

# Comprehensive Evaluation of Multimodality Imaging in SARS-CoV-2 Patients: A Review

Nadia Tahouneh, Ramin Ghasemi Shayan\*

Radiology Department, Paramedical Faculty, Tabriz University of Medical Sciences, Tabriz, Iran

## Email address:

raminghasemi1377@gmail.com (R. G. Shayan)

\*Corresponding author

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**Abstract:** Coronavirus disease 2019 (COVID-19) with its different symptoms has been widespread throughout the world for about two years and it has brought many deaths in different countries. Although the disease has been reported to target lung tissue as the first option but it can also cause damages in the heart and other tissues of the body. Many researches have been done on how to control and manage this pandemic to prevent further spread of this virus. There is always a percentage chance of error with RT-PCR test, when identifying the COVID-19, which was used as the first method of diagnosing the disease. In emergencies, low sensitivity of RT-PCR could lead to misdiagnosis of this virus. So, different imaging modalities can provide aid to detect the virus more precisely. So far, Radiology imaging especially Chest CT has played an important role in the process of recognizing the disease and in many cases, it has rushed to the aid of the healthcare staff for determining the stages and controlling of the disease. Although a number of countries have made good progress in the field of vaccines, it is very important for staff to know the advantages and disadvantages of each imaging modality in the disease assessment procedures, so that they can use them wisely to accelerate the elimination process of the disease. With this approach, this paper is an overview of various capabilities of different imaging modalities in the field of better management of SARS-CoV-2 disease.

**Keywords:** COVID-19, Helpful Diagnostic Imaging Modalities, Radiography, Chest CT, MRI, Ultrasonography

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## 1. Introduction

In 2019, a new corona virus disease (COVID-19) caused by the Severe Acute Respiratory Syndrome Coronavirus (SARS-CoV-2) was reported in the Wuhan Province of China. The virus originated first in China and then spread all over the world and was declared as a pandemic by the World Health Organization (WHO) [1-3]. Up until now, SARS - CoV - 2 is the seventh member of the viral group of COVIDs that infects people, causing diseases such as the common cold in humans [4]. The manifestations of COVID - 19 are like Severe Acute Respiratory Syndrome (SARS) and the Middle East Respiratory Syndrome (MERS) contaminated cases [3, 4]. The most common symptoms are fever, dry cough, fatigue, dyspnea, myalgia, and the minor common symptoms include headache, hemoptysis, diarrhea, or pleuritic chest pain [4, 5]. Covid-19 affects different people differently because most people with the disease are mild to moderate and recover without hospitalization. Still, older

people and those with fundamental medical problems like cardiovascular disease, diabetes, hypertension, and chronic respiratory disease are more likely to develop severe illness and even death [4, 6]. Although RT-PCR was primarily used to detect the Coronavirus, limitations such as collecting accurate samples, transferring them to the laboratory, and the quality and efficiency of test kits affect the initial results of the RT-PCR test by about 30 to 60% [7, 8]. Also, it takes up to 4 days to show a positive result in the patients with COVID-19 infection [9]. In emergencies, low sensitivity of RT-PCR in patients with COVID-19 may lead to insufficient disease recognition. Therefore, different imaging modalities can provide aid to the accurate evaluation of the virus [7]. As mentioned above, four imaging modalities including: Radiography, CT, MRI and even Ultrasonography are discussed comprehensively in the following. In cases where we do not have access to the RT-PCR test, imaging modalities including chest X-ray can be helpful in clinical evaluation and in managing patients who are positive for

COVID-19 [10-12]. A Chest CT scan with high-quality images can show pulmonary abnormalities even in COVID-19 patients whose RT-PCR test was negative [13]. More recently, MRI studies have also demonstrated great harmony with Chest CT in identifying characteristic features of COVID-19 disease [14]. For patients in whom radiation exposure should be avoided, especially pregnant patients and children, pulmonary MRI may be a proper alternative to Chest CT [15, 16]. The value of imaging modalities in screening and identifying suspected cases of COVID-19 has been passionately discussed since the beginning of the pandemic. As studies show, different radiology modalities have helped a lot in the early diagnosis, thus prevented the disease's spread to other people. Therefore, the purpose of this study is to summarize the typical imaging features of Four modalities of Radiography, Chest Computed Tomography (Chest CT), Magnetic Resonance Imaging (MRI) and Ultrasonography in regards to COVID-19 pneumonia disease.

## 2. Comprehensive Radiographic Analyze and Diagnose of SARS-CoV-2

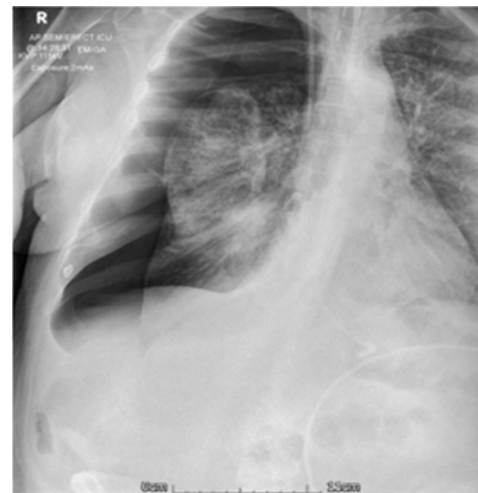
### 2.1. Basic Radiographic Imaging, Image Quality and Diagnose Radiographic Imaging Value of COVID-19

As the pandemic advances, chest X-ray could undertake an important part in detection of patients with high clinical doubt of COVID-19 [13, 17]. The most common indications in X-ray images are airspace opacities, whether described as consolidation or Ground Glass Opacities (GGO) and the distribution is mostly bilateral, peripheral, and lower zone predominant [5, 18, 19]. A significant factor in the dependability of X-ray discoveries could be the time elapsing between the presence of primary symptoms and the imaging process. A lot of studies report that usually there aren't any abnormalities in the radiographs taken in the early days of the disease (< 2-4 days) and about 10-12 days after symptoms onset, the severity of lung involvement reaches its maximum extent [18, 20]. Although the Fleischer Society agrees with the low sensitivity of Radiography in the early stages of the disease, but Chest radiographs can show lung changes in patients with the acute stages of the disease and with moderate to severe symptoms [5, 20, 21]. Two cases of CXR imaging in patients with suspected COVID-19 pneumonia are shown in below (figures 1, 2).

### 2.2. Indispensable Preventions of Radiographic Imaging of COVID-19

As the personnel in a Radiology section are regularly in the frontline when fighting against the COVID-19 virus, adherence to virus disinfection protocols is necessary [29]. Radiology units may have 2 radiographers in attendance using the 'one clean, one in interaction with the patient' method for lessening the possibility of dissemination of the disease [29, 30]. Moreover, it is necessary to disinfect the device after testing each patient because the virus can survive

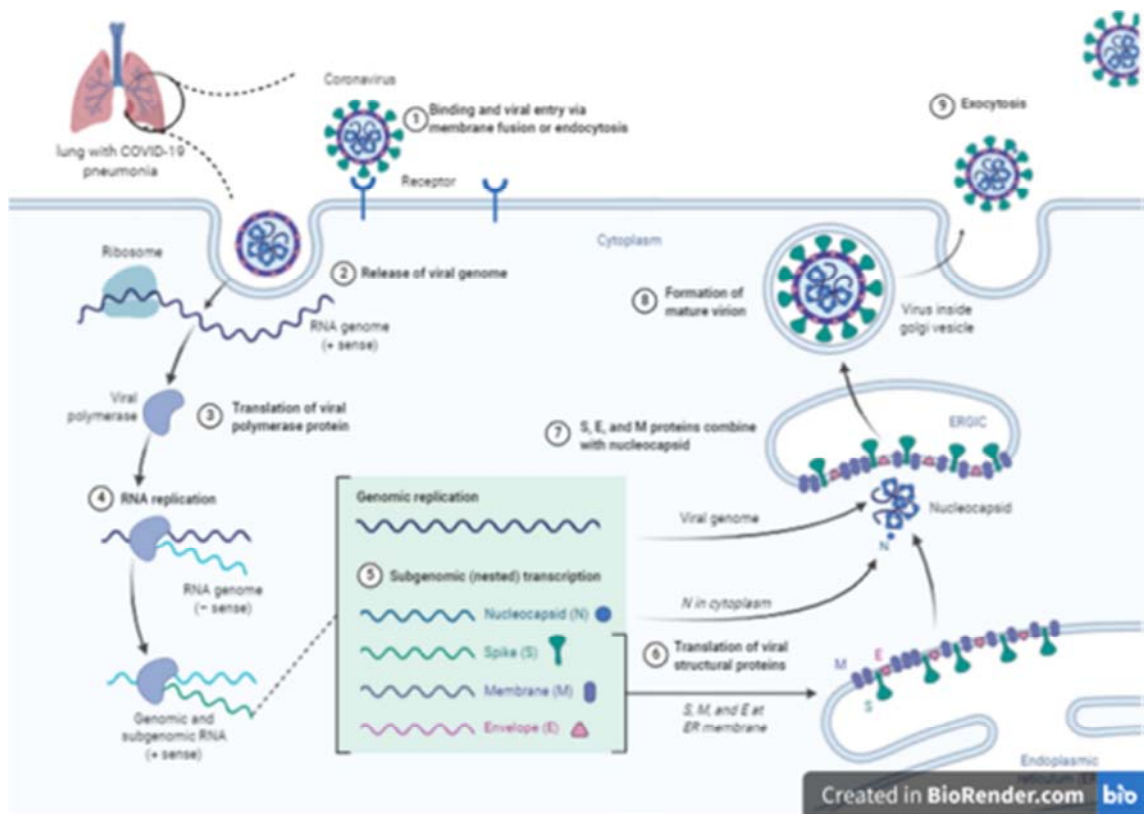
on surfaces for up to 72 hours [29, 31]. Usage of portable Radiography equipment is recommended by the ACR for ease of decontamination (compared to the CT) as the surfaces of these machines can be easily cleaned and we may avoid the need to bring patients into the Radiography room [5, 32]. According to the ACR recommendation, for infection control in the radiologic departments during the pandemic, the following conditions must be considered: 1. For easy temporal cleaning of the radiographic room, avoid putting unnecessary equipment in it, 2. Use portable HEPA filters to decrease the feasibility of airborne transmission by providing more air circulation [33]. The virus enters and multiplies in the cells of the human body as shown in the (figure 3) below.



