Infection Control for CT Equipment and Radiographers' Personal Protection During the Coronavirus Disease (COVID-19) Outbreak in China

Jieming Qu[1]
Wenjie Yang[2]
Yanzhao Yang[2]
Le Qin[2]
Fuhua Yan[2]

OBJECTIVE. Because CT plays an important role in diagnosis, isolation, treatment, and effective evaluation of coronavirus disease (COVID-19), infection prevention and control management of CT examination rooms is important.

CONCLUSION. We describe modifications to the CT examination process, strict disinfection of examination rooms, arrangement of waiting areas, and efforts to increase radiographers' awareness of personal protection made at our institution during the COVID-19 outbreak. In addition, we discuss the potential of using artificial intelligence in imaging patients with contagious diseases.

Keywords: AI, artificial intelligence, coronavirus disease, COVID-19, infection control, personal protection, radiology operations, SARS-CoV-2

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J. Qu and W. Yang contributed equally to this study.

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[1]Department of Respiratory and Critical Care Medicine, Shanghai Jiao Tong University Medical School Affiliated Ruijin Hospital, Shanghai, China.

[2]Department of Radiology, Shanghai Jiao Tong University Medical School Affiliated Ruijin Hospital, No. 197 Ruijin Er Rd, Shanghai 200025, China. Address correspondence to F. Yan (yfh11655@rjh.com.cn).

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Since December 2019, the outbreak of pneumonia cases caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has resulted in the declaration of a public health emergency of international concern. This virus-induced disease was named coronavirus disease (COVID-19) by the World Health Organization [1, 2]. SARS-CoV-2 belongs to the genus *Betacoronavirus* in the family Coronaviridae. Previously, six coronaviruses have been identified as viruses to which humans are susceptible, including severe acute respiratory syndrome coronavirus (SARS-CoV) and Middle East respiratory syndrome coronavirus (MERS-CoV), both of which can also lead to severe and potentially fatal respiratory tract infections. SARS-CoV-2 is an enveloped nonsegmented positive-sense RNA virus, which could use angiotensin-converting enzyme 2 (ACE2), the same receptor as SARS-CoV, to infect humans; this receptor is responsible for lower respiratory tract infection [1, 3]. The clinical scenario of COVID-19 is diverse; serious cases can progress to severe pneumonia, acute respiratory distress syndrome, failure of one or more organs, and death, whereas nonsevere cases present ordinary symptoms of respiratory system infection.

Cluster infections among family members and medical workers confirmed human-to-human transmission [4]. An emerging acute respiratory infectious disease, COVID-19 primarily spreads through the respiratory tract by droplets, respiratory secretions, and direct contact [5]. SARS-CoV-2 has also been detected on fecal swabs [6]. The virus has been reported to remain viable for 3 hours in aerosols and for up to 72 hours on plastic and stainless steel; its varied median estimated half-lives (approximately 1.1–1.2 hours in aerosols, 5.6 hours on stainless steel, and 6.8 hours on plastic) complicate disinfection procedures [7]. Nosocomial transmission presents another severe problem. By February 12, 2020, 3019 Chinese health workers were infected, which accounted for 3.8% of total infections [8]. Nosocomial infections can burden the health system, impede medical services to patients, and accelerate transmission, resulting in high mortality.

Definitive diagnosis of SARS-CoV-2 relies on a positive result of high-throughput sequencing or real-time reverse transcriptase–polymerase chain reaction testing. However, because of the known false-negative rate and issues with availability of these laboratory-dependent tests, at the early stages of outbreak these methods have been insufficient for early diagnosis and epidemic management, especially in Wuhan and other epicenters worldwide.

Consequently, imaging plays an important role in the diagnostic workup of patients with suspected infection and treatment evaluation for patients confirmed to be infected. Quick identification of suspected cases is essential to prevent the spread of COVID-19. Be-

cause chest radiography is not sensitive for detection of ground-glass opacity (GGO) and may yield false-negative findings in early stages of infection, it was not recommended as the first-line imaging modality for COVID-19 in the Chinese diagnosis and treatment guidelines promulgated by the Chinese National Health Committee [9, 10]. However, chest radiography (including portable radiography) remains useful for follow-up examination, especially in severe cases.

Chest CT is widely used to assess patients with COVID-19. Recent publications have described common lung CT manifestations of the disease [11–14]. Depending on the disease stage, CT manifestations vary from pure GGO or mixed GGO to consolidations, with a predominance in the subpleural lung field and lower lobes. In patients with severe COVID-19, CT has even shown diffuse lung lesions described as "white lungs."

