Diagn Interv Radiol 2021; 27:350–353

EMERGENCY RADIOLOGY

TECHNICAL NOTE

Container CT scanner: a solution for modular emergency radiology department during the COVID-19 pandemic

Zixing Huang*
Shuang Zhao*
Qi Leng
Shaoping Hu
Zhenlin Li
Bin Song

ABSTRACT

During the coronavirus disease 2019 (COVID-19) pandemic period, container computed tomography (CT) scanners were developed and used for the first time in China to perform CT examinations for patients with clinically mild to moderate COVID-19 who did not need to be hospitalized for comprehensive treatment, but needed to be isolated in Fangcang shelter hospitals (also known as makeshift hospitals) to receive some supportive treatment. The container CT is a multidetector CT scanner installed within a radiation-protected stand-alone container (a detachable lead shielding room) that is deployed outside the makeshift hospital buildings. The container CT approach provided various medical institutions with the solution not only for rapid CT installation and high adaptability to site environments, but also for significantly minimizing the risk of cross-infection between radiological personnel and patients during CT examination in the pandemic. In this article, we described the typical setup of a container CT and how it worked for chest CT examinations in Wuhan city, the epicenter of COVID-19 outbreak.

Fangcang shelter hospitals, also known as makeshift hospitals, were developed and used for the first time in China to tackle the coronavirus disease 2019 (COVID-19) outbreak by providing medical care and disease monitoring for patients with mild to moderate COVID-19 who were isolated from their families and communities (1). Similarly, stand-alone computed tomography (CT) scanners, known as container CTs, were developed and used for the first time in China to perform CT examinations on patients with clinically mild to moderate COVID-19 who received supportive treatment at makeshift hospitals. These container CTs were first deployed outside makeshift hospital buildings and later also at some regular hospitals as stand-alone CT scanners designated for fever patients and confirmed COVID-19 patients.

Chest CT images have been widely used to help with early diagnosis, assess the degree of pulmonary infectious involvement, monitor disease progression, and evaluate treatment effects (2). These CT examinations were originally performed in regular hospital settings with normally installed CT scanners. However, at makeshift hospitals that were converted from civil building facilities such as stadiums, schools, and exhibition halls, no space was available that could meet the shielding and radiation protection standards necessary to install CT scanners. Furthermore, during that critical pandemic period, many hospitals in Wuhan urgently needed to be equipped with more CT scanners to rapidly improve the imaging examination capabilities for patients with fever, suspected patients, and patients with confirmed COVID-19. Unfortunately, these hospitals usually lack readily available sites for rapid CT installations because it normally takes at least a month to build or remodel a CT shielding room even without the complications of the complete lockdown in Wuhan city. To figure out this issue, under tremendous pressure to rapidly install new CT scanners at both regular hospitals and makeshift hospitals, Chinese medical equipment companies worked closely with frontline radiologists and technologists and developed an innovative container CT, which functions as a modular emergency radiology department. To date, more than 140 container CTs have been installed at makeshift hospitals and regular hospitals in China since the COVID-19 outbreak.

In this article, we presented a typical in-depth solution for container CT deployment in Wuhan during the COVID-19 outbreak.

From the Department of Radiology (Z.H., S.Z., Q.L., Z.L., B.S. ✉ *songlab_radiology@163.com*), West China Hospital, Sichuan University, Chengdu, China; COVID-19 Medical Team (Hubei) of West China Hospital (Z.H., Q.L.), Department of Radiology (S.H.), Wuhan Red Cross Hospital, Wuhan, China.

*Zixing Huang and Shuang Zhao contributed equally to the work.

Received 2 September 2020; revision requested 7 October 2020; last revision received 11 December 2020; accepted 28 December 2020.

Published online 24 February 2021.

DOI 10.5152/dir.2021.20740

You may cite this article as: Huang Z, Zhao S, Leng Q, Hu S, Li Z, Song B. Container CT scanner: a solution for modular emergency radiology department during the COVID-19 pandemic. Diagn Interv Radiol 2021; 27:350–353

Construction of a typical container CT

A container CT comprises three parts: a detachable lead shielding room and ancillary equipment, a CT system, and an information system. The detailed descriptions of those three parts are listed in the following text.

Detachable lead shielding room and ancillary equipment

Container CTs were modularly spliced using a box house, which is also known as a prefabricated or industrial building. By pre-processing the components at the factory, the detachable lead shielding room could be rapidly assembled at the site within 2–3 days. A constructed container CT is shown in Fig. 1. The design also supports rapid disassembly and assembly and responds flexibly to site transfer needs.

To ensure that the equipment does not damage the temporary site when it is installed, container CTs use a special fixture design to support rapid assembly and disassembly. Installation of the CT rack and the scanning bed avoids damaging the ground, while simultaneously ensuring the stability of the equipment installation and image quality. Meanwhile, the CT scanner, particularly the rack, was designed to be shock absorbing using techniques such as the installation of eight shock absorbers made of metal rubber. The shock absorbers are distributed homogeneously under the rectangular container CT, annihilating the potential image artifact derived from the ground fluctuation. This series of shock absorption designs can meet the needs of shock absorption in different directions. The specific design enables container CTs or analogous stand-alone workstations to gather reliable medical images for performing clinical diagnoses in extreme conditions.