**Figure 1.** A 65-year-old woman with positive result for COVID-19, was already discharged from the clinic, came back due to spiking temperature and shortness of breath. A massive right-sided pneumothorax with associated lung collapse and consolidation was seen in her CXR, but the left lung was clear. For treatment, the patient was injected with intravenous antibiotics and had right chest drainage. She was discharged home after improvement in laboratory tests and CXR findings [18, 22- 26].



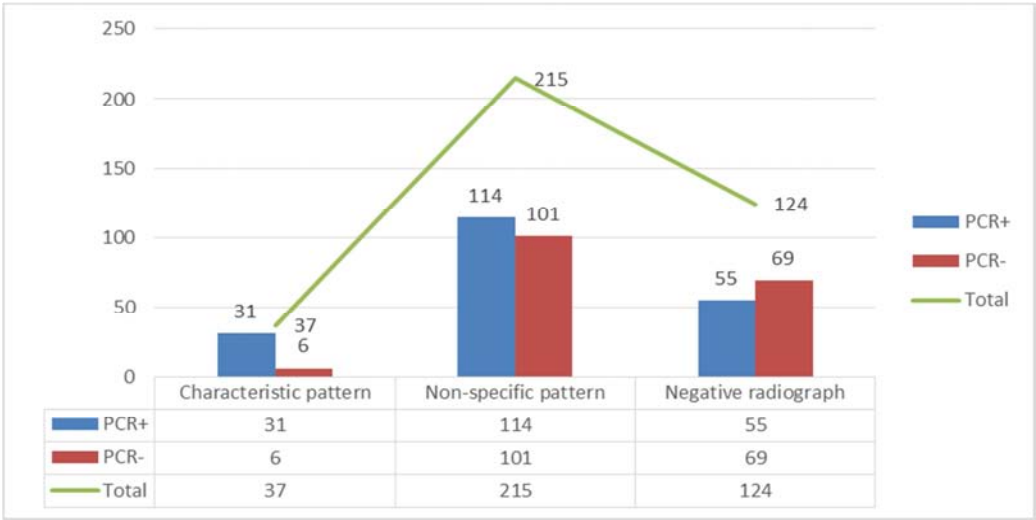
**Figure 2.** CXR done in a 75-year-old male patient with no respiratory symptoms but with a week of fever, malaise and diarrhea (only gastrointestinal indications). Several faint alveolar opacities were detected, with more infection in superior parts, and mainly in the peripheral areas. After these CXR findings, the requested PCR test result was also positive, which indicates early detection of CXR [6, 27, 28].



**Figure 3.** Schematic manifestation of the Coronavirus replication cycle in the lung cell of a person with COVID-19. Spikes or S proteins bind the SARS-CoV-2 virus to its specific receptor at the cell surface (ACE2). The host cell provides the virus replication and begins to replicate its genome and protein structures. With the exocytosis process, new viral particles with lipid membranes are released from the host cell.

Although chest Radiography is the most frequently used imaging modality for identifying the virus but CXR with a sensitivity of 69%, has limited sensitivity in discovering pulmonary lesions in the initial periods of the disease

because the early images of chest X-ray doesn't show any abnormalities in the lung [34-36]. The diagram below shows the Radiographic manifestations in comparison with different PCR test results (figure 4).



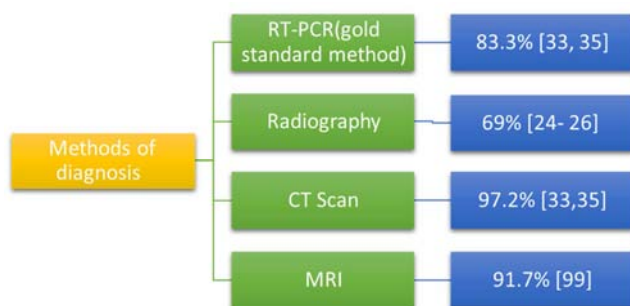
**Figure 4.** Quantity of characteristic pattern, nonspecific pattern and negative radiograph in compared with the positive and negative PCRs [37].

**2.3. Cross-Comparison of Radiographic Imaging Through MRI and CT**

Chest Radiography is the first accessible modality for the

assessment of lung anomalies especially in COVID-19 disease [5]. As a credible association in radiology cross-comparison, The American College of Radiology considers chest Radiography as an optional study in its criteria of

relevance for the signs of examinations in patients with COVID-19 disease. It has comparative advantages compared to CT regarding the COVID-19 pandemic, which includes its easy accessibility, lower radiation dose, and the possibility of carrying out a portable examination, reducing the possibility of contagion from health personnel [5, 20]. Furthermore, the European Society of Radiology (ESR) and the European Society of Thoracic Imaging (ESTI) suggest the utilize of portable X-ray imaging basically for COVID-19 patients in ICU who are not steady enough to be taken for a CT check-up [20, 38]. Moreover, X-ray systems are easier to disinfect than CT equipment and it can also be done on an outpatient basis or lying down and free up the CT scan sources [20], but its lack of specificity and sensitivity for the initial stages of the disease should also be considered [5, 21, 38] and in the case of MRI, unlike CT and Radiography, there is no risk of ionizing radiation. MRI is a helpful non-invasive procedure for various examination and clinical applications however it is extremely delicate to movement [39]. Specialists regularly use MRI to see portions of the body that are difficult to see with other imaging strategies, for example X-rays, Ultrasound, or CT scans. MR imaging is utilized to analyze various sorts of sicknesses including heart and vascular illness, stroke, muscle and bone issues, and malignant growth [41, 42, 96]. A number of methods of diagnosing COVID-19 disease have been written in the below (Figure 5).



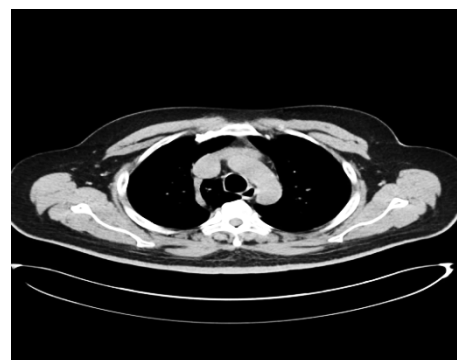
**Figure 5.** Sensitivity percentage of Coronavirus diagnostic methods. As it shows in the above, the sensitivity of Radiography images is lower than the RT-PCR test.

### 3. Comprehensive CT Analyze and Diagnose of SARS-CoV-2

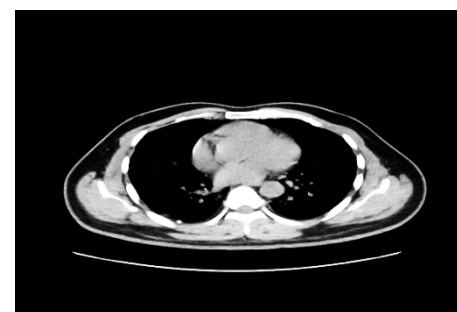
#### 3.1. Basic CT Scan Imaging of COVID-19

CT has a significant role in the diagnosis of patients with COVID-19 disease. As use of contrast agent in CT examinations could affect the analysis of Ground-Glass Opacification (GGO) patterns, it should be done in a non-contrast way with reconstructions of the volume at 0.625 mm to 1.5 mm slice thickness (gapless) and in cases such as CT Pulmonary Angiogram (CTPA), where contrast media must be used, a non-contrast test must be measured before contrast examination [30, 43, 44]. CT imaging can show serious damages to the lungs through the progress of the disease, which can be similar to Acute Respiratory Distress Syndrome

(ARDS), but its patterns may be very similar to those of various other pneumonias such as SARS and MERS [45, 46]. CT is a modality that can diagnose the disease in less time than a RT-PCR test kit (in 5–6 hours) [47, 48] and it can show more sensitivity (97.2%) in the early stages of the disease than RT-PCR (83.3%) [47, 49], but in spite of the impressive sensitivity, CT has a low specificity (39%) as a result of the overlapping similar features in SARS-CoV-2 disease and different pneumonias [45]. The positive and negative prognostic values of Chest CT in COVID-19 has been reported as 92% and 42% [47, 50]. The low negative predictive value and low specificity of CT is leading to concerns over utility of CT in screening the patients [47]. For these reasons, as well as the high risk of contamination in CT units, ACR has recommended that the use of CT should be limited and be reserved for the hospitalized and symptomatic patients and for complication assessment and it says that CT shouldn't be used for screening or as a first-line evaluation method for this disease [13, 18, 32, 51]. Within the classification of Radiological Society of North America (RSNA) expert consensus statement, there are different manifestations of CT examinations that can be classified into 3 categories (Table 1) [47] and two CT indications in patients without respiratory symptoms, but diagnosed positive for COVID-19 is shown in the below (figures 6, 7).



**Figure 6.** Chest CT of a 55-year-old man sick with abdominal pain, fever, diarrhea and no cough or quickness of breath. Scattered ground-glass opacities in two-sided lungs mostly at the marginal parts of the lung without any substantial lymphadenopathy be able to be seen in Chest CT and show the COVID-19 pneumonia infection [52].



**Figure 7.** This Chest CT is associated to a 40-year-old man sick with severe appendicitis as primary experimental assessment because he had fever and right iliac fossa soreness and there weren't any marks of respiratory indications. The CXR pictures taken were uncertain of COVID-19 virus thus later in the chest, tummy and pelvis CT scans, the severe appendicitis and also common CT appearances of COVID-19 were discovered [53, 54].



**Table 1.** Cataloging of Chest CT outcomes agreeing to RSNA's [47, 54-58].

Categories of Different Indications of Chest CT	
Typical Findings	1. Peripheral, bilateral GGO or multifocal GGO of rounded morphology with or without consolidation 2. Observable interlobular lines (crazy-paving pattern) 3. Reverse halo sign
Indeterminate Findings (Presence of Nonspecific Findings)	1. Non-rounded or non-peripheral multifocal, diffuse, perihilar, or unilateral GGO with or without consolidation without a specific distribution 2. A few very minor GGOs with a non-rounded and non-peripheral spreading.
Atypical Findings (Uncommon or Not Reported Findings in COVID-19 Pneumonia)	1. Isolated lobar or segmental consolidation without GGO 2. Separate minor nodules (centrilobular, tree-in-bud pattern) 3. Lung cavitation 4. Smooth interlobular septal thickening with pleural effusion
Negative for Pneumonia	There are no findings for pneumonia

### 3.2. Chest CT Imaging Features of COVID-19

As the severity of the infection and the period from the onset of symptoms rise, the appearances of CT modify [47, 59, 60]. The most classic CT discovery that were understood in up to 98% of patients is GGO [47, 61, 62] and were informed to be marginal or lower lung predominant, frequently seemed with a rounded morphology in this sickness [45, 63]. Other common CT appearances that happen one after another with growth of the disease include: consolidation, linear opacities, crazy paving pattern, and reserved halo sign, which demonstrate bigger contribution of

the respiratory organism [13, 64]. Pleural effusion, Pneumothorax, lymphadenopathy, and lung cavitation are uncommon findings that may be seen in later CT examinations with progress of the sickness [13, 57]. Pure GGO lesions are associated with primary steps of the sickness and the opacities become denser as the COVID-19 pneumonia starts to develop [45]. Therefore, owing to the different signs of CT images in different steps of the sickness, health care employees can be aware of infection severity and condition of the patients. In the table below, the CT manifestation changes over time is showed (Table 2).

