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REVIEW

COVID-19 Associated Pneumonia

A review of chest radiograph and computed tomography findings

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الالتهاب الرئوي المصاحب لكوفيد-19

مراجعة بحثية لنتائج التصوير بأشعة اكس والأشعة المقطعية

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abstract: Medical imaging, including chest radiography and computed tomography, plays a major role in the diagnosis and follow-up of patients with COVID-19 associated pneumonia. This review aims to summarise current information on this topic based on the existing literature. A search of the Google Scholar (Google LLC, Mountain View, California, USA) and MEDLINE® (National Library of Medicine, Bethesda, Maryland, USA) databases was conducted for articles published until April 2020. A total of 30 articles involving 4,002 patients were identified. The most frequently reported imaging findings were bilateral ground glass and consolidative pulmonary opacities with a predominant lower lobe and peripheral subpleural distribution.

Keywords: COVID-19; Viral Pneumonia; Diagnostic Imaging; X-Ray Computed Tomography; Radiography; Review.

الملخص: يلعب التصوير الطبي، بما في ذلك التصوير بأشعة اكس والأشعة المقطعية، دورا رئيسيا في تشخيص ومتابعة المرضى المصابين بالالتهاب الرئوي المرتبط بفيروس كوفيد-19. تهدف هذه المراجعة البحثية الى تلخيص المعلومات الحالية حول هذا الموضوع بناء على الأدبيات الموجودة. تم البحث في قواعد بيانات جوجل العلمي (شركة جوجل كاليفورنيا، الولايات المتحدة الامريكية) والببميد (من المكتبة الوطنية للطب، ماريلاند، الولايات المتحدة الأمريكية) عن المقالات المنشورة حتى ابريل 2020. تم تضمين ما مجموعه 30 مقالة في هذه المراجعة البحثية، ضمت ماعدده 4,002 مريض. أظهرت هذه المراجعة البحثية ان أكثر نتائج التصور شيوعا التي تم الإبلاغ عنها هي تصلد الزجاج المطحون وعتامة الرئة والتي عادة ما يصيب الرئتين معا وبتوزيع سائد لأطراف الرئتين وللفصين السفليين.

الكلمات المفتاحية: كوفيد-19؛ التهاب رئوي فيروسي؛ التصوير التشخيصي؛ الأشعة المقطعية؛ التصوير الاشعاعي؛ مراجعة.

In December 2019, an outbreak of severe pneumonia of unknown aetiology emerged in Wuhan, China; by January 2020, the infectious illness was termed COVID-19 and the causative virus identified as a novel strain of *betacoronavirus*, specifically severe acute respiratory syndrome (SARS) coronavirus 2 (CoV-2).[1] Since then, cases of COVID-19 have rapidly spread worldwide as a result of human-to-human transmission, with a total of 2,668,135 confirmed cases and 190,236 deaths globally as of April 2020.[2] Common clinical symptoms of COVID-19 include coughing and fever, while other symptoms such as chest pain, muscle ache, abdominal pain or diarrhoea, pharyngeal discomfort, headaches and dizziness are less frequent.[3–5]

In most cases, a diagnosis of COVID-19 is based on a combination of clinical findings and positive results from a real-time polymerase chain reaction (RT-PCR) assay of specimens and aspirates from the upper respiratory tract, bronchia or trachea.[6] However, medical imaging modalities, including chest radiography and computed tomography (CT), have proven to hold high diagnostic sensitivity and can act as a supplement to RT-PCR testing in establishing the diagnosis.[7] Moreover, such imaging is essential in monitoring disease progression during the admission period. This article provides an overview of the available evidence regarding characteristic chest radiograph and CT findings among patients with COVID-19 associated pneumonia, illustrated by cases from the authors' own experience at the Royal Hospital, Muscat, Oman.

Methods

This non-systematic narrative review was performed in April 2020. A search was conducted of the Google Scholar (Google LLC, Mountain View, California, USA) and MEDLINE® (National Library of Medicine, Bethesda, Maryland, USA) databases to identify all English-language research studies reporting chest radiograph and CT findings of patients with confirmed diagnoses of COVID-19 associated pneumonia. Articles were

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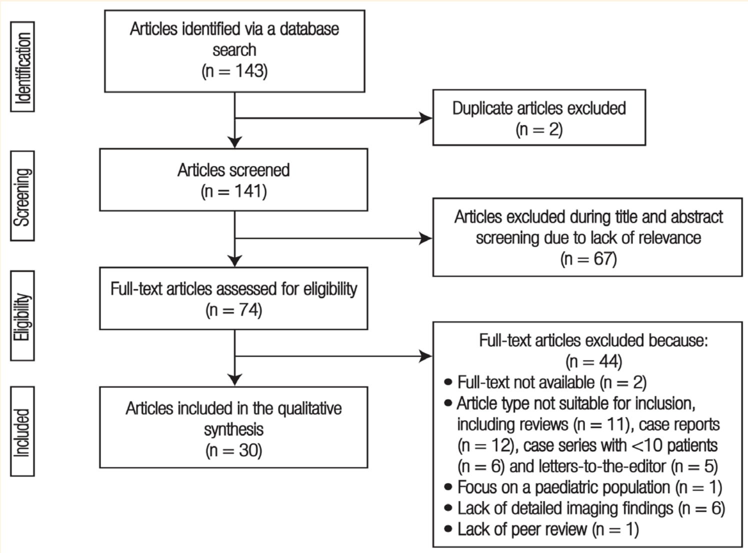

Figure 1: Flowchart showing the selection process used to identify articles included in the qualitative synthesis.

