CASE REPORT

An Insight of the First Community Infected COVID-19 Patient in Beijing by Imported Case: Role of Deep Learning-Assisted CT Diagnosis

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Abstract In the era of coronavirus disease 2019 (COVID-19) pandemic, imported COVID-19 cases pose great challenges to many countries. Chest CT examination is considered to be complementary to nucleic acid test for COVID-19 detection and diagnosis. We report the first community infected COVID-19 patient by an imported case in Beijing, which manifested as nodular lesions on chest CT imaging at the early stage. Deep Learning (DL)-based diagnostic systems quantitatively monitored the progress of pulmonary lesions in 6 days and timely made alert for suspected pneumonia, so that prompt medical isolation was taken. The patient was confirmed as COVID-19 case after nucleic acid test, for which the community transmission was prevented timely. The roles of DL-assisted diagnosis in helping radiologists screening suspected COVID cases were discussed.

SINCE the outbreak of coronavirus disease 2019 (COVID-19) at the end of December 2019, the pathogen of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has rapidly spread worldwide and resulted in a pandemic.^[1] To date, countries worldwide are actively taking great efforts to manage various rough situations to prevent spreading of COVID-19 and flatten the curve.

In China, the prevention of wide community transmission and second-wave outbreak currently are the focuses of public health system. Imported COVID-19 patients and asymptomatic carriers brought great challenges while resuming the regular economic activities. Thus, precise and stratified epidemic control strategies have been adopted to monitor people's health status in Beijing, which includes concentrated observation, home-based isolation, digital health certification, travel record monitoring, and so forth. Of note, deep learning (DL)-based diagnostic system integrated into the CT examination is a novel technique in screening imported

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cases of suspected COVID-19, and has been proved to be applicable in clinical practice.^[2] Here, we report the first imported case of COVID-19 infection in Beijing (the second case nationwide) and revealed nodular lesions as the early manifestation of this COVID-19 patient. The auxiliary roles of DL-based diagnostic systems were discussed in detail.

CASE DESCRIPTION

First visit to hospital

A 42-year-old male visited the fever clinic of the Beijing Haidian Hospital because of cough. The patient reported a transient fever 4 days ago and his body temperature peaked at 37.5°C and returned back normal by itself. No other symptoms. The patient denied direct contact or exposure history with any confirmed or suspected COVID-19 patients, nor did he travel out of Beijing or abroad. An imported COVID-19 case confirmed two days ago was undergoing home-based isolation in his residential community.

Laboratory examination showed normal counts of leukocyte ($4.13 \times 10^9/L$), neutrophil ($2.4 \times 10^9/L$), and lymphocyte ($1.36 \times 10^9/L$). C-reactive protein (CRP) level ($< 0.5 \text{ mg/mL}$) were within the reference ranges. Antigen tests for influenza A and B virus were negative too.

CT examination

The patient underwent CT examination on a multi-slice spiral CT scanner (uCT530, United Imaging, Shanghai, China) using low dose scanning protocol. The parameters were as follows: tube voltage 120KV, automatic tube current adjustment, reconstruction slice thickness 1.0 mm, slice interval 1.0 mm. CT images were saved in the picture archiving and communication system for interpretation and analysis.

Deep learning-based diagnostic systems

The diagnostic systems based on deep learning techniques (InferRead CT Pneumonia and InferRead CT Lung, Infervision, Beijing) were deployed in our hospital and used to screen suspected cases of COVID-19. The InferRead CT Lung system was developed using hundreds of thousands of annotated CT data with pathologically confirmed nodules for the purpose to detect and analyze pulmonary nodules. Pulmonary nodules on CT image can be automatically recognized, localized and characterized, based on which a score

for malignancy can be calculated using dedicated DL algorithm, and temporal changes can be monitored. The InferRead CT Pneumonia was developed with large amount data of COVID-19 cases and other community-acquired pneumonia cases in collaboration with hospitals in Wuhan, China. Experienced radiologists delineated the inflammatory lesions on CT images, which were used to train the DL algorithm of the diagnostic system to recognize subtle features on CT images. The diagnostic system can output predicting scores for COVID-19 and provide annotation, corresponding volume, as well as volumetric proportions of a recognized lesion areas in lobes and lungs.