**Table 2.** Changes in CT images during different stages of COVID-19 pneumonia [47, 59, 65].

Changes in CT Features		
Time of Onset of Symptoms (Days)	Stage	CT Features
0-4	Early stage	Bilateral or unilateral sub pleural GGO in the lower lobes
5-8	Progressive stage	Increased number and size of opacities, bilateral multi-lobar diffuse GGO, crazy-paving pattern
9-13	Peak stage	Predomination of crazy-paving pattern and massive consolidations, white appearance of the lung, loss of volume may also be seen
14 Days and later	Absorption stage	Decrease of consolidations and crazy-paving pattern, appearance of fibrosis and extensive GGO as the result of the consolidation absorption

### 3.3. Indispensable Preventions of CT Imaging of COVID-19

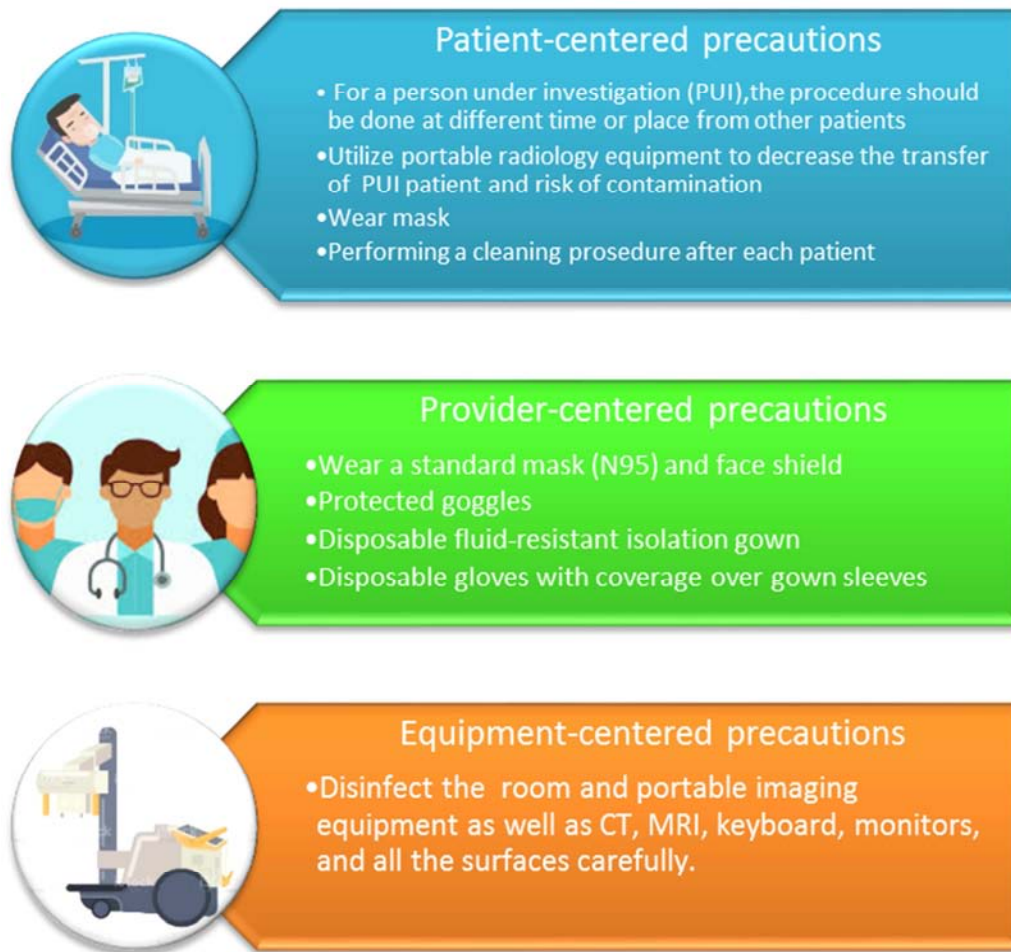
The use of imaging tests in the COVID-19 pandemic, gives results for setting up a conclusion for directing management, triage, or therapy in the patients [21]. That value is reduced by costs such as: the risk of radiation especially in Chest CT, excessive use of PPE, possibility of transmission of the virus to the other patients and health care staffs, the need for decontamination and downtime of equipment in radiology rooms in the centers with limited resources [21]. Therefore, imaging equipment should be used properly and in accordance with healthcare protocols to cause the least harm to everyone [21]. According to the latest statement of WHO and Center for Disease Control and Prevention (CDC) safety recommendations can be considered in three categories including: provider-centered precautions, patient-centered precautions, and equipment-centered precautions [66]. Further details are given in the figure 8.

### 3.4. Image Quality and Diagnose Value of CT in COVID-19

The diagnostic value of Chest CT imaging is basically for its ease of use, brief examination time and high-resolution indications and it provides a fast as well as precise assessment of infection progression [13]. Important benefits of Chest CT in identifying the abnormalities of lung are evaluation of infection severity, and changes of lung lesions during remedy [13, 67]. Hence, various studies underline follow-up CT check-ups in relation to the COVID-19 patients [13, 59, 67-72]. Although RT-PCR test have high specificity, its sensitivity has been reported to be low (60%-70%) [7, 49, 73]. Moreover, the definitive result of a patient suspected of COVID-19 disease is confirmed by several negative results for the RT-PCR test [73]. Also, some areas in China don't have accessible or sufficient resources for this test [73]. So, since we can see lung abnormalities in Chest CT sooner than the RT-PCR test is positive, Chinese authorities considered the patients with typical manifestations at CT images as suffering from the disease even though the RT-PCR wasn't

positive and this increased the role of the Chest CT in evaluating the disease [73]. No lung abnormalities in Chest

CT at many early cases of disease, highlights the challenges of early detection [63, 64, 73].



**Figure 8.** Precautions that are recommended by WHO and Center for Disease Control and Prevention (CDC) for imaging procedures in Radiology departments [66].

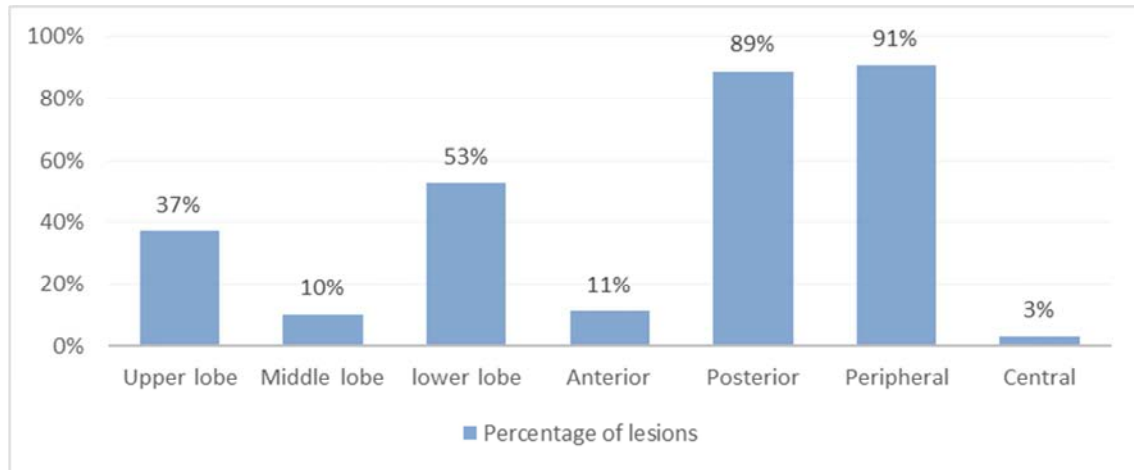
### 3.5. CT Severity Score

CT scoring may provide aid to classify patient's hazard and foresee short-term outcome of patients with COVID-19 pneumonia [74]. CT severity score is outlined to distinguish the severity of COVID-19 pneumonia. With such an approach, it may speed up the assessment and administration of patients with extreme infection in particular conditions where a quick triage strategy is required [75]. The CT-SS is based on the degree of involvement of the lungs. Each of the five lung lobes will be given a score on a scale of 0–5, with 0 demonstrating no involvement, 1 demonstrating less than 5% involvement, 2 showing 5–25% involvement, 3 demonstrating 26–49% involvement, 4 demonstrating 50–75% involvement, and 5 showing more than 75% involvement and the overall CT score can be calculated by summing up the individual lobar scores and it varies from 0 (no involvement) to 25 (greatest involvement) [59, 74, 76]. CT-SS of 1–17 is considered mild and severe group has the CT-SS of 18–25 [76]. As

noted by Zhou S et al [77], with increasing involvement of different parts of the lung, CT scores related to that anatomy also increases. For the anterior area it had significantly lower mean CT score than that for the posterior area [77]. We can conclude that in this disease, the posterior and lower parts of lung are most involved parts with the disease [77]. The Table and chart below (Table 3, figure 9) show where the lung lesions are most commonly distributed in the human body.

**Table 3.** Pulmonary anatomical involvement in COVID-19 [47]. Zhao W et al [78] studied the 101 cases of COVID-19 patients from Hunan, China and their imaging features were evaluated on the basis of clinical status (mild or severe). The most commonly involved lobes were lower lobes, and the right middle lobe was the least involved one [47, 58, 71].

Commonly Anatomical Involvement of the Lung with Lesions	
Most Affected Parts	Percentage
Peripheral part [47, 78]	87.1%
Both lungs [47] Bilateral involvement [78]	82.2%
Posterior part [47, 71]	80%
Lower zone [47, 78]	54.5%
Multi focal area [47, 78]	54.5%



**Figure 9.** In the study done by Song F et al [71] on 51 patients with the average age of 49 years, performed at the Center for Disease Control, Shanghai, China, the patients with positive RT-PCR went through Chest CT examinations. The lung lesions distribution can be seen at the chart above. The lower lobe, posterior and peripheral parts of the lung seem to have higher involvement in SARS-CoV-2 disease.

