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Опыт применения мобильного компьютерного томографа в резервном госпитале для лечения пациентов с новой коронавирусной инфекцией COVID-19

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АННОТАЦИЯ

Пандемия новой коронавирусной инфекции COVID-19 бросила вызов системам здравоохранения практически всех стран мира. От организаторов здравоохранения требовалось принятие оперативных и эффективных решений для обеспечения высокого качества оказания медицинской помощи в новых условиях. Потребность в формировании резервного коечного фонда при пандемии была обусловлена высокой нагрузкой на городские больницы в Москве, в связи с чем в непрофильных сооружениях (ледовые арены, торговые центры, выставочные павильоны) были организованы временные резервные госпитали для лечения пациентов с COVID-19. Это потребовало поиска решений для обеспечения необходимого уровня диагностики и лечения, соответствующего профильному медицинскому учреждению. С учётом технических и временных ограничений, связанных с установкой стационарного компьютерного томографа, одним из решений была установка мобильного компьютерного томографа.

Целью работы было поделиться опытом использования мобильного компьютерного томографа в условиях временного резервного госпиталя для лечения пациентов с коронавирусной инфекцией COVID-19. В работе представлена информация о характеристиках мобильного компьютерного томографа; отмечены его преимущества и недостатки; представлен вариант планировки аппаратной, пультовой комнат и вариант размещения томографа; представлены результаты дозиметрических исследований; дана клиническая оценка применимости подобного типа диагностических устройств.

Ключевые слова: мобильный компьютерный томограф; пандемия коронавирусной инфекции; COVID-19; отделение лучевой диагностики.

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Using a mobile computer tomography scanner in a field hospital setting to manage patients with COVID-19

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ABSTRACT

The global outbreak of COVID-19 has posed unprecedented challenges to healthcare systems worldwide. Healthcare administrators had to make quick and effective decisions to ensure high quality of medical care standards in new conditions. The need to form a reserve bed fund during the pandemic was due to the high load on city hospitals in Moscow. Due to this fact, temporary reserved hospitals for COVID-19 patients were organized in non-core facilities, such as ice arenas, shopping malls, and exhibition pavilions. This urgency prompted a search for solutions that could provide the necessary level of diagnosis and treatment appropriate to specialized medical facility. Given the technical and time constraints associated with the installation of a fixed computer tomographic scanner, the deployment of mobile computer tomographic scanners emerged as a viable option. The study aims to share insights gained from using a mobile computer tomographic scanner within a temporary backup hospital setting to treating patients with COVID-19 coronavirus infection. The paper discusses the features, advantages, and disadvantages of mobile computer tomography. It also presents hardware and control room layouts, along with the placement options for the computer tomography device. The research includes the results of dosimetry studies and provides a clinical assessment of the applicability of this type of diagnostic devices.

Keywords: computer tomographic scanner; COVID-19 pandemics; radiology departments.

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在备用医院使用移动式电脑断层扫描仪治疗新型冠状病毒感染（COVID-19）患者的经验

Nikita D. Kudryavtsev[1], Alexey V. Petraikin[1], Ekaterina S. Akhmad[1], Fyodor A. Kiselev[1], Vyacheslav V. Burashov[1], Anna N. Mukhortova[1], Ilya V. Soldatov[1], Andrey S. Shkoda[2]

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简评

新型冠状病毒感染（COVID-19）的大流行给世界上几乎所有国家的卫生系统带来了挑战。医疗保健组织者需要做出迅速有效的决定，以确保在新的条件下提供高质量的医疗保健服务。在大流行期间，由于莫斯科的城市医院负担格外沉重，因此需要建立一个备用床基金，并在非核心建筑物（冰上运动场、购物中心、展览馆）中建立临时备用医院，以治疗COVID-19患者。这就需要寻找解决方案，以在专业医疗机构中提供必要水平的诊断和治疗。考虑到安装固定式电脑断层扫描仪的技术和时间限制，解决方案之一是安装移动式电脑断层扫描仪。

本文旨在分享在临时备用医院使用移动式电脑断层扫描仪治疗冠状病毒感染COVID-19病人的经验。该文章介绍移动式电脑断层扫描仪的特性；指出其优缺点；介绍设备室、控制室的布局变式和电脑断层扫描仪的摆放变式；介绍剂量测定研究的结果；对此类诊断设备的适用性进行了临床评估。

