Association between incubation period and clinical characteristics of patients with COVID-19

Yeyu Cai¹, Jiayi Liu¹, Haitao Yang¹, Mian Wang², Qingping Guo³, Deng Huang⁴, Qizhi Yu⁵,* and Enhua Xiao¹,6,*

Abstract

Purpose: To investigate associations between the clinical characteristics and incubation periods of patients infected with coronavirus disease 2019 (COVID-19) in Wuhan, China.

Methods: Complete clinical and epidemiological data from 149 patients with COVID-19 at a hospital in Hunan Province, China, were collected and retrospectively analyzed.

Results: Analysis of the distribution and receiver operator characteristic curve of incubation periods showed that 7 days was the optimal cut-off value to assess differences in disease severity between groups. Patients with shorter (<7 days) incubation periods (n = 79) had more severe disease, longer durations of hospitalization, longer times from symptom onset to discharge, more abnormal laboratory findings, and more severe radiological findings than patients with longer (>7 days) incubation periods. Regression and correlation analyses also showed that a shorter incubation period was associated with longer times from symptom onset to discharge.

Conclusion: The associations between the incubation periods and clinical characteristics of COVID-19 patients suggest that the incubation period may be a useful marker of disease severity and prognosis.

¹Department of Radiology, The Second Xiangya Hospital, Central South University, Changsha, Hunan Province, China
²Department of Epidemiology and Health Statistics, Xiangya School of Public Health, Central South University, Changsha, Hunan Province, China
³Department of General Surgery, Changsha Central Hospital, Changsha, Hunan Province, China
⁴Department of Respiratory Medicine, Yangxin County People’s Hospital, Yangxin, Hubei Province, China
⁵Department of Radiology, The First Hospital of Changsha, Changsha, Hunan Province, China
⁶Molecular Imaging Research Center of Central South University, Changsha, Hunan Province, China

*These authors contributed equally to this work.

Corresponding authors:
Enhua Xiao, Department of Radiology, The Second Xiangya Hospital, Central South University, Renmin Road, Changsha, Hunan Province, 410011, China; Email: xiaoenhua64@csu.edu.cn
Qizhi Yu, Department of Radiology, The First Hospital of Changsha, Caie North Road, Changsha, Hunan Province, 410011, China. Email: yuqizhj@163.com

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).
Keywords
COVID-19, incubation period, clinical characteristics, disease severity, prognosis, retrospective analysis

Date received: 4 June 2020; accepted: 14 August 2020

Background
A cluster of patients with pneumonia caused by an unknown pathogen was reported in Wuhan, Hubei province, China, in December 2019.1 This pathogen was identified as a novel coronavirus, the seventh coronavirus capable of infecting humans, and named severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; previously known as novel coronavirus 2019, 2019-nCoV).2 Coronavirus disease 2019 (COVID-19) spread rapidly throughout China and was designated a global health emergency by the World Health Organization (WHO).3 Subsequently, COVID-19 pneumonia has spread worldwide to 212 countries and territories, with more than 3,000,000 cases confirmed.4 The COVID-19 pandemic resulted from an initial animal-to-human transmission followed by secondary human-to-human transmission, which was further fueled by travel.4–8 The incubation period, defined as the period between initial contact with the transmission source and symptom onset,9 is a critical determinant of disease spread and should be considered in any movement restriction policies instituted by governments.10 One prior study reported that the mean incubation period for COVID-19 is approximately 5 days (95% confidence interval [CI]: 2–14 days).10 However, correlations between the incubation period and clinical characteristics of the disease have not been examined. The purpose of the present study was, therefore, to investigate associations between clinical characteristics and the incubation period in patients with COVID-19.

Methods
This study was approved by our institutional medical ethics committee (approval number: 2020004). The requirement for informed consent was waived given the retrospective nature of this study, as per The Council for International Organizations of Medical Sciences guidelines. The study was performed in accordance with the ethical standards laid out in the 1964 Declaration of Helsinki and its later amendments.