### 3.6. Cross-Comparison of CT Imaging Through Radiography and MRI

The separation between clinical, laboratory, and imaging discoveries has been illustrated in a few cases [79]. Several studies report that most patients with primary negative RT-PCR had abnormal Chest CT indications [7, 13, 48, 49, 80]. Despite that, reports indicate that Chest CT was normal in almost half of the patients that went through Chest CT within 2 days of the symptoms onset and had tested positive in the RT-PCR test [64, 73, 79, 81]. Therefore, normal Chest CT shouldn't be a sufficient way to reach a definitive conclusion of patients' condition [79, 82] and it's better to be correlated with clinical and laboratory analysis of COVID-19

pneumonia [79]. A positive RT-PCR test can confirm the ultimate outcome of the patient [79]. In general, patients should receive as little radiation as possible. Especially for children, CT shouldn't be used as much as possible because they are more sensitive to radiation than adults and have a higher risk of cancer [83-85]. In these cases, CXR can be used especially as a monitoring method for disease because of its low radiation [83, 86]. As for Chest CT examinations, low radiation techniques should be applied to have less harm to patients [83, 87, 88] and repeated Chest CT scans must be used for patients with suspected complications, not in clinically stable patients [47]. Some MRI, CT and Radiographic features are summarized in the table below (Table 4).

**Table 4.** Comparison of MRI, Chest CT and Radiography in diagnosis of COVID\_19 pneumonia.

Modalities	Radiation (mSv)	Precautions	Severity	Shows No Image Abnormalities After the Onset of Symptoms
Radiography	0.05 mSv [83, 88-90]	1. Ease of decontamination than CT [5, 20] 2. Reduce the risk of transmitting the virus to staff and other patients using portable type of Radiography equipment [5, 20]	69% [34- 36]	< 2-4 days [18, 20]
Chest CT Scan	4-7 mSv [83, 88- 90]	It may take a long time to clean the CT room after each patient (almost 1 hour) and that may decrease the imaging availability [32].	97.2% [47, 49]	2Days [64, 73, 79, 81]
MRI	None [15]	1. Use of MR safety masks to prevent the risk of burns in patients underwent MRI test [91, 92]. 2. Use of 12 air changes per hour for low risk of spread of the virus [93, 94]	91.7% [95]	

### 3.7. Chest CT Protocol

Carrying out CT in a patient with suspected or confirmed COVID-19 needs full safety precautions. Chest CT Low dose radiation is recommended unless a Chest CT scan is needed to assess Pulmonary Embolism (PE). Patients of any age could be infected with SARS-CoV-2 and may require a chest X-ray. Additionally, although chest X-rays are most often utilized for follow-up imaging, a few patients with COVID-19 may require a follow-up Chest CT scan. Accordingly, enhanced chest computed tomography should not be

performed with a low-level regime to reduce radiation load. Low-dose CT images of radiation could be acquired using lower kilovoltage parameters, deep learning-based or more recently developed reconstructions to reduce noise and spectral shaping of the X-ray beams to decrease the low energy characteristics of X-ray components [41, 42, 96], depending on the accessibility of these technologies in each area. For CT scans where there is a risk of generating motion, a reduction in tube detection system turnaround time with high and wide collimation values can be considered [41, 42, 96]. Low-dose radiation Chest CT accomplished based on

these standards has been shown to be attainable for examination of patients with COVID-19, has no poorer diagnostic quality, and reduces radiation dose by around 90% compared with standard TDM reception. So, carrying out low-dose radiation CT rather than full-dose CT as a standard for lung parenchymal assessment in COVID-19 may be protective on the basis of the ALARA principle (As Low As Reasonably Achievable). CT images should be attained throughout a single breath hold. Inspiratory computed tomography increases radiation dose, and assessment of aspiration status has not been reported to raise suspicion of COVID-19 in thoracic computed tomography. The value of expiratory phase CT in the follow-up of COVID-19 patients and prognosis remains questionable.

3.8. Chest CT of COVID-19 Complications

The results of the RT-PCR test are the diagnostic criterion and an important component of clinical decision making. Meanwhile, the proposed chest scanner has potential value as a quick classification device in patients with distress moderate to serious respiratory indications in a resource-constrained setting where COVID-19 is predominant.

Alternatively, computed tomography of the chest may be accomplished if a different assessment is suspected. Common or unspecified characteristics of COVID-19 pneumonia may be distinguished on CT attained for other clinical purposes unexpectedly. In these cases, the radiologist’s interpreter ought to talk about the possibility of COVID-19 with the referring specialist. Reports standardized to guideline such as those proposed by RSNA can help this exchange of

information. In addition, chest computed tomography could be useful for patients whose lung involvement increases with the progression of COVID-19 disease or for secondary cardiopulmonary complications such as ARDS, EP or heart failure.

4. Comprehensive MRI Analyze and Diagnose of SARS-CoV-2

4.1. Basic MRI Imaging of COVID-19

In spite of the fact that pulmonary MRI isn't regularly performed as a first-line imaging test for screening the patients, initial reports have shown great harmony between MRI and Chest CT results in revealing consolidations of COVID-19 disease manifestations [14] (Figure 10). Respectively, the sensitivity of MRI in nodule recognition, specificity, positive predictive value, and negative predictive Value was calculated as 91.7%, 100%, 100% and 95.2% according to CT as reference [95]. It is presently conceivable to overcome challenges such as the low proton content and movement artifacts of lung parenchyma in MRI imaging, by using the new T2-weighted spin-echo PROPELLER MRI sequence [95, 97]. Additionally, since pulmonary consolidation and GGOs happening with this virus cause an increase in proton and signal intensity, the low proton content of the lung can be considered as an advantage in MRI imaging procedure of COVID-19 pneumonia [16, 95] and cranial MRI is very valuable for the assessment of anosmia which is commonly occurred in COVID-19 patients [95, 99].

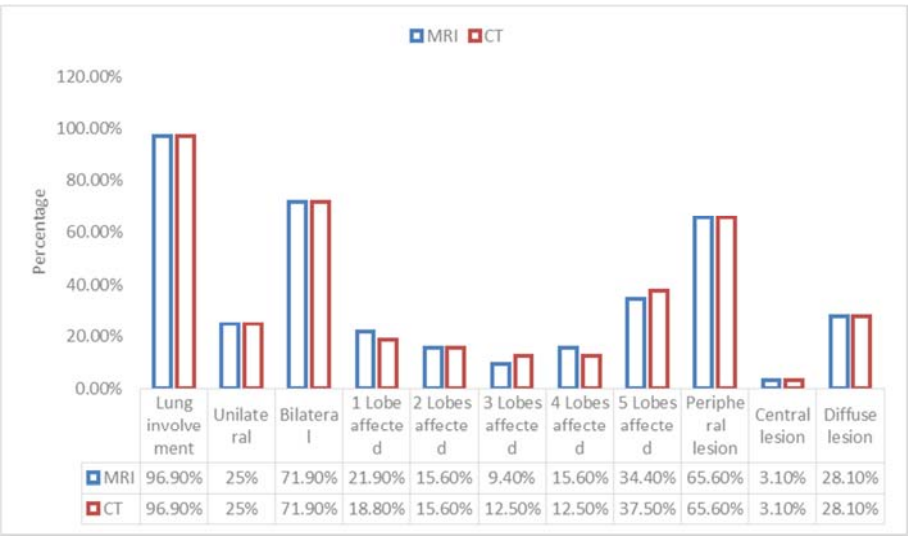


Figure 10. In one of the studies [95], a total of 32 patients underwent the CT and MRI examinations. Concordance of the MRI and CT findings can be seen in the chart above.

4.2. Indispensable Preventions of MRI Imaging of COVID-19

Patients must wear a MR Safe mask before coming to the MRI ward as well as other imaging units and it is noteworthy that these masks shouldn’t contain any metal, especially for the

nasal area (occasionally called nose clips or wires) because these metals heat up during the imaging procedure and it is dangerous for the patient who will undergo the MRI examination [91, 92]. FDA recently received a report in connection with the burning of the face of a patient who had a metal component in his mask during MRI procedure [92]



(Figure 11). One of the studies [93], suggest closing the waiting zones (ACR safety zone II) of MR suites to diminish the chance of airborne transmission of the infection. Standard MRI rooms are designed to have positive air pressure, making bulk air go out of the MRI area without permitting it to circulate back into the room [93]. According to the Department of Radiology at the University of Washington, the first epicenter of the COVID-19, the use of six air changes per hour can decrease the transmission of the COVID-19 virus to the Facilities of MR room and also personnel [93, 99] and as one of the studies reports, using the 12 air changes per hour instead of 6, may reduce the likelihood of virus transmission in other patients by 58% [93, 94].



Figure 11. FDA's warning about using the right mask in the MRI test [40, 92].

#### 4.3. Image Quality and Diagnose Value of MRI of COVID-19

MRI isn't the modality of choice for assessment of lung opacities, but it can be helpful in discovery of COVID-19 pneumonia like Chest CT examinations [100]. The pulmonary abnormalities of COVID-19 on MRI images are basilar and peripheral predominant similar to the CT and CXR examinations and it shows compatible features with them in terms of evaluation of the disease [45]. Areas with abnormal increased signal intensity on both T1 and T2-weighted sequences in MRI, can demonstrate the changes of the lung during disease [45] and it's equivalent to the GGOs or consolidations discovered in CXR or CT images [45]. Several studies have monitored the brain MRI findings of the COVID-19 patients [101]. Gulko E et al [101] reviewed the articles with same subject that had been published in 7

different countries and performed on 126 patients. Acute and sub-acute infarcts were reported to be the most frequently discovered damage on the brain MRI of the COVID-19 patients [101]. Different MRI sequences of the brain in different patients of the COVID-19 disease are shown in figures 12, 13 and 14 [111].

