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Cross Sectional HRCT Pulmonary Findings in Patients with COVID-19

Dennis Alfred Davison

M. D. Radiology Resident, Diagnostic Radiology, GR. T. Popa University of Medicine, Iasi, Romania
Corresponding Author Email: *dennis_davison82[at]yahoo.com*

Abstract: ***Objective**: HRCT chest provides an effective modality to evaluate patients with suspected coronavirus disease 2019 (COVID-19). While radiologists get familiar with the imaging appearance of this disease to identify its presence, confronting this virus during imaging investigations is challenging in the setting of other pulmonary pathologies and the purpose of this study after performing real-time reverse transcription polymerase chain reaction (RT-PCR) testing, is to review and analyze the CT chest manifestations pertaining to COVID-19 in a cohort of 12patients who presented with general viral flu clinical symptoms of fever, chest pain, severe cough and headache with body tenderness, sore throat, and lethargy. **Method and Materials**: This retrospective study was conducted during the period from Oct 2020 to Nov 2020. The examined cross sectional imaging studies involved two institutions, an imaging laboratory clinic and a tertiary academic hospital. Salient imaging findings and medical history were reviewed of patients who underwent RT-PCR testing and resulted positive during their visit to the Emergency (ER) and hospital admission. **Key Results**: Based on the diagnostic specificity and sensitivity of CT scanning in a total of 12 COVID-19 RT-PCR positive patients of the ages ranging from 22-80 years, mean age ± standard deviation, 50 years ± 18 and the following features were evident: a) 3-4 (33%) had confluent ground-glass opacities (GGO), 7-8 (75%) had GGO opacities with a patchy morphology, 7-8 (66%) had a peripheral distribution of disease, 3-4 (29%) had consolidation with ground-glass opacities, 11 (91%) had inter-septal thickening and 4-5 (41%) had crazy-paving pattern. One patient demonstrated consolidation without ground-glass opacification and no patients had cavitation in the lung, discrete pulmonary nodules, pleural effusions but signet ring sign, sub-pleural banding, pleural thickening, and fibrosis were present in 2-3 (10%) patients. b) Pleural effusions, solitary nodule, nodal calcifications, abscesses, lung cavitation, pnuematoceles, reticulation or ILD features were absent. c) Associated findings such as air-bronchgram, bronchial wall thickening/dilatation, sub-pleural bandings, reverse halo sign, pleural thickening (basal) were present in <5 (10%) patients. **Conclusion**: COVID-19 manifests with a spectrum of characteristic chest CT imaging features, which are helpful to the radiologist for co-relation and early diagnostic detection of this emerging global health emergency.*

Keywords: COVID-19, HRCT Features, Severiy Score

1. Introduction

Coronavirus disease 2019 (COVID-19) is caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), a newly emergent coronavirus, that was first recognized in Wuhan, Hubei province, China, in December 2019. SARS-CoV-2 is a positive-sense single-stranded RNA virus that is contagious in humans. It is the successor to SARS-CoV-1, the strain that caused the 2002–2004 SARS outbreak [**1**]. Spread rapidly around the world and causing a global pandemic, as of June 8, 2021, a total of 173, 331, 478 confirmed cases of COVID-19 including 3, 735, 571 deaths, reported to World Health Organization (WHO). As of 7 June 2021, a total of 2, 092, 863, 229 vaccine doses have been administered [**2**].

The diagnosis of Pneumonia, a major clinical manifestation in COVID-19 was based on clinical characteristics chest imaging, and the ruling out of common bacterial and viral pathogens that cause pneumonia **[3].** However, multi-organ dysfunctions have been reported at the later stages of the disease. Additionally, the spectrum of clinical manifestations is vast, ranging from asymptomatic/mild disturbances to critical status. Thus, early detection and isolation are of paramount importance in tackling the spreading of this contagious illness to the community for which lung computed tomography (CT) imaging provides a useful tool to evaluate this viral pneumonia [**4**]. In the intermediate to advanced stages of the disease, chest radiographs may show progression of features of acute respiratory distress syndrome (ARDS). Furthermore, CT findings have proven to be diagnostic in a number of cases with an initial false-negative reverse transcription polymerase chain reaction (RT-PCR) screening test [**5, 6**].

