Radiology

Correlation of Chest CT and RT-PCR Testing for Coronavirus Disease 2019 (COVID-19) in China: A Report of 1014 Cases

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Conflicts of interest are listed at the end of this article.

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Background: Chest CT is used in the diagnosis of coronavirus disease 2019 (COVID-19) and is an important complement to reverse-transcription polymerase chain reaction (RT-PCR) tests.

Purpose: To investigate the diagnostic value and consistency of chest CT as compared with RT-PCR assay in COVID-19.

Materials and Methods: This study included 1014 patients in Wuhan, China, who underwent both chest CT and RT-PCR tests between January 6 and February 6, 2020. With use of RT-PCR as the reference standard, the performance of chest CT in the diagnosis of COVID-19 was assessed. In addition, for patients with multiple RT-PCR assays, the dynamic conversion of RT-PCR results (negative to positive, positive to negative) was analyzed as compared with serial chest CT scans for those with a time interval between RT-PCR tests of 4 days or more.

Results: Of the 1014 patients, 601 of 1014 (59%) had positive RT-PCR results and 888 of 1014 (88%) had positive chest CT scans. The sensitivity of chest CT in suggesting COVID-19 was 97% (95% confidence interval: 95%, 98%; 580 of 601 patients) based on positive RT-PCR results. In the 413 patients with negative RT-PCR results, 308 of 413 (75%) had positive chest CT findings. Of those 308 patients, 48% (103 of 308) were considered as highly likely cases and 33% (103 of 308) as probable cases. At analysis of serial RT-PCR assays and CT scans, the mean interval between the initial negative to positive RT-PCR results was 5.1 days ± 1.5; the mean interval between initial positive to subsequent negative RT-PCR results was 6.9 days ± 2.3. Of the 1014 patients, 60% (34 of 57) to 93% (14 of 15) had initial positive CT scans consistent with COVID-19 before (or parallel to) the initial positive RT-PCR results. Twenty-four of 57 patients (42%) showed improvement on follow-up chest CT scans before the RT-PCR results turned negative.

Conclusion: Chest CT has a high sensitivity for diagnosis of coronavirus disease 2019 (COVID-19). Chest CT may be considered as a primary tool for the current COVID-19 detection in epidemic areas.

Online supplemental material is available for this article.

A translation of this abstract in Farsi is available in the supplement.

ترجمه چکیده این مقاله به فارسی، در ضمیمه موجود است.

Since December 2019, a number of cases of "unknown viral pneumonia" related to a local seafood wholesale market were reported in Wuhan City, Hubei Province, China (1). A novel coronavirus (severe acute respiratory syndrome coronavirus 2, or SARS-CoV-2) was suspected to be the cause, with Phinolophus bat as the alleged origin (2). In just 2 months, the virus has spread from Wuhan to the rest of China and another 33 countries. By 24:00 on February 24, accumulative 77 658 confirmed cases with 9126 severe cases and 2663 deaths were documented in China (3); 2309 confirmed cases with 33 deaths were reported in other countries (including Japan, Korea, Italy, Singapore, and Iran as the top five countries). As of 24:00 on February 11, a total of 1716 confirmed cases and 1303 clinically diagnosed cases of medical personnel were reported from 422 medical institutions, five of whom died, accounting for 0.4% of the nationwide deaths during the same time period (4).

In the absence of specific therapeutic drugs or vaccines for coronavirus disease 2019 (COVID-19), it is essential to detect the disease at an early stage and immediately isolate the infected person from the healthy population. According to the latest guideline of Diagnosis and Treatment of Pneumonitis Caused by 2019-nCoV (trial sixth version) published by the Chinese government (5), the diagnosis of COVID-19 must be confirmed by means of reverse-transcription polymerase chain reaction (RT-PCR) or gene sequencing for respiratory or blood specimens, as the key indicator for hospitalization. However, with limitations of sample collection and transportation and limitations in kit performance, the total positive rate of RT-PCR for throat swab samples was reported to be approximately 30%–60%

Abbreviations

CI = confidence interval, COVID-19 = coronavirus disease 2019, RT-PCR = reverse-transcription polymerase chain reaction

Summary

Chest CT had higher sensitivity for diagnosis of COVID-19 as compared with initial reverse-transcription polymerase chain reaction from swab samples in the epidemic area of China.

Key Results

- The positive rates of reverse-transcription polymerase chain reaction (RT-PCR) assay and chest CT in our cohort were 59% (601 of 1014 patients) and 88% (888 of 1014 patients), respectively, for the diagnosis of patients suspected of having coronavirus disease 2019 (COVID-19).
- With RT-PCR as a reference standard, the sensitivity of chest CT for COVID-19 was 97% (580 of 601 patients); in 308 patients with negative RT-PCR results but positive chest CT scans, 147 of 308 (48%) were reconsidered as highly likely cases and 103 of 308 (33%) as probable cases with a comprehensive evaluation.
- With analysis of serial RT-PCR assays and CT scans, 60% (34 of 57) to 93% (14 of 15) of patients had initial positive chest CT scans consistent with COVID-19 before the initial positive RT-PCR results; 42% of patients (24 of 57) showed improvement on follow-up chest CT scans before the RT-PCR results turned negative.

at initial presentation (6). In the current emergency, the low sensitivity of RT-PCR implies that many patients with COVID-19 may not be identified and may not receive appropriate treatment in time; such patients constitute a risk for infecting a larger population given the highly contagious nature of the virus. Chest CT, as a routine imaging tool for pneumonia diagnosis, is relatively easy to perform and can produce fast diagnosis. In this context, chest CT may provide benefit for diagnosis of COVID-19. As recently reported, chest CT demonstrates typical radiologic features in almost all patients with COVID-19, including ground-glass opacities, multifocal patchy consolidation, and/or interstitial changes with a peripheral distribution (7). Those typical features were also observed in patients with negative RT-PCR results but clinical symptoms. It has been noted in small-scale studies that the current RT-PCR testing has limited sensitivity, whereas chest CT may reveal pulmonary abnormalities consistent with COVID-19 in patients with initial negative RT-PCR results (8,9).