关键词：移动式电脑断层扫描仪；冠状病毒大流行；COVID-19；放射诊断科。

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INTRODUCTION

During the COVID-19 pandemic, in Moscow, a reserve bed capacity was required due to the high load on city hospitals. Field COVID-19 hospitals were deployed in noncore buildings (ice arenas, shopping centers, and exhibition halls), and special solutions were required to provide the necessary level of diagnosis and treatment comparable with a specialist healthcare institution [1]. One field hospital was located at the Krylatskoye Ice Palace (State Budgetary Healthcare Institution “L.A. Vorokhobov City Clinical Hospital No. 67,” Department of Healthcare of Moscow Fig. 1).

Diagnostic radiology techniques (particularly computed tomography [CT]) are recommended for detecting signs of COVID-19 pneumonia and to establishing a differential diagnosis for other lung diseases and assessing disease severity, changes in a patient’s condition, and treatment effectiveness [2–4]. A mobile Airo TruCT tomograph (Stryker, USA) was deployed due to technical and time constraints of employing a stationary computed tomograph.

The purpose of this study was to assess the efficacy of mobile CT in a field hospital for COVID-19 patients.

A MOBILE COMPUTED TOMOGRAPHER: EFFECTIVENESS IN SETTING OF A FIELD HOSPITAL FOR COVID-19 PATIENTS

General characteristics of a mobile CT

The Airo TruCT is designed for use in neurosurgery operating rooms, but the manufacturer claims that it can also be used to diagnose urgent conditions in other anatomical areas.[1] Airo TruCT has a compact size (Fig. 2), making it simple to install and transport. A moveable base, a gantry with a 107-cm aperture, and 32 rows of 1-mm detectors comprise this CT system. CT is controlled by a hard-wired console connected by a 5-m wire (Fig. 3). The mobile CT is adaptable to a variety of power supply conditions and is linked to a 1.5-kW network. A power supply system, on the other hand, permits scanning at 120 kV and 250 mA, which corresponds to a power of 30 kW.

Location and dosimetry

In accordance with current rules and measurement methods, a CT room was certified for compliance with technical requirements during technical equipment testing (monitoring of operating parameters) and radiation monitoring at the workplace and adjacent rooms.