With growing global concerns about the COVID-19 outbreak, a thorough understanding of the diagnostic imaging hallmarks, atypical features, and evolution of chest imaging findings is essential for effective patient management and treatment. Therefore, this comprehensive literature review has been prepared expressing a compiled systematic review of 12 COVID-19 patients to identify their CT characteristics of this life-threatening and rapidly spreading viral pneumonia, summarizing key imaging findings in different stages of the disease, and defining the evolution of CT findings associated with disease progression or clinical improvement.

2. Method and Materials

From February 19, 2021, to March 13, 2021, a total of 12 patients with COVID-19 underwent chest CT at two medical imaging institutions. All patients had findings positive for COVID-19 via quantitative real-time reverse transcription–polymerase chain reaction (RT-PCR) testing of respiratory secretions obtained by use of a nasopharyngeal swab. At a private COVID-19 scanning clinic, the imaging equipment used for four of these patients in this study was a 96 slice CT scanner (Siemens Somatom Dual Force) with a slice thickness of 1mm, tube voltage of 120 kVp, tube current modulation of 350–440 mA, and spiral pitch factor of 1.4. The remaining of the eight patients, in a general hospital setting underwent imaging performed using a Revolution ACT CT scanner (GE Healthcare) and a slice thickness of 5 mm, tube voltage of 120 kVp, tube current modulation of 41 mA, and spiral pitch factor of 1.8.

Scans performed in the supine position were acquired in end-inspiration for patients who were able to comply with breathing instructions. No IV or oral contrast medium was administered. Dicom images reviewed on a PACS workstation were interpreted from both mediastinal and lung windows in the axial plane. Patient age and clinical presentation given in the tables, which included headache, fever, cough, diarrhea, nausea, dyspnea, sore throat, and lethargy were obtained from the medical archives of the respective imaging institutions.

Table 1: Symptoms at Hospital Admission
Clinical Symptoms in COVID- 19

Sr. No	Symptoms	No. of Patients
1	Fever	12
2	Dry Cough	12
3	Headache	9
4	Muscle Ache	10
5	Nausea	7
6	Diarrhea	2
7	Dyspnea	4
8	Sore Throat	10
9	Chest Pains	2

The potential value of CT is that it is widely available and fast. RT-PCR, on the other hand, still is not readily available because of a lack of testing kits and reagents, and its turnaround times are variable, ranging from hours to days.

Typical CT characteristics of all the 12 COVID-19 positive patients were patchy or confluent ground-glass opacities (GGO), GGOs superimposed on interlobular septal thickening (i.e., crazy paving pattern), surrounding ring of consolidation (i.e., a reverse halo sign), and central consolidation (i.e., a halo sign), sub-pleural banding and air bronchograms. Associated features were linear atelectasis or fibrosis. The percentage of involvement is classified according to the grading system by Chung et al. Each of the five lung lobes was assessed for degree of involvement, which was classified as none (0%), minimal (1–25%), mild (26–50%), moderate (51–75%), or severe (76–100%) **[7, 8].**

CT Severity Score (Total Score 25) [21]

TWO LUNGS: Right lung and Left lung.

Right lung is divided into three lobes: Right Upper Lobe, Right Middle Lobe and Right Lower Lobe.

Left lung is divided into two lobes: Left Upper Lobe and Left Lower Lobe.
Each lobe is given the score of 1 to 5 based on the amount of lung volume involvement.

Scoring system (SINGLE LOBE):

5% INFECTED: SCORE 1
5%-25% INFECTED: SCORE 2
25%-50% INFECTED: SCORE 3
50%-75% INFECTED: SCORE 4
75%-100% INFECTED: SCORE 5

- Score calculation is done based on each lobe involvement
- Each lobe has a maximum score of 5. And so all lobes have a total score of 25.

