Radiology

Frequency and Distribution of Chest Radiographic Findings in Patients Positive for COVID-19

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Background: Current coronavirus disease 2019 (COVID-19) radiologic literature is dominated by CT, and a detailed description of chest radiography appearances in relation to the disease time course is lacking.

Purpose: To describe the time course and severity of findings of COVID-19 at chest radiography and correlate these with real-time reverse transcription polymerase chain reaction (RT-PCR) testing for severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2, nucleic acid.

Materials and Methods: This is a retrospective study of patients with COVID-19 confirmed by using RT-PCR and chest radiographic examinations who were admitted across four hospitals and evaluated between January and March 2020. Baseline and serial chest radiographs (n = 255) were reviewed with RT-PCR. Correlation with concurrent CT examinations (n = 28) was performed when available. Two radiologists scored each chest radiograph in consensus for consolidation, ground-glass opacity, location, and pleural fluid. A severity index was determined for each lung. The lung scores were summed to produce the final severity score.

Results: The study was composed of 64 patients (26 men; mean age, 56 years ± 19 [standard deviation]). Of these, 58 patients had initial positive findings with RT-PCR (91%; 95% confidence interval: 81%, 96%), 44 patients had abnormal findings at baseline chest radiography (69%; 95% confidence interval: 56%, 80%), and 38 patients had initial positive findings with RT-PCR testing and abnormal findings at baseline chest radiography (59%; 95% confidence interval: 46%, 71%). Six patients (9%) showed abnormalities at chest radiography before eventually testing positive for COVID-19 with RT-PCR. Sensitivity of initial RT-PCR (91%; 95% confidence interval: 83%, 97%) was higher than that of baseline chest radiography (69%; 95% confidence interval: 56%, 80%) (P = .009). Radiographic recovery (mean, 6 days ± 5) and virologic recovery (mean, 8 days ± 6) were not significantly different (P = .33). Consolidation was the most common finding (30 of 64; 47%) followed by ground-glass opacities (21 of 64; 33%). Abnormalities at chest radiography had a peripheral distribution (26 of 64; 41%) and lower zone distribution (32 of 64; 50%) with bilateral involvement (32 of 64; 50%). Pleural effusion was uncommon (two of 64; 3%). The severity of findings at chest radiography peaked at 10–12 days from the date of symptom onset.

Conclusion: Findings at chest radiography in patients with coronavirus disease 2019 frequently showed bilateral lower zone consolidation, which peaked at 10–12 days from symptom onset.

The recent radiologic literature about coronavirus disease 2019 (COVID-19) is primarily focused on findings at CT (1–6) because CT is more sensitive than chest radiography. In mainland China, CT was often a first-line investigation for COVID-19 (7,8). However, this practice placed a huge burden on radiology departments and posed an immense challenge for infection control in the CT suite. Some hospitals in China dedicated specific CT scanners for examining only patients suspected of having COVID-19 (9), a practice that is being instituted with difficulty in England (10). The American College of Radiology notes that the CT decontamination required after scanning patients with COVID-19 may disrupt radiologic service availability and suggests that portable chest radiography may be considered to minimize the risk of cross infection (11). Italian and British hospitals are beginning to use chest radiography as a first-line triage tool because of long turnaround times for real-time reverse transcription polymerase chain reaction (RT-PCR) as diagnostic test for severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2. (10,12). Therefore, in some countries, chest radiography cannot be superseded by CT in the current pandemic. As the prevalence of COVID-19 increases, it is also imperative for clinicians of all specialties to recognize COVID-19 features on chest radiographic images that may be acquired for other purposes.

Abbreviations

COVID-19 = coronavirus disease 2019, RT-PCR = reverse transcriptase polymerase chain reaction

Summary

Abnormalities at chest radiography in patients with coronavirus disease 2019 mirrored those at CT, demonstrating bilateral peripheral consolidation. Findings at chest radiography had a lower sensitivity than initial reverse transcription polymerase chain reaction testing (69% vs 91%, respectively).

Key Results

- In a cohort of patients with coronavirus disease 2019 (COVID-19) infection and imaging follow-up, baseline chest radiography had a sensitivity of 69% compared with 91% for initial reverse transcriptase polymerase chain reaction (RT-PCR) testing.
- Abnormalities at chest radiography preceded RT-PCR results that were positive for COVID-19 in six of 64 patients (9%).
- Common chest radiographic findings mirrored those previously described for CT: bilateral, peripheral, consolidation, and/or ground-glass opacities.