Study design and participants
This study of patients with laboratory-confirmed COVID-19 was retrospectively conducted at the First Hospital of Changsha outside of Wuhan, China, from 16 January 2020 to 15 March 2020. Patients with COVID-19 were diagnosed based on the China National Commission guidelines (Trial Version 5).11 Laboratory-confirmed COVID-19 was defined as: 1) detection of SARS-CoV-2 using real-time reverse-transcription polymerase chain reaction, and 2) amplification of a viral gene sequence highly homologous to SARS-CoV-2 from a respiratory tract blood sample. Only patients with known incubation periods and documented clinical outcomes were included. The incubation period was defined as the time elapsed between initial exposure to laboratory confirmation of COVID-19, or the time elapsed between
entry into Wuhan for a short-term stay (less than 3 days) and onset of symptoms and signs. Disease severity was defined according to WHO guidelines. Patients with non-severe COVID-19 had no need for supplemental oxygen; these patients had pneumonia but no signs of severe pneumonia. Patients with severe COVID-19 had respiratory infection plus at least one of the following: severe respiratory distress; respiratory rate > 30 breaths/minute; or \( \text{SpO}_2 \leq 93\% \) on room air. Discharge criteria were based on pre-existing guidelines (Trial Version 5) and included: 1) return to normal body temperature for more than 3 days and significant resolution of respiratory symptoms, 2) chest radiologic images demonstrating significant improvement in acute exudative lesions, and 3) negative nucleic acid test results of two consecutive real-time reverse-transcription polymerase chain reaction with a sampling interval of at least 1 day. Demographic information (age and sex), clinical features, date of symptom onset, and laboratory and radiological findings at first admission were obtained from patients’ electronic medical records and from the hospital picture archiving and communication system. Radiological images were analyzed independently in blinded fashion by two radiologists with 5 and 15 years’ experience interpreting chest computed tomography (CT) images, respectively. After separate evaluations by each radiologist, any disagreements were discussed until a consensus was reached.

Patients who stayed in Wuhan for 3 or more days, patients who did not provide clear contact information in an epidemiological survey including on social distancing practices (< 1 m), intimate contacts (touching, embracing or kissing) and staying in the same confined place, patients with incomplete medical records including missing laboratory and radiological results, and patients younger than 14 years old were excluded.

To investigate associations between clinical characteristics and incubation periods in patients with COVID-19, we determined a representative cut-off value for incubation period as the basis of grouping. This cut-off value represented the characteristics of the incubation period and was also relatively strongly correlated with clinical characteristics.

**Clinical characteristics**

The infection transmission event was defined based on a patient’s recent visit to Wuhan or based on contact with a confirmed patient. Clinical features included smoking history, underlying comorbidities, time from onset to admission, hospitalization duration, and time from onset to discharge. Laboratory results consisted of a complete blood count, blood chemistry analysis, hepatic and renal function assessments, coagulation testing, blood procalcitonin concentration evaluation, and measurements of blood creatinine kinase and D-dimer. Radiological findings included the distribution and density of lesions, number of lobes involved, presence of air bronchogram sign and bronchodilation, and degree of involvement of each lung lobe as determined using a semi-quantitative CT scoring system. Under this scoring system, no involvement corresponded to a score of 0, 1% to 25% involvement to a score of 1, 25% to 50% involvement to a score of 2, 50% to 75% involvement to a score of 3, and >75% involvement to a score of 4.

**Statistical analyses**

Receiver operating characteristic (ROC) curves were generate to assess the sensitivity and specificity of different cut-offs of the incubation period and to determine the
optimal cut-off value. Continuous variables were expressed as medians and interquartile ranges (IQR) or as means ± standard deviations (SD). Categorical variables were expressed as numbers and percentages in each category. Mann–Whitney U tests were used to assess differences between continuous variables. Frequency comparisons were conducted using the $\chi^2$ or Fisher’s exact tests. Associations between different incubation periods and clinical characteristics were evaluated using logistic regression or Pearson correlation coefficients. Statistical analyses were performed using SPSS software (IBM, Chicago, IL, USA). A two-sided p-value < 0.05 was considered statistically significant.