For example score 5 means that lobe has more than 75% lung volume affected by COVID-19 or involvement.
Mild involvement= 1-8 out of 25
Moderate involvement= 9-15 out of 25
Severe involvement= 15-25 out of 25

Imaging Review

All the CT scans were fully reviewed by a chief consultant radiologist with 15 years of experience and a respiratory medicine specialist. After co-relating each patient’s clinical aspects with their image presentation and ample of discussion, both reviewers agreed to the total severity CT scores and stage findings without any discrepancies. The pulmonary findings were discussed according to lobar involvement (with findings considered multi-lobar if they involved two or more lobes), location (peripheral, central, or mixed), distribution (mid-upper, mid-lower and mixed), attenuation (with findings defined as mass like ground-glass opacity [if ≥3 cm], solid nodule [if < 3 cm], consolidation and other findings like interstitial thickening or fibrosis.

3. Results

Age of the Patients: **22, 25, 39, 41**, **42, 46, 50, 54, 60, 70, 71**, **80.**

All 12 chest HRCT reports and findings raised concern for the confirmatory diagnosis of COVID-19, co-relating with their positive RT-PCR test results and clinical presentations. The reported clinical indications included inspiratory chest pain, fever, cough, headache, body ache, nausea and diarrhea. The mean time from clinical symptom onset to corona disease image findings in the chest HRCT was 6 to 7 days.

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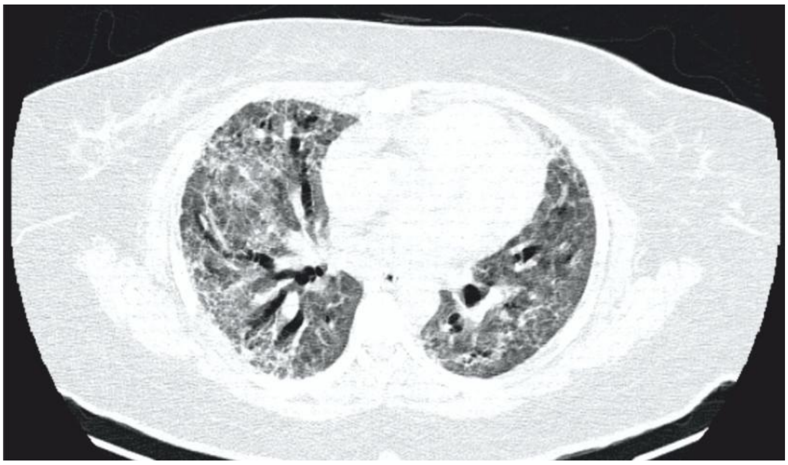

Figure 1: An 80 year old patient with all 5 lobes affected and the highest severity score

The Axial CT shows consolidative changes with diffuse bilateral ground glass appearance superimposed with interlobular septal thickening and sub-pleural banding.

Of the 12 initial chest CT scans, 3-4 (33%) had confluent ground-glass opacities (GGO), 7-8 (75%) had GGO opacities with a patchy morphology, 7-8 (66%) had a peripheral distribution of disease, 3-4 (29%) had consolidation with ground-glass opacities, 11 (91%) had inter-septal thickening and 4-5 (41%) had crazy-paving pattern. None of the patients demonstrated consolidation without ground-glass opacification and no patients had cavitation in the lung, discrete pulmonary nodules, pleural effusions but signet ring sign, sub-pleural banding, pleural thickening, and fibrosis were present in 2-3 (10%) patients.

Table 2: Imaging Features on Chest CT Images of Patients with Coronavirus Disease

CT FEATURES		
Axial distribution of opacification	Central Peripheral mixed	0 7 5
Cranio-caudal distribution	Middle upper Middle lower Mixed	0 3 9
Number of opacities	Single Multiple	2 10
Attention of opacities	FFOs Consolidation Mixed	7 1 4
Crazy Paving Patten	Present Absent	5 7
Reversed halo sign	Present Absent	1 11
Air Broncho gram sign	Present Absent	3 9
Tree in bud pattern	Present Absent	3 9
Signet sign	Present Absent	2 10
Lobar involvement	RUL RML RLL LUL LLL	4 6 11 9 11

Table 3: Characteristics of Twelve Patients with CT Findings Positive for Coronavirus Disease

