVID-19 cases, the number of imaging studies in persons under investigation or confirmed positive patients (both for COVID-19 related or unrelated reasons) are increasing overtime. This has placed a rising onus on understanding the common features of COVID-19 pneumonia on different imaging modalities.

Although not routinely recommended, chest computed tomography (CT) is still the cornerstone of the radiologic evaluation which aids in the detection of equivocal cases, follow-up of clinically deteriorating confirmed cases, predicting mortality and early detection of complications [2–5]. Cross-sectional imaging is recommended for patients with higher risk for complication, those with comorbidities, not responding to supportive treatment and presenting with acute clinical deterioration, per WHO rapid advice guide [6]. Chest CT imaging features of COVID-19 has been well described in the literature. A few recent studies have demonstrated radiologic features of COVID-19 pneumonia in other diagnostic modalities, like ultrasound and PET-CT [7,8] but no dedicated report has described magnetic resonance imaging (MRI) features of the disease.

Assessing the presence of common features of COVID-19 pneumonia as an incidental finding in MRIs performed for other reasons such as thoracic, abdomen or cardiac MRIs is necessary for every radiologist. Although MRI is not the modality of choice for evaluation of pulmonary opacities, it has similar capabilities in detection of COVID-19 pneumonia when compared to chest CT.
series, the first comprehensive reported cohort in the literature.

2. Materials and methods

Upon IRB approval, written informed consents were obtained from eight laboratory confirmed (positive RT-PCR test, three to six days before imaging) COVID-19 patients who presented to our outpatient imaging clinic in Rasht, Iran between March 20 and April 8, 2020. All included patients had mild symptoms during the acute phase of the disease and did not need supplementary oxygen therapy. They first underwent chest CT (1-mm slice thickness with a 16-slices SOMATOM Scope CT scanner, Siemens, Germany) and once typical, indeterminate or atypical features of COVID-19 pneumonia [9] were identified, a dedicated chest MRI (1.5 T MR system, Magnetom Avanto, Siemens, Erlangen, Germany) was performed on the same day.

Our MRI protocols included; 1—Coronal T2-half Fourier single-shot turbo spin-echo (HASTE), 2—Axial T2-HASTE, 3—Sagittal T2 HASTE, 4—Axial T1 3D-gradient echo volumetric interpolated breath-hold examination (VIBE), and 5—Coronal true fast imaging with steady state precession (FISP), obtained using the breath holding technique, as well as, 6—Coronal T2-turbo spin echo (TSE)-turbo inversion recovery magnitude (TIRM), 7—Axial T2-TSE-TIRM, and 8—Axial diffusion-weighted imaging (DWI) (with b-values equal to 0 s/mm², 400 s/mm², and 800 s/mm²), obtained using respiratory gating. All the protocols were implemented for each patient under a total cycle time of 12–15 min.

Both MRI and CT images were reviewed by a radiologist with 10-year experience and the morphology, laterality and location of the lesions were recorded for each case. The chest CT features were categorized as typical, indeterminate and atypical based on Radiological Society of North America (RSNA) expert consensus statement [10].

3. Results

Five males and three females with the mean age of

<table>
<thead>
<tr>
<th>Case</th>
<th>Age/gender</th>
<th>GGO</th>
<th>Consolidation</th>
<th>Reticular opacities</th>
<th>Reverse halo</th>
<th>Laterality</th>
<th>Peripheral disease</th>
<th>Involved lobes</th>
<th>Pleural effusion/thickening</th>
<th>CT chest features</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34/M</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Unilateral</td>
<td>No</td>
<td>RUL, RLL</td>
<td>No</td>
<td>Indeterminate</td>
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<tr>
<td>2</td>
<td>35/M</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Bilateral</td>
<td>No</td>
<td>All lobes</td>
<td>No, +thickening</td>
<td>Typical</td>
</tr>
<tr>
<td>3</td>
<td>36/F</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Unilateral</td>
<td>Yes</td>
<td>RLL</td>
<td>No</td>
<td>Typical</td>
</tr>
<tr>
<td>4</td>
<td>57/F</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Bilateral</td>
<td>Yes</td>
<td>RUL, RLL, LUL, LLL</td>
<td>No</td>
<td>Indeterminate</td>
</tr>
<tr>
<td>5</td>
<td>30/M</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Bilateral</td>
<td>Yes</td>
<td>RLL, LLL</td>
<td>No, +thickening</td>
<td>Typical</td>
</tr>
<tr>
<td>6</td>
<td>23/F</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Bilateral</td>
<td>No</td>
<td>RML, RLL, LUL, LLL</td>
<td>Yes</td>
<td>Atypical</td>
</tr>
<tr>
<td>7</td>
<td>38/F</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Bilateral</td>
<td>Yes</td>
<td>RUL, RLL, LUL, LLL</td>
<td>No</td>
<td>Typical</td>
</tr>
<tr>
<td>8</td>
<td>56/M</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Bilateral</td>
<td>No</td>
<td>All lobes</td>
<td>No</td>
<td>Typical</td>
</tr>
</tbody>
</table>