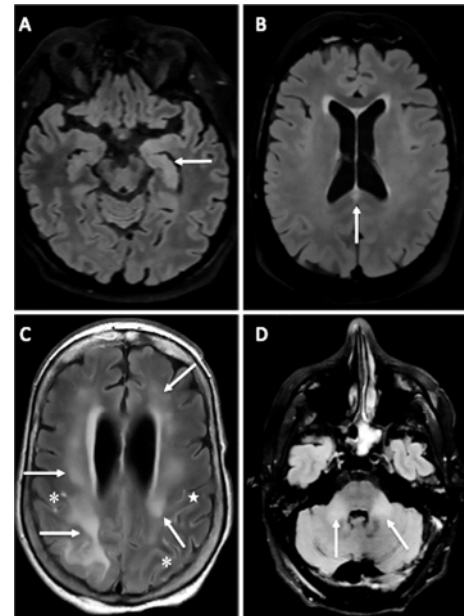


Figure 12. Axial fluid-attenuated inversion recovery (FLAIR) images in four different patients with Coronavirus pneumonia. A, A 58-year-old man with impaired consciousness has FLAIR hyperintensities (arrow) in the left medial temporal lobe. B, A 66-year-old man with impaired consciousness has a FLAIR ovoid hyperintense lesion (arrow) in the central part of the splenium of the corpus callosum. C, A 71-year-old woman with abnormal wakefulness after sedation has extensive and confluent supratentorial white matter FLAIR hyperintensities (arrows) in association with leptomeningeal enhancement (\*). D, A 61-year-old man with confusion has hyperintense lesions (arrows) involving both middle cerebellar peduncles.

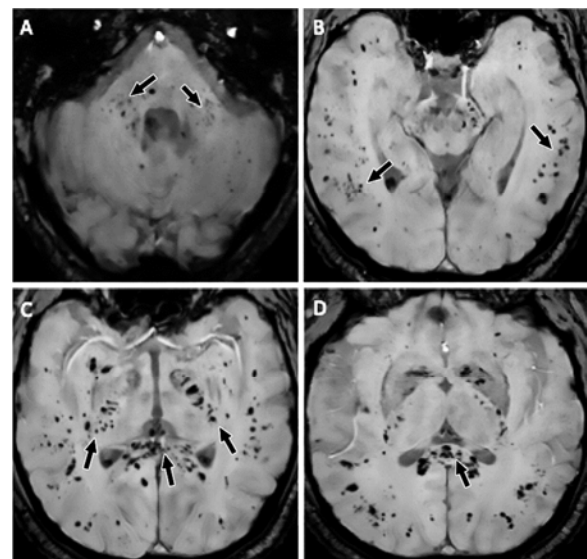
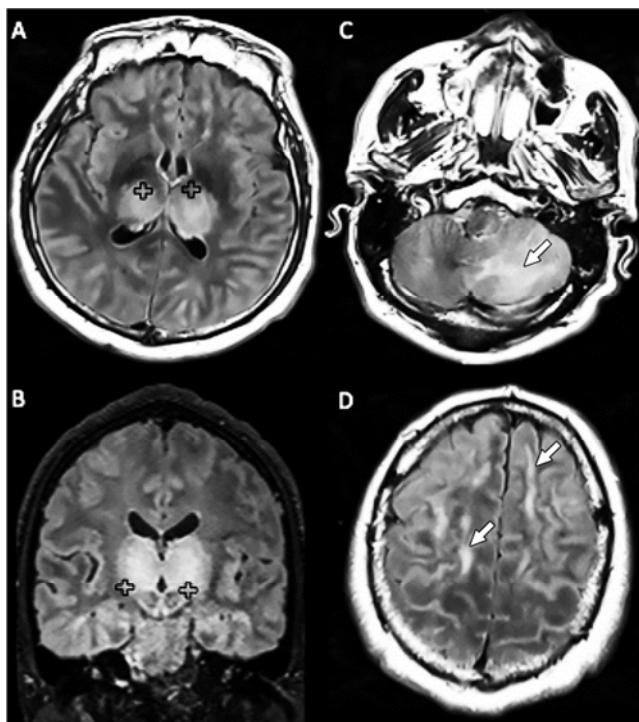


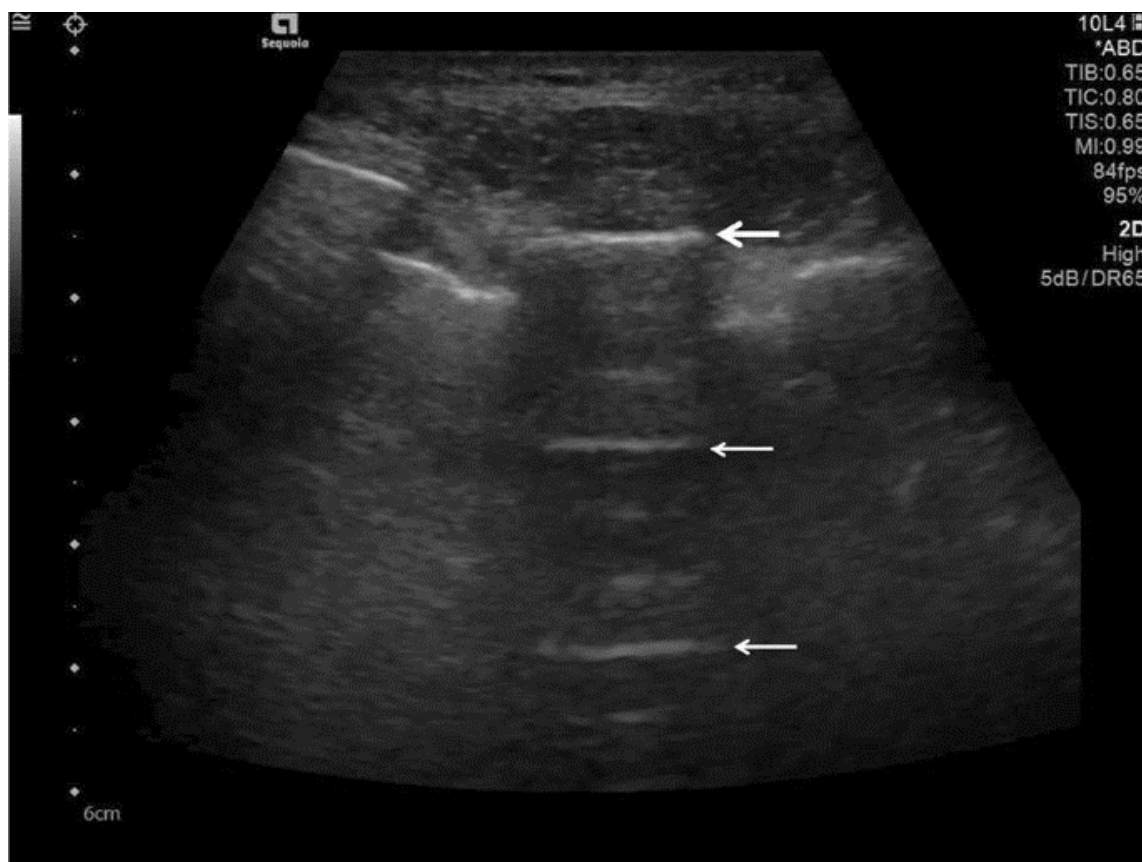
Figure 13. Axial susceptibility-weighted images (SWI) in a 57-year-old man with abnormal wakefulness after sedation represent extensive and isolated white matter microhemorrhages mostly affecting the, A, cerebellar peduncles, B, subcortical white matter, C, internal capsule, and, D, corpus callosum.



**Figure 14.** Images in a 51-year-old man with impaired consciousness and acute necrotizing encephalopathy. A, C, D, Axial fluid-attenuated inversion recovery (FLAIR), and, B, coronal FLAIR images show bilateral FLAIR hyperintensity (+) in, A, B, both thalami associated with involvement of the, C, cerebellar, and, D, cerebral white matter (arrows).

#### 4.4. Cross-Comparison of MRI Through Radiography and CT

Although MRI is not a routine modality for assessing COVID-19 pneumonia disease [14], multiple MRIs can be performed on a patient to complement CT findings in the diagnosis of lesions [95], because it's a radiation-free and non-invasive modality that can be a good alternative for sensitive groups to radiation especially for children and pregnant women [14, 95, 100, 102-104]. However, MRI also has a few disadvantages just like the other modalities such as long scanning time, high cost and less availability than CT [95]. Shortness of breath in the patients who is going through MRI and CT scan may result an increased motion-artifacts in both of the cases [95]. The respiratory navigator used in MRI imaging can cause longer scan time in patients with irregular breathing because of its sensitivity to motion artifact but it could be an advantage because unlike breath-hold CT, even the lesions near to the diaphragm can be seen easily without the need to hold their breath [95]. Recent studies have shown that the virus also affects heart, vessels, liver, kidney and other organs in addition to the lungs [15, 105] because of angiotensin converting enzyme 2 (ACE2) that exists in these organs and it's the key for the virus to enter these cells [15]. High-precision MRI provide aid to detect the virus in various soft organs for example in a study by Inciardi RM et al [106], cardiac MRI showed acute myopericarditis with systolic dysfunction in the patients with COVID-19 disease.



**Figure 15.** Ultrasonography detected A-lines using an abdominal probe. A-lines (white arrows) appears as bright horizontal lines deep to the pleural line (bold white arrow).

## 5. Fundamentals of Lung Ultrasonography Examinations

Thoracic and lung Ultrasonography have improved in importance over the past decade [107] principally in the setting of Point of Care Ultrasonography (POCUS). A lung Ultrasonography was first executed more than half century ago. Excepting echocardiography and obstetrical use, Ultrasonography has mainly been a tool used by radiologists and the lung wasn't considered appropriate for this imaging modality historically [108]. Even so, since 1991, intensivists have been using Ultrasonography in a variety of settings, including in vascular access, to discover free fluid in body cavities and, to a lesser extent, in lung evaluation. Severe dyspnea is a communal offering primary sign in the emergency room and the ICU. The variety of thinkable variance diagnoses is extensive; after history-taking, physical examination and determination of the vital parameters, quick bedside emergency Ultrasonography can be helpful. Focused Pulmonary Ultrasonography is a significant component of emergency Ultrasonography beside dedicated Ultrasonography of the abdomen and heart. While recommendations exist for elective chest Ultrasonography and Point of Care Pulmonary Ultrasonography, emergency pulmonary Ultrasonography has not yet been widely accepted in ordinary practice. In knowledgeable hands, Pulmonary Ultrasonography displays great accurateness in discovery of pleural effusion, pneumothorax, pulmonary venous congestion and consolidation, compared to clinical checkup and CXR [109]. In the analysis of lung pathologies, Ultrasonography artifacts arising from the chest wall and pleural surface can provide valuable data and might correlate with the existing lung pathophysiology. There are two main Ultrasonography artifact patterns: "A-lines" and "B-lines" in rare cases even "C-lines" are visible. A-lines are reverberation artifacts triggered by oscillating tissue with an air interface, causing the Ultrasonography waves to be reflected powerfully and to resonate. Among the probe and lung surface, the Ultrasonography waves bounce back and forth. A-lines are parallel horizontal repetition lines of the pleural surface, appearing deeper on the display screen (Figure 13). The distance from the skin to the pleural surface equals the distance from the pleural line to the first A-line, the first A-line to the second A-line, and so forth because this is a classic reverberation artifact. The A-profile is shaped by intact ("dry") lung parenchyma containing air when it is combined with normal lung sliding. If sliding is absent, it is intensely suggestive of a pneumothorax [110].

