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Review

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On the Possibilities and Significance of Unmanned Aerial Vehicles for the Pre-Hospital Stage of Medical Care

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ABSTRACT Unmanned aerial vehicles are an important force in search and rescue operations. They help reduce the time needed to search for and provide assistance to the wounded, sick and injured who are located at a large territorial distance and in hard-to-reach places. With the help of computer "vision" and sensors such as noise sensing, binary sensing, vibration and thermal sensing, drones are able to search for living patients not only in the sea, high in the mountains and in mines, but also buried under the rubble of buildings and structures. Such devices demonstrate advantages in emergency and urgent delivery of medical resuscitation and other medical equipment, medicines, blood products and organs for transplantation to patients, especially those in remote locations. With the help of drones, it is possible to effectively sort patients in case of mass sanitary losses, carry out disinfection and remotely monitor the health status of patients with highly contagious infectious diseases and other pathological conditions, as well as reduce the time for providing other medical and humanitarian services to the population. It is obvious that the use of drones requires further study of their promising capabilities, especially in the actual conditions of emergency medical services.

Keywords: unmanned aerial vehicles, drones, pre-hospital stage, search and rescue operations, emergency and emergency medical care

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AED — automated external defibrillator
EMC — emergency medical care
ES — emergency situation
EUMC — emergency and urgent medical care
CPR — cardiopulmonary resuscitation
UASs — unmanned aircraft systems
UAVs — unmanned aerial vehicles

INTRODUCTION

The Russian Federation is the largest country in the world in terms of its territorial size. More than 70% of its territory is located in the Asian part of the country, but almost 80% of the population lives in the European part, where the average density is 10 times higher. According to Rosstat (2021), there are 622 urban and 119 municipal districts, as well as 1,599 municipalities, including 1,117 cities, 1,181 urban-type settlements and more than 16.2 thousand rural settlements consisting of populated places, registered in Russia. About 70% of the population lives in urban areas and only 30% in rural and village settlements. This unevenness affects both the quality and effectiveness of medical care for the population living in these conditions.

In 2015, the UN outlined 17 sustainable development goals for countries around the world, which proclaimed the rights of people to access a quality health care system, including emergency and urgent medical care (EUMC) services.

According to the order of the Ministry of Health of the Russian Federation dated June 20, 2013, No. 388n, the arrival time of emergency medical care (EMC) teams to a patient to provide emergency medical care should not exceed 20 minutes from the moment of its call; and the waiting period for primary health care for urgent indications should not exceed 2 hours from the moment the patient contacts the emergency medical service [1]. At the same time, in similar territorial programs this time can be reasonably adjusted taking into account transport accessibility, population density, as well as climatic and geographical features of the regions. Any delay in providing EUMC is the main cause of complications and fatalities, especially in emergency situations (ES), when death is registered in 70% of cases even before the arrival of EMC teams, and in 2–11% – during the evacuation transportation of patients to the hospital [2].

The results of a comprehensive survey conducted in 2018 by Rosstat show that a third of Russian residents waited for the EUMC team for 21 to 40 minutes, 10% - more than 40 minutes, and 3% of the population - more than an hour from the moment of the call [3]. On average, the EUMC vehicle arrived to patients in rural areas within 30 minutes, and in cities – within 25 minutes. If the positive effect of EUMC during the first 30 minutes occurred in 65.2% of patients, then at a later stage – in 31.3%, and in 3.5% of cases patients did not notice any effect from the treatment measures carried out by the EUMC team [4]. The reasons for this situation were as follows: a reduction in the number of EMC stations across the country; an increase in the transport distance of medical services; quality of road surfaces and level of traffic congestion; the availability and condition of operational medical evacuation vehicles and their purchase price; burnout and shortage of medical personnel, etc. These and many other factors significantly affect both the timeliness of assistance and the mortality rate of the population.

Not only Russia, but also many other countries around the world also experience difficulties in ensuring sufficient coverage of residents with EUMC services, ground ambulances, and timely saving of their lives [5, 6]. The global community also faces many health challenges, including population aging, disability, natural disasters, emerging diseases, urbanization, global warming, etc.