Results

Incubation period distribution and cut-off value selection

As of 15 March 2020, 149 discharged patients with COVID-19 had complete clinical and epidemiological data and were enrolled in the present study. Forty-seven patients who did not meet the inclusion criteria were excluded. The median incubation period was 7 days (IQR: 4–10 days) and the average incubation period was 7.48 days. ROC curves of the incubation periods of patients with severe and non-severe COVID-19 showed that the optimal cut-off value to maximize sensitivity and specificity in differentiating severe and non-severe patients was 7 days. Thus, we assumed that 7 days could be a suitable cut-off value to investigate associations between clinical characteristics and incubation periods in patients with COVID-19. Patients were stratified based on whether they had a shorter incubation period (≤7 days) or a longer incubation period (>7 days). Figure 1 depicts the cut-off value selection for the incubation period.

Clinical characteristics

Patient clinical characteristics are shown in Table 1. The median patient age was 41 years (IQR: 32–58 years) and 53.0% were men. A history of contact with confirmed patients was documented for 48.3% of patients. A minority of patients (13.4%) had a history of smoking. Furthermore, 46 (30.9%) patients had at least one comorbidity, with hypertension being the most common (16.1% of patients). There were

Figure 1. Cut-off value selection for incubation period. (a) The distribution of incubation periods shows that the median and average incubation period was 7 days and 7.48 days, respectively. (b) ROC curves of incubation period for differentiation of severe and non-severe COVID-19 patients. The AUC was 0.802 (95% CI: 0.71–0.89). The optimal cut-off value was 7 days.
|                                | All patients (n = 149) | Incubation period ≤ 7 days (n = 79) | Incubation period > 7 days (n = 70) | p value |
|--------------------------------|------------------------|-------------------------------------|------------------------------------|---------|
| **Age (years)**                |                        |                                     |                                    |         |
| 14–40                          | 70 (47.0%)             | 37 (46.8%)                          | 33 (47.1%)                        | 0.91    |
| 41–65                          | 58 (38.9%)             | 30 (38%)                            | 28 (40.0%)                        |         |
| >65                            | 21 (14.1%)             | 12 (15.2%)                          | 9 (12.9%)                         |         |
| **Sex**                        |                        |                                     |                                    | 0.09    |
| Male                           | 79 (53.0%)             | 41 (51.9%)                          | 38 (48.1%)                        |         |
| Female                         | 70 (47.0%)             | 38 (54.3%)                          | 32 (45.7%)                        |         |
| **Infection pathway**          |                        |                                     |                                    | 0.51    |
| Recently visited Wuhan         | 77 (51.7%)             | 43 (54.4%)                          | 34 (48.6%)                        |         |
| Contact with confirmed case    | 72 (48.3%)             | 36 (45.6%)                          | 36 (51.4%)                        |         |
| **Smoking history**            |                        |                                     |                                    | 0.08    |
| Chronic obstructive pulmonary disease | 3 (2%)    | 2 (3%)                              | 1 (1%)                            | 0.63    |
| Hypertension                   | 24 (16.1%)             | 15 (19.0%)                          | 9 (12.9%)                         | 0.31    |
| Diabetes                       | 8 (5.4%)               | 3 (3.8%)                            | 5 (7.1%)                          | 0.37    |
| Coronary heart disease         | 3 (2.0%)               | 1 (1.3%)                            | 2 (2.9%)                          | 0.49    |
| Hepatitis B infection          | 5 (3.4%)               | 4 (5.1%)                            | 1 (1.4%)                          | 0.37    |
| Any                            | 46 (30.9%)             | 27 (34.2%)                          | 19 (27.1%)                        | 0.35    |
| **Onset symptoms**             |                        |                                     |                                    |         |
| Fever                          | 96 (64.4%)             | 50 (63.3%)                          | 46 (65.7%)                        | 0.76    |
| Cough                          | 68 (45.6%)             | 35 (44.3%)                          | 33 (47.1%)                        | 0.73    |
| Fatigue                        | 22 (14.8%)             | 14 (17.7%)                          | 8 (11.4%)                         | 0.28    |
| Sore throat                    | 16 (10.7%)             | 12 (15.2%)                          | 4 (5.7%)                          | 0.06    |
| More than one onset symptom    | 90 (60.4%)             | 54 (68.4%)                          | 36 (51.4%)                        | 0.04    |
| **Disease severity**           |                        |                                     |                                    | <0.01   |
| Non-severe                     | 134 (89.9%)            | 65 (82.3%)                          | 69 (98.6%)                        |         |
| Severe                         | 15 (10.1%)             | 14 (17.7%)                          | 1 (1.4%)                          |         |
| **Clinical outcomes**          |                        |                                     |                                    | 1.00    |
| Discharge from hospital        | 148 (99.3%)            | 78 (98.7%)                          | 70 (100%)                         |         |
| Death                          | 1 (0.7%)               | 1 (1.3%)                            | 0 (0%)                            |         |
| **Time from onset to admission (days)** | 4 (3–7)    | 5 (3–8)                             | 4 (2–6)                           | 0.06    |
| Median (IQR)                   | 5.23 ± 3.32            | 5.72 ± 3.09                         | 4.67 ± 3.50                       |         |
| Mean ± SD                      |                        |                                    |                                    |         |
| **Time during hospitalization (days)** | 13 (11–19)          | 16 (12–26)                          | 12 (11–16)                        | <0.01   |
| Median (IQR)                   | 16.18 ± 8.03           | 18.85 ± 9.14                        | 13.31 ± 4.89                      |         |
| Mean ± SD                      |                        |                                    |                                    |         |
| **Time from onset to discharge (days)** | 19 (16–24)          | 20 (18–27)                          | 17 (15–21)                        | <0.01   |
| Median (IQR)                   | 21.61 ± 8.07           | 23.39 ± 8.28                        | 17.99 ± 4.92                      |         |
| Mean ± SD                      |                        |                                    |                                    |         |