To further our understanding of the radiographic features of COVID-19, our study aims to describe the appearances of COVID-19 at chest radiography, correlate the appearances on chest radiographic images with RT-PCR, compare findings at chest radiography with findings at CT, and describe the time course of chest radiography appearances relative to symptom onset.

Materials and Methods

This retrospective study was approved by the institutional review boards of the Hong Kong Hospital Authority Hong Kong West (Queen Mary Hospital), Hong Kong East (Pamela Youde Nethersole Eastern Hospital and Ruttonjee Hospital), and Kowloon Central Clusters (Queen Elizabeth Hospital). Written consent was waived.

Patients

We included 64 patients from four tertiary and regional hospitals in Hong Kong (Queen Mary Hospital, Pamela Youde Nethersole Eastern Hospital, Queen Elizabeth Hospital, and Ruttonjee Hospital) from January 1, 2020, to March 5, 2020 (Fig 1). COVID-19 infection was confirmed by RT-PCR testing on nasopharyngeal swabs and throat swabs. Thirty-nine patients had serial RT-PCR results available. All patients underwent chest radiography at admission, and follow-up chest radiography was performed in all but one patient. Timing of symptom onset was obtained from public epidemiologic data provided by the Hong Kong Center for Health Protection (13). In the case of asymptomatic patients (nine of 64; 14%), date of first RT-PCR positive for COVID-19 was substituted for symptom onset.

Image Acquisition and Analysis

All chest radiographs were acquired as computed or digital radiographs by following usual local protocols. Chest radiography was performed at the posteroanterior or anteroposterior projection. Follow-up chest radiography was performed at the anteroposterior projection by using portable radiography units. Over half of the chest radiography at patient presentation was anteroposterior (36 of 64; 56%) and the rest was posteroanterior. Follow-up anteroposterior chest radiography was performed with portable radiography units in the isolation wards.

Two radiologists (H.Y.S.L., a thoracic radiologist with 15 years of experience, and H.Y.F.W., general radiologist with 5 years of experience) reviewed all chest radiographs by consensus. Further review was performed by a third radiologist (M.Y.N., a thoracic radiologist with 8 years of experience) if there was disagreement. Radiographic features including consolidation, ground-glass opacities, and pulmonary nodules were diagnosed according to the Fleischner Society glossary of terms (14). Distribution of the lung changes was categorized into peripheral predominance, perihilar predominance (peripheral and perihilar demarcation was defined as halfway between lateral edge of the lung and hilum), or neither; right, left, or bilateral lung involvement; and upper zone, lower zone (defined as upper or lower halves), or no zonal predominance. Manifestation of pleural effusion was also recorded.

All CT examinations were performed as noncontrast agent–enhanced volumetric scans of the thorax at 1–1.25-mm section thickness by following usual local protocols. Two radiologists (H.Y.S.L. and H.Y.F.W.) reviewed the CT examinations for presence or absence of consolidation and ground-glass opacities.

Radiograph Scoring

To quantify the extent of infection, a severity score was calculated by adapting and simplifying the Radiographic Assessment of Lung Edema score proposed by Warren et al (15) A score of 0–4 was assigned to each lung depending on the extent of involvement by consolidation or ground-glass opacities (0, no involvement; 1, <25% involvement; 2, 25%–50% involvement; 3, 50%–75% involvement; 4, >75% involvement). The scores for each lung were summed to produce the final severity score. Examples are in Figure 2.

Real-time RT-PCR

Except for 10 patients who were tested and confirmed by using standard Hong Kong Hospital Authority and Department of Health RT-PCR protocol for diagnosis, virologic monitoring was performed (QuantiNova Probe RT-PCR Kit; Qiagen, Hilden, Germany) by targeting the RNA-dependent RNA polymerase (*RdRp*)/helicase (*Hel*) gene of severe acute respiratory syndrome coronavirus 2, or SARS-Cov-2, until patient discharge. The technical method of the nucleic acid testing was described previously (16).

