

New Technological Approaches to the Organization of the Work of Medical Personnel Performing Auscultation of Patients with COVID-19

A. A. Gavrishchev^{1*} and N. V. Gavrishcheva²

Due to the COVID-19 epidemic, the challenge of introducing methods for investigating patients reducing or eliminating the probability of infection of medical staff is currently relevant. This article provides an analytical review of new technological approaches to organizing the work of medical personnel in carrying out auscultation of patients with COVID-19. The development and approval of such technologies is shown to have started around the world. The ubiquitous and large-scale introduction of these methods into medical practice therefore seems expedient.

Introduction

Currently, in accordance with normative guideline documentation [1], auscultation is an obligatory investigation for the diagnosis and treatment of patients with coronavirus infection (COVID-19). It provides a quite simple, effective, and noninvasive method of investigating patients with lung and heart diseases. However, auscultation of COVID-19 patients, like other diagnostic investigations such as ultrasound diagnosis, echocardiography, electrocardiography, pulse oximetry, and various others [2, 3], creates a situation of high risk of COVID-19 infection of medical staff because of the impossibility of maintaining a safe distance between patient and medical worker. Thus, during all procedures involving provision of care to patients with signs of acute respiratory virus infection (ARVI) as suspected or confirmed (probably) COVID-19, medical workers are obliged to use personal protective equipment (PPE) to ensure their own safety, as well as that of the patient [4, 5]. However, despite taking protective measures against COVID-19, statistics show [6-9] that a considerable proportion of cases of COVID-19 infection occur among medical workers in close contact with COVID-19 patients while on duty.

Analysis of sources [10-39] shows that one of the most difficult problems with auscultation of COVID-19 patients is the impossibility of performing classical auscultation because medical workers in protective costumes with hoods and protective glasses are simply unable to place the stethoscope earpieces in their ears without disrupting the sealing of the PPE. Furthermore, the lack of a single method for safe auscultation of COVID-19 patients and the equipment required makes the diagnosis and treatment of COVID-19 patients difficult, forcing medical staff to make adaptations to solve these problems [2, 3, 10-39]: using their medical experience, using special scales, such as the NEWS scale, and relying exclusively on investigations which are expensive and harm patients' health (X-rays, CT, etc.). Thus, the exploration of new technological approaches to organizing the work of medical personnel performing auscultation of COVID-19 patients is a relevant scientific and practical task [2, 3, 10-39].

The aim of this work was to produce an analytical review of new technological approaches to organizing the work of medical staff in performing auscultation in COVID-19 patients.

Materials and Methods

To generate an analytical review of new technological approaches to organizing the work of medical staff in per-

¹ Institute of Intelligent Cybernetic Systems, National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia; E-mail: alexxx.2008@inbox.ru

² Medical College No. 2, St. Petersburg, Russia.

* To whom correspondence should be addressed.

forming auscultation in COVID-19 patients, the authors analyzed and summarized data on this theme from a variety of sources, particularly RSCI, FIPS, CyberLeninka, Google Scholar, PubMed, Physionet, EBSCO, Springer, and search engines Yandex, Google, etc.

Results

Before considering new technological approaches to organizing the work of medical staff in performing auscultation in COVID-19 patients, we will address studies on related themes published before 2020.

Thus, work reported in [18] described an electronic stethoscope for remote auscultation. This stethoscope can be used via various communication channels to transmit data from the patient to the physician, including wirelessly, expanding its functional potentials.

Work described in [19] developed a multifunctional diagnostic device based on an FSE-1M electronic stethoscope with standard Bluetooth for transmitting acoustic signals to a computer or smartphone. This provided for remote auscultation of patients and the processing, display, and storage of the data obtained.

Report [20] presented studies using an auscultation jacket with built-in electronic stethoscopes and classification software able to discriminate normal and a number of auscultatory abnormalities.