Table 1: Review of chest radiograph findings in studies of patients with COVID-19 (N = 2)[21,29]

Author and year of publication	Sample size	Mean/ median age in years	Male/female distribution	Chest radiograph findings,n (%)					
				No abnormality	CONS	GGO	Increased hazy opacity	PE	Distribution/ predominance
Lomoro *et al.*[21] (2020)	32*	66.3	36/22*	5 (15.6)	15 (46.9)	-	12 (37.5)	-	• Bilateral: 25 (78.1) • Unilateral: 2 (6.2) • Neither bilateral nor unilateral: 5 (15.6)
Wong *et al.*[29] (2020)	64	56	26/38	13 (20.3)	30 (47)	21 (33)	-	2 (3)	• Bilateral: 32 (50) • Unilateral, right lung: 10 (16) • Unilateral, left lung: 9 (14) • Peripheral: 26 (41) • Perihilar: 6 (9) • Neither peripheral nor perihilar: 19 (30) • Lower zone: 32 (50)

*CONS = consolidation; GGO = ground glass opacity; PE = pleural effusion. *Out of a total of 58 patients, including 22 who underwent chest ultrasonography, 32 who underwent chest radiography and 42 who underwent computed tomography.*

identified using a combination of search terms including "coronavirus", "SARS-CoV-2", "COVID-19", "computed tomography" and "chest radiograph".

Following the initial search, the titles and abstracts of all articles were screened for eligibility by two reviewers [Figure 1]. Only peer-reviewed studies published in English as of April 2020 with extractable full texts and conducted on humans were included in the review. Studies with no medical imaging findings, those focusing on paediatric populations and those involving fewer than 10 cases were excluded, as were case reports, editorials, letters to the editor and systematic and pictorial reviews.

Subsequently, important data regarding chest radiograph and CT findings were extracted from the studies, including lung parenchymal findings (i.e. the presence of ground glass opacities [GGOs], consolidation, crazy paving, interstitial thickening/ reticulation and fibrotic streaks/lineal opacities), pleural findings (i.e. the presence of pleural effusion and pleural thickening/retraction) and lymph node findings (i.e. the presence of lymphadenopathy).

Results

A total of 30 studies involving the chest radiograph and CT findings of patients with COVID-19 associated pneumonia were identified and included in the analysis.[8–37] Overall, these studies involved a total of 4,002 patients with confirmed COVID-19 diagnoses. The mean age was 49.6 years.[8–37]

Chest radiograph findings were reported in only two studies [Table 1].[21,29] Lomoro *et al.* confirmed bilateral lung consolidation to be the most common chest radiograph finding among 32 patients with COVID-19.[21] Similarly, Wong *et al.* found bilateral and lower lung peripheral consolidation to be most frequent among 64 patients.[29]

In contrast, chest CT findings were reported in 29 studies [Table 2].[8–28,30–37] The most common CT findings were GGOs followed by consolidation.[8–28,30–37] Such features were usually bilateral with predominant lower lobe and peripheral subpleural distribution. Another common finding was crazy paving (5–70.6%).[9–11,14,17–21,24,30,32,34,37] Notably, pleural effusion and lymphadenopathy were reported in a minority of patients (1–13.9% and 1–14.3%, respectively).[9–11,19–21,26,27,30–34,36,37] Other uncommon manifestations included interstitial thickening/reticulation, linear opacities/fibrotic streaks, pleural thickening, reverse halo signs, pulmonary nodules, air bronchograms and vascular enlargement.[8,10,11,13,16,22,25–27,31,32,34,36,37]

Discussion

Medical imaging can help to supplement RT-PCR assay results in the diagnosis of COVID-19 by showing characteristic imaging findings. In fact, Fang *et al.* demonstrated that the sensitivity of chest CT imaging was actually higher than that of RT-PCR assay results (98% versus 71%).[15] Similarly, in a recent meta-analysis, Kim *et al.* reported that chest CT had a high sensitivity in the diagnosis of COVID-19 (rate: 94%, 95% confidence interval: 91–96%).38 Falaschi *et al.* also reported the sensitivity, specificity, positive predictive value, negative predictive value and accuracy of CT imaging in the identification of SARS-CoV-2 infections to be 90.7%, 78.8%, 86.4%, 85.1% and 85.9%, respectively.[7] Moreover, chest CT scans have been able to detect COVID-19 associated lung changes even in asymptomatic patients.[18]