Statistical Analysis

Statistical analysis was performed by using software (SPSS Build 1.0.0.1347; IBM, Armonk, New York). The difference between chest radiography severity scores at various times during the disease course was analyzed by Kruskal-Wallis test. To evaluate the sensitivity of chest radiography, baseline chest radiography severity scores greater than 0 were interpreted as positive for COVID-19, and they were then compared with initial RT-PCR results by McNemar χ^2 test. Comparison of the baseline chest radiography severity score between initial positive and negative RT-PCR was assessed by Mann-Whitney *U* test. Radiographic and virologic recovery (defined as reaching a severity score of 0 at chest radiography and negative findings at RT-PCR, respectively) were compared by using paired-sample *t* test. Statistical significance was indicated by a *P* value less than .05.

Results

Patient Characteristics

The clinical characteristics of the 64 patients at presentation are summarized in Table 1 (26 men [41%] and 38 women [59%]; mean age, 56 years; age range, 16–96 years). Fever (38 of 64; 59%) and cough (26 of 64; 41%) were the most frequent symptoms. Nine patients (14%) were asymptomatic. The most common comorbidities were hypertension (13 of 64; 20%) and diabetes (eight of 64; 13%).

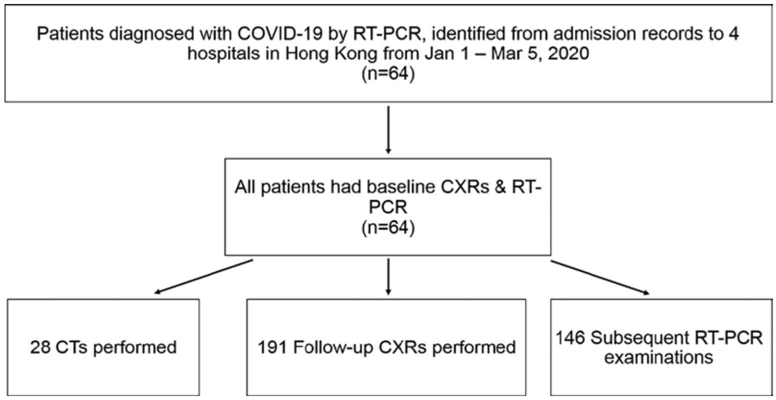

Figure 1: Study flowchart. COVID-19 = coronavirus disease 2019, CXR = chest radiography, RT-PCR = reverse transcriptase polymerase chain reaction.