Fig. 1. a. A 36-year-old female with confirmed COVID-19, seven days from her symptom onset. (A) Axial CT image demonstrating ground glass opacity (GGO) in the right lower lobe. (B) T2W True-FISP sequence demonstrating hyperintense opacity in the right lower lobe of the lung (arrow) corresponding to chest CT finding. (C) T1W VIBE sequence revealed intermediate to hypointense signal at the same region. (D) T2W TSE-TIRM sequence demonstrating heterogeneous high signal intensity within the known GGO, due to its different components admixed with minimal pleural thickening/effusion, the later not clearly visible in CT. b. In same patient, (A) Axial CT images demonstrating “reverse halo” sign. (B) Axial True-FISP sequence of MRI demonstrating central areas of GGO attenuation with surrounding consolidation, also representing “reverse halo”.

Table 1
Demographic data with morphology, laterality and location of the MRI features of COVID-19 pneumonia in our case series. Presence or absence of pleural effusion/thickening and CT classification of the disease were also mentioned.
40.63 ± 12.64 years old were present in this case series. A comprehensive review of MRI features for each case have been presented in Table 1. We also reported type of CT manifestation based on the recent RSNA expert consensus statement. Several representative MR images with distinguishing features are exemplified in the following five cases (Figs. 1–5). The remaining three cases had similar radiologic pattern to one or more of the below mentioned cases. Although these features are not specific for COVID-19 pneumonia, given the clinical presentation, confirmed laboratory RT-PCR, and ongoing pandemic, finding are highly suggestive of COVID-19 pneumonia.

Case 1. Ground Glass Opacities (GGO) and Reverse Halo Sign (Fig. 1 and b).

Case 2. Consolidation (Fig. 2).

Case 3. Consolidation + Reticulation (Fig. 3).

Case 4a. Dominant reticular pattern with improving pneumonia (Fig. 4a).

Case 4b. GGO pattern with resolving pneumonia (Fig. 4b).

Case 5. Consolidation in DWI sequence (Fig. 5).

4. Discussion

Although American College of Radiology statement recommends minimizing MRI utilization in COVID-19 pandemic [11], urgent cases are still performed, and elective MRIs will show increasing trend in upcoming days. Lung parenchyma is at least partially visible on different protocols of cardiac, thoracic spine and abdomen MRIs. Given the high prevalence and contagiousness of the COVID-19 infection, radiologists are going to encounter the many features of the associated pneumonia in their daily practice even when the MR studies are performed for other reasons. Furthermore, the reported cardiac involvement in COVID-19 infection will occasionally necessitate acquiring cardiac MR [12]. There is also open debate over associated radiation burden with CTs performed in at-risk groups like pediatric patients and pregnant females, hence raising the potential for performing state-of-the-art chest MR as a radiation-free modality in diagnosing COVID-19 pneumonia in such groups, although the challenges related to disinfection of the equipment still exists. Finally, though not well studied yet, it appears that clinically recovered COVID-19 patients may have cardiopulmonary sequelae later which may need dedicated radiologic surveillance. In that case, chest MRI examination is a viable alternative in the aforementioned groups and those who may need frequent follow up imaging.