To better understand the diagnostic value of chest CT compared with RT-PCR testing, we report the results of chest CT in comparison to the initial and serial RT-PCR results in 1014 patients suspected of having COVID-19. A Farsi translation of the abstract is available in Appendix E1 (online).

Materials and Methods

Patients and Data Sources of RT-PCR Results

The institutional review board of our hospital (Tongji Hospital of Tongji Medical College of Huazhong University of Science and Technology, Wuhan, Hubei, China) approved this retrospective study. The requirement to obtain written informed consent was waived. W.L. is an employee of Julei Technology Company. The data from this study were analyzed and controlled by authors who are not employees of medical industry.

From January 6 to February 6, 2020, a total of 1049 patients (mean age ± standard deviation, 51 years ± 15; 467 men [46%]) who were suspected of having severe acute respiratory syndrome coronavirus 2 infection and who underwent both chest CT and laboratory virus nucleic acid testing (RT-PCR assay with throat swab samples) were retrospectively enrolled in our study (Fig 1). The RT-PCR results were extracted from the patients' electronic medical records in our hospital information system. The RT-PCR assays were performed by using TaqMan One-Step RT-PCR Kits (Shanghai Huirui Biotechnology [Shanghai, China] or Shanghai BioGerm Medical Biotechnology [Shanghai, China]), which have approved use by the China Food and Drug Administration. For patients with multiple RT-PCR assays, the repeated testing conducted up to and including 3 days after the initial test was adopted as confirmation of diagnosis. Repeated testing more than 3 days after the initial RT-PCR test was used to analyze conversion of RT-PCR results, in correlation with the chest CT scan(s).

For patients with multiple RT-PCR assays, the diagnosis of COVID-19 was confirmed when any one of the nucleic acid test results was positive. If a patient had multiple chest CT scans, we included the scan with the shortest interval (≤7 days) to compare with the RT-PCR assay for the analysis of diagnostic performance; any other chest CT scans in the same patient were used to assess the temporal change of the disease. Patients were excluded when the time between chest CT and the RT-PCR assay was longer than 7 days.

Chest CT Protocols

All images were obtained with one of three CT systems (uCT 780 [United Imaging, Shanghai, China], Optima 660 [GE Healthcare, Chicago, Ill], or Somatom Definition AS+ [Siemens Healthineers, Erlangen, Germany]) with patients in the supine position. The main scanning parameters were as follows: tube voltage, 120 kVp; automatic tube current modulation; tube current, 30–70 mAs; pitch, 0.99–1.22 mm; matrix, 512 × 512; slice thickness, 10 mm; and field of view, 350 mm × 350 mm. All images were then reconstructed with a slice thickness of 0.625–1.250 mm with the same increment.

Image Analysis

Two radiologists (T.A. and Z.Y., with 12 and 3 years of experience in interpreting chest CT images, respectively) who were blinded to RT-PCR results reviewed all chest CT images and decided on positive or negative CT findings by consensus. The epidemiologic history and clinical symptoms (fever and/dry cough) were available for both readers. The radiologists classified the chest CT scan as positive or negative for COVID-19. The radiologists also described main CT features (ground-glass opacity, consolidation, reticulation and/or thickened interlobular septa, nodules) and lesion distribution (left, right, or bilateral lungs).

Statistical Analysis

The statistical analysis was performed with software (SPSS, version 21.0; SPSS, Chicago, Ill). Continuous variables are displayed as means ± standard deviations and categoric variables as counts and percentages.

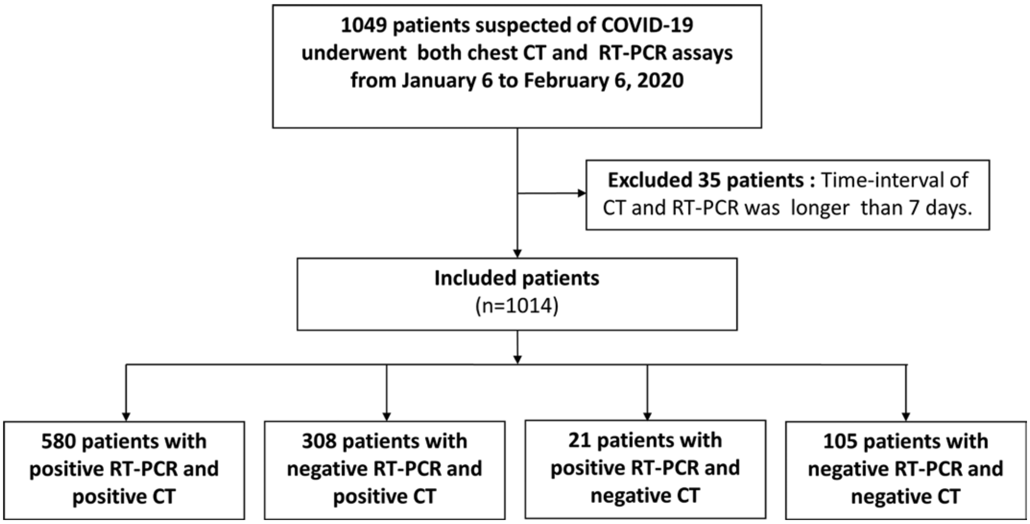

Figure 1: Study flowchart. COVID-19 = coronavirus 2019, RT-PCR = reverse-transcription polymerase chain reaction.