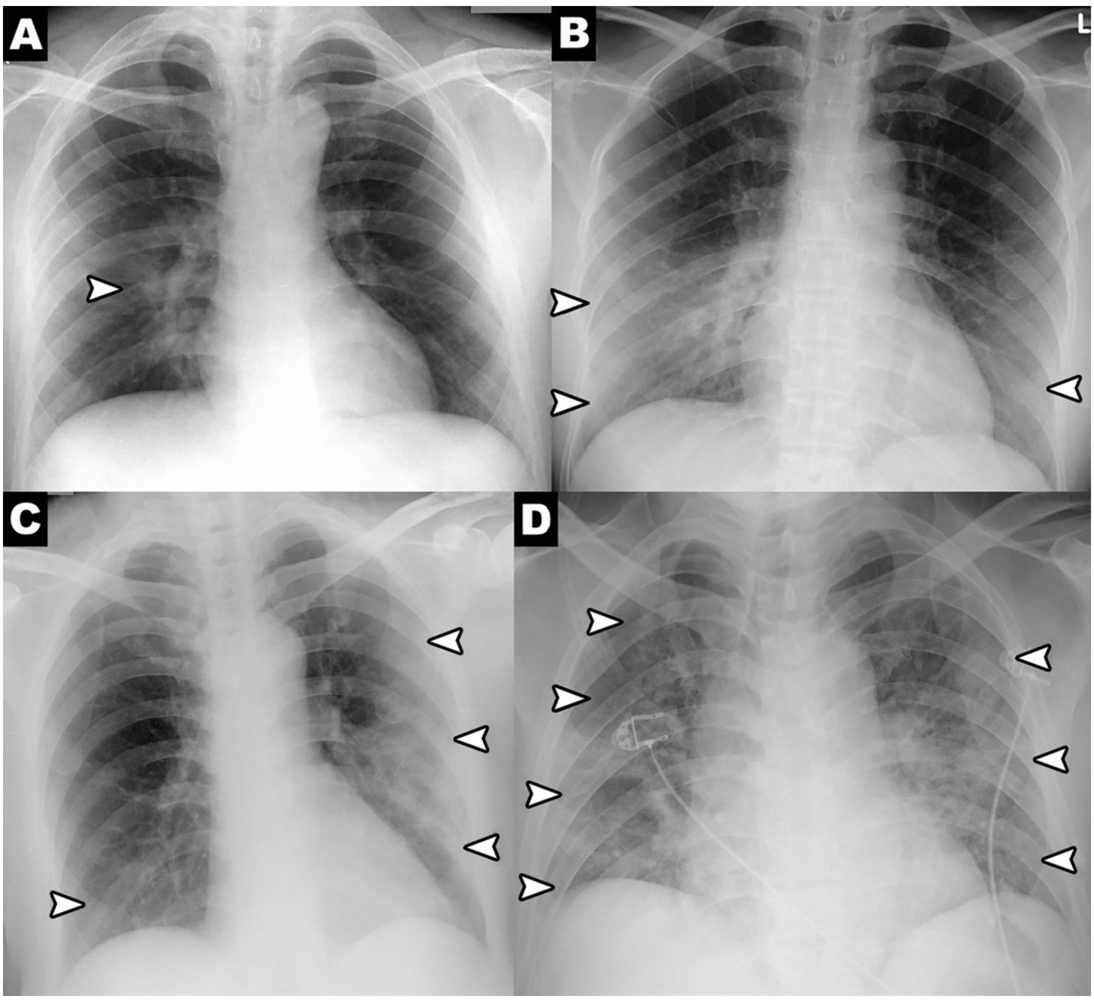

Figure 2: Chest radiography scoring system. A score of 0–4 was assigned to each lung depending on the extent of involvement by consolidation or ground-glass opacities (0, no involvement; 1, <25%; 2, 25%–50%; 3, 50%–75%; and 4, >75% involvement). The scores for each lung were summed to produce the final severity score. Examples of chest radiography severity scoring in patients with coronavirus disease 2019 and days from symptom onset are shown as follows (the calculation right lung score + left lung score = total score was used): *A*, day 12 (1 + 0 = 1); *B*, day 5 (2 + 1 = 3); *C*, day 3 (1 + 3 = 4); and, *D*, day 10 (4 + 3 = 7). Arrowheads indicate areas of consolidation or ground glass.

Table 1: Patient Characteristics at Presentation

Parameter	No. of Patients (n = 64)
Patient characteristic	
Male sex	26 (41)
Female sex	38 (59)
Age (y)	56 ± 19
Travel history to Wuhan	7 (11)
Clinical presentation	
Mild fever*	24 (38)
High fever†	14 (22)
Cough	26 (41)
Sputum	13 (20)
Hemoptysis	0 (0)
Sore throat	9 (14)
Diarrhea	3 (5)
Chest discomfort	6 (9)
Dyspnea	4 (6)
Asymptomatic	9 (14)
Comorbidities	
Diabetes	8 (13)
Hypertension	13 (20)
Chronic obstructive pulmonary disease	0 (0)
Malignancy	0 (0)
Chronic liver disease	1 (2)

Note.—Data in parentheses are percentages. Mean is ± standard deviation.

* Mild fever was indicated by patient temperature of 37°–38°C.

† High fever was indicated by patient temperature of 38°C or higher.

Table 2: Radiographic Findings at Chest Radiography

Characteristic	No. of Findings
No. of normal baseline chest radiographs	20 (31)
No. of abnormal baseline chest radiographs	44 (69)
No. of patients with normal baseline chest radiographs later becoming abnormal	7 (11)
Type of parenchymal opacity at baseline chest radiography	
Consolidation	30 (47)
Ground-glass opacities	21 (33)
Distribution at baseline chest radiography	
Peripheral predominant	26 (41)
Perihilar predominant	6 (9)
Neither peripheral nor perihilar	19 (30)
Right lung	10 (16)
Left lung	9 (14)
Bilateral lungs	32 (50)
Upper zone predominant	0 (0)
Lower zone predominant	32 (50)
No zonal predominance	19 (30)
Other features on baseline chest radiographs	
Pleural effusion	2 (3)
Pulmonary nodules	0 (0)

Note.—Data in parentheses are percentages; percentages were calculated on the basis of 64 patients.