Data are presented as median (IQR), mean ± SD, or n (%). The p values denote comparisons between patients with incubation periods ≤ 7 days and patients with incubation periods > 7 days. IQR, interquartile range; SD, standard deviation.
no significant differences in any of these variables between patients with short or long incubation periods. The most common symptoms at disease onset were fever (64.4%), cough (45.6%), and fatigue (14.8%). Ninety (60.4%) patients had more than one symptom at the time of symptom onset. Compared with patients who had a longer incubation period (>7 days), those with a shorter incubation period (≤7 days) were significantly more likely to have severe disease at diagnosis (p < 0.01), a longer duration of hospitalization (p < 0.01), and a longer time from symptom onset to discharge (p < 0.01).

**Laboratory and radiological findings**

We next compared the laboratory and radiological findings (Table 2) of patients

| Laboratory findings | All patients (n=149) | Incubation period ≤ 7 days (n=79) | Incubation period > 7 days (n=70) | p value |
|---------------------|----------------------|----------------------------------|----------------------------------|---------|
| White blood cell count, >10×10⁹/L | 19 (12.8%) | 15 (19.0%) | 4 (5.7%) | 0.02 |
| Lymphocyte count, >1×10⁹/L | 19 (12.8%) | 9 (11.4%) | 10 (14.3%) | 0.60 |
| Total bilirubin, >21 mmol/L | 20 (12.6%) | 12 (15.3%) | 8 (11.4%) | 0.70 |
| Alanine aminotransferase, >40 U/L | 32 (21.5%) | 20 (25.3%) | 12 (17.1%) | 0.23 |
| Aspartate aminotransferase, >40 U/L | 29 (19.5%) | 20 (25.3%) | 9 (12.9%) | 0.41 |
| Lactate dehydrogenase, >225 U/L | 42 (28.2%) | 28 (35.4%) | 14 (20.0%) | 0.04 |
| Procalcitonin, >0.05 ng/mL | 31 (20.8%) | 19 (24.1%) | 12 (17.1%) | 0.30 |
| Blood urea nitrogen, >8.2 mmol/L | 10 (6.7%) | 9 (11.4%) | 1 (1.4%) | 0.02 |
| Creatinine, >104 μmol/L | 5 (3.3%) | 3 (3.8%) | 2 (2.9%) | 0.90 |
| Creatinine kinase, >200 U/L | 23 (15.4%) | 15 (19.0%) | 8 (11.4%) | 0.20 |
| D-dimer, >1 mg/L | 14 (9.4%) | 9 (11.4%) | 5 (7.1%) | 0.41 |
| **Radiological findings** | | | | |
| **Density** | | | | |
| Pure ground-glass opacity | 9 (6.0%) | 2 (2.5%) | 7 (10.0%) | 0.06 |
| Pure consolidation | 18 (12.1%) | 13 (16.5%) | 5 (7.1%) | 0.08 |
| Mixed lesions | 107 (71.8%) | 57 (72.2%) | 50 (71.4%) | 0.92 |
| **Distribution** | | | | |
| Bilateral | 104 (69.8%) | 60 (75.9%) | 44 (62.9%) | 0.08 |
| Unilateral | 30 (20.1%) | 12 (15.2%) | 18 (25.7%) | 0.11 |
| **Bronchus** | | | | |
| Air bronchogram sign | 48 (32.2%) | 30 (38.0%) | 18 (25.7%) | 0.11 |
| Bronchodilation | 26 (17.4%) | 18 (22.8%) | 8 (11.4%) | 0.07 |
| No abnormal findings | 15 (10.1%) | 7 (9.0%) | 8 (11.4%) | 0.60 |
| **Average number of lobes involved** | | | | 0.04 |
| Median (IQR) | 3 (2-4) | 3 (2-5) | 2 (1-4) | |
| Mean ± SD | 2.99 ± 1.53 | 3.35 ± 1.51 | 2.67 ± 1.46 | |
| **CT score** | | | | 0.11 |
| Median (IQR) | 4 (2-6) | 4 (2-7) | 3 (1-5) | |
| Mean ± SD | 4.28 ± 3.20 | 4.84 ± 3.77 | 3.73 ± 2.45 | |