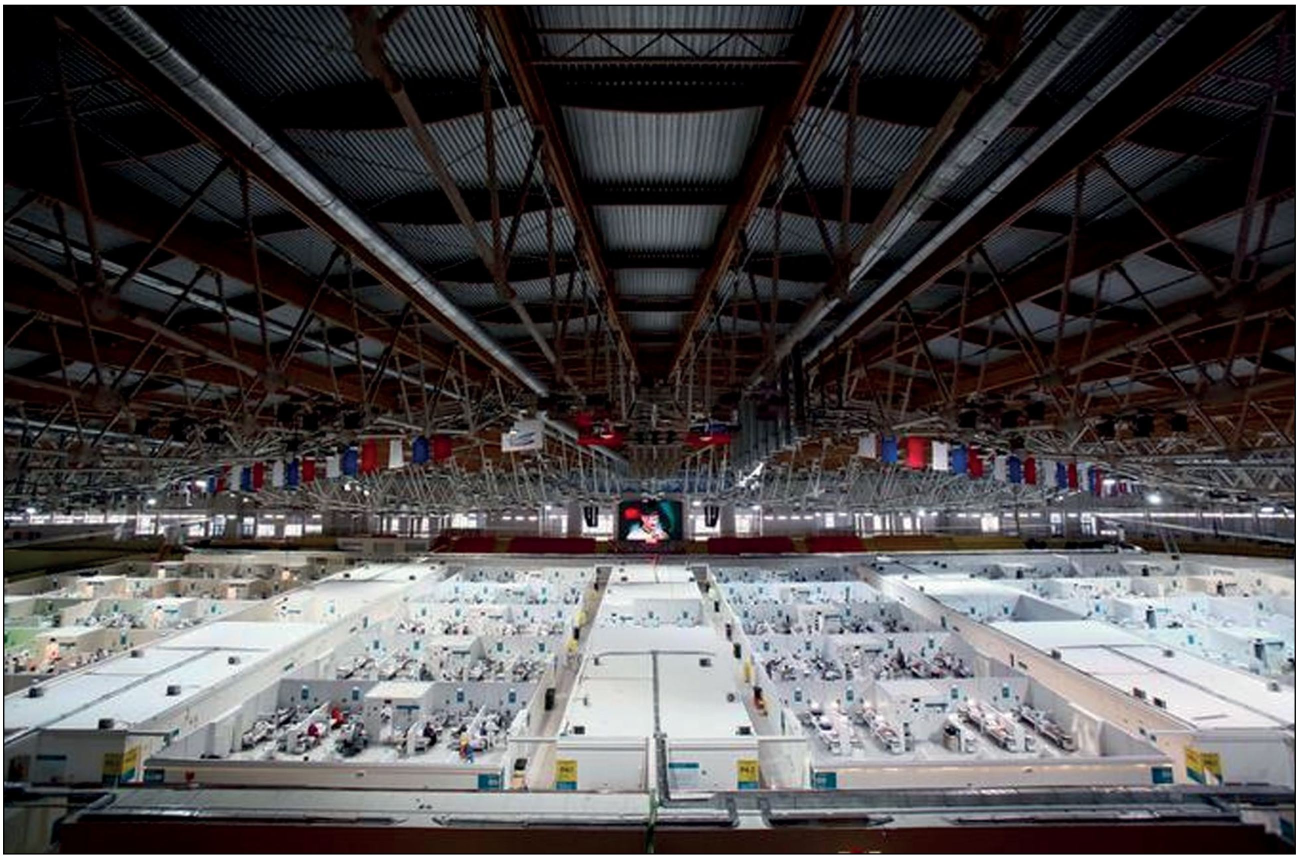

Fig. 1. A field hospital for COVID-19 patients in Krylatskoye Ice Palace (Moscow, Russia). Reuters (https://pictures.reuters.com/).

[1] Stryker.com [Internet]. Neurosurgery (https://www.stryker.com/us/en/spine/products/airo-truct/imaging/clinical/neurosurgery.html); Airo Truct Mobile Imaging System (https://www.stryker.com/us/en/spine/products/airo-truct/imaging.html).

Fig. 2. A mobile computed tomograph ready for scanning.

Fig. 3. Airo TruCT control console.

The CT room is located on the first floor of Krylatskoye Ice Palace, in the Emergency Department (Fig. 4). Due to the increased patient flow and off label use of this device, some technical solutions were required:

1. The CT console was relocated to the control room to ensure technicians' radiation safety.
2. A video system was constructed to monitor the patient's status and the progress of the scanning because there was no viewing in the control room.
3. Baofeng portable radios were used for communicating with patients during scanning due to the lack of built-in voice commands for holding breath.

Radiation protection in adjacent rooms complied with Russian requirements for design and operation of X-ray rooms, considering operating parameters of Airo TruCT (during scanning, the gantry moves, whereas the patient table is fixed). Sheets of X-ray protective plasterboard from Knauf (Iphofen, Germany) were used to safeguard stationary building envelops.

Dosimetry monitoring at workplaces, in adjacent rooms, and in adjacent regions revealed that exposure levels did not exceed values defined in current regulatory regulations at the observed spots (see Fig. 4).

Technical quality control

In accordance with current norms, a standard assessment of the CT system's operational parameters was performed[2]. Sum filtering, half-value layer, anode voltage ripple, anode