The standard container CT has an internal length, width, and height of 8, 4, and 2.7 m, respectively. The scanning room has a length of 6 m, and the operation room a length of 2 m. We should note that although the free-space of container CT is tight, patients with clinically mild to moderate COVID-19 could access on foot, wheelchair, and even hospital bed. The scanning room and operation room are separated by a doctor-patient isolation door, and each of these rooms has separate entrances and exits (Fig. 2). Different isolated rooms are connected by an intercom system, establishing a faithful channel for information exchange with distance. Since the container CT is a standard modular unit that contains a detachable lead shielding room and ancillary equipment, a CT system, and an information system, it can be rapidly put into mass production for meeting the market requirement even during a pandemic.

The walls and roof of the detachable lead shielding room are made of waterproof and heat-insulating materials (e.g., the color steel sandwich panel filled with rock wool) and have complete rain protection in terms of outdoor installation scenarios. The walls comprise lead plates that are generally 4 mm thick. The lead glass between the scanning room and operation room is also 4 mm thick. The shielding scheme uses high-density lead for comprehensive protection around the scanning room. The protection equivalent is at least 4 mmpb. A lead glass observation window is placed between the scanning room and operation room, and the protective equivalent is at least 4 mmpb.

The detachable lead shielding room has its own air conditioner and dehumidifier to ensure that the temperature and humidity,

Figure 1. a, b. The detachable lead shielding room of the container CT **(a)** and its virtual side view **(b)** showing the whole CT scanning and control rooms.

Main points

- Container CT scanner comprises a detachable lead shielding room and ancillary equipment, a CT system, and the information system connected to RIS and PACS.
- Container CT can be rapidly deployed at makeshift hospitals and regular hospitals through modular assembly.
- Container CT can meet the requirements of hospital infection control and radiation protection.

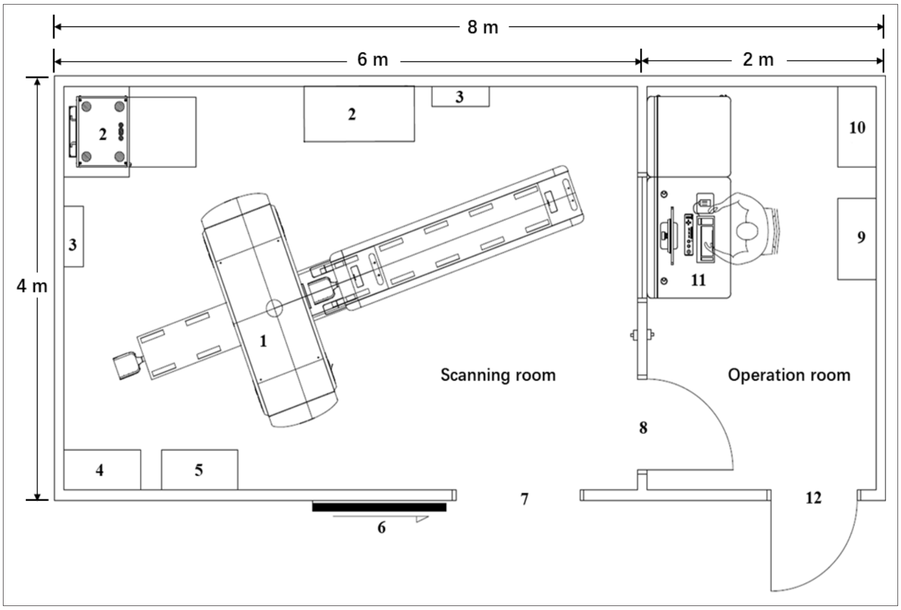

Figure 2. Floor plan of a container CT. 1, CT scanner; 2, accessories of CT scanner; 3, ultraviolet disinfection lamp; 4, 3P air conditioner; 5, air disinfection machine; 6, sliding lead door; 7, the entrance to the scanning room; 8, lead door between the scanning room and the operation room; 9, field distribution box; 10, 1.5P air conditioner; 11, CT operating system; 12, the entrance to the operating room.

respectively, in the scanning room remain constant under changing weather conditions to meet the operating environment requirements of the CT system. The ancillary equipment includes temperature and humidity control devices (air conditioners and dehumidifiers, respectively), a disinfection equipment, and a power distribution system. Dehumidifiers and air conditioners with a power of 3P are installed in the scanning room. Air conditioning systems should be located close to the floor in the scanning room. An air conditioner with a power of 1.5P is installed in the operation room. Separate air conditioning systems in the scanning room and operation room ensure effective air isolation.