Nevertheless, it is important to note that routine CT screening is not currently recommended as a method of identifying COVID-19 infections. According to a statement issued by the Fleischner Society in April 2020, the use of imaging is not indicated for the purposes of triaging asymptomatic or mildly symptomatic patients; instead, chest CT is advocated only for COVID-19 patients with worsening respiratory statuses or those with moderate to severe symptoms, regardless of RT-PCR test results.[39]

Chest Radiograph Findings

There is evidence to demonstrate that chest radiography is less sensitive in the early stages of COVID-19 compared to CT.[29] However, due to issues related to infection control while transporting patients to the CT room and the lack of availability of CT equipment in many parts of the world, chest radiography is widely accepted as an alternative imaging modality for the identification and follow-up of lung abnormalities.[40] Moreover, portable X-ray machines can be used to image infected patients in isolation rooms, thereby lowering the risk of avoidable infectious exposure along the transport route. In addition, the low radiation dose involved in radiography compared to CT makes it an ideal imaging modality for follow-up purposes.[41]

In COVID-19 cases, the appearance of lung changes on chest radiography is dependent on the stage of disease. Initially, chest radiographs are usually insensitive to mild changes in patients with early disease; however, at later or more advanced stages, radiograph abnormalities are usually apparent.[29] Based on the results of the current review, the most common radiograph findings in patients with COVID-19 associated pneumonia included consolidation, GGOs or increased hazy opacity, most frequently bilateral with a lower lobe and peripheral subpleural predominance [Figure 2].[21,29] However, these findings can overlap with those observed in other forms of viral pneumonia; as such, chest radiograph findings should be interpreted in view of the specific clinical context of the patient.[42]

Chest Computed Tomography Findings

As demonstrated by the present review, a wide variety of CT findings for COVID-19 have been reported in the literature.[8–28,30–37] Of these, the most frequently reported were GGOs, either as an isolated abnormality or combined with other features such as consolidation, crazy paving, interstitial thickening/reticulation and linear opacities/fibrotic streaks.[8–28,30–37] Such findings tended to be bilateral, multifocal and with a lower lobe peripheral subpleural predominance [Figure 3].

In contrast, pleural effusion, pleural thickening and lymphadenopathy were uncommon CT findings in patients with COVID-19 associated pneumonia.[9–11,19–21,26,27,30–34,36,37] Other rare findings reportedly include organising pneumonia and both reversed halo and halo signs; however, such features have been reported in only a few case series and are not specific to COVID-19 associated pneumonia.[43–45] The underlying pathological mechanism of such findings is unclear; however, it is thought that they represent the healing process of lung injuries related to COVID-19 infection.

As with radiography, CT findings in COVID-19 patients appear to vary according to different disease stages.[24,27] Typical CT manifestations in the ultra-early stage (i.e. 1–2 weeks after exposure, when patients are

Table 2: Review of computed tomography findings in studies of patients with COVID-19 (N = 29)[8–28,30–37]