Chest Radiography Features

Fifty-one of 64 patients demonstrated abnormalities on chest radiographs at some point during their illness (Table 2, Fig 3). At baseline chest radiography, consolidation was the most common finding (30 of 64; 47%), followed by ground-glass opacities (21 of 64; 33%). Peripheral distribution (26 of 64; 41%) and lower zone distribution (32 of 64; 50%) were the more common locations, and most had bilateral involvement (32 of 64; 50%). Pleural effusion was found in two patients (3%).

Baseline chest radiography findings.—All patients underwent baseline chest radiography at presentation. Baseline chest radiography was normal in 20 patients (31%). Twenty-six patients (41%) had mild findings with total severity score of 1–2. More extensive involvement was observed in 13 (20%) and five (8%) patients, who had severity scores of 3–4 and 5–6, respectively. No patient had a severity score greater than 6 at baseline chest radiography.

Time course of radiographic changes on chest radiographs.—The chest radiography severity scores from symptom onset are in Figure 4. The highest chest radiography severity score recorded was 8 (of maximum possible score of 8). Chest radiography severity scores changed over time (Fig 4; P = .01). Peak severity was reached at 10–12 days, at which time the median chest radiography severity score was 3.

Of the 20 patients with normal results at baseline chest radiography, seven developed abnormalities on follow-up radiographs.

Chest Radiography Correlation with RT-PCR

Each patient underwent a median of three RT-PCR tests (interquartile range, 1–4; range, 1–15). At presentation, 60 of 64 patients (94%) underwent both baseline chest radiography and initial RT-PCR testing within the first 24 hours, whereas four of 64 patients (6%) underwent chest radiography and RT-PCR within 48 hours. The chest radiography severity scores at baseline showed no significant difference between patients with positive or negative RT-PCR at initial testing (P = .62) (Fig 5). Of the 58 patients (91%) who tested positive for COVID-19 at initial RT-PCR, 38 patients (59%) showed abnormalities at baseline chest radiography. Six patients (9%) were negative for COVID-19 with initial RT-PCR but showed abnormalities at baseline chest radiography. Two of these patients are shown in Figure 2, *A* and *B*. Of these six patients, five subsequently tested positive for COVID-19 after 24 hours and one tested positive for COVID-19 after 48 hours.

By using RT-PCR results as the standard, the observed detection rate of baseline RT-PCR was 58 of 64 (91% sensitivity; 95% confidence interval: 83%, 97%), which was higher than that of baseline chest radiography (44 of 64; 69% sensitivity; 95% confidence interval: 56%, 80%) (P = .009).

Twenty-three patients underwent follow-up virologic recovery; 18 patients underwent follow-up to chest radiography recovery. The mean time from initial positive RT-PCR to negative RT-PCR was 8 days ± 7 (standard deviation; 23 patients;