The CT images were sent to the DL-based diagnostic systems for analysis, where a prediction result could be processed within 2 minutes. The diagnostic systems highlight the case of high risk and list it in a separate window before radiologists start interpreting CT images, so that timely isolation and treatment of high risk COVID-19 cases become possible.

Diagnosis and management

On the first CT examination, the InferRead CT Lung system alerted the presence of solid and ground glass nodules in both lungs, which was further confirmed by junior and senior radiologists. Given the absence of epidemiological exposure, normal laboratory examination results, and no inflammatory finding on chest CT, the patient was not suspected for COVID-19 at that moment; he received regular symptomatic treatment with Tylenol and Lianhua Qingwen Capsule. Close follow-up was suggested.

Six days later, the patient revisited the fever clinic, complaining about sustained low fever, cough, and intermittent chest tightness. Physical examination showed body temperature 37.5°C, peripheral oxygen saturation 98%. The patient recalled a fever three days ago with body temperature peaked at 37.7 °C. Of note, the patient reported that the confirmed COVID-19 case in his community was his neighbor downstairs who had ever gone out during quarantine, so the patient had a high possibility of being exposed with this COVID-19 positive neighbor due to they usually took the same stairway.

The Laboratory examinations and chest CT examination were performed promptly. Leukocyte count ($5.75 \times 10^9/L$), neutrophil count ($3.44 \times 10^9/L$), lymphocyte count ($1.82 \times 10^9/L$), and C-reactive protein level ($< 0.5 \text{ mg/mL}$) were still within the reference

ranges. The InferRead CT Lung system revealed growth of the nodules detected 6 days before, with multiple new lesions found. Details of all detected lesions and changes are presented in **Table 1**. Meanwhile, CT Pneumonia system alerted radiologists for a suspected COVID-19 infection case, and annotated inflammatory lesions on chest CT images. A senior radiologist further confirmed the imaging findings. The representative lesions interpreted by the systems were presented in **Fig. 1**. Given the typical clinical symptoms, high epidemiological exposure probability, the suspected infection of COVID-19 on CT images, and the increased risk of community transmission by the imported COVID-19 case, the patient was regarded as the suspected COVID-19 case by an expert group

of hospital, and then immediately underwent medical isolation, took throat swab and rRT-PCR test for SARS-CoV-2, which finally confirmed the COVID-19 infection (mild type). Of note, due to the timely isolation upon rapid diagnosis, there was no new SARS-CoV-2 infection or community spread of COVID-19. The patient received antiviral treatment under medical isolation in a designated hospital for COVID-19 and was discharged from hospital after two consecutive negative rRT-PCR tests.

DISCUSSION

Screening imported COVID-19 cases and preventing the related community transmission have become the key task in China during the global pandemic of

Table 1. Summary of pulmonary lesions of the first imported COVID-19 patient in Beijing interpreted by a DL-based diagnostic system