Data are presented as the median (IQR), mean ± SD, or n (%).
The p values denote comparisons between patients with incubation periods ≤7 days and patients with incubation periods > 7 days.

IQR, interquartile range; SD, standard deviation; CT, computed tomography.
with shorter and longer incubation periods. Elevated levels of alanine aminotransferase, lactate dehydrogenase, and procalcitonin were observed in 21.5%, 28.2%, and 20.8% of patients, respectively. Patients with longer incubation periods had significantly higher white blood cell counts \((p = 0.02)\), lactate dehydrogenase levels \((p = 0.04)\) and blood urea nitrogen levels \((p = 0.02)\) compared with patients with shorter incubation periods. No abnormal findings were observed on chest CT images in 15 (10.1%) patients. Mixed lesions (71.8%), bilateral lesion distribution (68.9%), and the air bronchogram sign (32.2%) were the most common CT findings. Patients with shorter incubation periods had significantly greater lung lobe involvement \((p < 0.04)\) on chest CT images than did patients with longer incubation periods. CT scores did not differ significantly between the groups.

**Association between incubation period and prognosis**

A univariate logistic regression analysis revealed that the time from symptom onset to discharge was independently associated with incubation period length \((p < 0.01; \text{Table } 3)\). Pearson correlation analyses revealed that the time from onset to discharge was significantly inversely correlated with the length of the incubation period \((p < 0.01; \text{Figure } 2)\).

**Discussion**

Assessment of COVID-19 patients in the Hunan province of China is advantageous for several reasons. First, there are fewer laboratory-confirmed COVID-19 patients in Hunan province than in Hubei province. Furthermore, strict government regulations mandating compulsory isolation and epidemiological investigation of patients, prohibiting public gatherings, and requiring supervision of close contacts allow patients to totally isolate themselves following contact with individuals from Hubei or confirmed COVID-19 cases, prior to confirmation of their own infection status. Thus, the incubation periods been reported for patients in the present study are quite accurate. By assessing patients’ medical histories, conducting telephone follow-ups, and applying strict inclusion and exclusion criteria, we were able to evaluate the contact histories and clinical endpoints of 149 patients with COVID-19. Using this approach, we were able to examine associations between the incubation period and the clinical characteristics of COVID-19 patients. To the best of our knowledge, no previous studies have examined these associations.