Table 1: Summary of Patient Characteristics

Characteristic	Value
No. of patients	1014
Age (y)	
Mean ± standard deviation*	51 ± 15 (2–95)
<20	7 (1)
20–39	267 (26)
40–59	409 (40)
≥60	331 (33)
No. of men	467 (46)
Median time between chest CT and RT-PCR assay (d)*	1 (0–7)
Results of RT-PCR assay	
Positive	601 (59)
Negative	413 (41)
Findings and manifestations of chest CT	
Consistent with viral pneumonia (positive)	888 (88)
Ground-glass opacity	409/888 (46)
Consolidation	447/888 (50)
Reticulation and/or thickened interlobular septa	8/888 (1)
Nodular lesions	24/888 (3)
No CT findings of viral pneumonia	126 (12)

Note.—Except where indicated, data are numbers of patients with percentages in parentheses. RT-PCR = reverse-transcription polymerase chain reaction.

* Numbers in parentheses are the range.

With use of RT-PCR results as the reference standard, the sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of chest CT were calculated. A 95% confidence interval was obtained with the Wilson score method. The performance of chest CT in the identification of COVID-19 in different age groups (<60 years and ≥60 years) and according to sex was compared with the χ^2 test.

For patients with negative RT-PCR tests but positive CT results, follow-up chest CT images were rereviewed to further confirm the imaging diagnosis if available. Clinical symptoms, typical imaging features on the initial chest CT scan, and dynamic changes on the serial follow-up chest CT scans were combined to classify the patients as highly likely cases, probable cases, and uncertain cases for those without serial CT scans. Highly likely cases were defined as patients with clinical symptoms (fever, cough, fatigue and/or shortness of breath) and typical CT features with dynamic changes (obvious progression or improvement in a short time) on serial CT scans. Probable cases were defined as patients with the aforementioned clinical symptoms and typical CT features but with stable findings on the follow-up CT scans or without follow-up CT scans. Uncertain cases were defined as patients with only one positive chest CT scan indicating viral pneumonia.

As to patients with multiple RT-PCR assays (with time interval of 4 days or more for two consecutive assays), the conversion of RT-PCR test results (negative to positive and positive to negative) was analyzed in correlation with the corresponding serial chest CT scans if available. Change in RT-PCR and CT findings may reflect viral proliferation or clearance in infected patients.

Results

General Description

Thirty-five patients were excluded because the time between chest CT and the RT-PCR assay was longer than 7 days. After exclusion of these patients, 1014 patients (mean age, 51 years ± 15; 467 men [46%]) were available for analysis. Figure 1 shows the study flowchart.

Of the 1014 patients, 601 had positive RT-PCR results and 413 had negative RT-PCR results, for a positive rate of 59% (95% confidence interval [CI]: 56%, 62%) (Fig 1). Of the 601 patients with positive RT-PCR results, 580 (97%) had positive chest CT scans. Of the 413 patients with negative RT-PCR result, 308 (75%) had positive chest CT scans.

The median time between the paired chest CT examinations and RT-PCR assays was 1 day (range, 0–7 days). Of the 1014 patients, 888 (88%; 95% CI: 86%, 90%) had positive chest CT

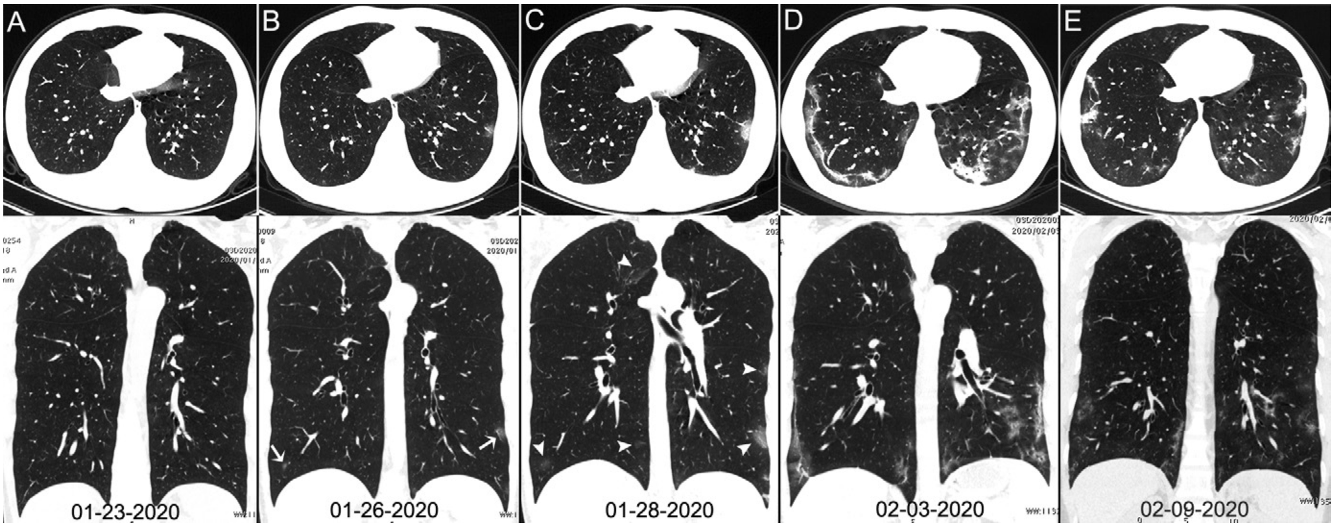

Figure 2: Axial (top) and coronal (bottom) chest CT images in a 29-year-old man with fever for 6 days. Reverse-transcription polymerase chain reaction assay for severe acute respiratory syndrome coronavirus 2 using a swab sample was performed on February 5, 2020, with a positive result. Dates of examination are shown on images. *A*, Chest CT scans obtained at onset show normal findings. *B*, Chest CT scans show minimal ground-glass opacities in bilateral lower lung lobes (arrows). *C*, Chest CT scans show increased ground-glass opacities (arrowheads). *D*, Chest CT scans show the progression of pneumonia with mixed ground-glass opacities and linear opacities in the subpleural area. *E*, Chest CT scans show absorption of both ground-glass opacities and organizing pneumonia.