Lesion No.	Location	Density type	Volume ^a (mm ³)			Alerts
			First visit	Second visit	Alteration ^b	
1	APLU	Solid	ND	8.41	+	/
2	APLU	Solid	35.83	39.34	+	/
3	ARU	Solid	ND	3.98	+	/
4	ARU	Solid	9.03	14.76	+	/
5	ARU	Solid	17.97	21.27	+	/
6	ARU	Solid	9.07	5.28	-	/
7	APLU	Solid	10.24	23.03	++	/
8	AnRU	GGO	ND	10.40	++	/
9	AnRU	Solid	9.00	7.09	-	/
10	APLU	Solid	ND	13.60	+	/
11	AnLU	Solid	ND	11.53	++	/
12	DRL	Solid	ND	20.38	++	/
13	DLL	Solid	5.97	4.21	-	/
14	PRU	Solid	ND	4.85	+	/
15	PBRL	GGO	ND	606.17	+++	/
16	PBLL	Solid	ND	11.06	++	/
17	Interlobular	Solid	ND	16.28	++	/
18	MBRL	GGO	309.42	140.04	- - -	Suspected Pneumonia
19	MBRL	SM	ND	4713.95	++++	Suspected Pneumonia
20	MRM	Solid	3.47	6.65	+	/
21	PBRL	SM	105.08	7784.19	++++	Suspected Pneumonia
22	PBRL	GGO	ND	46.98	++	/
23	LBRL	GGO	ND	35.46	++	/
24	MBRL	GGO	ND	215.55	+++	Suspected Pneumonia
25	PBRL	GGO	ND	202.37	+++	/
26	PBRL	GGO	ND	54.07	++	/
27	PBRL	SM	34.17	5136.25	++++	Suspected Pneumonia

Continued Table 1. Summary of pulmonary lesions of the first imported COVID-19 patient in Beijing interpreted by a DL-based diagnostic system

Lesion No.	Location	Density type	Volume ^a (mm ³)			Alerts
			First visit	Second visit	Alteration ^b	
28	PBRL	GGO	ND	32.30	++	/
29	PBRL	SM	ND	4821.64	++++	Suspected Pneumonia
30	LBRL	mGGO	ND	207.56	+++	Suspected Pneumonia
31	LBRL	GGO	ND	43.72	++	/
32	APLU	Solid	17.11	ND	NA	NA

APLU, apical posterior segment of left upper lobe; ARU, apical segment of right upper lobe; AnRU, anterior segment of right upper lobe; AnLU, anterior segment of left upper lobe; DRL, dorsal segment of right lower lobe; DLL, dorsal segment of left lower lobe; PRU, posterior segment of right upper lobe; PBRL, posterior basal segment of right lower lobe; PBLL, posterior basal segment of left lower lobe; MBRL, medial basal segment of right lower lobe; MRM, medial segment of right middle lobe; LBRL, lateral basal segment of right lower lobe; GGO, ground glass opacity; mGGO, mixed ground glass opacity; SM, suspected mass. ND, not detected; NA, not applicable.

^a Measured by the InferRead CT Lung system. ^b volume increase: +, < 10 mm³; ++, 10 - 100 mm³; +++, 100 - 1000 mm³; +++, 1000 - 10 000 mm³; volume decrease: -, < 10 mm³; --, 10 - 100 mm³; ---, 100 - 1000 mm³.

Figure 1. Image findings of a COVID-19 patient analyzed using deep learning (DL)-based CT diagnostic systems.

(A) Ground glass opacity nodular detected on the prior CT scan developed to pneumonia-like lesions on the primary CT scan. The DL-based diagnostic system (CT Lung) detected it and quantitatively monitored the growth. (B) A new nodule on the primary CT scan was alerted as medium risk for malignancy. (C) A ground glass opacity detected in the medial basal segment of the right lower lobe on the primary CT scan was automatically registered and compared with the prior one quantitatively, with a significant volume increase to 15.68 times, which suggested the rapid development pattern of inflammatory lesion. (D) The DL-based diagnostic system (CT Pneumonia) alerted the lesion in (C) as a suspected COVID-19 lesion on the primary CT scan, which was consistent to the diagnosis by the CT Lung system. Its volume proportions of the whole lungs and of the selected pulmonary lobes were calculated.

COVID-19. In addition to body temperature monitoring, rRT-PCR tests and concentrated observation are the standard procedures in screening returnees from abroad. Home-based observation is also suggested after the concentrated isolation. Considering the false-negative results of rRT-PCR, CT examination has been utilized as a complementary approach in many designated hospitals. In this study, we reported the first COVID-19 patient in Beijing (the second case nationwide) infected through an imported case. In this case, the DL-based CT diagnostic systems played an important role in timely diagnosis and transmission block.