Patients N=12	Age	(TSS) CT Severity Score	STAGE	TOTAL % OF LUNG INVOLVEMENT	LOBAR DISTRIBUTION
1	22	3/25	Ultra Early	5-10% (minimal)	TRI-LOBAR (Bilateral lungs)
2	25	5/25	Early	5-10% (minimal)	Multi – lobar (Bilateral lung)
3	39	14/25	Dissipation/Absorption	30-35% (mild)	Multi-lobar (bilateral lung)
4	41	9/25	Consolidation	35-40% (mild)	Tri-LOBAR (bilateral lung)
5	42	9/25	Rapid Progressive	50% (Moderate)	Bi-lobar (Unilateral lung)
6	46	6/25	Consolidation	25-30% (mild)	Tri-LOBAR (bilateral lung)
7	50	6/25	Early	10-15% (Minimal)	Tri-LOBAR (bilateral lung)
8	54	10/25	Rapid Progressive	50-60% (moderate)	Multi-lobar (Bilateral lungs)

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9	60	9/25	Consolidation	45-55% (moderate)	Multi-lobar (Bilateral lungs)
10	70	5/25	Early	10-20% (minimal)	Bi-lobar (Bilateral lung)
11	71	10/25	Early	30-40 % (mild)	Multi-lobar (Bilateral lungs)
12	80	23/25	Peak	80-90-% (severe)	Multi-lobar (Bilateral lungs)

Lobar Distribution

Of the 12 patients, all had at least one lobe affected, one patient had one affected lobe, two patients had two affected lobes, four patients had three affected lobes, four patients had four affected lobes, and the patient who did not survive had all five lobes affected with also the highest lung severity score. The right upper lobe was involved in 4 of the 12 patients at initial CT (33 %), the right middle lobe was involved in 6 (50%), the right lower lobe was involved in 11 (91%), the left upper lobe was involved in 9 (75%), and the left lower lobe was involved in 11 (91%). All 12 patients had lung opacities, eleven had bilateral disease and one had unilateral disease with right lung involvement only. The total lung severity score ranged from a minimum of 3 to a maximum of 23, with a mean score of 9.

4. Discussion

When routinely used for the detection of COVID-19, CT has typically been used along with RT-PCR testing. This dual testing approach along with the clinical indications guarantees optimal sensitivity while retaining the high specificity of RT-PCR as a reference standard and it is an essential component of immediate control and successful diagnosis of this viral outbreak. However, to determine whether the current role of CT in the screening, or combined screening and diagnosis of COVID-19 can function potentially, a thorough understanding is imperative on its sensitivity and specificity towards the diagnosis of COVID-19.

Sensitivity of CT in Detecting Coronavirus Disease

Similar to many other studies in clinical scenarios involving a viral contagious disease, the sensitivity of a diagnostic test in this cohort study is vital as well because misdiagnosis of even a single patient can result in large infectious outbreaks among current and future contacts.

The first study to report the sensitivity of CT in detecting COVID-19 pneumonia was a study by Fang et al. that included 51 patients who were ultimately proven to have positive RT-PCR tests and had CT scans obtained at various time points during the course of their disease. Fang et al. and colleagues retrospectively determined that 50 of the 51 patients (98%) had abnormal findings on baseline CT scans, whereas only 36 of the 51 patients (71%) had positive initial RT-PCR tests. The authors concluded that the "results support the use of chest CT for screening for COVID-19 for patients with clinical and epidemiologic features compatible with COVID-19 infection particularly when RT-PCR testing is negative. Although speculative opinions state that patient selection in that study was biased toward individuals with more severe disease presentation as a cohort with more severe symptoms would be different from a cohort without symptoms (i.e., a cohort typically used for a screening examination), or a cohort with risk factors or generalized symptoms worrisome for COVID-19 [**9**]. If the balance of patient severity conditions is met inappropriately in a cohort study as such, specificity is compromised and sensitivity is overestimated.