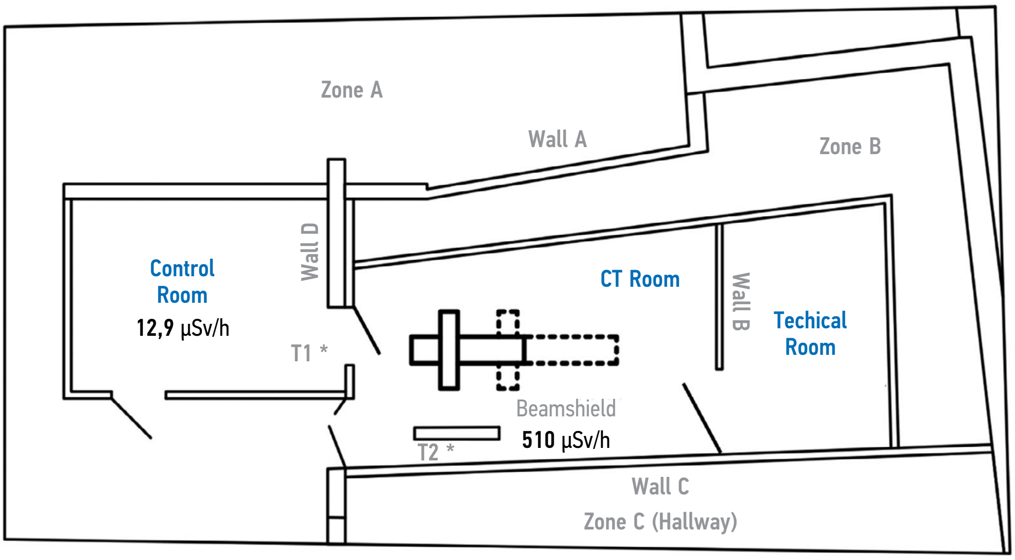

Fig. 4. The project of a computed tomography room, control room, and radiologist's office: Zone A—pavilion; Zone B—technical area; Zone C—hallway (zones A to C are areas without permanent presence of personnel).

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[2] Electronic base of legal and regulatory technical documents of Codex JSC [Internet]. GOST R IEC 61223-2-6-2001 Evaluation and routine testing in medical imaging departments. Parts 2-6. Constancy tests. X-ray equipment for computed tomography(https://docs.cntd.ru/document/1200029048); GOST R 51746-2001 Evaluation and routine testing in medical imaging departments. Part 1. General requirements. (https://docs.cntd.ru/document/1200012982); GOST R IEC 61223-3-5-2008 Evaluation and routine testing in medical imaging departments. Parts 3-5. Acceptance tests. Imaging performance of computed tomography X-ray equipment. (https://docs.cntd.ru/document/1200071695); GOST R IEC 60601-2-44-2013 Medical electrical equipment. Parts 2-44. Special requirements for the basic safety and essential performance of X-ray equipment for computed tomography (https://docs.cntd.ru/document/1200105919).

Table 1. Standardized scanning protocols for different anatomical regions

Anatomic region parameter	Chest	Brain	Abdomen
Scanning direction	Craniocaudal	Craniocaudal	Craniocaudal
Scan type	Spiral	Spiral	Spiral
Electric voltage (kV)	120	120	120
Electric current (mA)	38	155	69
Slice thickness (mm)	1.0	1.0	1.0
Pitch factor	1.415	1.415	1.415
X-ray tube rotation time (s)	1.92	1.92	1.92
Reconstruction matrix (px)	512 × 512	512 × 512	512 × 512
Duration of scan (s)	12	8	16
Absorbed radiation dose (mGy*cm)	230.7	1,186.8	564
Scan length (cm)	30	20	40

voltage, exposure time, radiation dose linearity, radiation dose repeatability, and image quality characteristics were evaluated.

According to the test results, the CT system meets performance and standard requirements.

Clinical use

A field hospital accepted patients with mild and moderate COVID-19 [2] with CT-1 and CT-2 lung parenchyma damage, requiring hospital treatment and observation. The chest CT was performed on all hospitalized patients. The only exception was for patients who had a recent CT (4 days). CT data revealed that 155 (31.0%) of 500 randomly selected patients had CT-1, 202 (40.4%) had CT-2, 109 (21.8%) had CT-3, and 34 (6.8%) had CT-4. Due to the high-power consumption and possibility of X-ray tube overheating during multiphase scanning, contrast-enhanced CT was not performed. The relative duration of scanning was a limitation of that technique.

Computed tomography scans of the brain and head, abdomen and retroperitoneum, pelvic organs, spine, and extremities were conducted when clinically required (scanning parameters are listed in Table 1).

The system's wide (107 cm) gantry aperture was an apparent advantage.

Chest CT was conducted in the majority of cases to obtain a diagnosis or to provide continuing observation for patients with COVID-19 pneumonia. The scanning parameters (Table 1) enable us to obtain images of adequate quality to differentiate between viral pneumonia, cardiogenic pulmonary edema, and bacterial pneumonia. Fig. 5 shows CT data for COVID-19-associated viral pneumonia patients.