Author and year of public-ation	Sample size	Mean/ median age in years	Male/ female distrib-ution	CT findings, n (%)									
				CONS	GGO	Both CONS and GGO	Crazy paving	ITR	FS or linear opacity	PE	PT or retraction	LAP	Distribution/ predominance
Ai *et al.*[8] (2020)	888	51		447 (50)	409 (46)	-	-	8 (1)	-	-	-	-	• Bilateral: 801 (90)
Bai *et al.*[9] (2020)	219	45	119/100	150 (69)	200 (91)	-	11 (5)	-	111 (51)	9 (4)	32 (15)	6 (3)	• Unilateral: 41F (19) • Bilateral: 165 (75) • Central: 3 (1) • Peripheral: 176 (80) • Both central and peripheral: 31 (14)
Bernheim *et al.*[10] (2020)	121	45	61/60	2 (2)	41 (34)	50 (51)	6 (5)	-	9 (7)	1 (1)	-	-	• Bilateral: 73 (60) • Peripheral: 63 (52)
Chate *et al.*[11] (2020)	12	-	-	4 (33)	12 (100)	-	7 (58)	-	-	1 (8)	-	-	• Bilateral: 11 (92) • Peripheral: 9 (75) • Lower lobes: 8 (67)
Chen *et al.*[12] (2020)	99	55.5	67/32	-	14 (14)	-	-	-	-	-	-	-	• Bilateral: 74 (75) • Unilateral: 25 (25)
Cheng *et al.*[13] (2020)	11	50.4	8/3	6 (54.5)	11 (100)	-	-	9 (81.8)	2 (18.2)	-	-	-	• Peripheral: 11 (100) • Right lower lobe: 8 (72.7) • Left lower lobe: 7 (63.6)
Chung *et al.*[14] (2020)	21	51	13/8	-	12 (57)	6 (29)	4 (19)	-	3 (14)	-	-	-	• Bilateral: 16 (76) • Unilateral: 2 (10) • Peripheral: 7 (33)
Fang *et al.*[15] (2020)	51	45	29/22	36 (71)	-	-	-	-	-	-	-	-	• Peripheral: 36 (51) • Lower lobes: 36 (51)
Guan *et al.*[16] (2020)	1,099	47	640/459	409 (37.2)	550 (50)	-	-	143 (13)	-	-	-	-	• Bilateral: 505 (46)
Han *et al.*[17] (2020)	108	45	38/70	6 (6)	65 (60)	44 (41)	43 (40)	-	-	-	-	-	• Peripheral: 97 (90) • Central: 2 (2) • Both peripheral and central: 9 (8)
Inui *et al.*[18] (2020)	104	62	54/50	-	22 (21)	30 (29)	11 (11)	-	-	-	-	-	• Peripheral: 35 (34) • Central: 4 (4) • Mixed: 24 (23)
Li *et al.*[19] (2020)	83	45.5	44/39	53 (63.9)	81 (97.6)	-	30 (36.1)	-	54 (65.1)	7 (8.4)	-	-	• Bilateral: 79 (95.2) • Lower lobes: 80 (96.4%)
Li *et al.*[20] (2020)	51	58	28/23	3 (5.9)	18 (35.3)	28 (54.9)	36 (70.6)	-	-	1 (2)	-	-	• Peripheral and subpleural: 49 (96.1)
Lomoro *et al.*[21] (2020)	42*	66.3*	36/22*	-	15 (35.7)	25 (59.5)	24 (57.1)	-	21 (50)	3 (7.1)	-	6 (14.3)	• Peripheral: 27 (64.3) • Central: 1 (2.4) • Peripheral and central: 12 (28.6) • Neither peripheral nor central: 2 (4.8)
Meng *et al.*[22] (2020)	58	42.6	26/32	3 (5.2)	30 (51.7)	-	-	-	-	-	-	-	• Bilateral: 24 (41.4) • Peripheral: 44 (75.9) • Central: 14 (24.1)
Ng *et al.*[23] (2020)	21	56	13/8	13 (62)	18 (86)	-	-	-	-	-	-	-	• Peripheral: 18 (86) • Perihilar: 1 (5)
Pan *et al.*[24] (2020)	21	40	6/15	19 (90)	15 (71)	-	4 (19)	-	-	-	-	-	• Peripheral: 13 (62) • Random: 7 (33) • Diffuse: 1 (4.8)
Pan *et al.*[25] (2020)	63	44.9	33/30	12 (19)	54 (85.7)	-	-	-	11 (17.5)	-	-	-	-
Shi *et al.*[26] (2020)	81	49.5	42/39	14 (17.3)	53 (65.5)	-	-	3 (3.7)	-	4 (4.9)	26 (32.1)	5 (6.2)	• Unilateral: 17 (21) • Bilateral: 64 (79) • Central: 10 (12.4) • Peripheral: 44 (54.3) • Both central and peripheral: 27 (33.3)
Song *et al.*[27] (2020)	51	49	25/26	28 (55)	39 (77)	30 (59)	-	-	1(2)	4 (8)	-	3 (6)	• Bilateral: 44 (86) • Lower lobes: 46 (90) • Peripheral: 44 (86)
Wang *et al.*[28] (2020)	138	56	75/63	-	138 (100)	-	-	-	-	-	-	-	• Bilateral: 138 (100)
Wu *et al.*[30] (2020)	80	44	42/38	50 (63)	73 (91)	-	23 (29)	-	-	5 (6)			• Subpleural: 42 (53) • Diffuse: 7 (9) • Peribronchial: 3 (4) • Mixed: 24 (30)

*CT = computed tomography; CONS = consolidation; GGO = ground glass opacity; ITR = interstitial thickening or reticulation; FS = fibrotic streaks; PE = pleural effusion; PT = pleural thickening; LAP = lymphadenopathy; inc. = including. *Out of a total of 58 patients, including 22 who underwent chest ultrasonography, 32 who underwent chest radiography and 42 who underwent CT. †Within the lobes of 41 moderate/severe/critically ill patients.*

Table 2 (cont'd): Review of computed tomography findings in studies of patients with COVID-19 (N = 29)[8–28,30–37]

Author and year of publication	Sample size	Mean/ median age in years	Male/ female distribution	CT findings, n (%)									
				CONS	GGO	Both CONS and GGO	Crazy paving	ITR	FS or linear opacity	PE	PT or retraction	LAP	Distribution/ predominance
Xu *et al.*[32] (2020)	90	50	39/51	12 (13)	65 (72)	-	11 (12)	33 (37)	55 (61)	4 (4)	50 (56)	1 (1)	• Peripheral: 46 (51) • Bilateral: 53 (59) • Lower lobes: 47 (52) • Upper lobes: 40 (44)
Xu *et al.*[33] (2020)	50	43.9	29/21	15 (30)	30 (60)	25 (50)	-	-	-	4 (8)	-	-	• Peripheral†: 39 (95.1) • Central†: 19 (46.3) • Peripheral involving central†: 23 (56.1) • Symmetrical†: 26 (63.4)
Zhang *et al.*[34] (2020)	120	45.4	43/77	62 (52)	107 (89)	-	30 (25)	-	75 (63)	9 (8)	-	5 (4)	• Bilateral: 68 (57) • Peripheral: 109 (91) • Central: 39 (33)
Zhao *et al.*[35] (2020)	19	48	11/8	-	17 (89.47)	-	-	-	-	-	-	-	• Bilateral: 15 (78.95)
Zhao *et al.*[36] (2020)	101	44.44	56/45	44 (43.6)	87 (86.1)	65 (64.4)	-	49 (48.5)	-	14 (13.9)	-	1 (1)	• Unilateral: 10 (9.9) • Bilateral: 83 (82.2) • Peripheral: 88 (87.1) • Lower lobes: 55 (54.5) • Upper lobes: 6 (5.9)
Zhou *et al.*[37] (2020)	62	52.8	39/23	21 (33.9)	25 (40.3)	-	39 (62.9)	-	35 (56.5)	6 (9.7)	35 (56.5)	-	• Peripheral: 48 (77.4) • Both peripheral and central: 14 (22.6)