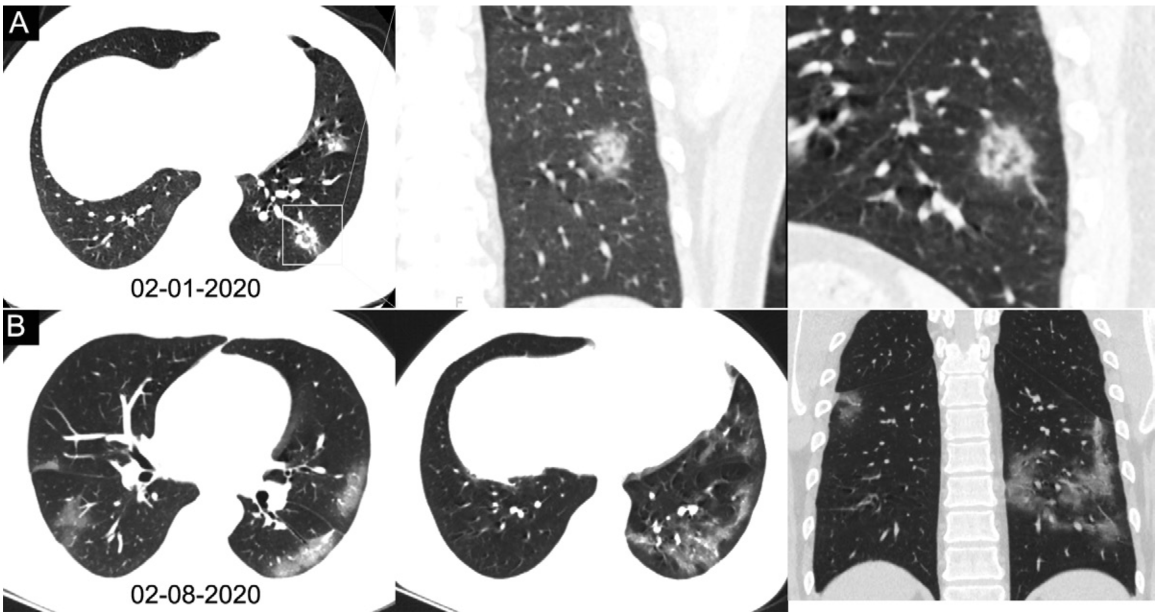

Figure 3: Chest CT images in a 34-year-old man with fever for 4 days. Positive result of reverse-transcription polymerase chain reaction assay for severe acute respiratory syndrome coronavirus 2 using a swab sample was obtained on February 8, 2020. Dates of examination are shown on images. *A*, Chest CT scan with magnification of lesions in coronal and sagittal planes shows a nodule with reversed halo sign in left lower lobe (box) at the early stage of the pneumonia. *B*, Chest CT scans in different axial planes and coronal reconstruction show bilateral multifocal ground-glass opacities. The nodular opacity resolved.

findings. The main chest CT findings were ground-glass opacity (409 of 888 patients [46%]) and consolidations (447 of 888 patients [50%]) (Table 1, Figs 2–4). Most patients (801 of 888 [90%]) had bilateral chest CT findings.

Performance of Chest CT in Diagnosing COVID-19

There were 888 patients with positive chest CT findings (<60 years, n = 587; ≥60 years, n = 301; 420 men, 468 women). With RT-PCR results as the reference standard, the sensitivity, specificity, and accuracy of chest CT in indicating COVID-19 infection were 97% (95% CI: 95%, 98%; 580 of 601 patients), 25% (95% CI: 22%, 30%; 105 of 413 patients), and 68% (95% CI: 65%, 70%; 685 of 1014 patients), respectively.

The performance of chest CT in diagnosing COVID-19 in different age and sex groups is reported in Table 2. The positive predictive values and accuracy of chest CT in diagnosing COVID-19 were higher in patients aged 60 years or older than in