Nevertheless, society is developing rapidly, thanks to a variety of advanced technologies, especially information and communication technologies [6]. The accelerated development of these technologies and the expansion of the range of technical innovations, including automation and robotization of various types of machinery and equipment, often radically increase production efficiency and thereby facilitate human life [7]. It is interesting that many technical innovations are not actually know-how, as they are characterized by their rather long “life” history – from the idea and its development to practical implementation. Therefore, national policymakers need to take this into account in a timely and appropriate manner when planning their economic policies or directly and quickly introduce new directions into private and public business activities [8].

One of these areas was the emergence of aviation, the development of which led to the idea of creating unmanned devices [7]. Recently, in various mass media, scientific reports and publications, in the part concerning unmanned systems, one can also come across such general concepts as "drones", which include, among other things, "unmanned systems" (US), "unmanned aircraft systems" (UAS), "unmanned aerial vehicles" (UAV) and "drones". What is their practical difference?

A UAS is a complex that includes one or more unmanned aerial vehicles, as well as ground-based technical means and navigation, and communication equipment used to control the flight of aircraft.

A UAV is an unmanned aerial vehicle that is controlled remotely by an operator, or autonomously by means of a radio-controlled hardware and software complex.

A drone (meaning “loafer, parasite, buzzing, humming”) is an independent or remotely controlled unmanned vehicle that can move not only in the air or gas environment, but also on the earth's surface and its objects, as well as on water and under water.

The use of the last two terms is usually interchangeable [9]. It is drones that are UAVs, since from their general understanding, individual types of their use in a particular environment of movement are distinguished, taking into account their physical characteristics and capabilities.

Over the past decade, in most countries of the world, not only such unmanned systems technologies as aircraft or helicopter-type UAVs have been rapidly developing, but also drone variants and their robotic hybrids-transformers, increasingly covering various areas of activity, including: mass media, culture, agriculture, wildlife, environmental supervision, infrastructure, surveying and cartography, construction, public safety, delivery of commercial products, recreation, healthcare and a number of others; as their technologies have become more advanced and costs have noticeably decreased [10, 11].

Drones are a promising technology to improve survival and to achieve high quality of life for patients, especially for those living in remote areas or where there is a lack of resources or infrastructure [12]. Compared with ground transportation, drones' cost-effectiveness, speed capabilities, and practical convenience make them particularly applicable in the field of emergency medicine. Research conducted to date shows that the use of drones in emergency medical care is feasible and will be accepted by the public, as it has great potential for future widespread use.

The increasing population density in large urban centers worldwide poses serious challenges to transportation systems [13]. Unlike traditional modes of transportation such as cars or trains, which are limited by the space for ground movement, flying cars (UAVs, drones and air taxis) do not occupy their two-dimensional space of movement. They have a certain degree of freedom in space and time, less travel and therefore less stress for their users [14, 15]. Air transport services could be a solution to this growing problem by moving the existing transport system into three-dimensional space [16].

In contrast to traditional means of transportation in the field of urban passenger mobility, much less attention has been paid to the corresponding business models of more complex passenger air vehicles for urban use [13]. Nevertheless, large companies and enthusiastic researchers around the world are continuously working with various architectures, algorithms and methods to test the air transport of the near future for safe and autonomous service of a significant part of the population [14, 17]. Currently, the foreign scientific press and mass media widely cover the incredible prospects and progress of fully electric and hybrid aircraft, and vertical takeoff and landing machines for transporting passengers in populated areas [14–18].

The aim of our work is to review current scientific research on the study of modern and promising possibilities of using unmanned systems to conduct search and rescue operations, and provide EUMC to the population at the pre-hospital stage..

MATERIAL AND METHODS

This is a literature review, mainly by foreign authors, followed by an analytical study of the possibilities of using UAVs in search and rescue operations, as well as in providing medical care to the wounded, sick and injured at the pre-hospital stage.

The search for information was conducted for the period of 2018–2023 using Medline, PubMed, Scopus, ISI Web of Science medical databases. We analyzed prospective and retrospective observational studies of high methodological quality, meta-analyses and systematic reviews of more than 230 literature sources, from which only 55 were selected. For statistical evaluation of frequency characteristics, incidence and prevalence indicators were used. Calculation of generalized frequency indicators for large samples was carried out with an indication of 95% or higher confidence interval.