*CT = computed tomography; CONS = consolidation; GGO = ground glass opacity; ITR = interstitial thickening or reticulation; FS = fibrotic streaks; PE = pleural effusion; PT = pleural thickening; LAP = lymphadenopathy; inc. = including. *Out of a total of 58 patients, including 22 who underwent chest ultrasonography, 32 who underwent chest radiography and 42 who underwent CT. †Within the lobes of 41 moderate/severe/critically ill patients.*

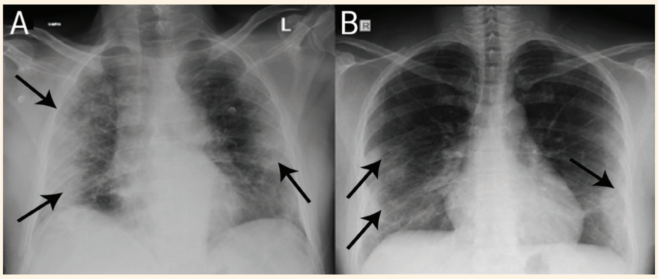

Figure 2: Chest X-rays of (**A**) a 67-year-old man with COVID-19 showing bilateral consolidation with a predominant peripheral distribution (arrows) and (**B**) a 44-year-old women with COVID-19 showing bilateral consolidation with a predominant lower lobe and peripheral distribution (arrows).

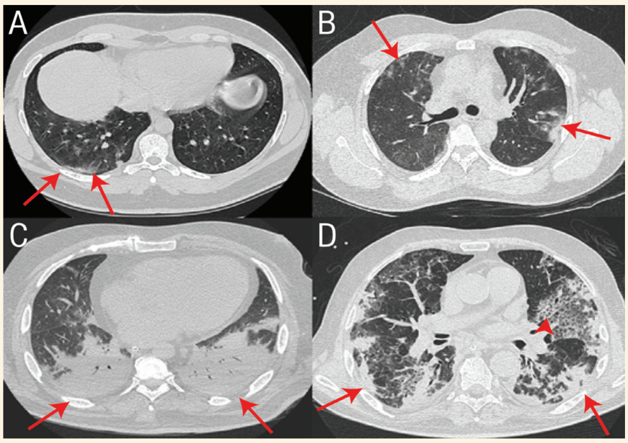

Figure 3: High-resolution axial chest computed tomography scans of (**A**) a 35-year-old male patient with COVID-19 showing right lower peripheral subpleural consolidation and ground glass opacity (GGO; arrows), (**B**) a 46-year-old male patient with COVID-19 showing bilateral predominant peripheral subpleural consolidation and GGO (arrows), (**C**) a 62-year-old male patient with COVID-19 showing bilateral lower lobe consolidation (arrows) and (**D**) a 67-year-old male patient with COVID-19 showing bilateral predominant peripheral subpleural consolidation and GGO (arrows) and interlobular septal thickening with crazy paving involving the lingula (arrowhead).

usually asymptomatic) include patchy consolidation and air bronchograms, nodules surrounded by GGO and single or multifocal GGOs, progressing to single or multiple patchy GGOs or GGOs associated with interlobular septal thickening in the early stage (i.e. 1–3 days after the onset of symptoms).[46] During the rapid progression stage (i.e. 3–7 days after the onset of symptoms), CT findings include large areas of consolidation with air bronchograms. In the consolidation stage (i.e. 7–14 days after the onset of symptoms), the size and density of this consolidation appears to regress. Finally, during the dissipation stage (i.e. 2–3 weeks after the onset of symptoms), CT imaging shows further regression of the consolidation seen in the earlier stages, with a few residual patchy and scattered areas associated with interlobular septal thickening and the strip-like twisting of the bronchial wall.[46] Pan *et al.* noted that 85% of 63 patients who underwent follow-up chest CT scans within two weeks of the initial scan showed signs associated with disease progression, such as an increase in GGOs, consolidative opacities, interstitial septal thickening and pulmonary nodules.[25]