Under the background of shortage of RT-PCR assay, chest CT played an important role in early detection of COVID-19 especially in the initial and peak periods, despite this measure are taken in addition to environmental cleaning and decontamination of rooms occupied by a patient with suspected or known COVID-19 infection by thorough cleaning of surfaces by someone wearing proper protective equipment, air-flow within fixed CT scanner rooms should be considered before imaging the next patient. Ventilation is an important consideration for the control of airborne transmission in health care facilities. Depending on the air exchange rates, rooms may need to be unavailable for approximately 1 hour after imaging infected patients; air circulation rooms can be tested [**10**]. Chest CT had higher sensitivity for diagnosis of COVID-19 as compared with initial reverse-transcription polymerase chain reaction (RT-PCR) from swab samples in the epidemic area of China. A study by Ai et al. which presented a larger cohort of 1014 patients and reported a 97% sensitivity of CT in diagnosing COVID-19, had limitations similar to those in the study by Fang et al. The patient population in the study by Ai and colleagues was not clearly defined, but we inferred that the cohort included hospitalized patients who, compared with outpatients, are more likely to have abnormal CT findings [**11**].

Both Fang et al. [**9**] and Ai et al. [**11**] also attempted to compare the sensitivity of CT to the sensitivity of RT-PCR in their cohorts. Fang and colleagues reported a time-to-positivity comparison and showed that of their 51 patients, 36 had initial positive RT-PCR findings, whereas 50 had initial positive CT findings; all 51 patients were reported to have positive RT-PCR test findings later in the course of the disease. The imaging examples provided by the authors showed focal ground-glass opacities that could be seen in many other diseases [**9**].

Specificity of CT in Detecting Coronavirus Disease

In addition to early detection, with the increase of experienced image reading skills of radiologists, more and more specific features have been found to distinguish COVID-19 from other pneumonias, such as multifocal or bilateral involvement as well as helping in the management of COVID-19 that depends on the severity of the disease which is also positively related to the individual's chest CT findings. In the case of the patients of this cohort study, they specifically presented with bilateral GGOs and bilateral multiple lobular, sub-segmental peak consolidations with the usage of chest CT to monitor COVID-19 resolution or progression.

The typical chest CT findings of COVID-19 included GGOs, consolidations, and interlobular thickening, which were usually multifocal and involved bilateral lungs, which

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was consistent with the results according to a study from Salehi. S et al **[12].** In mild patients or early period of COVID-19, chest CT could be negative or pure GGO lesions. The CT imaging features might overlap between COVID-19 and other viral pneumonias, which could reduce the specificity of chest COVID-19. Due to the low specificity of chest CT which might overwhelm available recourses, especially during an influenza epidemic, the American College of Radiology discourages systemic use for diagnosing COVID-19 **[13]**.

Nevertheless, with further investigation and more experienced radiologist, more and more features have been found to be helpful in distinguishing COVID-19 from other pneumonias, such as multifocal or bilateral involvement. So, the specificity of chest CT might improve in the future. In addition, considering the rapidly spreading epidemic of COVID-19, it was a priority to identify any suspicious case in order to isolate the patients and avoid cross infection. Therefore, in the context of emergency disease control, sensitivity was more important than specificity [**14].**

CT Findings According to the Stage of the Disease

In a study by Jin et al. described the characteristic CT findings of COVID-19 in five temporal stages as ultra-early, early, rapid progression, consolidation, and dissipation stages **[15]:**

Figure 2: The ultra-early stage (22 years old): This stage usually refers to the stage of patients without clinical manifestation, negative laboratory test but positive RT-PCR throat swab within 1–2 weeks after being exposed to a virus-contaminated environment (history of contact with a patient or patient-related family members, unit, or medical staff in a cluster environment). The main imaging manifestations are single, double or scattered focal ground-glass opacity, located in central lobule surrounded by patchy ground-glass opacities.