Infection Prevention and Control in CT Examination Areas

Modification of CT Examination Process

Since the outbreak of COVID-19, all medical institutions in China have been required to set up a triage system for screening and to designate fever clinics for patients with suspected COVID-19 symptoms. Approximately 15,000 fever clinics have been set up throughout the country. The arrangement of these clinics is critical to discover suspected cases and to ascertain the developing trend of disease, but most fever clinics are relatively simple and do not include CT equipment. To undergo CT, patients have to leave the fever clinic and go to an examination room in other parts of the institution, such as the emergency department. Furthermore, CT examination rooms are not designed according to the rule of three zones and two aisles (clean zone, semicontaminated zone, and contaminated zone; patient aisle and health care worker aisle) for spaces in which contagious diseases are being treated.

Some medical institutions expedited installation of dedicated CT scanners exclusively for use with patients in fever clinics. This availability allows quick diagnosis, helps avoid cross infection, and permits isolation, prevention, and control of suspected cases. For example, in our hospital, we were able to urgently install a CT scanner in the fever clinic at the beginning of the outbreak, which allowed rapid screening and early diagnosis (Fig. 1). A safe infection control strategy for examination of patients with suspected SARS-CoV-2 infection was also generated, including reconstructing the area, planning the path patients would take, disinfecting the examination room, and protecting radiographers. We converted the walking pathway to be one-way with limited entrances and exits and assigned and separated contaminated zones from clean zones.

In hospitals without dedicated CT scanners, specific examination times should be designated for imaging patients with suspected SARS-CoV-2 infection. Patients need to wear surgical masks and be accompanied by a nurse. Radiographers should be informed by telephone in advance that potentially contagious patients are coming for imaging both to reduce the waiting time for those patients and to prevent other patients from coming into contact with patients from the fever clinic. After patients with suspected infection have been scanned, strict disinfection procedures should be followed for equipment and the overall examination area.

Disinfection of CT Examination Rooms

According to results from Nyirenda et al. [15], knowledge of infection control among radiographers can be suboptimal. During the COVID-19 outbreak, our institution's infection control department updated infection prevention and control recommendations for the CT division (Table 1). Scanning room disinfection included use of an air disinfector that was equipped with a maximum air volume of 4000 m^3/h. The air disinfector can be used dynamically with or without manual operation.

Additionally, a movable ultraviolet light (30 W; to be effective, the intensity of the ultraviolet light must be higher than 70 $\mu W/cm^2$ per meter) should be used for examination room disinfection three times a day when examinations are not taking place, for more than 30 minutes each time. Nonplastic equipment surfaces, radiation protection items, and doorknobs should be disinfected with a solution that is at least 75% alcohol or with alcohol-containing wipes after each scan. Plastic surfaces should be cleaned only with soap solution. If technicians are uncertain of the material in an equipment surface, they should contact the equipment vendor to determine appropriate methods for disinfection. Caution should be exercised when using disinfectant sprays, because they may penetrate equipment, resulting in short circuits, metal corrosion, or other damage.

The floor of scanning room should be disinfected with disinfectant containing 2000 mg Cl per liter of water. At least twice a day, any visible contaminants should be completely removed with disposable absorbent material with the surrounding area subsequently disinfected. All patient waste should be regarded as infectious medical waste and managed in strict accordance with regulations on the management of medical wastes and of COVID-19 in health institutions, such as that published by the National Health

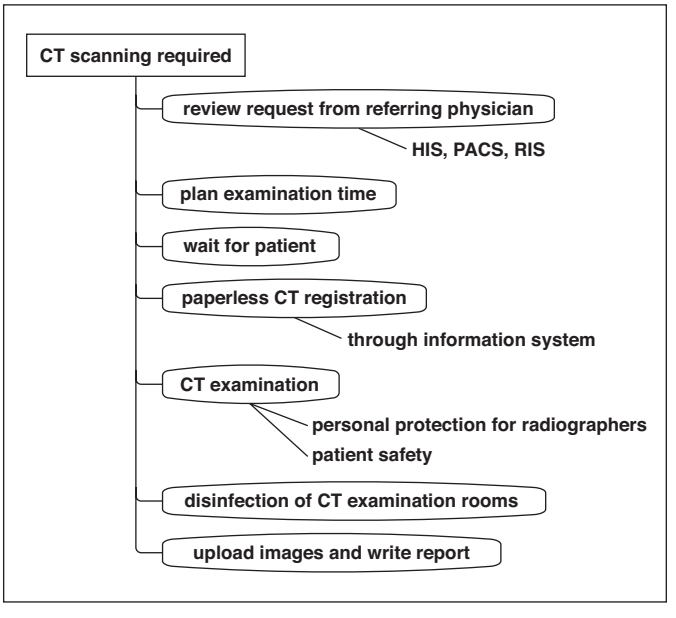

Fig. 1—CT flowchart in fever clinics. HIS = hospital information system, RIS = radiology information system.