Long-term (15–25 s) scanning was too long for patients with respiratory insufficiency to remain their breath for the entire examination compared with stationary CT (3–5 s). As a result, motion artifacts (Fig. 6*a*) and steps (Fig. 6b) were

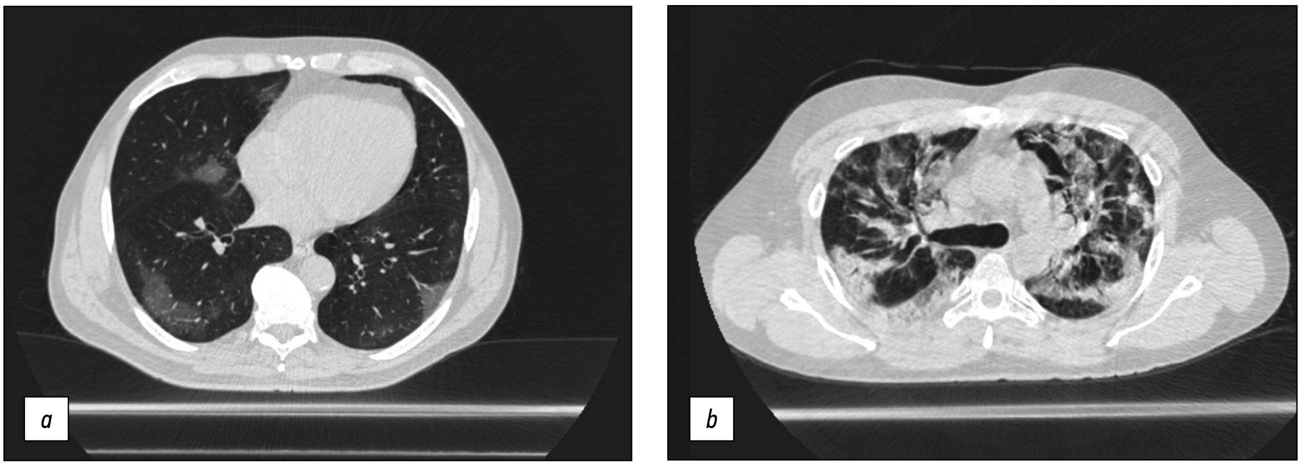

Fig. 5. Axial computed tomographic slices of chest organs in the lung window: (*a*) polymorphic, predominantly subpleural areas of ground-glass opacity, corresponding to the CT image of viral pneumonia (including COVID-19), CT-1, and (*b*) multiple polymorphic areas of parenchyma compaction with a tendency to merge, with ground-glass opacity areas and mild reticular changes, CT-3.

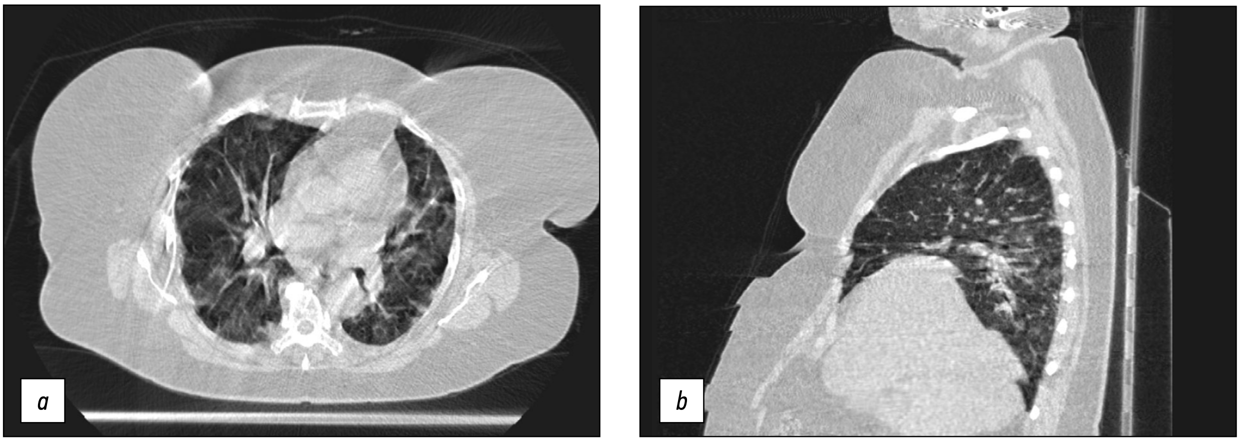

Fig. 6. Axial and sagittal computed tomographic slices of chest organs in the lung window: (*a*) motion artifacts and (*b*) step artifacts caused by respiratory chest movements during scanning.

present in CT images produced by breathing motions of the chest (Fig. 6).