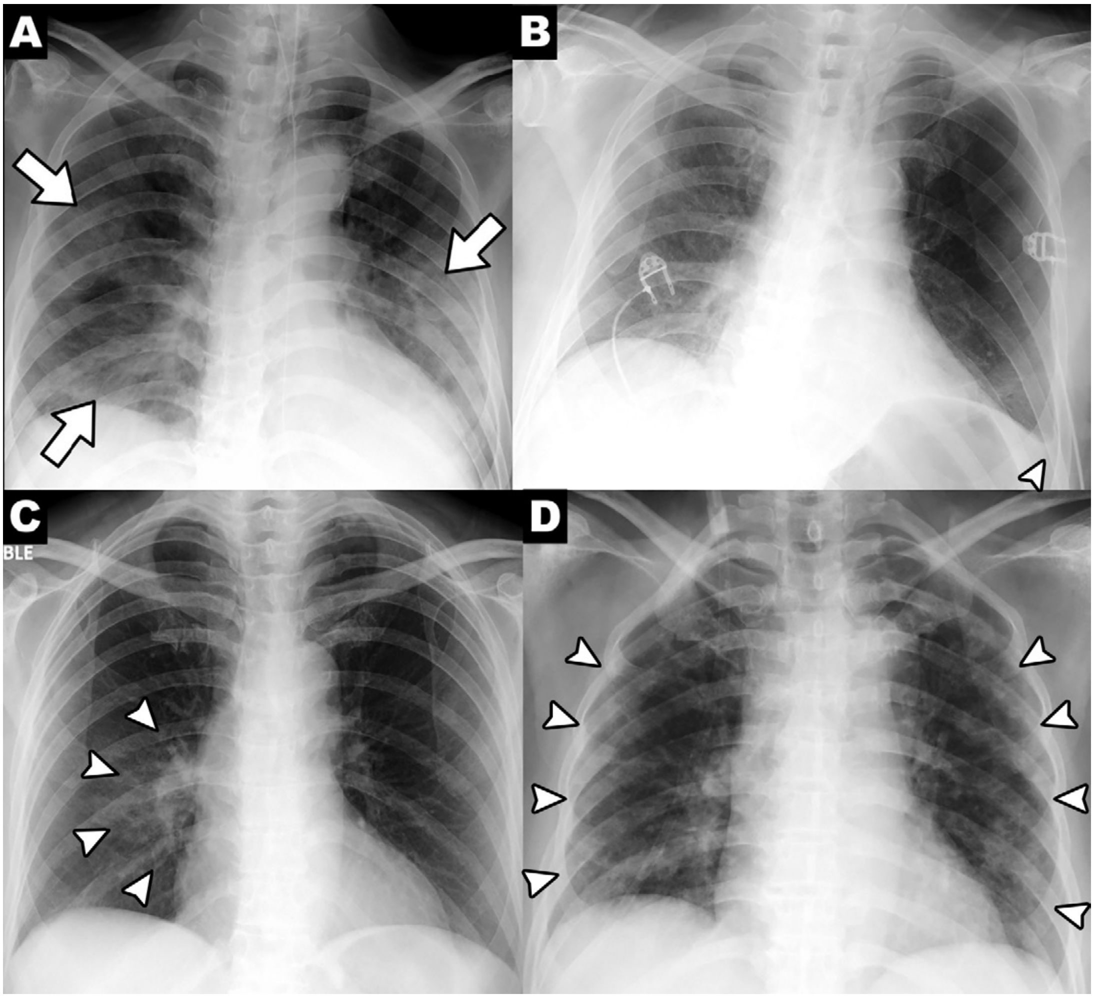

Figure 3: Findings on chest radiographs in patients with coronavirus disease 2019. *A*, Patchy consolidations (arrows) in a 69-year-old male patient, *B*, pleural effusion (arrowhead) in an 80-year-old male patient, *C*, perihilar distribution (arrowheads) in a 59-year-old female patient, and, *D*, peripheral distribution (arrowheads) in a 57-year-old femal patient are shown.

range, 1–24 days). The mean time from initial chest radiography positive for COVID-19 to negative for COVID-19 was 6 days ± 5 (18 patients; range, 1–18 days). Five patients never exhibited radiographic abnormalities and were not included in the radiographic recovery group. There was no statistically significant difference in the recovery time for RT-PCR and chest radiography recovery groups (P = .33).

Chest Radiography Correlation with CT

Twenty-eight of 64 patients (44%) in our cohort underwent CT within 48 hours of undergoing chest radiography, at a mean of 11 days ± 7 (range, 0–26 days) after symptom onset. Twenty-four of 28 patients had chest radiography severity scores greater than 0, all of whom had positive findings at CT. Four patients had negative findings at chest radiography; of these patients, three had CT examinations with negative findings and one patient had ground-glass opacities at CT (Fig 6).

Discussion

The main feature of consolidation at chest radiography in coronavirus disease 2019 (COVID-19)-related pneumonia is consistent with previously published case series (5,17). Of the 58 patients (of 64; 91%) who tested positive for COVID-19 with initial reverse transcription polymerase chain reaction (RT-PCR), 38 patients (of 64; 59%) showed abnormal results on baseline chest radiographs. Forty patients had abnormal results at baseline chest radiography. Six patients had abnormal results at chest radiography before eventually testing positive for COVID-19 with RT-PCR. Sensitivity of initial RT-PCR (91%; 95% confidence interval: 83%, 97%) was higher than that of baseline chest radiography (69%; 95% confidence interval: 56%, 80%) (P = .009). Radiographic recovery (mean, 6 days ± 5) and virologic recovery (mean, 8 days ± 7) were not significantly different (P = .33). Consolidation was the most common finding (30 of 64; 47%), followed by ground-glass opacities (21 of 64; 33%). These had a peripheral distribution (26 of 64; 41%) and lower zone distribution (32 of 64; 50%) with bilateral involvement (32 of 64; 50%). Pleural effusion was not common (two of 64; 3%). The severity of findings at chest radiography peaked at 10–12 days from the date of symptom onset.