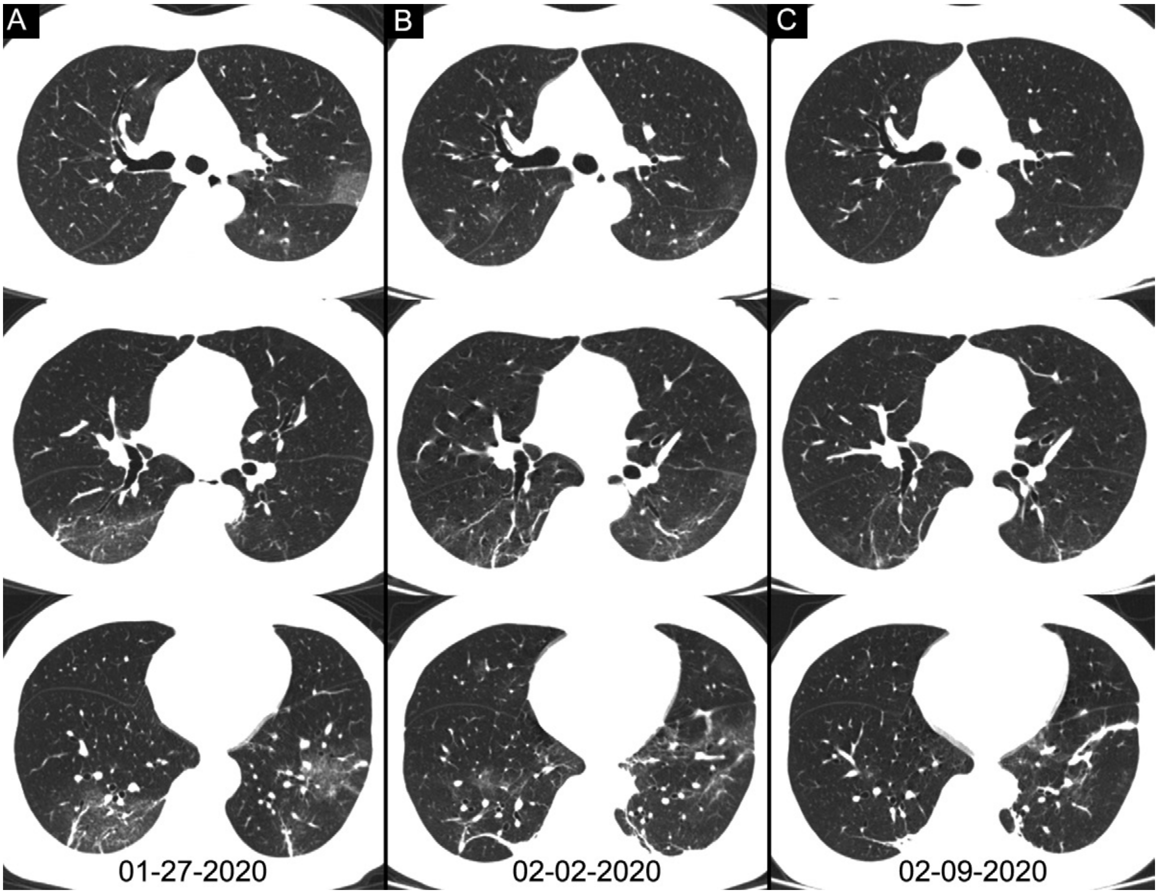

Figure 4: Chest CT images in a 46-year-old woman with fever for 4 days. The result of reverse-transcription polymerase chain reaction assay for severe acute respiratory syndrome coronavirus 2 using a swab sample was positive on February 4, 2020, and was negative on February 12. Chest CT scans obtained on, *A*, January 27, 2019, *B*, February 2, 2020, and, *C*, February 09, 2020, show gradual absorption of bilateral ground-glass opacities and linear consolidation.

Table 2: Performance of Chest CT in the Diagnosis of COVID-19

	Results*				Test Performance				
Parameter	TP	TN	FP	FN	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Overall	580	105	308	21	97 (580/601) [95, 98]	25 (105/413) [22, 30]	65 (580/888) [62, 68]	83 (105/126) [76, 89]	68 (685/1014) [65, 70]
Age									
<60 y	362	81	225	15	96 (362/377) [94, 98]	27 (81/306) [22, 32]	62 (362/587) [58, 66]	84 (81/96) [76, 90]	65 (443/683) [61, 68]
≥60 y	218	24	83	6	97 (218/224) [94, 99]	22 (24/107) [16, 31]	72 (218/301) [67, 77]	80 (24/30) [63, 91]	73 (242/331) [68, 78]
Sex									
M	272	35	148	12	96 (272/284) [93, 98]	19 (35/183) [14, 25]	65 (272/420) [60, 69]	75 (35/47) [61, 85]	66 (307/467) [61, 70]
F	308	70	160	9	97 (308/317) [95, 99]	30 (70/230) [25, 37]	66 (308/468) [61, 70]	89 (70/79) [80, 94]	69 (378/547) [65, 73]

Note.—Results of RT-PCR were used as the reference standard. Data in parentheses are numbers of patients used to calculate percentages. Data in brackets are 95% confidence intervals. COVID-19 = coronavirus disease 2019, FN = false negative, FP = false positive, NPV = negative predictive value, PPV = positive predictive value, RT-PCR = reverse-transcription polymerase chain reaction, TN = true negative, TP = true positive.

* Data are numbers of patients.