Brain CT was used to diagnose acute cerebrovascular accident, intracranial hematomas, brain tumors, and traumatic skull injuries (Fig. 7).

Windmill artifacts (Fig. 8a) were mixed with strike artifacts and helical scanning [5], and artifacts intensified at the level of skull base, where significant beam hardening and scattering artifacts occurred (Fig. 8, *b*). Therefore, subtentorial brain areas were challenging to assess.

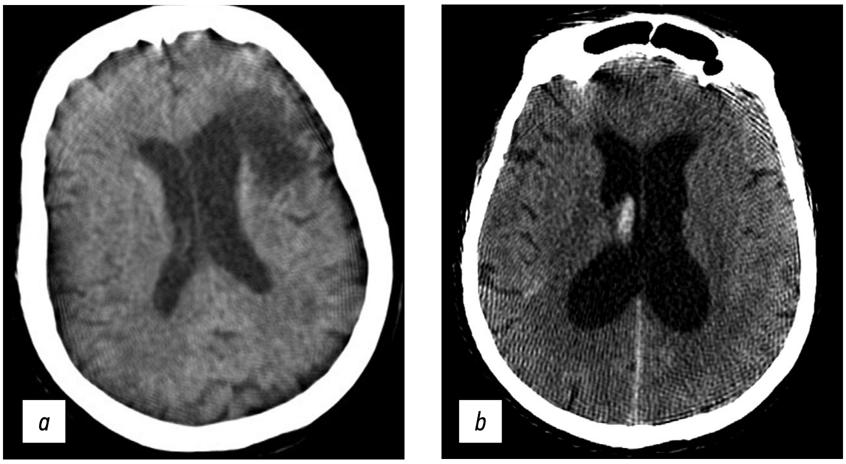

Fig. 7. Axial computed tomographic images of the brain: (*a*) reconstruction of a 3-mm low-density area at the anterior horn of the left lateral ventricle, in the periventricular, subcortical direction (CT image of subacute cerebrovascular accident of the left middle cerebral artery), and (*b*) a 1-mm site of subarachnoid hemorrhage with blood breakthrough into the ventricular system (vicarious hydrocephalus).

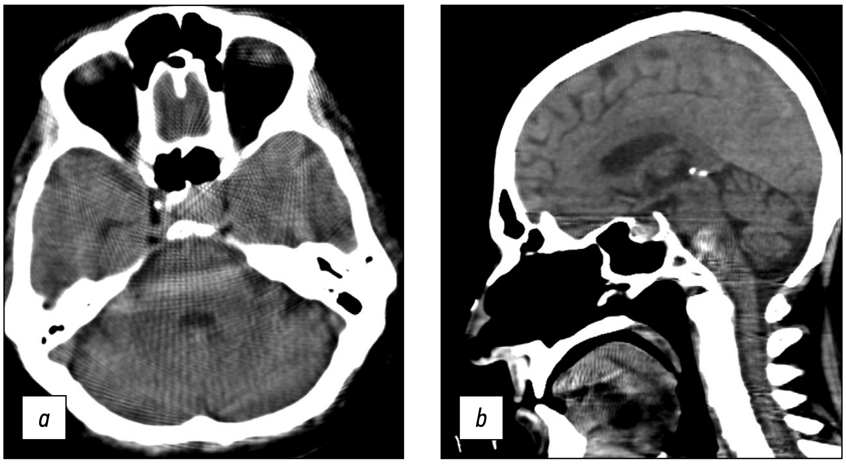

Fig. 8. Axial (*a*) and sagittal (*b*) computed tomographic images of the head in the region of the posterior cranial fossa and base of skull showed windmill, strike, beam hardening, and scattering artifacts. Area of bone structures and the posterior fossa is hard to evaluate.