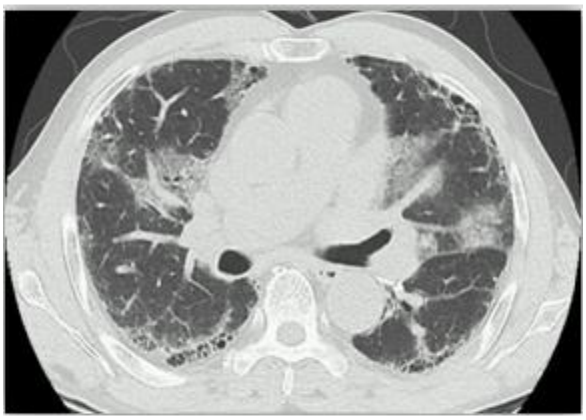

Figure 3: The early stage (71 years old): This stage refers to the period of 1–3daysafter clinical manifestations (fever, cough, dry coughed.). The pathological process during this stage is dilatation and congestion of alveolar septal capillary, exudation of fluid in alveolar cavity and interlobular interstitial edema. It showed that single or multiple scattered patchy or confluent ground-glass opacities, separated by honey-combing or grid-like thickened of interlobular septa.

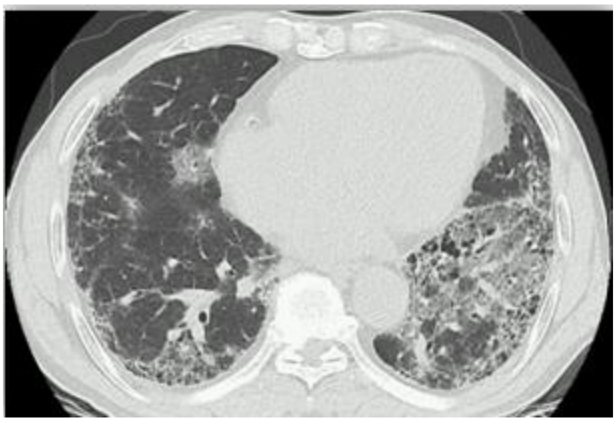

Figure 4: The rapid progression stage (54 years old): This stage refers to the period about 3–7 days after clinical manifestations started, the pathological features in this stage are the accumulation of a large number of cell-rich exudates in the alveolar cavity, vascular expansion and exudation in the interstitium, both of which lead to further aggravation of alveolar and Interstitial edema. The fibrous exudation connects each alveolus through the inter-alveolar space to form a fusion state with crazy paving.

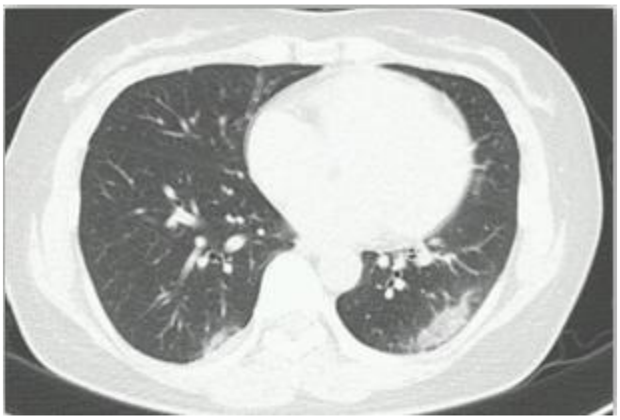

Figure 5: The consolidation stage (60 years old): This stage refers to the period around 7–14 days after clinical manifestations appeared. The main pathological features in

this stage are the fibrous exudation of the alveolar cavity and the disappearance of capillary congestion in the alveolar wall. CT imaging showed the patchy consolidations.

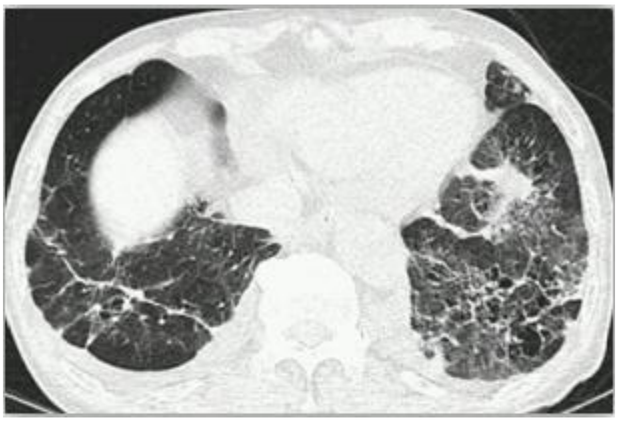

Figure 6: The dissipation stage (39 years old): This stage refers to the period roughly between 2 and 3 weeks after the onset of clinical manifestations. The range of lesions was further reduced. CT imaging showed patchy consolidation or strip-like opacity. As time goes on, it showed grid-like thickening of interlobular septum, thickening and strip-like twist of bronchial wall and a few scattered patchy consolidations.