## 6. Conclusion

As we discussed in this study, each of the different imaging modalities can contribute to the diagnosis and follow-up of patients of COVID-19 pneumonia. Chest Radiography, despite its low sensitivity, can detect the

disease 2-4 days after the onset of symptoms and has less ionizing radiation than Chest CT. Also, portable Radiography is a good option to reduce the contamination caused by testing different patients and the number of CT patients for emergency situations. In the case of Chest CT, it can produce high resolution images of the lung with its very sensitive and fast diagnosis and inform healthcare crew of the extent of lung involvement in the COVID-19 disease progress. Chest CT has some disadvantages such as high ionization radiation and low specificity in the disease assessment and hard decontamination compared to Radiography. Additionally, ACR agrees with the view that CT shouldn't be used as a tool for initial screening, but rather to monitor the progression of the disease step by step and assess for complications. Fewer articles have been published on the role of MRI in diagnosing COVID-19 disease, but it can be said that since it is highly consistent with CT manifestations in showing the disease and also lacks any harmful radiation to humans, it can be a good alternative for Chest CT with its great sensitivity. However, more comprehensive researches are needed to more accurately compare the characteristics of this modality with CT in the diagnosis of the disease. In spite of different Ultrasonography artifact patterns such as "A-lines" and "B-lines" and even "C-lines" in rare cases, pulmonary Ultrasonography shows brilliant investigative accurateness in finding pleural effusion, pneumothorax, pulmonary venous congestion and consolidation, compared to clinical examination and CXR. In general, because of the possibility of early misdiagnosis, it's best to use both laboratory test methods and imaging modalities for the final evaluation of suspected patients of COVID-19.

## 7. Key Points

- 1) Each of the different imaging modalities can play a useful role in diagnosis and follow-up of patients of COVID-19 pneumonia. Chest Radiography, despite its low sensitivity, it can detect the disease 2-4 days after the onset of symptoms with its easy accessibility and less ionizing radiation than Chest CT. Also, portable Radiography is a good option in the case of discount contamination caused by patients and it frees up the CT resources.
- 2) In the case of Chest CT, it can show the extent of lung involvements of COVID-19 patients step by step with its high resolution and fast diagnosis. Moreover, Chest CT has disadvantages such as high ionization radiation and low specificity in the disease assessment and hard decontamination compared to Radiography. Also, ACR states that CT shouldn't be used for initial screening, but rather to monitor the progression of the disease and judge for complications.
- 3) In a small number of articles that investigated the role of MRI in the diagnosis of the disease, this radiation-free and highly sensitive modality was attentively

correlated with CT manifestations. On the other hand, pulmonary Ultrasonography shows brilliant investigative accurateness in finding pleural effusion, pneumothorax, pulmonary venous congestion and consolidation, compared to clinical examination and CXR. Generally, because of the probability of initial misdiagnosis, it's best to use both laboratory test methods and imaging modalities to obtain final results of suspicious COVID-19 patients.

## Abbreviations

SARS-CoV-2: Severe Acute Respiratory Syndrome Coronavirus 2, WHO: World Health Organization, MERS: Middle East Respiratory Syndrome, COVID-19: Coronavirus Disease 2019, RT-PCR: Reverse Transcription Polymerase Chain Reaction, Chest CT: Chest Computed Tomography, MRI: Magnetic Resonance Imaging, CXR: Chest X-ray, X-ray: X-radiation, ACR: American College of Radiology, HEPA: High-Efficiency Particulate Absorbing, ACE2: Angiotensin-Converting Enzyme 2, ESR: European Society of Radiology, ESTI: European Society of Thoracic Imaging, GGO: Ground-Glass Opacification, CTPA: Computed Tomography Pulmonary Angiogram, ARDS: Acute Respiratory Distress Syndrome, RSNA: Radiological Society of North America, PPE: Personal Protective Equipment, CDC: Center for Disease Control and Prevention, PUI: Person Under Investigation, CT-SS: Computed Tomography Severity Score, FDA: Food and Drug Administration (in United States of America), MR: Magnetic Resonance, PE: Pulmonary Embolism, TDM: Time Division Multiplexing, ALARA: As Low as Reasonably Achievable, FLAIR: Fluid-Attenuated Inversion Recovery, WM: White Matter, SWI: Susceptibility-Weighted Images, POCUS: Point of Care Ultrasonography, ICU: Intensive Care Unit.

## Declarations

### *Ethics Approval and Consent to Participate*

All authors declare approval and consent to participate.

### *Consent for Publication*

All authors declare Accord for publication.

### *Availability of Data, Material*

All data and material are available in manuscript.

### *Competing Interests*

The authors declare that they have no competing interests.

### *Authors' Contributions*

The main idea was from Nadia Tahounneh and all the authors critically revised the manuscript.

## References

- [1] Mossa-Basha M, Meltzer CC, Kim DC, Tuite MJ, Kolli KP, Tan BS. Radiology Department Preparedness for COVID-19: Radiology Scientific Expert Review Panel. *Radiology*. 2020; 296 (2): E106-E12.
- [2] Zu ZY, Jiang MD, Xu PP, Chen W, Ni QQ, Lu GM, et al. Coronavirus Disease 2019 (COVID-19): A Perspective from China. *Radiology*. 2020; 296 (2): E15-E25.
- [3] Liu J, Zheng X, Tong Q, Li W, Wang B, Sutter K, et al. Overlapping and discrete aspects of the pathology and pathogenesis of the emerging human pathogenic Coronaviruses SARS-CoV, MERS-CoV, and 2019-nCoV. *Journal of Medical Virology*. 2020; 92 (5): 491-4.
- [4] He F, Deng Y, Li W. Coronavirus disease 2019: What we know? *Journal of medical virology*. 2020; 92 (7): 719-25.
- [5] Jajodia A, Ebner L, Heidinger B, Chaturvedi A, Prosch H. Imaging in corona virus disease 2019 (COVID-19)—A Scoping review. *European Journal of Radiology Open*. 2020; 7: 100237.
- [6] Wu Z, McGoogan JM. Characteristics of and Important Lessons From the Coronavirus Disease 2019 (COVID-19) Outbreak in China: Summary of a Report of 72 314 Cases From the Chinese Center for Disease Control and Prevention. *JAMA*. 2020; 323 (13): 1239-42.
- [7] Ai T, Yang Z, Hou H, Zhan C, Chen C, Lv W, et al. Correlation of Chest CT and RT-PCR Testing for Coronavirus Disease 2019 (COVID-19) in China: A Report of 1014 Cases. *Radiology*. 2020; 296 (2): E32-E40.
- [8] Yang Y, Yang M, Shen C, Wang F, Yuan J, Li J, et al. Evaluating the accuracy of different respiratory specimens in the laboratory diagnosis and monitoring the viral shedding of 2019-nCoV infections. *medRxiv*. 2020: 2020.02.11.20021493.
- [9] Castillo F, Bazaes D, Huete Á. Radiology in the COVID-19 Pandemic: Current role, recommendations for structuring the radiological report and our Departments experience. *Rev Chil Radiol*. 2020; 26 (3): 88-99.
- [10] WHO. nCoV/Clinical/Radiology\_imaging/2020.1: <https://www.who.int/publications/i/item/use-of-chest-imaging-in-covid-19>; 2019.
- [11] World Health O. Coronavirus disease (COVID-19) outbreak: rights, roles and responsibilities of health workers, including key considerations for occupational safety and health: interim guidance, 19 March 2020. Geneva: World Health Organization; 2020. Contract No.: WHO/2019-nCov/HCW\_advice/2020.2.
- [12] <https://www.iaea.org>. Radiation Protection and Safety in Medical Uses of Ionizing Radiation Specific Safety Guide: <https://www.iaea.org/publications/11102/radiation-protection-and-safety-in-medical-uses-of-ionizing-radiation>; 2020.
- [13] Aljondi R, Alghamdi S. Diagnostic Value of Imaging Modalities for COVID-19: Scoping Review. *J Med Internet Res*. 2020; 22 (8): e19673.
- [14] Fields BKK, Demirjian NL, Dadgar H, Gholamrezanezhad A. Imaging of COVID-19: CT, MRI, and PET. *Semin Nucl Med*. 2020.