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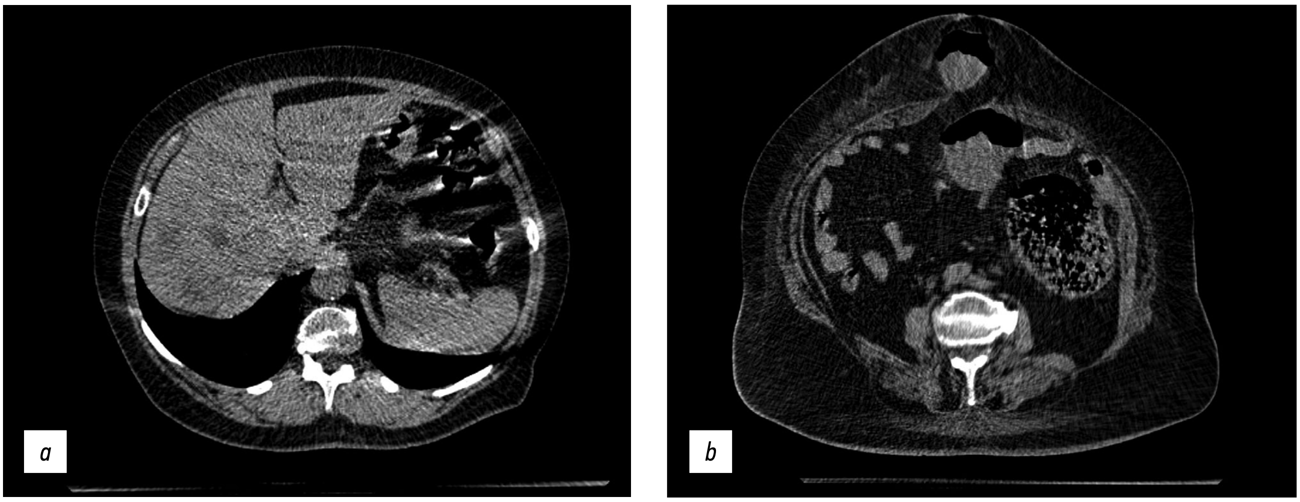

Fig. 9. Axial computed tomographic images of the abdomen: (*a*) CT image of multiple hypodense lesions of both liver lobes, helical artifacts, and gas interface artifacts in the intestinal area and (*b*) CT image of a strangulated umbilical hernia.

Abdomen CT was used to assess acute abdominal problems, such as suspected intestinal blockage, and detect free liquid or gas (Fig. 9).

Artifacts were also identified during abdomen CT at the point of contact of various density media, such as intestine gas and surrounding soft tissue (gas-interface artifact) and helical scanning artifacts.

The scanning parameters (Table 1) enable the acquisition of images of sufficient quality for the diagnosis of abdominal and retroperitoneal disorders (liver steatosis, gallstone disease, adrenal hyperplasia and incidentaloma, kidney cysts and urolithiasis, focal liver lesions, and other conditions).

Evaluation of a mobile CT effectiveness

From the start of the field hospital operation (August 11, 2020) to January 31, 2021, 6,264 CT scans were performed, including 6,126 (97.80%) chest CTs, 98 (1.56%) brain CTs, 31 (0.49%) abdomen CTs, and nine (0.14%) other CTs. The average radiation exposure was 3.22 mSv for chest CT, 2.49 mSv for brain CT, and 8.46 mSv for abdomen CT.

To assess CT effectiveness, a load equal to the ratio of the average number of CT scans per day to the Moscow standard (41 scans per day for three-shift work) was determined. The average number of scans performed in such case was 44 a day (ranging 14 scans at the start of the temporary hospital operation to >110 scans per day in days with the highest inpatient flow). This amounted to 106% of the recommended load. When Airo TruCT was compared with stationary Aquilion Prime or Revolution EVO tomographs, the utilization levels were equivalent. The average level of utilization for stationary CT in two hospitals was 113%, according to data. As previously stated, no contrast-enhanced CT scans were conducted.