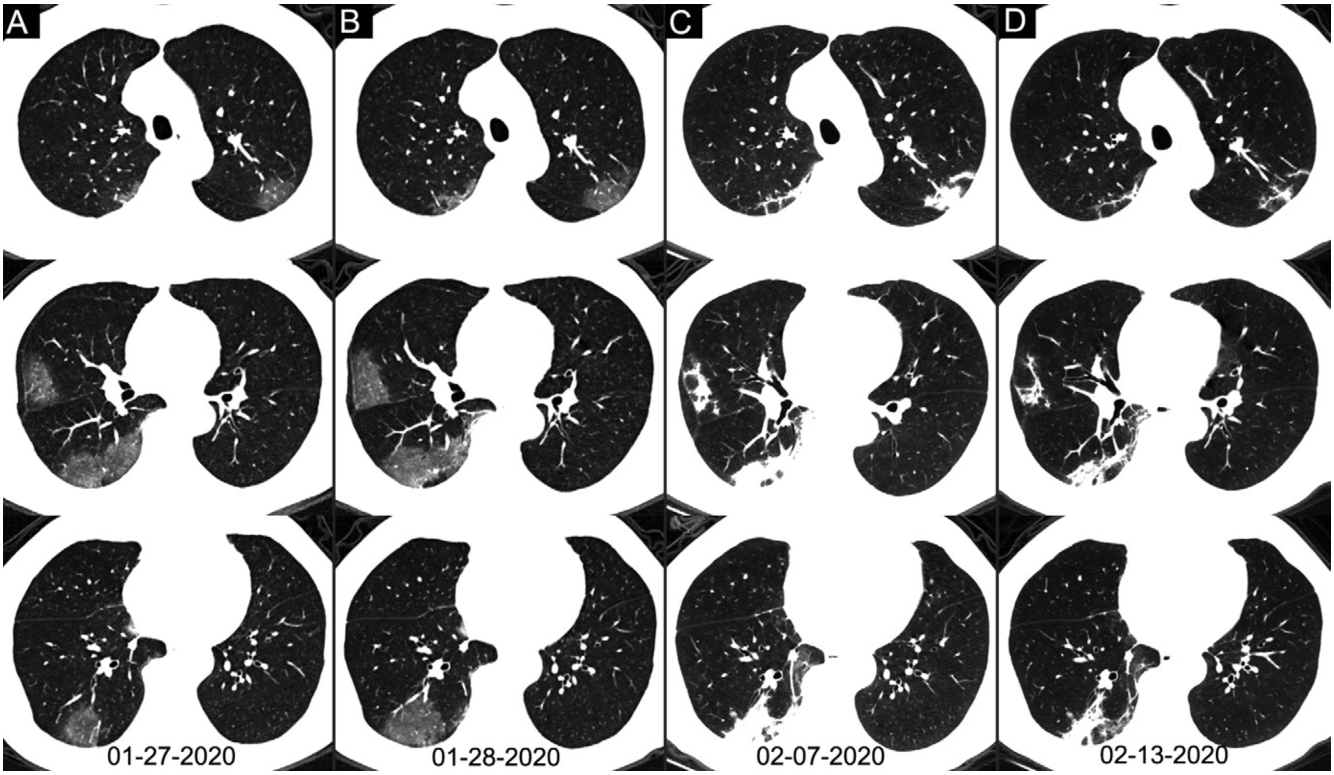

Figure 5: Chest CT images in a 62-year-old man with fever for 2 weeks and dyspnea for 1 day. Negative results of reverse-transcription polymerase chain reaction assay for severe acute respiratory syndrome coronavirus 2 using a swab samples were obtained on February 3 and 11, 2020, respectively. Dates of examination are shown on images. *A*, Axial chest CT images show multiple ground-glass opacities in bilateral lungs. *B*, Axial chest CT images show enlarged multiple ground-glass opacities. *C*, Axial chest CT images show progression of disease from ground-glass opacities to multifocal organizing consolidation. *D*, Axial chest CT scans show partial absorption of the organizing consolidation.

those younger than 60 years (P = .001 and .009, respectively); and no difference existed for sensitivity, specificity, and negative predictive value (P = .40, .41, and .58, respectively). The specificity and negative predictive value of chest CT in diagnosing COVID-19 were greater for women than for men (P = .009 and .04, respectively); no difference existed for sensitivity, positive predictive value, and accuracy (P = .36, .74, and .25, respectively).

Discrepant Findings between Chest CT and RT-PCR

Twenty-one patients (mean age, 46 years ± 24; 12 men [57%]) had positive RT-PCR results but without lesions at initial chest CT. The chest CT images in 308 patients (mean age, 47 years ± 14; 148 men [48%]) were suggestive of COVID-19, while their RT-PCR assays from throat swab samples were negative (Figs 5, 6). Of these 308 patients, 256 (83%) had bilateral lung lesions consisting of ground-glass opacities (126 of 308 patients [41%]) and consolidations (172 of 308 patients [56%]) at chest CT.

On the basis of the analysis of clinical symptoms, CT features, and serial CT scans if available, 147 of the 308 patients (48%) were considered as highly likely cases, 103 (33%) as probable cases, and 58 (19%) as uncertain cases.

Analysis of Multiple RT-PCR Assays and Serial Chest CT Scans

A total of 258 patients underwent multiple RT-PCR assays (Table 3). For patients with follow-up RT-PCR testing (with time interval >3 days for two consecutive assays), the mean interval between initial negative to positive RT-PCR results was 5.1 days ± 1.5, with a range of 4–8 days and a median of 4 days (n = 15). The mean time between initial positive RT-PCR testing and subsequent negative change was 6.9 days ± 2.3, with a range of 4–15 days and a median of 7 days (n = 57). In the subgroup of patients with negative to positive RT-PCR results, 67% (10 of 15 patients) showed initial positive chest CT findings before the initial negative RT-PCR results and 93% (14 of 15 patients) showed that the initial chest CT scan had typical imaging features consistent with COVID-19 before (or parallel to) the initial positive RT-PCR results, with a median lead time of 8 days (range, 0–21 days). In the subgroup of patients with positive to negative RT-PCR results, 60% (34 of 57 patients) showed the initial chest CT scan had typical imaging features consistent with COVID-19 before (or parallel to) the initial positive RT-PCR results, with a median lead time of 6 days (range, 0–27 days); almost all patients (56 of 57) had initial positive chest CT scans before or within 6 days of the initial positive RT-PCR results. In addition, 42% (24 of 57 patients) showed improvement on follow-up chest CT scans before the RT-PCR results turned negative; only 3.5% (two of 57 patients) showed disease progression on the follow-up CT scans after the RT-PCR results turned negative (Fig 7).