- [15] Dong D, Tang Z, Wang S, Hui H, Gong L, Lu Y, et al. The Role of Imaging in the Detection and Management of COVID-19: A Review. *IEEE Reviews in Biomedical Engineering*. 2021; 14: 16-29.
- [16] Liszewski MC, Gorkem S, Sodhi KS, Lee EY. Lung magnetic resonance imaging for pneumonia in children. *Pediatric Radiology*. 2017; 47 (11): 1420-30.
- [17] Jacobi A, Chung M, Bernheim A, Eber C. Portable chest X-ray in Coronavirus disease-19 (COVID-19): A pictorial review. *Clin Imaging*. 2020; 64: 35-42.
- [18] Wong HYF, Lam HYS, Fong AH-T, Leung ST, Chin TW-Y, Lo CSY, et al. Frequency and Distribution of Chest Radiographic Findings in Patients Positive for COVID-19. *Radiology*. 2020; 296 (2): E72-E8.
- [19] Yoon SH, Lee KH, Kim JY, Lee YK, Ko H, Kim KH, et al. Chest radiographic and CT findings of the 2019 novel Coronavirus disease (COVID-19): analysis of nine patients treated in Korea. *Korean journal of radiology*. 2020; 21 (4): 494.
- [20] Manych M. X-ray imaging for COVID-19 patients: <https://www.siemens-healthineers.com/news/mso-x-ray-imaging-for-covid-19.html>; 2020-05-15.
- [21] Rubin GD, Ryerson CJ, Haramati LB, Sverzellati N, Kanne JP, Raoof S, et al. The Role of Chest Imaging in Patient Management During the COVID-19 Pandemic: A Multinational Consensus Statement From the Fleischner Society. *Chest*. 2020; 158 (1): 106-16.
- [22] Oliva D, LFDG. COVID-19 - pneumothorax: <https://radiopaedia.org/cases/covid-19-pneumothorax>; 2020.
- [23] Kong W, Agarwal PP. Chest Imaging Appearance of COVID-19 Infection. *Radiology: Cardiothoracic Imaging*. 2020; 2 (1): e200028.
- [24] Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel Coronavirus pneumonia in Wuhan, China: a descriptive study. *The Lancet*. 2020; 395 (10223): 507-13.
- [25] Huang C., Wang Y., Li X. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet*. 2020; 395: 497-506. doi: 10.1016/S0140-6736(20)30183-5.
- [26] Aydin S, Oz G, Dumanli A, Balci A, Gencer A. A Case of Spontaneous Pneumothorax in Covid-19 Pneumonia. *Journal of Surgery and Research*. 2020; 03.
- [27] Lorente DE. COVID-19 infection - exclusive gastrointestinal symptoms: <https://radiopaedia.org/cases/covid-19-infection-exclusive-gastrointestinal-symptoms>; 2020.
- [28] Julia Tran M, Justin Glavis-Bloom M, Theodore Bryan M, Karen Tran Harding M, Chantal Chahine M, Roozbeh Houshyar M. COVID-19 patient presenting with initial gastrointestinal symptoms: <https://www.eurorad.org/case/16654>; 2020.
- [29] Bickle DI, Bell DDJ, et al. COVID-19: <https://radiopaedia.org/articles/covid-19-4>; 2020.
- [30] Rodrigues JCL, Hare SS, Edey A, Devaraj A, Jacob J, Johnstone A, et al. An update on COVID-19 for the radiologist - A British society of Thoracic Imaging statement. *Clin Radiol*. 2020; 75 (5): 323-5.
- [31] van Doremalen N, Bushmaker T, Morris DH, Holbrook MG, Gamble A, Williamson BN, et al. Aerosol and Surface Stability of SARS-CoV-2 as Compared with SARS-CoV-1. *N Engl J Med*. 2020; 382 (16): 1564-7.
- [32] ACR. ACR Recommendations for the use of Chest Radiography and Computed Tomography (CT) for Suspected COVID-19 Infection: <https://www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Recommendations-for-Chest-Radiography-and-CT-for-Suspected-COVID19-Infection>; 2020.
- [33] ACR. ACR Information on Field Radiology Care During the COVID-19 Pandemic: <https://www.acr.org/Advocacy-and-Economics/Advocacy-News/Advocacy-News-Issues/In-the-April-4-2020-Issue/ACR-Information-on-Field-Radiology-Care-During-the-COVID-19-Pandemic>; 2020.
- [34] Rousan LA, Elobeid E, Karrar M, Khader Y. Chest x-ray findings and temporal lung changes in patients with COVID-19 pneumonia. *BMC Pulmonary Medicine*. 2020; 20 (1): 245.
- [35] Lei Y, Zhang H-W, Yu J, Patlas MN. COVID-19 Infection: Early Lessons. *Canadian Association of Radiologists Journal*. 2020; 71 (3): 251-2.
- [36] Zhang J, Tian S, Lou J, Chen Y. Familial cluster of COVID-19 infection from an asymptomatic. *Critical Care*. 2020; 24 (1): 119.
- [37] Smith DL, Grenier J-P, Batte C, Spieler B. A Characteristic Chest Radiographic Pattern in the Setting of the COVID-19 Pandemic. *Radiology: Cardiothoracic Imaging*. 2020; 2 (5): e200280.
- [38] Revel M-P, Parkar AP, Prosch H, Silva M, Sverzellati N, Gleeson F, et al. COVID-19 patients and the radiology department - advice from the European Society of Radiology (ESR) and the European Society of Thoracic Imaging (ESTI). *European radiology*. 2020; 30 (9): 4903-9.
- [39] Thieba C, Frayne A, Walton M, Mah A, Benischek A, Dewey D, et al. Factors Associated With Successful MRI Scanning in Unsedated Young Children. *Front Pediatr*. 2018; 6: 146.
- [40] Benefits and Risks. FDA. 2017.
- [41] MRI. *Cancer Quest* 2021.
- [42] Itoh S, Ikeda M, Arahata S, et al: Lung cancer screening: Minimum tube current required for helical CT. *Radiology* 215: 175-183, 2000.
- [43] "COVID-19 Updates". Ranzcr.com, [Link]. <https://www.ranzcr.com/our-work/coronavirus> 2020.
- [44] RANZCR. COVID-19 Updates: <https://www.ranzcr.com/our-work/Coronavirus>; 2020.
- [45] Manna S, Wruble J, Maron SZ, Toussie D, Voutsinas N, Finkelstein M, et al. COVID-19: A Multimodality Review of Radiologic Techniques, Clinical Utility, and Imaging Features. *Radiology: Cardiothoracic Imaging*. 2020; 2 (3): e200210.
- [46] Kligerman SJ, Franks TJ, Galvin JR. From the Radiologic Pathology Archives: Organization and Fibrosis as a Response to Lung Injury in Diffuse Alveolar Damage, Organizing Pneumonia, and Acute Fibrinous and Organizing Pneumonia. *RadioGraphics*. 2013; 33 (7): 1951-75.

- [47] Güneyli S, Atçeken Z, Doğan H, Altınmakas E, Atasoy KÇ. Radiological approach to COVID-19 pneumonia with an emphasis on Chest CT. *Diagn Interv Radiol*. 2020; 26 (4): 323-32.
- [48] Long C, Xu H, Shen Q, Zhang X, Fan B, Wang C, et al. Diagnosis of the Coronavirus disease (COVID-19): rRT-PCR or CT? *Eur J Radiol*. 2020; 126: 108961.
- [49] Fang Y, Zhang H, Xie J, Lin M, Ying L, Pang P, et al. Sensitivity of Chest CT for COVID-19: Comparison to RT-PCR. *Radiology*. 2020; 296 (2): E115-E7.
- [50] Wen Z, Chi Y, Zhang L, Liu H, Du K, Li Z, et al. Coronavirus Disease 2019: Initial Detection on Chest CT in a Retrospective Multicenter Study of 103 Chinese Patients. *Radiology: Cardiothoracic Imaging*. 2020; 2 (2): e200092.
- [51] Raptis CA, Hammer MM, Short RG, Shah A, Bhalla S, Bierhals AJ, et al. Chest CT and Coronavirus Disease (COVID-19): A Critical Review of the Literature to Date. *American Journal of Roentgenology*. 2020; 215 (4): 839-42.
- [52] Rizk DO. COVID-19 pneumonia: <https://radiopaedia.org/cases/covid-19-pneumonia-139?lang=us>; 2020.
- [53] Samir DA. Acute appendicitis and COVID-19 pneumonia: <https://radiopaedia.org/cases/acute-appendicitis-and-covid-19-pneumonia?lang=us>; 2020.
- [54] Simpson S, Kay FU, Abbara S, Bhalla S, Chung JH, Chung M, et al. Radiological Society of North America Expert Consensus Document on Reporting Chest CT Findings Related to COVID-19: Endorsed by the Society of Thoracic Radiology, the American College of Radiology, and RSNA. *Radiology: Cardiothoracic Imaging*. 2020; 2 (2): e200152.
- [55] Bai HX, Hsieh B, Xiong Z, Halsey K, Choi JW, Tran TML, et al. Performance of Radiologists in Differentiating COVID-19 from Non-COVID-19 Viral Pneumonia at Chest CT. *Radiology*. 2020; 296 (2): E46-E54.
- [56] Hani C, Trieu NH, Saab I, Dangeard S, Bennani S, Chassagnon G, et al. COVID-19 pneumonia: A review of typical CT findings and differential diagnosis. *Diagnostic and Interventional Imaging*. 2020; 101 (5): 263-8.
- [57] Salehi S, Abedi A, Balakrishnan S, Gholamrezanezhad A. Coronavirus Disease 2019 (COVID-19): A Systematic Review of Imaging Findings in 919 Patients. *American Journal of Roentgenology*. 2020; 215 (1): 87-93.
- [58] Li K, Fang Y, Li W, Pan C, Qin P, Zhong Y, et al. CT image visual quantitative evaluation and clinical classification of Coronavirus disease (COVID-19). *European Radiology*. 2020; 30 (8): 4397-16.
- [59] Pan F, Ye T, Sun P, Gui S, Liang B, Li L, et al. Time Course of Lung Changes at Chest CT during Recovery from Coronavirus Disease 2019 (COVID-19). *Radiology*. 2020; 295 (3): 715-21.
- [60] Z Na, Z Ding, W Wen, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China *Lancet*. 395 (2020), pp. 497-605.
- [61] Li K, Wu J, Wu F, Guo D, Chen L, Fang Z, et al. The Clinical and Chest CT Features Associated With Severe and Critical COVID-19 Pneumonia. *Invest Radiol*. 2020; 55 (6): 327-31.
- [62] Hamer OW, Salzberger B, Gebauer J, Stroszczynski C, Pfeifer M. CT morphology of COVID-19: Case report and review of literature. *Rofo*. 2020; 192 (5): 386-92.
- [63] Chung M, Bernheim A, Mei X, Zhang N, Huang M, Zeng X, et al. CT Imaging Features of 2019 Novel Coronavirus (2019-nCoV). *Radiology*. 2020; 295 (1): 202-7.
- [64] Bernheim A, Mei X, Huang M, Yang Y, Fayad ZA, Zhang N, et al. Chest CT Findings in Coronavirus Disease-19 (COVID-19): Relationship to Duration of Infection. *Radiology*. 2020; 295 (3): 200463.
- [65] Asefi H, Safaie A. The role of Chest CT scan in diagnosis of COVID-19. *Frontiers in Emergency Medicine*. 2020; 4 (2s): e64-e.
- [66] Kord A, Rabiee B, Wang S, Rostami S, Gaba RC, Xie KL. A Concise Review and Required Precautions for COVID-19 Outbreak in Diagnostic and Interventional Radiology. *Radiology Research and Practice*. 2020; 2020: 7159091.
- [67] Wang K, Kang S, Tian R, Zhang X, Zhang X, Wang Y. Imaging manifestations and diagnostic value of Chest CT of Coronavirus disease 2019 (COVID-19) in the Xiaogan area. *Clin Radiol*. 2020; 75 (5): 341-7.
- [68] Pan Y, Guan H, Zhou S, Wang Y, Li Q, Zhu T, et al. Initial CT findings and temporal changes in patients with the novel Coronavirus pneumonia (2019-nCoV): a study of 63 patients in Wuhan, China. *European Radiology*. 2020; 30 (6): 3306-9.
- [69] Zhao W, Zhong Z, Xie X, Yu Q, Liu J. CT Scans of Patients with 2019 Novel Coronavirus (COVID-19) Pneumonia. *Theranostics*. 2020; 10 (10): 4606-13.
- [70] Shi H, Han X, Jiang N, Cao Y, Alwalid O, Gu J, et al. Radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China: a descriptive study. *The Lancet Infectious Diseases*. 2020; 20 (4): 425-34.
- [71] Song F, Shi N, Shan F, Zhang Z, Shen J, Lu H, et al. Emerging 2019 Novel Coronavirus (2019-nCoV) Pneumonia. *Radiology*. 2020; 295 (1): 210-7.
- [72] Li Y, Xia L. Coronavirus Disease 2019 (COVID-19): Role of Chest CT in Diagnosis and Management. *AJR Am J Roentgenol*. 2020; 214 (6): 1280-6.
- [73] Kanne JP, Little BP, Chung JH, Elicker BM, Ketani LH. Essentials for Radiologists on COVID-19: An Update—Radiology Scientific Expert Panel. *Radiology*. 2020; 296 (2): E113-E4.
- [74] Francone M, Iafrate F, Masci GM, Coco S, Cilia F, Manganaro L, et al. Chest CT score in COVID-19 patients: correlation with disease severity and short-term prognosis. *European radiology*. 2020; 30 (12): 6808-17.
- [75] Yang R, Li X, Liu H, Zhen Y, Zhang X, Xiong Q, et al. Chest CT Severity Score: An Imaging Tool for Assessing Severe COVID-19. *Radiol Cardiothorac Imaging*. 2020; 2 (2): e200047.
- [76] Hafez MAF. The mean severity score and its correlation with common computed tomography chest manifestations in Egyptian patients with COVID-2019 pneumonia. *The Egyptian Journal of Radiology and Nuclear Medicine*. 2020; 51 (1): 254.