In humans, coronaviruses can cause a variety of respiratory illnesses ranging from the common cold to severe pneumonia, including SARS and Middle East respiratory syndrome (MERS).[47,48] Chest CT findings in COVID-19 cases can imitate manifestations of both infectious and non-infectious disease, especially those observed in other viral pneumonias. According to a recent meta-analysis, Altmayer *et al.* found that both COVID-19 associated and other types of viral pneumonia had overlapping CT findings, except for a higher prevalence of peripheral distribution and involvement of the upper and middle lobes.[42] Both SARS and MERS share common findings with COVID-19 due to their similar pathogenesis.[47,48] However, CT changes related to SARS and MERS are commonly unifocal, as opposed to the multifocal changes usually seen in COVID-19. Moreover, reversed halo signs and pulmonary nodules have been described in COVID-19 cases, but not in SARS and MERS.[5,47,48]

Similarly, several non-infectious conditions can have similar CT manifestations to COVID-19, such as organising pneumonia and interstitial lung changes related to drug toxicity and radiation therapy.[49] Therefore, both radiologists and clinicians should remain aware of common conditions that can simulate the appearance of COVID-19 associated pneumonia on chest CT scans. In order to help decrease variability and reduce uncertainty in reporting CT findings and to allow for the better integration of such findings into clinical decision-making, the Radiological Society of North America have proposed four categories for reporting CT findings in COVID-19 cases: (1) typical appearance; (2) indeterminate appearance; (3) atypical appearance; and (4) negative for pneumonia.[50]

It is important to acknowledge growing concern that the increase in the utilisation of radiation-based imaging during the current COVID-19 pandemic could increase the radiation dose burden of the population; this is particularly concerning because ionising radiation increases the lifetime likelihood of developing cancer.[51] Therefore, as suggested by the International Commission on Radiological Protection, the ALARA principle of reducing risk (i.e. "as low as reasonably achievable") should be followed in the daily practice of radiology, even in the setting of epidemic events.[52] Moreover, this approach does not necessarily reduce diagnostic efficacy, as recent research has shown that low-dose chest CT scans can be used with reliable sensitivity in the detection of intrathoracic abnormalities including COVID-19 associated pneumonia.[53]

LIMITATIONS

This review is subject to certain limitations. First, most of the studies included in the analysis were descriptive, non-blinded and heterogeneous in terms of sample size, methodological quality and data availability, potentially resulting in bias. Second, case series and reports involving <10 patients were excluded, a factor which might have precluded rare imaging findings seen in COVID-19 patients. Finally, studies focusing on the paediatric population were excluded; as such, it is possible that chest CT and radiograph findings among children may differ to those seen in the adult population.

Conclusion

Medical imaging is a critical component in the diagnosis and follow-up of patients with COVID-19 associated pneumonia. Current evidence indicates that the most common chest radiograph and CT findings are bilateral predominant lower lobe peripheral subpleural GGOs, with or without accompanying consolidation. Awareness of these characteristic imaging features is essential to ensure the appropriate integration of such findings into the clinical management of affected patients.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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References