We demonstrated that the common CT findings of bilateral involvement, peripheral distribution, and lower zone

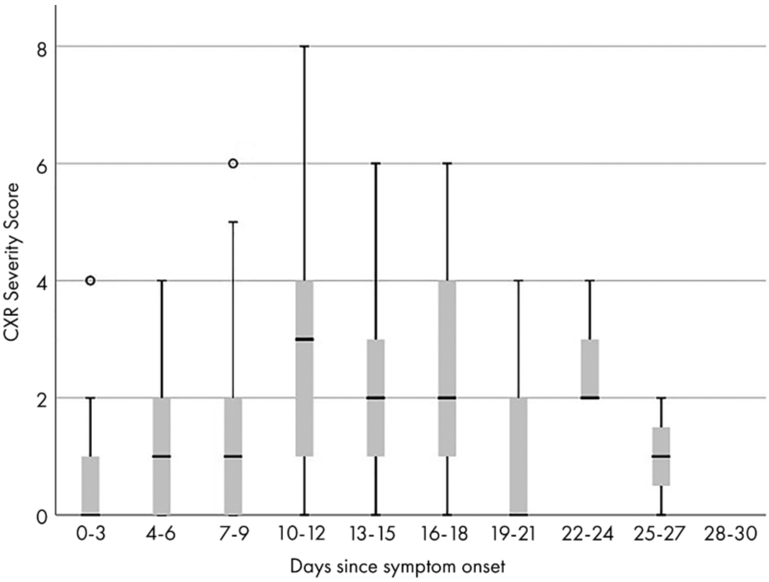

Figure 4: Box-and-whisker plot shows change in coronavirus disease 2019 at chest radiography (CXR) severity score with duration since symptom onset. A score of 0–4 was assigned to each lung depending on the extent of involvement by consolidation or ground-glass opacities (0, no involvement; 1, <25%; 2, 25%–50%; 3, 50%–75%; 4, >75% involvement). The scores for each lung were summed to produce the final severity score. Kruskal-Wallis test ($P = .01$) indicated a significant difference between the scores at different points.

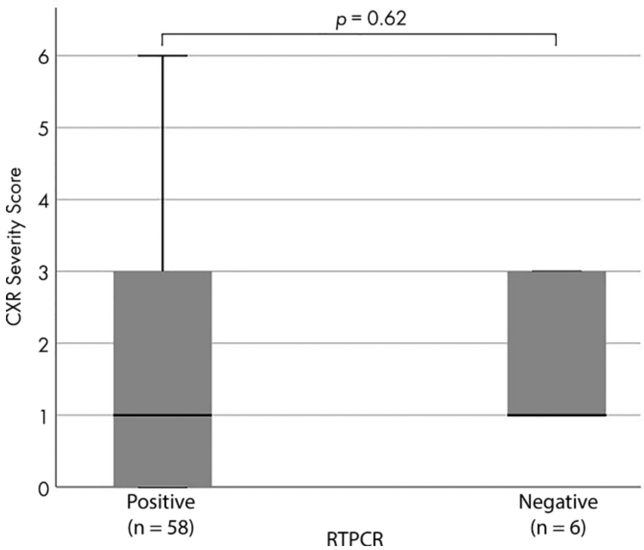

Figure 5: Baseline chest radiography (CXR) severity scores between patients with coronavirus disease 2019 with initially positive ($n = 58$) and negative reverse transcriptase polymerase chain reaction (RTPCR; $n = 6$) for severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2, nucleic acid. There was no statistical difference ($P = .62$).

dominance (1,5,6,18) can also be viewed on chest radiographs. Peak chest radiography severity score at 10–12 days after symptom onset is commensurate with previous findings at CT, at which peak severity was reported at 6–11 days (4,19). The proportion of patients in our study who exhibited abnormal radiographic findings (51 of 64; 80%) was higher than that in the case series of nine patients published by Yoon et al (17) (five of nine; 56%). Furthermore, abnormalities at chest radiography were able to be depicted in six patients whose initial RT-PCR was negative for COVID-19 (six of 64; 9%). Baseline chest radiography sensitivity was 69% (95% confidence interval: 56%, 80%). Albeit lower than the reported 97%–98% sensitivity of CT (2,20), our results suggest that chest radiography can have a role in the initial screening for COVID-19. Although further studies are needed, if there is high clinical suspicion of COVID-19 it is conceivable that a chest radiograph with positive findings may obviate the need for a CT examination, thus reducing burden on CT units during this pandemic.