TABLE 1: Disinfection of CT Examination Rooms

Disinfecting Item	Use
Air disinfector	Used dynamically with or without conscious operation
Movable ultraviolet light (≥ 70 μW/cm^2 per meter)	Three times per day for at least 30 min (when examinations are not taking place)
75% alcohol solution or alcohol-containing disinfectant wipe	To disinfect equipment surfaces
Soap solution	To clean plastic surfaces
Disinfectant containing 2000 mg Cl per liter of water	To clean the floor of the examination room
Disposable absorbent material	To clean visible contaminants

Commission of the People's Republic of China [10].

Waiting Area

In general, the space in the waiting area outside a CT examination room is limited and can be crowded, which increases the chance of cluster infection and the risk of cross infection. Before the installment of a dedicated CT scanner in our fever clinic, to avoid clusters of patients, we arranged a specific time period in advance for patients with fever to allow them to be transferred to the CT examination room as quickly as possible. Within the fever clinic, CT examinations are scheduled as needed via the information system. All of these arrangements were made to minimize contact and avoid cross infection in the waiting area.

Personal Protection Measures for Radiographers

Strengthen Training and Supervision of Infection Control

Although they are members of the radiology staff, radiographers' awareness of prevention and control of infectious diseases can be poor, particularly with regard to biohazard situations. During the MERS outbreak in Korea in 2015, Ki et al. [16] reported an instance of nosocomial MERS infection in a radiographer that resulted from talking to and touching an infected patient. According to another report of the MERS outbreak in Jeddah, Saudi Arabia, radiographers had the highest infection rate (29.4%) among affected healthcare workers [17]. Since the outbreak of COVID-19, both the Chinese government and our hospital have strengthened special biohazard training and regular supervision, with constant optimization of clinical workflow to minimize infection of medical staff. As mentioned, a total of 3019 Chinese medical workers had been infected with COVID-19 by February 12, 2020, accounting for 3.8% of the overall confirmed cases in China; this figure unfortunately includes radiographers. Because radiographers have direct contact with patients, levels of protection higher than what might be appropriate for other radiology department staff must be emphasized.

Personal Protection for Radiographers

Personal protection of radiographers is necessary, especially in fever clinics (Fig. 2). In addition, a fixed roster for radiographers who work on the frontline is preferable, with a 2-week rotation.

Our radiographers put on protective equipment items in the clean zone and discard them in the buffer zone after a shift is com-