Common Initial and Follow-up CT Presentations

The known imaging features of initial CT in COVID-19 cases include bilateral, multi-lobar GGO with a peripheral or posterior distribution (or both), mainly in the lower lobes and less frequently within the right middle lobe. Consolidation superimposed on GGO as the initial imaging presentation is found in a smaller number of cases, mainly in the elderly population. Septal thickening, bronchiectasis, pleural thickening, and sub-pleural involvement are some of the less common findings, mainly in the later stages of the disease. Pleural effusion, pericardial effusion, lymphadenopathy, cavitation, CT halo sign, and pneumothorax are some of the uncommon but possible findings seen with disease progression.

Routinely, follow-up CT in the intermediate stages of the disease shows an increase in the number and size of GGOs, progressive transformation of GGO into multifocal consolidation, septal thickening and development of a crazy paving pattern. The greatest severity of CT findings was visible around day 10 after symptom onset. In severely ill patients, the most commonly reported CT findings were bilateral and multi-lobar involvement and sub-segmental consolidative opacities. ARDS was the most common indication for transfer to the ICU, with the majority of COVID-19 mortalities occurring among patients with ARDS in the ICU. The imaging signs associated with clinical improvement usually occur after week 2 of the disease and include gradual resolution of consolidative opacities and decrease in the number of lesions and involved lobes. In the majority of documented COVID-19 cases, the initial chest CT is abnormal. Even some patients without any evident symptoms who were imaged solely on the basis of exposure have abnormal CT findings. Chest CT findings in confirmed cases of COVID-19 generally resembled those associated with MERS and severe acute respiratory syndrome (SARS), manifesting with viral pneumonia and acute lung injury that may progress to the typical imaging features of ARDS in critically ill patients [**16-19].**