To our knowledge, this is the first case series evaluating COVID-19 pneumonia on chest MRI. Our preliminary data on eight COVID-19 positive patients, showed that common CT manifestation of COVID-19 pneumonia such as bilateral multifocal ground-glass, consolidative, nodular or reticular opacities can be identified and distinguished on MRI, although the imaging features are not specific.

It has been shown that lung MRI is as efficient and accurate as chest CT imaging in providing fine details of the lung parenchyma and pleural abnormalities in patients with lower respiratory tract infection [13], but the actual practical role is limited by loss of signal due to physiologic respiratory and cardiac motion, and low amount of

![Fig. 2. A 31-year-old male patient with confirmed COVID-19, presenting after three days of his symptom onset. (A) Axial CT image demonstrating areas of peripheral consolidative and nodular opacities in bilateral lower lobes. (B) T2W HASTE sequence showing multiple peripheral located consolidations in both lobes that are hyperintense to skeletal muscle. (C) T1W VIBE sequence demonstrating isointense areas when compared skeletal muscle. This finding was different from hypointensity of GGO in Case 1. (D) T2W TSE-TIRM sequence demonstrating similar findings to T2W HASTE sequence, slightly brighter.]

![Fig. 3. Axial images of 35-year-old male patient with COVID-19 six days from his symptom onset. (A) Axial CT image demonstrating peripheral consolidation in the right lower lobe of the lung, accompanied by pleural-based reticulation in both lower lobes. (B) T2W TSE-TIRM sequence demonstrating consolidation in the right lower lobe of the lung which shows heterogeneous high-signal-intensity lesion. (C) T2W True-FISP and (D) T2W HASTE sequence have shown a more precise delineation of reticular opacities.]

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hydrogen protons in the lung parenchyma [14]. Advancement in applicable sequence techniques has enabled to compensate for these defects by providing different aspects of lung pathology. As part of the inflammatory process, any increase in lung proton density due to solid lesions or infiltration with fluids corresponds to areas of increased signal intensity, which can be easily detected with MRI [15]. T2-weighted sequences such as HASTE, TSE, FISP and TIRM are widely accepted to increase the detection accuracy of lung infiltration [16]. Hence, various radiologic manifestation of COVID-19 pneumonia such as GGO, consolidations and ill-defined reticulations can be easily distinguished with lung MRI.

Among various MRI sequences, the T2W TSE-TIRM sequence shows lesions more brightly compared to other sequences. The increased signal intensity of the lesion in the T2W TSE-TIRM sequence is mostly due to edema, which is expected to be more observed in the inflammatory process of COVID-19 pneumonia. Also, our limited cases suggested that lung MRI could determine the different infiltration stages of the lung parenchyma. Dedicated statistically higher-level studies should be performed to determine the importance of each sequence in evaluation of COVID-19 pneumonia.

Overall, our study drives home the fact that chest MRI can act as a potential alternative to chest CT in follow-up of COVID-19 pneumonia although further studies are warranted. This also holds true in patients who require chest MRI for other indications such as vascular emergencies, myocardial infarction, or myocarditis, or routine MR spine and MR-PET for cancer staging. It is worth mentioning that a major limitation to MRI utilization in COVID-19 era is the potential risks associated with infection control after using the imaging equipment.
Another limitation to our study is that our case series consisted of relatively young patients. Thus, larger and more diverse studies including different spectrum of ages are warranted to elucidate more details about the lung MRI findings of COVID-19 and to reliably examine the diagnostic accuracy, sensitivity, specificity, false negative rate, and cost-effectiveness of lung MRI compared to the CT in diagnosis of COVID-19 pneumonia. There is no doubt that development and adoption of a standardized MRI protocol is required prior to clinical implementation of this technique.

5. Conclusion

Becoming familiar with typical findings of COVID-19 pneumonia in MRI is crucial for every radiologist. Although MRI is not the modality of choice for evaluation of pulmonary opacities, it has similar capabilities in detection of COVID-19 pneumonia when compared to chest CT.

Declaration of competing interest

The authors declare no conflict of interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. Protocol of the study and data will be available upon request.

References