1. Rothan HA, Byrareddy SN. The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. J Autoimmun 2020; 109:102433. https://doi.org/10.1016/j.jaut.2020.102433.
2. World Health Organization. Rolling updates on coronavirus disease (COVID-19). From: www.who.int/emergencies/diseases/novel-coronavirus-2019/events-as-they-happen Accessed: Apr 2020.
3. Singhal T. A review of coronavirus disease-2019 (COVID-19). Indian J Pediatr 2020; 87:281–6. https://doi.org/10.1007/s12098-020-03263-6.
4. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 2020; 395:497–506. https://doi.org/10.1016/S0140-6736(20)30183-5.
5. Yang W, Cao Q, Qin L, Wang X, Cheng Z, Pan A, et al. Clinical characteristics and imaging manifestations of the 2019 novel coronavirus disease (COVID-19): A multi-center study in Wenzhou city, Zhejiang, China. J Infect 2020; 80:388–93. https://doi.org/10.1016/j.jinf.2020.02.016.
6. Udugama B, Kadhiresan P, Kozlowski HN, Malekjahani A, Osborne M, Li VY, et al. Diagnosing COVID-19: The disease and tools for detection. ACS Nano 2020; 14:3822–35. https://doi.org/10.1021/acsnano.0c02624.
7. Falaschi Z, Danna PSC, Arioli R, Pasché A, Zagaria D, Percivale I, et al. Chest CT accuracy in diagnosing COVID-19 during the peak of the Italian epidemic: A retrospective correlation with RT-PCR testing and analysis of discordant cases. Euro J Radiol 2020; 130: 109192. https://doi.org/10.1016/j.ejrad.2020.109192.
8. 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:E32–40. https://doi.org/10.1148/radiol.2020200642.
9. 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:E46–54. https://doi.org/10.1148/radiol.2020200823.
10. 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; 295:200463. https://doi.org/10.1148/radiol.2020200463.
11. Chate CR, Fonseca EKUN, Passos RBD, Teles GBDS, Shoji H, Szarf G. Presentation of pulmonary infection on CT in COVID-19: Initial experience in Brazil. J Bras Pneumol 2020; 46:e20200121. https://doi.org/10.36416/1806-3756/e20200121.
12. 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. Lancet 2020; 395:507–13. https://doi.org/10.1016/s0140-6736(20)30211-7.
13. Cheng Z, Lu Y, Cao Q, Qin L, Pan Z, Yan F, et al. Clinical features and chest CT manifestations of coronavirus disease 2019 (COVID-19) in a single-center study in Shanghai, China. AJR Am J Roentgenol 2020; 215:121–6. https://doi.org/10.2214/ajr.20.22959.
14. 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; 295:202–7. https://doi.org/10.1148/radiol.2020200230.
15. 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:E115–17. https://doi.org/10.1148/radiol.2020200432.
16. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020; 382:1708–20. https://doi.org/10.1056/NEJMoa2002032.
17. Han R, Huang L, Jiang H, Dong J, Peng H, Zhang D. Early clinical and CT manifestations of coronavirus disease 2019 (COVID-19) pneumonia. AJR Am J Roentgenol 2020; 215:338–43. https://doi.org/10.2214/ajr.20.22961.
18. Inui S, Fujikawa A, Jitsu M, Kunishima N, Watanabe S, Suzuki Y, et al. Chest CT findings in cases from the cruise ship Diamond Princess with coronavirus disease (COVID-19). Radiol Cardiothorac Imaging 2020; 2:e200110. https://doi.org/10.1148/ryct.2020200110.
19. 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; 55:327–31. https://doi.org/10.1097/RLI.0000000000000672.
20. Li Y, Xia L. Coronavirus disease 2019 (COVID-19): Role of chest CT in diagnosis and management. AJR Am J Roentgenol 2020; 214:1280–6. https://doi.org/10.2214/ajr.20.22954.
21. Lomoro P, Verde F, Zerboni F, Simonetti I, Borghi C, Fachinetti C, et al. COVID-19 pneumonia manifestations at the admission on chest ultrasound, radiographs, and CT: Single-center study and comprehensive radiologic literature review. Eur J Radiol Open 2020; 7:100231. https://doi.org/10.1016/j.ejro.2020.100231.
22. Meng H, Xiong R, He R, Lin W, Hao B, Zhang L, et al. CT imaging and clinical course of asymptomatic cases with COVID-19 pneumonia at admission in Wuhan, China. J Infect 2020; 81:e33–9. https://doi.org/10.1016/j.jinf.2020.04.004.
23. Ng MY, Lee EYP, Yang J, Yang F, Li X, Wang H, et al. Imaging profile of the COVID-19 infection: Radiologic findings and literature review. Radiol Cardiothorac Imaging 2020; 2:e200034. https://doi.org/10.1148/ryct.2020200034.
24. 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; 295:715–21. https://doi.org/10.1148/radiol.2020200370.
25. 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. Eur Radiol 2020; 30:3306–9. https://doi.org/10.1007/s00330-020-06731-x.
26. 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. Lancet Infect Dis 2020; 20:425–34. https://doi.org/10.1016/s1473-3099(20)30086-4.
27. Song F, Shi N, Shan F, Zhang Z, Shen J, Lu H, et al. Emerging 2019 novel coronavirus (2019-nCoV) pneumonia. Radiology 2020; 295:210–17. https://doi.org/10.1148/radiol.2020200274.
28. Wang D, Hu B, Hu C, Zhu F, Liu X, Zhang J, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. JAMA 2020; 323:1061–9. https://doi.org/10.1001/jama.2020.1585.
29. Wong HYF, Lam HYS, Fong AH, Leung ST, Chin TW, Lo CSY, et al. Frequency and distribution of chest radiographic findings in patients positive for COVID-19. Radiology 2020; 296:E72–8. https://doi.org/10.1148/radiol.2020201160.
30. Wu J, Wu X, Zeng W, Guo D, Fang Z, Chen L, et al. Chest CT findings in patients with coronavirus disease 2019 and its relationship with clinical features. Invest Radiol 2020; 55:257–61. https://doi.org/10.1097/rli.0000000000000670.
31. Xiong Y, Sun D, Liu Y, Fan Y, Zhao L, Li X, et al. Clinical and high-resolution CT features of the COVID-19 infection: Comparison of the initial and follow-up changes. Invest Radiol 2020; 55:332–9. https://doi.org/10.1097/rli.0000000000000674.

32. Xu X, Yu C, Qu J, Zhang L, Jiang S, Huang D, et al. Imaging and clinical features of patients with 2019 novel coronavirus SARS-CoV-2. Eur J Nucl Med Mol Imaging 2020; 47:1275–80. https://doi.org/10.1007/s00259-020-04735-9.

33. Xu YH, Dong JH, An WM, Lv XY, Yin XP, Zhang JZ, et al. Clinical and computed tomographic imaging features of novel coronavirus pneumonia caused by SARS-CoV-2. J Infect 2020; 80:394–400. https://doi.org/10.1016/j.jinf.2020.02.017.

34. Zhang R, Ouyang H, Fu L, Wang S, Han J, Huang K, et al. CT features of SARS-CoV-2 pneumonia according to clinical presentation: A retrospective analysis of 120 consecutive patients from Wuhan city. Eur Radiol 2020; 30:4417–26. https://doi.org/10.1007/s00330-020-06854-1.