In our patient subgroup with both chest radiography and CT available ($n = 28$), all chest radiographs with positive results also showed positive results on CT images, and only one patient (one of four; 25%) had false-negative findings at chest radiography compared with CT. A major caveat is that during the study period, our institutions did not routinely perform CT in all patients with COVID-19. CT was performed later in the disease course (11 days on average) than was chest radiography. CT was reserved for patients with clinical deterioration or poor response to treatment. Thus, the CT group in our study was likely skewed toward patients with more severe radiologic manifestations.

The role of chest radiography in clinical monitoring is less clear. In our subgroups that were followed to both virologic ($n = 23$) and radiographic ($n = 18$) recovery, there was no statistically significant ($P = .33$) difference in their mean durations to recovery. To compare, in a subgroup analysis of 57 patients by Ai et al (2), 42% of patients showed improvement at CT before negative results from RT-PCR testing; the other patients either showed progression at CT or only showed improvement after RT-PCR results became negative for COVID-19. Because the situation has been further confounded by reports of discharged patients testing positive for COVID-19 with RT-PCR again after discharge (21,22), our opinion is that imaging should be used as an adjunct to clinical parameters in monitoring of disease course until further evidence is available.

Our study had several limitations. First, not all patients were followed to their final outcome, and therefore correlation with disease course is truncated for some patients. Second, the intervals between serial chest radiographs and RT-PCR testing were dictated by clinical need and were not uniform, thus potentially affecting the precision of our analysis. Third, some of the radiographic features were subtle, which may limit reproducibility in suboptimal viewing conditions or by nonspecialists. Fourth, there was a lack of a control group without COVID-19 and CT was only available for a subgroup, which limited evaluation of the sensitivity and specificity of chest radiography.

In summary, we described the features of coronavirus disease 2019 (COVID-19) on chest radiographs to complement the publications about CT. Baseline chest radiography had a sensitivity of 69% in our cohort. As the COVID-19 pandemic threatens to overwhelm health care systems worldwide, chest

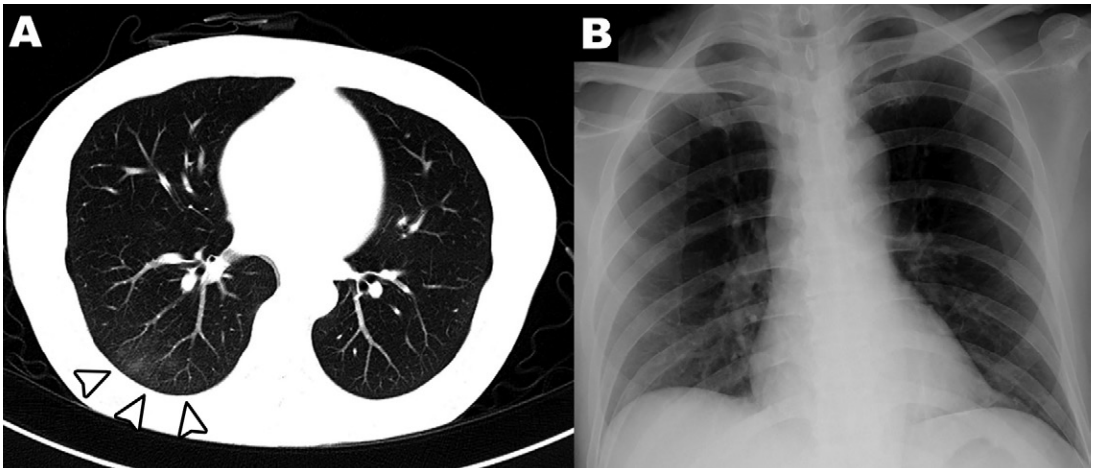

Figure 6: Images in a 43-year-old male patient with coronavirus disease 2019. Ground-glass opacities were observed at, *A*, CT (arrowheads) but they were not observed on, *B*, a chest radiograph.

radiography may be considered as a tool for identifying COVID-19 but is less sensitive than CT.

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