Discussion

Early diagnosis of coronavirus disease 2019 (COVID-19) is crucial for disease treatment and control. Compared with reverse-transcription polymerase chain reaction (RT-PCR), chest

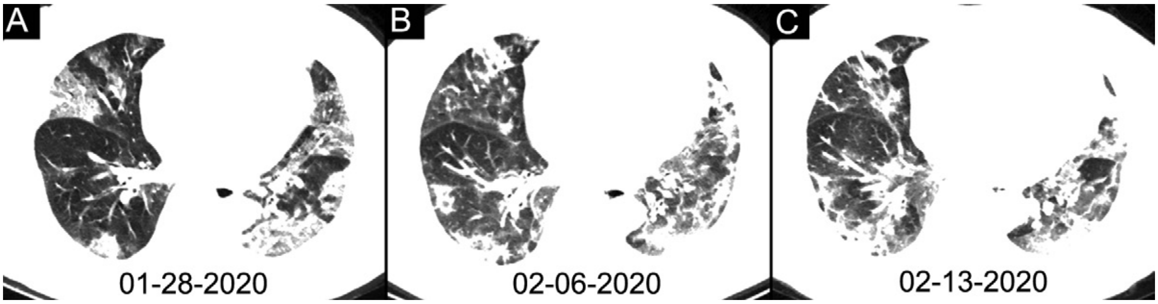

Figure 6: Chest CT images in a 63-year-old woman with fever for 11 days. Negative results of reverse-transcription polymerase chain reaction assay for severe acute respiratory syndrome coronavirus 2 using swab samples were obtained on February 2 and 11, 2020, respectively. Chest CT scans obtained on, *A*, January 28, 2020, *B*, February 6, and, *C*, February 13 show typical mixed ground-glass opacities and multifocal consolidation shadows in bilateral lungs without evidence of resolution over 16 days.

Table 3: Details of Multiple RT-PCR Assays in 258 Patients

Characteristic	Patients	Pairs of Consecutive Tests
No. of tests performed		
2	205 (80)	…
3	45 (17)	…
4	8 (3)	…
Time between consecutive tests (d)		
0–3		178 (56, *n* = 158)
≥4		141 (44, *n* = 129)
Dynamic change*		
From positive to negative results	57 (44)	57/129
From negative to positive results	15 (12)	15/129

Note.—Data are numbers of patients, with percentages in parentheses. The mean interval between initial positive RT-PCR test result and subsequent negative change was 6.9 days ± 2.3 (range, 4–15 days; median, 7 days). The mean interval between initial negative RT-PCR test result and subsequent positive change was 5.1 days ± 1.5 (range, 4–8 days; median, 4 days). RT-PCR = reverse-transcription polymerase chain reaction.

* Dynamic change of two consecutive tests with time interval of 4 days or more.

CT may be a more reliable, practical, and rapid method to diagnose and assess COVID-19, especially in the area affected by the epidemic. With RT-PCR results as the reference standard in 1014 patients, the sensitivity, specificity, and accuracy of chest CT in indicating COVID-19 infection were 97% (580 of 601 patients), 25% (105 of 413 patients), and 68% (685 of 1014 patients), respectively. The positive predictive value and negative predictive value were 65% (580 of 888 patients) and 83% (105 of 126 patients), respectively.

According to current diagnostic criteria, viral nucleic acid tests by means of RT-PCR assay play a vital role in determining hospitalization and isolation for individual patients. However, its lack of sensitivity, insufficient stability, and relatively long processing time were detrimental to the control of the disease epidemic. In our study, the positive rate of RT-PCR assay for throat swab samples was 59% (95% CI: 56%, 62%), which was consistent with that in a previous report (95% CI: 30%, 60%) (6). In addition, a number of any external factors may affect RT-PCR testing results, including sampling operations, specimen source (upper or lower respiratory tract), sampling timing (different periods of the disease development) (6), and performance of detection kits. As such, the results of RT-PCR tests must be interpreted with caution.

Chest CT is a conventional, noninvasive imaging modality with high accuracy and speed. On the basis of available data published in recent literature, almost all patients with COVID-19 had characteristic CT features in the disease process (8,10–13), such as different degrees of ground-glass opacities with and/or without crazy-paving sign, multifocal organizing pneumonia, and architectural distortion in a peripheral distribution. From our study, in addition, about 60% of patients (34 of 57) had typical CT features consistent with COVID-19 before (or parallel to) the initial positive RT-PCR results, and almost all patients (56 of 57) had initial positive chest CT scans before or within 6 days of the initial positive RT-PCR results. This indicates that CT can be very useful in the early detection of suspected cases.

In this study, 97% of patients confirmed to have COVID-19 with RT-PCR assays showed positive findings at chest CT, which was higher than that reported by Guan et al (86.2%) (14). A likely explanation is that patients in this study were all from the largest hospital in Wuhan, China, the central area of the outbreak of COVID-19. In this context, radiologists were more likely to make a diagnosis of COVID-19 when typical CT features were found. Given the sensitivity of chest CT (hence its value in preventing further spread of disease), clinical diagnosis criteria based on typical CT imaging features were temporarily adopted in the revised 5th edition of the Guideline of Diagnosis and Treatment, which was only applicable in Hubei Province, China (15). In addition, Pan et al (12) demonstrated that multiple repeat chest CT examinations can accurately reflect disease evolution and monitor the treatment effect. We also observed that 42% of patients (24 of 57) showed improvement on follow-up chest CT scans, which was earlier than the RT-PCT results turning negative. Only two of 57 patients (3.5%) showed progression on follow-up chest CT scans after RT-PCR test results turned negative.

For patients with negative RT-PCR tests, more than 70% had typical CT manifestations. On one hand, due to the overlap of CT imaging features between COVID-19 and other viral