The disinfection equipment includes ultraviolet disinfection lamps and air disinfection machines. The power distribution system mainly includes distribution boxes, power supply cables, sockets, and switches. Power is introduced into the distribution box from outside through the power supply cable. The power input requires a three-phase 380 V alternating current. The length of the power supply cable can be configured according to the site conditions. Power is distributed to the CT system, air conditioner, dehumidifier, ultraviolet disinfection lamp, and other accessories through the distribution box. Multiple 220 V power sockets are provided in the detachable lead shielding room to support the use of additional equipment such as high-pressure injectors.

CT system

The CT system includes a CT scanner and accessories. Container CTs have no special requirements regarding the type of CT. Multi-slice spiral CT systems are included in the currently installed CT containers in China; no dual-source CT or energy spectrum CT systems are installed, potentially due to economic reasons. Since such chest CT imaging does not require contrast pumps, the associated equipment is lacking but its installation position has already been reserved.

Information system

In the operation room, in addition to the CT operating system, there are terminals for a radiology information system (RIS) and a picture archiving and communication system (PACS), which are connected to the RIS, PACS, and hospital information system of the hospital through the gateway. Therefore, the radiologist can diagnose the image in the diagnostic room of the radiology department or in the operation room of the container CT. The patient's examination information entry and appointment registration can also be independently completed in the operation room. Some news reports noted that some container CTs used a compact 5-G equipment to rapidly achieve network communication.

At present, some commercial companies are capable to provide additional information services, such as auxiliary scanning software based on artificial intelligence (AI), auxiliary diagnostic software based on AI, as well as telemedicine consultation systems. The hospital can choose to install these systems according to the demand.

Location of container CT deployment

The location where the container CT is deployed must be chosen considering the requirements of personnel movement based on hospital infection control and radiation protection. The container CT should be placed in an open area as much as possible. The patient entrance of the container CT should be connected to the contaminated line of the makeshift hospital or regular hospital. In addition, the entrance of the operation room and scanning room of the container CT should be connected to the contaminated route of the hospital. The entrance of the operation room of the container CT may be connected to the clean area/route of the hospital. This design provides one more protection for avoiding the cross-infection of COVID-19 in container CT.

Based on radiation protection safety considerations, roadblocks should be set up outside the container CT to maintain a sufficiently safe distance. When the container CT is working, we can measure the radiation dose outside the container CT with a handheld instrument to determine a safe distance to comply with the laws of the country or region where the container CT is installed.

Infection control policy and examination procedure

Currently, a safe infection control policy generated for COVID-19 is equally adapted to container CT, which includes reconstructing the area, planning the path for patients, disinfecting the examination room, and protecting CT technologists (3). The hospital infection control department takes charge of planning the infection control procedure. The specific steps of the procedure could refer to the existing infection control plan for severe infectious diseases of the radiology department (3). We should note that both CT technologists and patients should strictly respect the CT protocol as mentioned in reference (3) for avoiding cross-infection, where the CT technologists are required to wear personal protection equipment, for instance, surgical cap, goggles, face shields, N95 mask, medical protective clothing, gloves, and disposable shoe covers.

Limitations of container CT

Container CTs have some shortcomings. 1) The installation location of container CT is restricted. There should be enough space around the container to meet the requirements of radiation protection. The installation site should be integrated into the design of personnel movement line in the hospital to meet the requirements of hospital infection control. 2) Whether the physical structure of the container meets the radiation protection of various CT examinations still needs to be tested. So far, container CT has been mostly used for plain chest CT scan. 3) At present, the air exchange in the container is done by air conditioning. In the future, more professional air exchange and filtering devices can be used to form a negative pressure in the container to avoid cross-infection.

Conclusion

Container CTs are able to transfer CT systems from the traditional brick-concrete structure building to a steel structure-lead plate house building and use a targeted optimized design for equipment layout, electrical system, radiation protection, temperature and humidity adjustment, and disinfection. After the container CT is placed at the site, it can be used once electricity is installed, which is convenient and fast. Moreover, the container CT system can maintain the same system stability and reliability as that at regular hospital installations.

During pandemics, container CTs can not only meet the CT requirements of various medical institutions of rapid installation and adapt to various site environments, but also reduce the risk of cross-infection between doctors and patients during CT examination. We think container CTs should have a broader application. Deployable CT systems can be used in field/makeshift hospitals, not only during the COVID-19 pandemic, but also wherever and whenever they are needed. For example, during natural disasters such as major/great earthquakes or for military medicine in the battlefield.

Acknowledgments

We would like to acknowledge Chenwei Li and Jiatai Feng from United Imaging for helping us check some technical parameters.

Conflict of interest disclosure

The authors declared no conflicts of interest.

References

1. Chen S, Zhang Z, Yang J, et al. Fangcang shelter hospitals: a novel concept for responding to public health emergencies. Lancet 2020; 395:1305–1314. [Crossref]
2. Yang W, Sirajuddin A, Zhang X, et al. The role of imaging in 2019 novel coronavirus pneumonia (COVID-19). Eur Radiol 2020; 30:4874–4882. [Crossref]
3. Huang Z, Zhao S, Li Z, et al. The battle against coronavirus disease 2019 (COVID-19): emergency management and infection control in a radiology department. J Am Coll Radiol 2020; 17:710–716. [Crossref]