RESULTS AND DISCUSSION

From history. If we do not take into account the invention by ancient man of the first wooden spear with a stone tip and the first arrow with a tail feather, released into the air from a bow, which definitely became the prototype of modern cruise missiles, then the first unmanned aerial vehicle was created by Chinese philosophers of the 5th century BC Mozi and Lu Banu who launched into the sky the first kite on a string. During the same period, ancient Greek philosopher and mathematician Archytas of Tarentum developed the first autonomous flying machine in the form of a bird model, which flew about 200 meters in the airspace.

The historical evolution of drones began with the discovery of autonomous mechanisms during the time of Pythagoras, to which Archytas of Tarantas contributed. The first to produce a prototype of a modern helicopter in his epochal drawings and sketches, having envisaged the possibility of using the surrounding air environment as a supporting and driving force for its probable and stable flight, was world-famous Leonardo da Vinci. Later, M.V. Lomonosov and Horatio Phillips designed and created their first flying machines.

Based on the achievements of the "second industrial revolution", with the emergence of practical aeronautics and the invention of radio, scientists and enthusiasts needed more complex unmanned systems. Already in 1898, the famous inventor N. Tesla created the world's first drone boat with remote radio control, which subsequently prompted scientists to develop unmanned controlled objects in various environments of their movement, which was seen as a very promising future [7].

A real breakthrough in the field of unmanned aerial vehicles was achieved in 1907, when Greek engineer Archidamos Pappadakis created the first unmanned aircraft equipped with a radio control system, which could perform aerial photography tasks of the earth's surface from a distance.

The development of the world's first radio-controlled UAV with four rotors and a clock mechanism belongs to Charles Kettering (1916), and on its basis in 1917, by order of the US Army,

N. Kieffer developed one of the predecessors of modern cruise missiles - an experimental model of an unmanned "Aerial torpedo" called the "Kettering Bug", laying the foundation for the future development of combat UASs. However, the development of a radio-controlled UAV with vertical takeoff and landing belongs to our compatriot G.A. Botezat, who emigrated to the USA and in 1922 built and then personally tested his own reusable quadcopter capable of taking to the air with a person on board.

Since then, such technologies have been a priority for any army in the world, and these drones were often called military drones. Thus, during the Second World War, Germany and the USSR, and then the USA, began similar developments. In the army, similar new technologies in the form of UAVs were used as targets for aviation and in the development of anti-aircraft systems; in military reconnaissance and for bombing; for the delivery of ammunition and other cargo. Later, such military technologies began to emerge in Japan, Great Britain and France, and later in all other developed countries of the world. Only since the late 90s and early 2000s, based on many military developments and engineering solutions, the first developments of UAVs for civilian purposes appeared and began to be intensively developed [7, 10].

Use of UAVs in search and rescue operations. As it turned out, drones are capable of not only flying fast, but also effectively collecting the necessary information in real time and delivering payload, which laid the foundation for the intensive economic development of many industrial, commercial and social enterprises and organizations, and even in the provision of entertainment and other services [7, 11, 18]. Drones are now produced in a variety of configurations and sizes. Even miniature models are capable of operating in the modes of medium-sized devices.

Nowadays, UAVs are an important force in search and rescue operations [6]. The application of UAVs in these cases is mainly based on remote sensing technology [19]. The UAV flight control includes ground control and air control. Through wireless communication, the ground control sends commands to the flying UAV and collects relevant data from it for further processing, modeling and analysis. Satellite remote sensing and manned airborne remote sensing are limited in obtaining rescue information due to the nature of the rescue situation, their cost and some other factors. The UAV remote sensing system with better spatial-temporal resolution and real-time performance is useful in search and rescue situations, especially in identifying disaster victims [19–21]. In addition, the UAV can carry various means and equipment, including high-definition cameras, thermal imagers, infrared night vision equipment, gas detectors to locate the toxic gas leak area, and emergency communication equipment [20]. These tools can be used according to the needs of the situation, take clear pictures and transmit data more effectively from a distance of 10 km or more, thereby improving the efficiency of rescue work. Having received comprehensive and accurate information about the situation, the decision maker can then dispatch rescue forces and organize the timely evacuation of people.