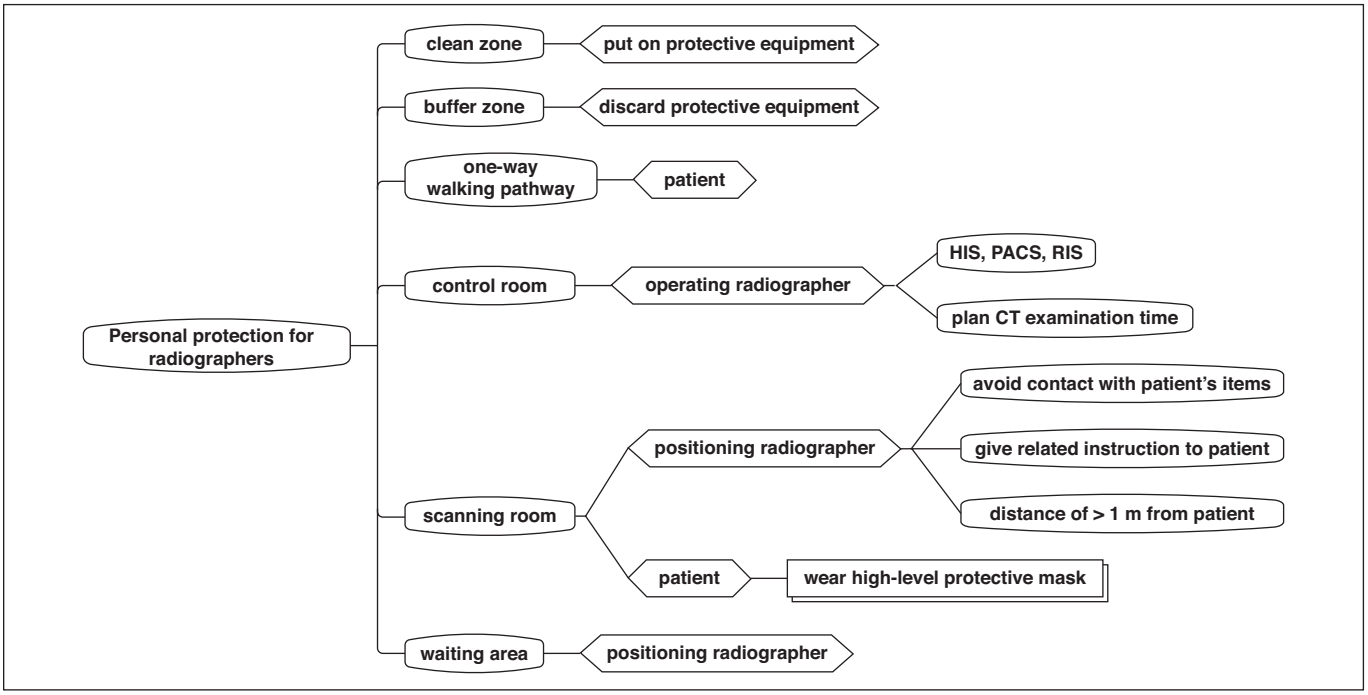

Fig. 2—Personal protection considerations for radiographers. HIS = hospital information system, RIS = radiology information system.

plete. Protective equipment items include disposable work caps, antifog safety goggles (preferably nonvented) with or without face shields, medical protective masks, protective gowns, disposable gloves, and disposable shoe covers. When putting on and taking off any protective equipment, care must be taken to follow safety guidelines.

CT scanning is usually performed by two radiographers. The operating radiographer works in the locked control room and controls the scanner (contaminated area). The positioning radiographer works inside and outside the scanning room (contaminated area) and is responsible for communicating with and positioning the patient. The positioning radiographer is not allowed to enter into the control room until the shift ends. Once a shift is finished, the positioning radiographer is permitted to enter the clean zone only after protective equipment has been properly discarded in the buffer zone, with strict implementation of hygiene processes.

Administrative Adjustments

To reduce patient contact and the associated risks of viral transmission, paperless processing should be used, and contact with surfaces should be minimized. Full use should be made of any health information system, PACS, and radiology information system (RIS). Our clinicians use electronic application forms that obtain detailed paperless medical histories. Radiologists and radiographers can review requests through the RIS; complete the protocol, information check, and registration; and handle any special instruction in advance. To reduce patient contact, the CT room in fever clinics does not have a separate reception desk; instead, patients are checked in by the positioning radiographer. The positioning radiographer must avoid any direct contact with any patient items at the time of consultation. Patients must wear high-level protective masks (preferably N95) when they enter the CT examination room. Before scanning, the positioning radiographer provides scan-related instruction, particularly breathing training; a distance of more than 1 m should be kept from patients during communication. Care must be taken when instructing patients how to follow the breathing instructions, especially to caution against coughing. Images should be reviewed for quality control and uploaded to the PACS immediately so that radiologists can provide reports quickly. The clinician can also view the patient's imaging instantly through the PACS.

Using Artificial Intelligence to Optimize Infection Prevention and Control

Routine CT examination requires two radiographers, one to operate the scanner and the other to position patients and provide breathing instructions in the scanning room. Stringent protection measures should be carried out by the positioning radiographer because of the high risk of infection. This scenario has motivated equipment manufacturers to adapt CT for epidemic situations to minimize contact between radiographers and patients. Some CT devices are now equipped with artificial intelligence technology that enables radiographers to perform an examination without leaving the control room, complete with precise positioning and automatic scanning, thus greatly reducing the risk of contagion between technicians and patients and speeding up the examination. Our hospital has used uVision (version uCT 528, Shanghai United Imaging Healthcare) with favorable results. High-definition monitoring begins when the patient enters the CT examination room. Using voice prompts, the radiographer instructs the patient to lie on the table and put their hands over their head. Then, the uVision technology can intelligently recognize the patient's face and body surface and accurately locate the scanning range of the chest, even if the patient is wearing a mask. It can simultaneously automatically adjust the scanning table to the optimal position depending on the scanning target and provide breathing instructions. Generally, after six practice rounds, the patient will be asked to hold her or his breath, and scanning will begin. The patient is prompted to breathe when scanning is complete, at which time the scanning table will move out of the gantry and lower to a height suitable for the patient to stand up. The patient then leaves the scanning room. The advantage of this process is that, although the radiographer does not need to enter the scanning room or have contact with the patient, the patient's actions can be monitored throughout the process to ensure patient safety. At the same time, the equipment can automatically complete patient positioning and scanning by intelligently identifying the patient's body parts. In this way, only one radiographer is needed to complete the CT examination, which considerably reduces the risk of cross infection.

In conclusion, CT plays an important role in diagnosis, isolation, treatment, and effective evaluation of COVID-19, but infection prevention and management of CT examination rooms should be emphasized. In addition, radiographers' awareness of infection control and personal protection needs to be strengthened. Finally, with continuous improvement and development, artificial intelligence technology offers promising solutions for imaging of patients with contagious diseases.

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