The reported case had no typical pneumonia presentations on chest CT images at its early stage; however, the detected nodules further developed to inflammatory lesions of patchy ground glass shadow and suspected masses. Although it has been previously reported that COVID-19 cases might manifested as only nodular lesions,^[3-5] this case suggests that nodular lesions could be the only imaging finding for COVID-19 patients at the early stage. Therefore, nodular lesions on CT might be used as potential imaging marker of COVID-19 infection. More studies are needed to support this hypothesis.

Considering the mild or asymptomatic COVID-19 patients,^[6, 7] and the false-negative of rRT-PCR examination,^[2, 8] timely detection of infected lesions using chest CT is of great value in screening suspected patients. However, large volume of daily CT workload makes the standard radiological diagnostic workflow impractical for rapid screening of COVID-19. In addition, some physicians, especially in primary care facilities, lack the diagnostic experience of COVID-19, or were unfamiliar with the manifestation of mild and asymptomatic cases. DL-based diagnostic systems^[9-12] just come in handy to conquer these problems. The DL based diagnostic system (CT Lung) assist radiologist to efficiently detect nodules on CT images, which helps in rapid detection of COVID-19 in its early stage. Besides, the registration of pulmonary nodules on the prior and the primary CT scans realizes the quantitative monitoring of the growth. In the current case, it detected and alerted the small nodules at the first visit which were later identified as inflammatory lesions by the changes of sizes. Obviously, DL-based diagnostic system (CT Lung) was an approach to efficiently screen suspected cases with nodular lesions, while intensive quantitative follow-up could help the characterization of nodular lesions.

In addition, the DL-based diagnostic system (CT Pneumonia) could directly detected the inflammatory lesions on CT scans and raise alarms to radiologist for priority processing; quantitative measurement of lesions also enable the evaluation of illness severity and the monitor the disease progress. In the current case, the system detected imaging manifestation of viral pneumonia and timely alerted the suspected COVID, for which medical isolation of the patient was enforced, and none of the other 199 people in the same residential building was infected. Potential community transmission of SARS-CoV-2 was terminated in time. DL-based CT diagnostic system played an important role in detecting COVID-19 infection, timely block the community transmission, even the second-wave outbreak.

Since more patients infected by imported cases were diagnosed, the prevention strategy and precautions for screening imported COVID-19 cases and their contacts had greatly improved in Beijing.

In conclusion, the first COVID-19 patient infected by the imported case in Beijing revealed pulmonary nodules as the potential CT findings of COVID-19 infection at early stage. The DL-based diagnostic systems present important values in assisting radiologists to promptly screen out suspicious imaging findings and quantitatively monitor the development of COVID-19 in clinical practice.

Consent

Written consent of the reported patient was acquired.

Conflict of interests

The author Dawei Wang and Chen Xia are employees of the Infervision Medical Technology Co., Ltd. and report personal fees outside the submitted work.

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个案报道

北京首例由输入病例导致社区感染的新型冠状病毒肺炎患者: 深度学习 CT 辅助诊断的作用

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摘要

在新型冠状病毒肺炎 (COVID-19) 全球大流行的时代, 输入型 COVID-19 病例给许多国家的疫情防控带来巨大挑战。对于 COVID-19 的检测和诊断, 胸部 CT 检查可以作为核酸检测结果的有效补充手段。我们报道了中国北京第一例由输入型病例获得 COVID-19 感染的患者。我们发现胸部 CT 上结节性病变是该 COVID-19 患者的早期影像学表现, 深度学习 (deep learning, DL) 辅助诊断系统定量监测患者肺部病变的发展情况, 并及时预警为疑似肺炎, 由此我们迅速对该患者进行了医学隔离。经核酸检测, 患者最终被确诊为 COVID-19, 因而社区传播获得了及时的控制。本文进一步讨论了基于 DL 的 CT 辅助诊断系统在协助医生筛查和预警 COVID-19 疑似病例过程中的作用。

关键词: 输入型病例; 新型冠状病毒肺炎; CT 检查; 深度学习; 诊断