Modern UAVs equipped with an intelligent search and analysis system are capable of operating autonomously [22]. The capabilities of autonomous flight of such UAVs over the sea surface during a simulated shipwreck were studied, where the following automatic communication procedure was identified:

1. Each UAV, upon initial takeoff, flies in a random direction until it detects signals from a wounded or injured survivor.

2. Once a radio signal from the survivor's radio module is detected, the UAV exchanges information with other UAVs over the cellular radio network using OLSR routing protocols.

3. Each UAV launches its intelligent search module and transmits general data about the survivor to the unified intelligent search module (system).

4. The unified intelligent search module estimates the location of the survivor if possible. If the received data is insufficient to localize the patient, it sends back a packet with an invalid tag.

5. If the intelligent search module sends reliable information about the location of the survivor, the unified search system and the UAV switch to searching for the survivor, generating a detour to the estimated location of the survivor.

6. The drones fly autonomously to waypoints, avoiding obstacles on the way to the expected location.

7. As the drone approaches the survivor, more accurate signal information about him is recorded, which re-sends the survivor information to the intelligent search algorithm and updates the location of the survivor with simultaneous transmission of coordinate data, the altitude and tilt of the UAV, as well as the direction and speed of the wind during the flight. The authors claim that with such a search scan of the territory in areas of 4x4 km and 1x1 km, this intelligent system tracked the survivor with errors over an area of approximately 20x50 m. Moreover, the authors provided the possibility of identifying the victim using the genetic code data embedded in the individual radio module.

Large and medium drones with a relatively greater carrying capacity can drop lifebuoys for drowning people. Thus, in 2018, the efficiency of using UAVs was studied taking into account the time factor required to provide a floating device to a simulated victim in different stormy sea conditions in comparison with standard rescue operations [23]. It was established that in moderate sea conditions in the form of calm, this time reliably did not exceed 81 seconds against 179 seconds when delivering a rescue device by a traditional boat or motorboat; and in high storm sea conditions, the time to deliver such a means to the victim was 99 seconds and 198 seconds, respectively ($p<0.001$).

Underground mining operations are also associated with significant risks of man-made accidents, which can be catastrophic. Mitigation of the consequences of such phenomena directly depends on the reliability and timeliness of information on the state of the parameters of many technological processes, mine workings and structures located in them. In case of failure of standard industrial telemetry systems in underground mining conditions, the creation of new information channels and data measurement locations becomes virtually impossible in the event of an emergency. This predetermines the need to use fundamentally new systems for collecting and transmitting information based on robotic autonomous complexes [24]. The authors developed a system for automatic control of UAV movement in a limited space of a mine working with significant disturbances of the airflow in the mine. Thus, when the UAV was flying at a speed of 6 m/s with a payload weight of up to 0.6 kg, the average deviation did not exceed 0.3 m, and the maximum was 1.2 m. When the UAV was moving towards a turbulent mine air flow, the device withstood the oncoming flow of up to 8 m/s without deviation. In addition, when the UAV speed decreased to 6 m/s, its braking distance did not exceed 6 m, and when the UAV speed was 10 m/s, the braking distance reached 12 m.

A group of authors experimentally studied the potential of using UAVs in high-altitude search and rescue operations in comparison with traditional methods [25]. It was found that the average time of search and arrival of the UAV to the mannequin in the snowy mountains did not exceed 8.9 minutes, while in the control series this figure was 57.3 minutes. In this case, the average value of the total search area was 88,322.0 m^2, and the control values exceeded 228,613.0 m^2. In addition, the average area searched per minute was 1489.6 m^2 and 32,979.9 m^2, respectively ($p<0.01$ for all comparisons). The conclusion of this study is that detection and subsequent transportation of the victim in mountainous, especially snowy conditions, was carried out much faster using UAVs, which is also confirmed by studies by a number of other scientists [26, 27].

UAVs in Pre-Hospital Medical Care. The rapidly growing field of medical UAVs is on the verge of revolutionizing pre-hospital medicine, allowing the provision of emergency and urgent medical and humanitarian assistance to patients that were previously inaccessible to them.