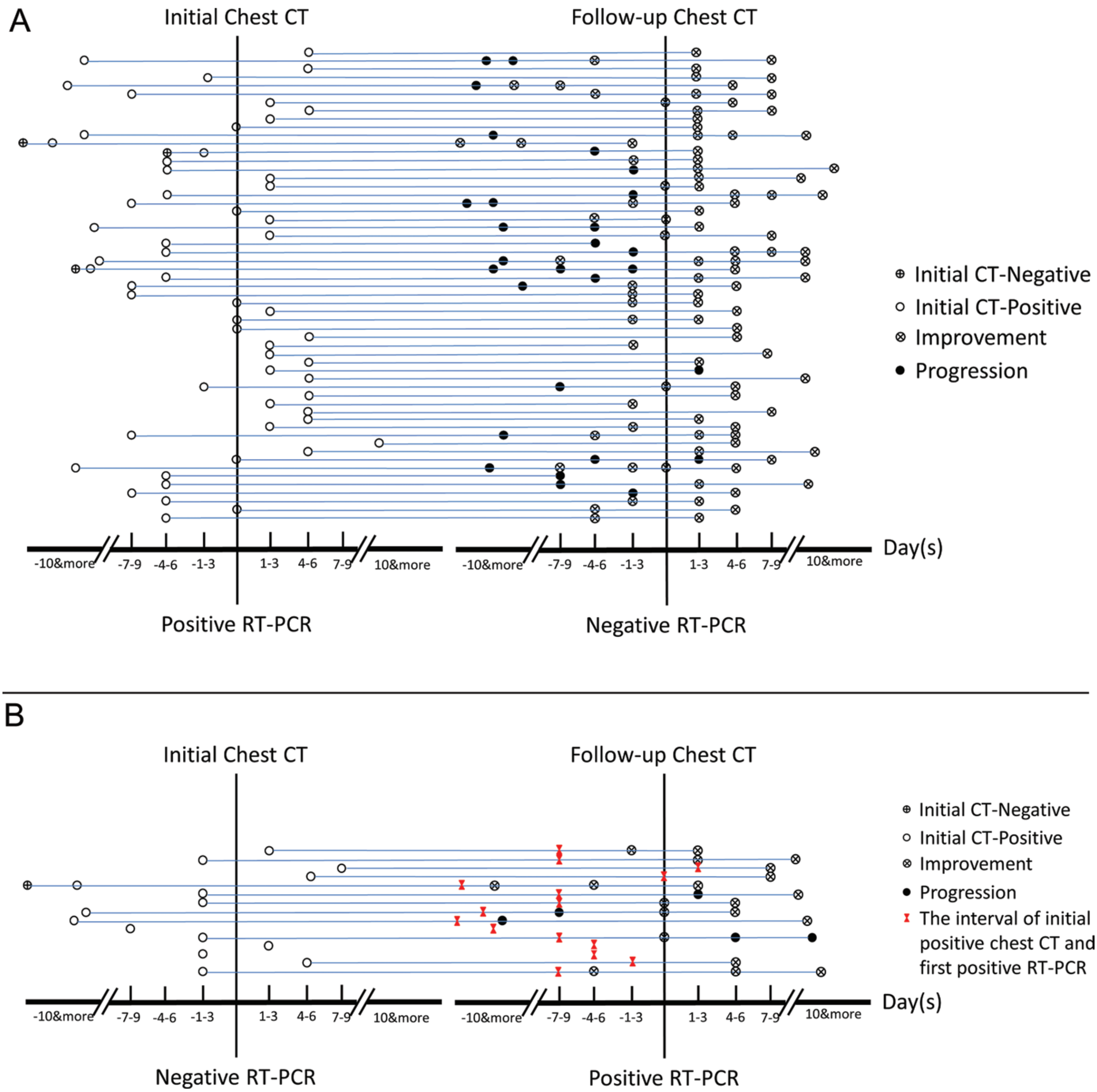

Figure 7: Analysis of serial reverse-transcription polymerase chain reaction (RT-PCR) assays in correlation with serial chest CT scans. *A*, Chart shows subgroup with positive to negative RT-PCR results ($n = 57$). *B*, Chart shows subgroup with negative to positive RT-PCR results ($n = 15$). Horizontal axis is the time point of initial chest CT and follow-up chest CT scans relative to the time point of the consecutive two RT-PCR tests (before positive RT-PCR, negative numbers; after RT-PCR, positive numbers).

pneumonia, false-positive cases of COVID-19 can be identified with chest CT. Nevertheless, considering the rapidly spreading epidemic of COVID-19, the priority was to identify any CT case suspicious for COVID-19 to isolate the patients and administer appropriate treatment. In the context of emergency disease control, some false-positive cases may be acceptable. On the other hand, given the relatively low positive rate of RT-PCR assay, some "false-positive" cases at CT may indeed be "true-positive" if RT-PCR assay is an imperfect standard of reference. In fact, from the results of this study, about 81% of the patients with negative RT-PCR results but positive chest CT scans were reclassified as highly likely or probable cases of COVID-19 by means of the comprehensive analysis of clinical symptoms, typical CT manifestations, and dynamic CT follow-up. On the basis of serial RT-PCR tests and CT scans, 90% of patients (14 of 15) had initial positive chest CT consistent with COVID-19 before (or parallel to) the initial positive RT-PCR results. As such, it can be speculated that those negative RT-PCR results could be problematic. In patients with negative RT-PCR tests, a combination of exposure history, clinical symptoms, typical CT imaging features, and dynamic changes should be used to identify COVID-19 with higher sensitivity.

Our study has several limitations. First, by using RT-PCR assays with a relatively low positive rate as the reference standard, the sensitivity of chest CT for COVID-19 may be overestimated and the specificity underestimated. In an area affected by epidemic, negative RT-PCR findings but positive CT features can still be highly suggestive of COVID-19. This has important clinical and societal implications; rapid detection with high sensitivity of viral infection may allow better control of viral spread. A second limitation is that clinical and laboratory data were limited during this urgent period when regional hospitals were overloaded. Nevertheless, the results reported herein from the center of the epidemic area should supply important information regarding the value of CT and RT-PCR in combating the prevalent disease.

In conclusion, chest CT has high sensitivity for the diagnosis of COVID-19. Our data and analysis suggest that chest CT should be considered for COVID-19 screening, comprehensive evaluation, and follow-up, especially in epidemic areas with high pretest probability for disease.

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