Such a load validated excellent efficacy of using a mobile CT in temporary hospitals. However, technical difficulties were recorded during periods of extensive mobile CT use, which could result in the tomograph being shut down for maintenance. The manufacturer suggests conducting six scans per hour to extend the operational time of a mobile CT and avoid technical concerns.

DISCUSSION

The COVID-19 pandemic has raised various challenges regarding inpatient care organization, such as how to enhance bed capacity, organize field hospitals, and provide logistics for such solutions [6].

One method for ensuring CT availability in field hospitals is to use tiny transportable computed tomographs. This paper summarizes experience of using an Airo TruCT mobile CT. Apparent advantages of this CT system include compatibility with various power supply parameters, ease of installation and transportation, and the ability to quickly design a room for a mobile CT scan and put this equipment into operation.

A mobile CT generated acceptable quality chest CT images detecting viral pneumonia (see Fig. 5 *a*), and the patient capacity was sufficient for a temporary hospital with 1,300 beds in overload circumstances. The peak load was 110 scans per day, with an average of 44. This system differs from modular and mobile CTs mounted on trailers [7], mostly due to the use different types of CT.

However, some limitations were observed, indicating that the present modification's usage of a mobile CT was a forced solution. Some motion artifacts developed as a result of low scanning speed compared with stationary CT scanners. The caudal–cranial direction was proposed for chest CT scanning to limit the amount of respiratory artifacts [8]. Due to the configuration of the CT room (gantry movement was limited due to insufficient console wire length) in our situation of using Airo TruCT, such a solution proved unacceptable. The problem was fixed by postponing the command to hold the breath for 3–4 s after the scan began. Although the apical lung segment exhibited significant motion abnormalities and steps, the basal portions were clearly visible. This observation is significant because patches of ground-glass opacity or consolidation are precisely situated in the dorsal sections of the lower lobes in COVID-19 pneumonia [9]. Simple technical solutions, such as handheld transceivers and video communication, were also used to adopt off-label use of Airo TruCT. Due to the significant number of artifacts detected, additional scanning, reconstruction, and postprocessing algorithms should be developed, and scanning parameters should be optimized [10].

Despite the mobility and easy installation of mobile CTs, design of an equipment room should comply with all radiation safety requirements (see Fig. 2).

In addition to field COVID-19 hospitals, mobile CTs can be used efficiently in healthcare institutions where there are no conditions for fixed CT installation or when the main CT scanner has failed. Mobile CT scanners can be used in remote communities and temporary mobile hospitals for emergency recovery.

The use of mobile CT also opens up new avenues for scientific research; for example, in our case, the mobile CT was used to investigate the influence of COVID-19 on the cardiovascular system [11]. When preforming chest, brain, abdomen, and retroperitoneum CT at temporary hospital for COVID-19 patients, the use of Airo TruCT provide requisite diagnostic effectiveness.

Based on the identified disadvantages, a list of requirements for mobile CT systems was prepared, and the need to develop a new type of CT was demonstrated, including high compatibility with various power supply sources, the ability to quickly design rooms for CT deployment in temporary hospitals, and the ability of use in emergency situations and remote areas with unprepared infrastructure.

CONCLUSION

The installation of mobile CT in a field COVID-19 hospital was a forced solution due to the rapid development of the pandemic. The Airo TruCT is intended for use in neurosurgical operating rooms. Despite the off-label use, the mobile CT produced images of satisfactory quality. A fixed CT situated on a trailer or a separate module is an alternative to mobile CT, although this type of equipment has its disadvantages (e.g., difficult transport and placement outside the healthcare institution and problems with scanning in severe patients). In turn, the Airo TruCT has excellent mobility and reduced space and power requirements, allowing it to be transported by a single person. However, the high mobility of this tomograph affects the quality of images.

ADDITIONAL INFORMATION

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Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. N.D. Kudryavtsev — the concept of publication, text writing, clinical analysis of mobile CT; A.V. Petraikin — clinical analysis of mobile CT; E.S. Akhmad — technical quality control of mobile CT, text writing; F.A. Kiselev, V.V. Burashov — technical quality control of mobile CT; A.N. Mukhortova — evaluation of the effectiveness of the use of mobile CT; I.V. Soldatov — design of the radiology department, text editing; A.S. Shkoda — organization of the work in the radiology department, text editing.

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