35. Zhao D, Yao F, Wang L, Zheng L, Gao Y, Ye J, et al. A comparative study on the clinical features of coronavirus 2019 (COVID-19) pneumonia with other pneumonias. Clin Infect Dis 2020; 71:756–61. https://doi.org/10.1093/cid/ciaa247.

36. 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. AJR Am J Roentgenol 2020; 214:1072–7. https://doi.org/10.2214/ajr.20.22976.

37. Zhou S, Wang Y, Zhu T, Xia L. CT features of coronavirus disease 2019 (COVID-19) pneumonia in 62 patients in Wuhan, China. AJR Am J Roentgenol 2020; 214:1287–94. https://doi.org/10.2214/ajr.20.22975.

38. Kim H, Hong H, Yoon SH. Diagnostic performance of CT and reverse transcriptase polymerase chain reaction for coronavirus disease 2019: A meta-analysis. Radiology 2020; 296:E145–55. https://doi.org/10.1148/radiol.2020201343.

39. 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. Radiology 2020; 296:172–80. https://doi.org/10.1148/radiol.2020201365.

40. American College of Radiology. ACR recommendations for the use of chest radiography and computed tomography (CT) for suspected COVID-19 infection. From: www.acr.org/Advocacy-and-Economics/ACR-Position-Statements/Recommendations-for-Chest-Radiography-and-CT-for-Suspected-COVID19-Infection Accessed: Sep 2020.

41. Brady Z, Scoullar H, Grinsted B, Ewert K, Kavnoudias H, Jarema A, et al. Technique, radiation safety and image quality for chest X-ray imaging through glass and in mobile settings during the COVID-19 pandemic. Phys Eng Sci Med 2020; 43:765–79. https://doi.org/10.1007/s13246-020-00899-8.

42. Altmayer S, Zanon M, Pacini GS, Watte G, Barros MC, Mohammed TL, et al. Comparison of the computed tomography findings in COVID-19 and other viral pneumonia in immunocompetent adults: A systematic review and meta-analysis. Eur Radiol 2020; 30:6485–96. https://doi.org/10.1007/s00330-020-07018-x.

43. Wang Y, Jin C, Wu CC, Zhao H, Liang T, Liu Z, et al. Organizing pneumonia of COVID-19: Time-dependent evolution and outcome in CT findings. PLoS One 2020; 15:e0240347. https://doi.org/10.1371/journal.pone.0240347.

44. Shaghaghi S, Daskareh M, Irannejad M, Shaghaghi M, Kamel IR. Target-shaped combined halo and reversed-halo sign, an atypical chest CT finding in COVID-19. Clin Imaging 2021; 69:72–4. https://doi.org/10.1016/j.clinimag.2020.06.038.

45. Li X, Zeng X, Liu B, Yu Y. COVID-19 infection presenting with CT halo sign. Radiol Cardiothorac Imaging 2020; 2:e200026. https://doi.org/10.1148/ryct.2020200026.

46. Jin YH, Cai L, Cheng ZS, Cheng H, Deng T, Fan YP, et al. A rapid advice guideline for the diagnosis and treatment of 2019 novel coronavirus (2019-nCoV) infected pneumonia (standard version). Mil Med Res 2020; 7:4. https://doi.org/10.1186/s40779-020-0233-6.

47. World Health Organization. Summary of probable SARS cases with onset of illness from 1 November 2002 to 31 July 2003 December 31, 2003. From: www.who.int/csr/sars/country/table2004_04_21/en/ Accessed: Sep 2020.

48. World Health Organization. Middle East respiratory syndrome coronavirus (MERS-CoV). From: www.who.int/emergencies/mers-cov/en/ Accessed: Sep 2020.

49. 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. AJR Am J Roentgenol 2020; 215:839–42. https://doi.org/10.2214/ajr.20.23202.

50. Simpson S, Kay FU, Abbara S, Bhalla S, Chung JH, Chung M, et al. Radiological Society of North America expert consensus statement on reporting chest CT findings related to COVID-19: Endorsed by the Society of Thoracic Radiology, the American College of Radiology, and RSNA. Radiol Cardiothorac Imaging 2020; 2:e200152. https://doi.org/10.1148/ryct.2020200152.

51. Gilbert ES. Ionising radiation and cancer risks: What have we learned from epidemiology? Int J Radiat Biol 2009; 85:467–82. https://doi.org/10.1080/09553000902883836.

52. Yeung AW. The “as low as reasonably achievable” (ALARA) principle: A brief historical overview and a bibliometric analysis of the most cited publications. Radioprotection 2019; 54:103–9. https://doi.org/10.1051/radiopro/2019016.

53. Tabatabaei SM, Talari H, Gholamrezanezhad A, Farhood B, Rahimi H, Razzaghi R, et al. A low-dose chest CT protocol for the diagnosis of COVID-19 pneumonia: A prospective study. Emerg Radiol 2020; 27:607–15. https://doi.org/10.1007/s10140-020-01838-6.