**Table 3.** Univariate logistic regression analysis of factors related to incubation period.

| Factors                                      | OR   | 95% CI      | p value |
|----------------------------------------------|------|-------------|---------|
| More than one onset symptom                   | 1.11 | 0.53–2.34   | 0.78    |
| Disease severity                             | 2.75 | 0.24–31.39  | 0.42    |
| Time during hospitalization                   | 1.10 | 0.98–1.24   | 0.12    |
| Time from onset to discharge                 | 0.81 | 0.71–0.92   | <0.01   |
| White blood cell count, >10 \times 10^9/L    | 1.41 | 0.36–5.45   | 0.62    |
| Lactate dehydrogenase, >225 U/L              | 1.10 | 0.44–2.71   | 0.85    |
| Blood urea nitrogen, >8.2 mmol/L             | 6.43 | 0.58–71.86  | 0.13    |
| Average number of lobes involved             | 0.77 | 0.60–1.01   | 0.06    |

OR, odds ratio; CI, confidence interval.
In the present study, the mean incubation period was approximately 7 days. This incubation period is similar to that reported by Backer et al.\textsuperscript{14} (6.4 days), but slightly longer than that reported by Li et al.\textsuperscript{8} (5.2 days) and Guan et al.\textsuperscript{9} (4.0 days). This discrepancy may be related to the different geographical regions and populations studied.

We observed no significant differences between patients with an incubation period \(\leq 7\) days and those with an incubation period \(>7\) days in terms of age, sex, infection pathway, or comorbidities. It is possible that no difference in infection pathway was detected because patients who had previously lived in Hubei province for an extended period were excluded to reduce confounding and to more accurately calculate the incubation period. However, these strict exclusion criteria may have also introduced some selection bias.

Notably, an association between increased risk of death and a shorter incubation period was previously described in patients with severe acute respiratory syndrome.\textsuperscript{15} Our results dovetail with these prior ones, revealing significant differences in disease severity in patients with differing incubation periods. Moreover, other factors related to disease severity, including the duration of hospitalization and time from disease onset to discharge, also varied based on the length of the incubation period. In addition, patients with a shorter incubation period exhibited: 1) a higher number of symptoms at symptom onset; 2) abnormal laboratory findings, including elevated levels of white blood cells, lactate dehydrogenase, and blood urea nitrogen; and 3) radiological findings indicating greater lung lobe involvement. These results indicated that a shorter incubation period may be associated with a stronger inflammatory response and heart or kidney dysfunction, as observed in severely ill COVID-19 patients.\textsuperscript{16,17} Univariate logistic regression modeling and correlation analyses further revealed that a shorter incubation period was associated with a longer duration of hospitalization and a longer time between symptom onset and discharge. Our results do not indicate that the incubation period itself was casually related to disease severity, but rather that this period may serve as a marker of disease severity and prognosis.
Our study had several limitations. First, as a single-center study, the clinical characteristics of the patients included here may not be representative of those in the broader population. Therefore, these results should be confirmed by larger, multi-center clinical studies. Second, as we only had access to data on confirmed patients from a single hospital, some severely ill patients not seen at this hospital, particularly during the early stages of the epidemic, were not included. Finally, despite government-directed measures and the collection of a large pool of patient and contact data, the contact history of patients was self-reported and could thus be subject to information bias.

**Conclusions**

The associations between incubation period and clinical characteristics of COVID-19 patients in the present study suggest that the incubation period may be a useful marker of disease severity and prognosis. Clinicians should be aware of the importance of the incubation period for treatment of patients with COVID-19.

**Ethics approval and consent**

This study was approved by our institutional medical ethics committee (approval number: 2020004) and was performed in accordance with the ethical standards laid out in the 1964 Declaration of Helsinki and its later amendments. The requirement for informed consent was waived given the retrospective nature of this study as per the Council for International Organizations of Medical Sciences guidelines.

**Availability of data and material**

The materials described in the manuscript are freely available to any scientist wishing to use them for non-commercial purposes.

**Reporting checklist statement**

The authors have completed the STROBE reporting checklist.

**Acknowledgements**

We would like to convey our greatest respects to the medical personnel who are fighting COVID-19. The authors received no financial support for the research, authorship, and/or publication of this article.

**Author contributions**

Enhua Xiao and Qizhi Yu conceived the study. Haitao Yang, Deng Huang, and Qizhi Yu curated the data. Mian Wang and Qingping Guo provided formal analysis. Enhua Xiao conducted the investigation. Zhu Chen, Quan-Liang Shang, and Cong Ma were responsible for the methodology. Enhua Xiao was responsible for project administration. Qizhi Yu and Enhua Xiao provided the resources. Taili Chen supervised the study. Qizhi Yu provided validation. Jiayi Liu and Yeyu Cai wrote the original draft. Yeyu Cai was responsible for writing, review and editing.