Report [21] described an electronic medical stethoscope for auscultation, which increases the signal-to-noise ratio, eliminates the influences of incidental noises, and sends investigation results to a remote terminal. The wireless channel can be Bluetooth, wi-fi, etc.

Report [22] described a device for wide-band auscultation significantly expanding the arsenal of tools for auscultation of the human body. The wireless channel can be wi-fi, Bluetooth, etc.

As can be seen from these sources, published before the onset of the COVID-19 pandemic, this direction of work, addressing remote auscultation using electronic stethoscopes, was developed to some extent, though not as actively as at present. However, the start of the pandemic gave new impetus to its development.

We will now address new technological approaches to organizing the work of medical personnel in carrying out auscultation of patients with COVID-19 published from 2020 onwards.

Study [23] presented an electronic stethoscope for remote auscultation, decreasing the risk of infection among medical workers. This electronic stethoscope can be connected of wireless audio devices such as headphones or loudspeakers using a Bluetooth transmitter.

Report [24] suggested a remote stethoscope developed by the authors allowing the physician to carry out auscultation of patients without the need to place earpieces in the ears while working in PPE. This system consists of the autonomous stethoscope head and a wireless receiver which can be connected either to a mobile phone or a headset.

Study [25] proposed use of a remote stethoscope for transmitting lung sounds via wireless communication channel directly to a smartphone. The wireless channel can be the 3G or 4G network or wi-fi.

Report [26] described a portable digital device for identifying lung sounds in different diseases. This has a defined frequency range and the physician can receive sound from patients remotely via various data transmission channels.

Report [28] developed a portable device for remote assessment of the course of a patient's illness. The system is based on a wireless digital stethoscope able to record auscultatory phenomena (noises, wheezing, etc.) and transmit them to a smartphone app via Bluetooth. Sounds are processed and classified in the cloud using a neural network.

Work reported in [29] developed a medical robot assistant consisting of a floor-based robot with a manipulator connected to a Raspberry Pi 4. The Raspberry Pi has built-in Bluetooth allowing the robot to be controlled remotely using a smartphone with a wireless channel. The robot is currently able to give patients food and water, as well as medicines. The potential functionality of the robot may expand, for example, to carry out auscultation of patients with COVID-19.

Studies described in [30] proposed the use of a device consisting of hardware with Bluetooth technology and a software app allowing transmission of sound to a smartphone via wireless connection. In the authors' view, the main feature of this device is that the physician can carry out auscultation while wearing PPE.

Work reported in [31] proposed use of a remote stethoscope developed by the authors for auscultation, based on a Raspberry Pi and transmitting data via wi-fi. The proposed device provides for real-time recording of auscultation sounds using a microphone and can store data files for subsequent analysis.

Report [32] developed a scheme using the simplest possible single-channel device for wireless recording of lung sounds on a smartphone and a microcontroller for a single-channel device with simultaneous recording of lung sound at different points of the patient's thoracic cage. The single-channel device with a Bluetooth microphone makes recordings on a smartphone at distances of up to 10 m.

Report [33] presented technology for an electronic stethoscope. The device developed here has a standard headphone jack and a small ready-made Bluetooth transmitter that can be connected to provide wireless transmis-

sion of auscultation sounds from the patient to the physician's headphones.

Report [34] described a diagnostic system for diagnosis of bronchopulmonary diseases in children. One feature of the electronic phonendoscope developed here is that it has no sound-conducting tube; it is applied to various points on the chest and sounds are recorded by specific software installed on a smartphone. The resulting files are stored in a database for later analysis.

Report [35] developed an inexpensive system converting an existing user's stethoscope into a digital stethoscope. The system as developed consists of a microphone connected to a stethoscope, a specific Android app, and headphones. These can be deployed rapidly and can influence patient care not only in hospitals, but also in clinics, where doctors can perform auscultation on patients from a safe distance.