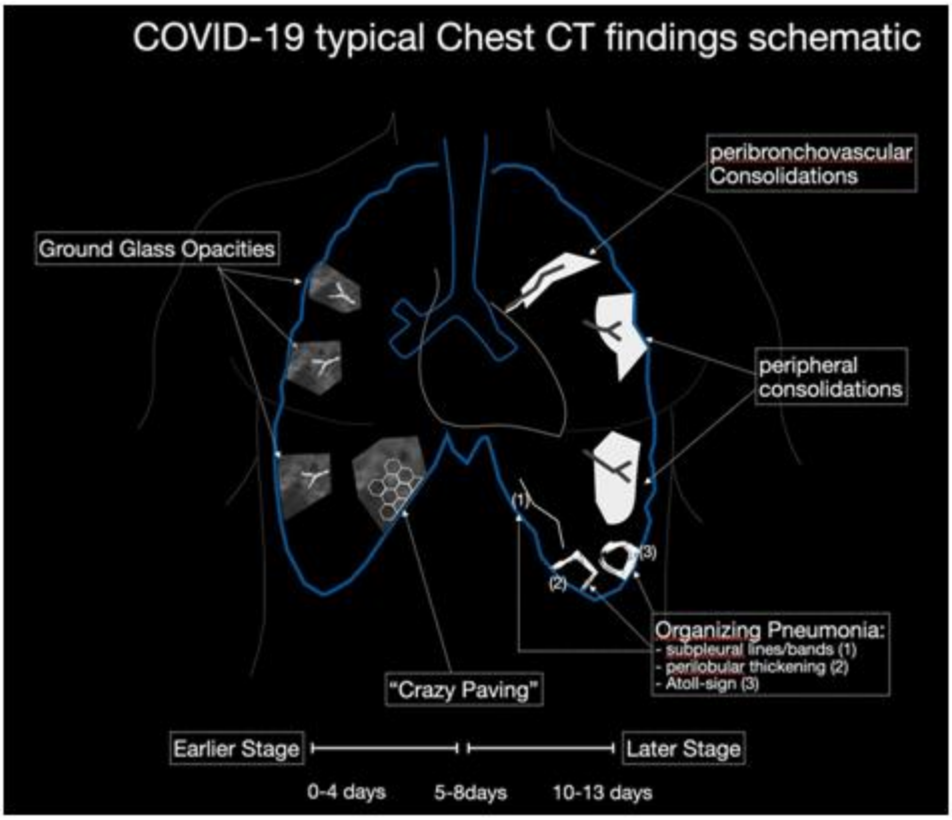

Figure 7: COVID 19 typical CT chest findings schematic (Diagram) [20]

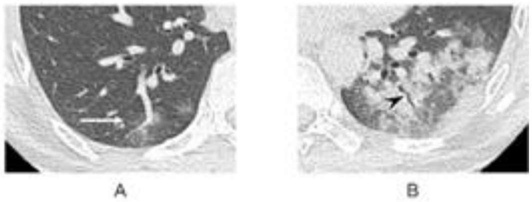

Figure 8: (A) 46 year old patient's CT scan shows bilateral GGOs (white arrow) and (B) patchy consolidations of the left lower lobe with an air bronchogram (black arrow head).

Figure 9: 70 year old patient's CT scan shows airway changes with bronchial wall thickening, as well as peripheral consolidation without air bronchograms. COVID-19 lesions with ground glass nodules are also seen.

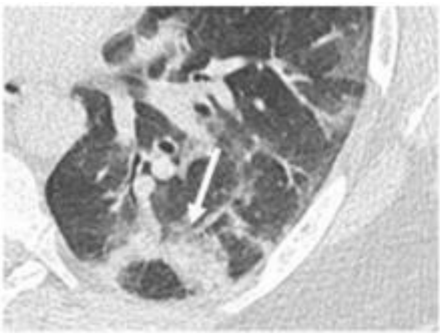

Figure 10: 41 year old patient's CT scan shows patchy GGOs and reverse halo sign (white arrow) which is a centered ground glass area surrounded by a denser consolidation consistent with areas of organizing pneumonia.

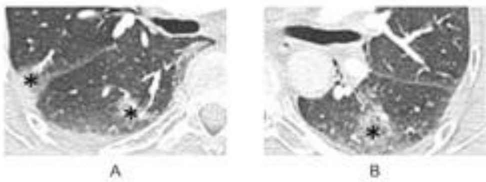

Figure 12 (A) and 12 (B): 50 year old patient's CT scan shows bilateral multiple Ground Glass opacities (black asterisk) situated along the periphery.

Figure 11: 25 year old patient's CT scan Shows multiple nodular GGOs with Peri-bronchovascular distribution.

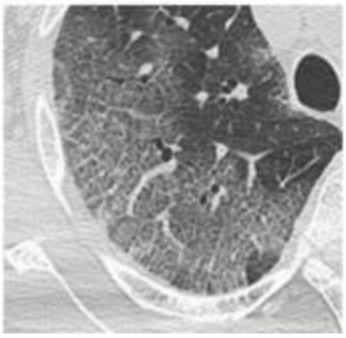

Figure 13: 42 year old patient's CT scan shows bilateral peripheral and pleural based GGOs with interlobular septal thickening exhibiting a crazy paving pattern.

5. Conclusion

The goal of the study has been achieved according to these imaging pearls, elaborating similar chest CT characteristics in the majority of patients, stating important factors concerning CT chest sensitivity and specificity, featuring stages of the disease and providing insight into the initial and follow-up CT imaging findings for COVID-19 pneumonia.

6. Acknowledgements

This study was instrumental in determining how physicians and patients formulate the understanding of COVID-19 infection's CT manifestation and features in stages and this was achieved by the support of Dr. Ramgopal Pansuriya (Consulting Radiologist) and Dr. Tauseef (Consulting Respiratory Medicine Specialist).

7. Funding information

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8. Conflict of interest

The author of this manuscript declares no relationships with any companies whose products or services may be related to the subject matter of the article.

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