**Declaration of conflicting interest**

The authors declare that there is no conflict of interest.

**Funding**

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

**ORCID iD**

Enhua Xiao [https://orcid.org/0000-0002-3281-6384](https://orcid.org/0000-0002-3281-6384)

**References**

1. Park A, Chute C, Rajpurkar P, et al. Deep learning–assisted diagnosis of cerebral aneurysms using the HeadXNet model. *JAMA Network Open* 2019; 2: e195600. DOI: 10.1001/jamanetworkopen.2019.5600.
2. Zhu N, Zhang D, Wang W, et al. A novel coronavirus from patients with pneumonia in China, 2019. *N Engl J Med* 2020; 382: 727–733. DOI: 10.1056/NEJMoa2001017.
3. Lei J, Li J, Li X, et al. CT imaging of the 2019 novel coronavirus (2019-nCoV)
pneumonia. Radiology 2020; 295: 18. DOI: 10.1148/radiol.2020200236.

4. Chan JFW, Yuan S, Kok KH, et al. A familial cluster of pneumonia associated with the 2019 novel coronavirus indicating person-to-person transmission: a study of a family cluster. Lancet 2020; 395: 514–523. DOI: https://doi.org/10.1016/S0140-6736(20)30154-9.

5. Phan LT, Nguyen TV, Luong QC, et al. Importation and human-to-human transmission of a novel coronavirus in Vietnam. N Engl J Med 2020; 382: 872–874. DOI: 10.1056/NEJMec2001272.

6. Rothe C, Schunk M, Sothmann P, et al. Transmission of 2019-nCoV infection from an asymptomatic contact in Germany. N Engl J Med 2020; 382: 970–971. DOI: 10.1056/NEJMec2001468.

7. Wu JT, Leung K and Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: A modelling study. Lancet 2020; 395: 689–697. DOI: 10.1016/S0140-6736(20)30260-9.

8. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus–infected pneumonia. N Engl J Med 2020; 382: 1199–1207. DOI: 10.1056/NEJMoa2001316.

9. Guan WJ, Ni ZY, Hu Y, et al. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med 2020; 382: 1708–1720. DOI: 10.1056/NEJMoa200232.

10. Linton NM, Kobayashi T, Yang Y, et al. Incubation period and other epidemiological characteristics of 2019 novel coronavirus infections with right truncation: A statistical analysis of publicly available case data. J Clin Med 2020; 9: 538. DOI: 10.3390/jcm9020538.

11. China National Health Commission. Diagnosis and treatment of pneumonitis caused by new coronavirus (trial version 5). Beijing: China National Health Commission, 2020. http://www.nhc.gov.cn/yy是对/s7653p/202001/4294563ed35b43209b31739bd0785e67.shtml (accessed Feb 15, 2020).

12. Clinical management of severe acute respiratory infection when novel coronavirus (2019-nCoV) infection is suspected: interim guidance, (2020, accessed 28 February 2020).

13. Chung M, Bernheim A, Mei X, et al. CT imaging features of 2019 novel coronavirus (2019-nCoV). Radiology 2020; 295: 202–207. DOI: 10.1148/radiol.2020200230.

14. Backer JA, Klinkenberg D and Wallinga J. Incubation period of 2019 novel coronavirus (2019-nCoV) infections among travellers from Wuhan, China, 20-28 January 2020. Euro Surveill 2020; 25: 2000062. DOI: 10.2807/1560-7917.es.2020.25.5.2000062.

15. Virlogeux V, Fang VJ, Wu JT, et al. Incubation period duration and severity of clinical Disease following severe acute respiratory syndrome coronavirus infection. Epidemiology 2015; 26: 666–669. DOI: 10.1097/ede.0000000000000339.

16. Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. Lancet 2020; 395: 497–506. DOI: 10.1016/s0140-6736(20)30183-5.

17. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. JAMA 2020; 323: 1061–1069. DOI: 10.1001/jama.2020.1585.