Work reported in [36] presented a digital stethoscope for auscultation giving high quality and signal processing speed with low energy consumption, providing the opportunity for safe auscultation of patients with COVID-19. The wireless channel for data transmission can be, for example, Bluetooth.

Report [37] presented results from studies addressing questions of using information systems for wireless monitoring of distributed determination of medical parameters. Results of the development of a working prototype of the system based on the use of ZigBee wireless technology are presented.

Report [38] described the use of experimental 5G technology in the practical work of the Sino-Japanese Friendship Hospital for the treatment of patients and the introduction of remote computerized auscultation. In February 2020, remote computerized auscultation helped medical workers in this hospital to be one of the world's first to hear lung sounds in COVID-19 patients. The 5G connection allows sounds to be transmitted to a central platform in real time for remote multispecialty analysis by specialists using artificial intelligence systems.

Paper [39] described Russia's first use of a 5G test facility at the Botkin Hospital piloting various innovative medical services, particularly round-the-clock monitoring of patient's conditions and VR and AR modeling of X-ray films, ultrasound scans, CT results, etc. Studies of innovative medical services also addressed remote computerized auscultation of COVID-19 patients.

Analysis and Summary of Results

Analysis and summary of the obtained results show that:

1) the approach using remote auscultation using electronic stethoscopes received a new impetus for its development with the onset of the pandemic;

2) safe auscultation of COVID-19 patients can potentially be performed by remote auscultation, which can be based on the use of wireless information transmission systems;

3) Bluetooth is a potential technology for wireless data transmission for remote auscultation in small and intermediate medical institutions, this providing for information exchange between different widely used devices (headsets, smartphones, computers, etc.) at distances of up to 100 m at unlicensed frequencies;

4) 5G is a potential technology for wireless data transmission for remote auscultation in large medical institutions, which within a single institution provides rapid and distant collection and processing of data from significant numbers of different information sources, such as sensors carried by patients, etc.;

5) systems for processing and storing auscultation sounds for subsequent analysis and production of advice for medical staff using machine learning or neural network technologies are receiving ever wider use in medical practice in the conditions obtaining in the COVID-19 pandemic and therefore requires more detailed study;

6) there is no clear widespread and large-scale introduction of new technical approaches to the organization of the work of medical staff for auscultation of COVID-19 patients into medical practice; many of the approaches presented above are either isolated cases within the work of a particular medical institution or are experimental studies;

7) there is a clear absence of normative and legal documents regulating safe auscultation using new technological approaches to organizing the work of medical staff under the conditions obtaining in the COVID-19 pandemic.

Conclusions

This article presents an analytical review of new technological approaches to organizing the work of medical staff performing auscultation of patients with COVID-19. The article shows that new technological approaches to organizing the work of medical staff performing auscultation of patients with COVID-19 are being developed, particularly those based on the use of remote auscultation, which uses wireless data transmission systems (for example Bluetooth or 5G) to conducted investigations at a safe distance between the patient and the medical worker wearing PPE. Furthermore, introduction of machine learning and neural network technologies in the work of

medical staff performing auscultation in the conditions of the COVID-19 pandemic is noted. However, many of the approaches discussed above are either isolated cases in the context of the work of medical institutions or are experimental studies. Thus, widespread and large-scale introduction of these technologies into medical practice is desirable. In this regard, it will also be necessary to develop normative and legal documentation regulating safe auscultation using new technological approaches to organizing the work of medical staff in the conditions of the COVID-19 pandemic.

Despite problems in this area, medical staff should not avoid performing auscultation in the COVID-19 pandemic [10-39], as it provides a quite simple and effective noninvasive investigation for patients with COVID-19 and supplements other investigations. It is desirable to generalize and propagate the experience in remote auscultation obtained as a result of investigation and observation of patients with COVID-19 to other areas of medicine where there is also a risk of infection to medical staff while working with patients with other infectious diseases, such as tuberculosis.

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