- [77] Zhou S, Wang Y, Zhu T, Xia L. CT Features of Coronavirus Disease 2019 (COVID-19) Pneumonia in 62 Patients in Wuhan, China. *American Journal of Roentgenology*. 2020; 214: 1-8.
- [78] Zhao W, Zhong Z, Xie X, Yu Q, Liu J. Relation Between Chest CT Findings and Clinical Conditions of Coronavirus Disease (COVID-19) Pneumonia: A Multicenter Study. *American Journal of Roentgenology*. 2020; 214 (5): 1072-7.
- [79] Araujo-Filho JdAB, Sawamura MVY, Costa AN, Cerri GG, Nomura CH. COVID-19 pneumonia: what is the role of imaging in diagnosis? *Jornal Brasileiro de Pneumologia*. 2020; 46.
- [80] Hao W, Li M. Clinical diagnostic value of CT imaging in COVID-19 with multiple negative RT-PCR testing. *Travel Med Infect Dis*. 2020; 34: 101627.
- [81] Chua F, Armstrong-James D, Desai SR, Barnett J, Kouranos V, Kon OM, et al. The role of CT in case ascertainment and management of COVID-19 pneumonia in the UK: insights from high-incidence regions. *Lancet Respir Med*. 2020; 8 (5): 438-40.
- [82] Yang W, Yan F. Patients with RT-PCR-confirmed COVID-19 and Normal Chest CT. *Radiology*. 2020; 295 (2): E3.
- [83] Wang YXJ, Liu W-H, Yang M, Chen W. The role of CT for Covid-19 patient's management remains poorly defined. *Ann Transl Med*. 2020; 8 (4): 145.
- [84] Hall E. Lessons we have learned from our children: Cancer risk from diagnostic radiology. *Pediatric radiology*. 2002; 32: 700-6.
- [85] Mathews JD, Forsythe AV, Brady Z, Butler MW, Goergen SK, Byrnes GB, et al. Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. *Bmj*. 2013; 346: f2360.
- [86] Holshue ML, DeBolt C, Lindquist S, Lofy KH, Wiesman J, Bruce H, et al. First Case of 2019 Novel Coronavirus in the United States. *New England Journal of Medicine*. 2020; 382 (10): 929-36.
- [87] Jin S, Zhang B, Zhang L, Li S, Li S, Li P. Lung nodules assessment in ultra-low-dose CT with iterative reconstruction compared to conventional dose CT. *Quantitative Imaging in Medicine and Surgery*. 2018; 8 (5): 480-90.
- [88] Kalra MK, Maher MM, Rizzo S, Kanarek D, Shepard J-AO. Radiation exposure from Chest CT: issues and strategies. *J Korean Med Sci*. 2004; 19 (2): 159-66.
- [89] School HM. Radiation risk from medical imaging: <https://www.health.harvard.edu/cancer/radiation-risk-from-medical-imaging>; 2020.
- [90] FDA. What are the Radiation Risks from CT?: <https://www.fda.gov/radiation-emitting-products/medical-x-ray-imaging/what-are-radiation-risks-ct>; 12/05/2017.
- [91] ACR. ACR Guidance on COVID-19 and MR Use: <https://www.acr.org/Clinical-Resources/Radiology-Safety/MR-Safety/COVID-19-and-MR-Use>; 2020.
- [92] FDA. Wear Face Masks with No Metal During MRI Exams: FDA Safety Communication: <https://www.fda.gov/medical-devices/safety-communications/wear-face-masks-no-metal-during-mri-exams-fda-safety-communication>; 01/07/2021.
- [93] Kooraki S, Hosseiny M, Raman SS, Myers L, Gholamrezaezhad A. Coronavirus Disease 2019 (COVID-19) Precautions: What the MRI Suite Should Know. *J Am Coll Radiol*. 2020; 17 (7): 830.
- [94] Adhikari U, Chabrelie A, Weir M, Boehnke K, McKenzie E, Ikner L, et al. A Case Study Evaluating the Risk of Infection from Middle Eastern Respiratory Syndrome Coronavirus (MERS-CoV) in a Hospital Setting Through Bioaerosols. *Risk Anal*. 2019; 39 (12): 2608-24.
- [95] Ates OF, Taydas O, Dheir H. Thorax Magnetic Resonance Imaging Findings in Patients with Coronavirus Disease (COVID-19). *Acad Radiol*. 2020; 27 (10): 1373-8.
- [96] Barentsz J, Takahashi S, Oyen W, Mus R, De Mulder P, Reznik R, et al. Commonly used imaging techniques for diagnosis and staging. *J Clin Oncol*. 2006; 24 (20): 3234-44.
- [97] Meier-Schroers M, Kukuk G, Homsy R, Skowasch D, Schild HH, Thomas D. MRI of the lung using the PROPELLER technique: Artifact reduction, better image quality and improved nodule detection. *Eur J Radiol*. 2016; 85 (4): 707-13.
- [98] Galougahi MK, Ghorbani J, Bakhshayeshkaram M, Naeini AS, Haseli S. Olfactory Bulb Magnetic Resonance Imaging in SARS-CoV-2-Induced Anosmia: The First Report. *Acad Radiol*. 2020; 27 (6): 892-3.
- [99] Mossa-Basha M, Medverd J, Linnau KF, Lynch JB, Wener MH, Kicska G, et al. Policies and Guidelines for COVID-19 Preparedness: Experiences from the University of Washington. *Radiology*. 2020; 296 (2): E26-E31.
- [100] Torkian P, Rajebi H, Zamani T, Ramezani N, Kiani P, Akhlaghpour S. Magnetic resonance imaging features of Coronavirus disease 2019 (COVID-19) pneumonia: The first preliminary case series. *Clin Imaging*. 2021; 69: 261-5.
- [101] Gulko E, Oleks ML, Gomes W, Ali S, Mehta H, Overby P, et al. MRI Brain Findings in 126 Patients with COVID-19: Initial Observations from a Descriptive Literature Review. *American Journal of Neuroradiology*. 2020; 41 (12): 2199.
- [102] Yang S, Zhang Y, Shen J, Dai Y, Ling Y, Lu H, et al. Clinical Potential of UTE-MRI for Assessing COVID-19: Patient- and Lesion-Based Comparative Analysis. *Journal of Magnetic Resonance Imaging*. 2020; 52 (2): 397-406.
- [103] Syrjala H, Broas M, Ohtonen P, Jartti A, Pääkkö E. Chest magnetic resonance imaging for pneumonia diagnosis in outpatients with lower respiratory tract infection. *European Respiratory Journal*. 2017; 49 (1): 1601303.
- [104] Caro-Dominguez P, Shelmerdine SC, Toso S, Secinaro A, Toma P, Damasio MB, et al. Thoracic imaging of Coronavirus disease 2019 (COVID-19) in children: a series of 91 cases. *Pediatric Radiology*. 2020; 50 (10): 1354-68.
- [105] Yao XH, Li TY, He ZC, Ping YF, Liu HW, Yu SC, et al. [A pathological report of three COVID-19 cases by minimal invasive autopsies]. *Zhonghua Bing Li Xue Za Zhi*. 2020; 49 (5): 411-7.
- [106] Inciardi RM, Lupi L, Zacccone G, Italia L, Raffo M, Tomasoni D, et al. Cardiac Involvement in a Patient With Coronavirus Disease 2019 (COVID-19). *JAMA Cardiology*. 2020; 5 (7): 819-24.

- [107] Gargani L, Pang PS, Frassi F, Miglioranza MH, Dini FL, Landi P, et al. Persistent pulmonary congestion before discharge predicts rehospitalization in heart failure: a lung Ultrasound study. *Cardiovasc Ultrasound*. 2015; 13: 40.
- [108] Lichtenstein DA. BLUE-Protocol and FALLS-Protocol: Two Applications of Lung Ultrasound in the Critically Ill. *Chest*. 2015; 147 (6): 1659-70.
- [109] Lichtenstein DA. Lung Ultrasound in the critically ill. *Ann Intensive Care*. 2014; 4 (1): 1.
- [110] Efremov SM, Kuzkov VV, Fot EV, Kirov MY, Ponomarev DN, Lakhin RE, et al. Lung Ultrasonography and cardiac surgery: a narrative review. *Journal of cardiothoracic and vascular anesthesia*. 2020; 34 (11): 3113-24.
- [111] Kremer, S., et al., Brain MRI Findings in Severe COVID-19: A Retrospective Observational Study. *Radiology*, 2020. 297 (2): p. E242-E251.