Medical drones can be of great benefit in increasing the survivability of deployed forces on and off the battlefield [28]. Detection of life signs is an effective tool for searching for survivors at disaster sites. Traditionally, rescue sensors are carried by rescue personnel, which can be cumbersome and risky. In contrast, UAVs equipped with rescue sensors perform this task quickly and with good safety guarantees for rescue personnel. In particular, multi-rotor drones are ideal in this regard, as they are more controllable and do not have special requirements for take-off and landing sites. Equipped with infrared detectors, they perceive a certain infrared range emitted by human bodies, and with radar detectors, they can analyze signs of life using the Doppler effect.

Considering the certain difficulty of searching for people only by an image from a great height, a number of authors have proposed installing highly sensitive microphones on drones to detect the human voice, which would significantly increase the efficiency of search and rescue operations in real time [20, 29].

Drones are expected to be more accurate and precise in assessing the state of human external physiological functions when they land on patients' bodies than when they hover above them.

Al-Naji A. et al. (2019) proposed a new method for detecting victims, in which UAV data can detect cardiopulmonary movements caused by periodic movements of their chests from a distance [30]. Moreover, the system successfully detects life signs in various other human poses with 100% accuracy, indicating its potential as a future tool for emergency search and rescue operations. This technology has also become an excellent tool for detecting people not only on the earth's surface, but also in the open sea [31].

UAVs can play a special role in pre-hospital triage for the purpose of providing first aid and evacuating the wounded and injured from dangerous areas of the territory or battlefield [32]. In the case of a mass influx of patients, the most important factors are the rational organization of rescue forces for the majority of groups of wounded; rapid response and coordination of rescue units, as well as timely transportation of the wounded to the stage of qualified medical care for their comprehensive treatment.

Lu J. et al. (2023) used a UAV with artificial intelligence and fifth-generation (5G) mobile communication technology with real-time data transmission to conduct primary triage on the spot in a simulated mass casualty scene during an emergency [33]. Seven postures of victims based on changes in the head and limbs were developed and recognized to perform rapid but meaningful triage. Thus, using a recorded voice instruction coming from the UAV, uninjured patients were asked to raise both upper limbs up; slightly injured patients were asked to raise only one arm; non-ambulatory patients (moderate injury) were asked to raise any one healthy limb; and patients who were unable to answer questions were considered severe. This made it possible to quickly conduct a conventional sorting of the wounded and promptly transmit the information to the central analytical control body for the urgent adoption of appropriate medical and evacuation decisions. This measure allows for a significant increase in the efficiency of on-site triage, thereby ensuring a faster response by medical teams.

Jain T. et al. (2018) conducted an experimental study of the effectiveness of pre-hospital medical triage of the wounded and injured both during the day and at night using UAV technologies in comparison with traditional triage by medical students [34]. It was found that the reliable difference in traditional patient triage between daytime and nighttime by medical students averaged 63 minutes, while in the case of UAV triage it was only 3.49 minutes. This indicates that the use of UAVs during triage was virtually independent of the time of day, and did not increase the time patients spent at the scene.

Drone technologies combined with GLONASS and GPS global navigation satellite systems, real-time computer vision, and deep learning techniques can enable drones to provide precise assistance to emergency responders in a short period of time [35]. A new technique that uses a swarm of UAVs rather than a single drone is effective in locating missing persons over large areas, at high altitudes, and in hard-to-reach locations, reducing costs and time while improving or maintaining the quality of search and rescue operations [36]. The authors also proposed a new technical solution called the layered search and rescue (LSAR) algorithm, which helps increase the number of rescued injured and victims as the number of drones increases [37].

For many years, researchers have been interested in the timely delivery of medical supplies and essential equipment to a disaster-stricken region or to emergency sites. The experience of some researchers has shown that timely delivery of these medical materials in many emergency and urgent conditions leads to improved patient treatment outcomes [29, 38].

Promising data from a number of researchers indicate that UAVs can reduce the time to intervention through rapid delivery of, for example, automated external defibrillators (AEDs), or antidotes, or antiepileptic drugs, or blood products and other medical supplies [5, 39]. Thus, Banerjee P. et al. (2021) argue that every minute delay in resuscitation by the emergency medical service at the scene of an incident after out-of-hospital cardiac arrest in children reduces the rate of return of spontaneous circulation by 5%; while the chances of surviving until discharge from the hospital with each such minute of delay also decrease proportionally by an average of 12% [40].

Based on experimental studies, Cheskes S. et al. (2020) argue that emergency delivery of an AED to a patient is more efficient and expedient using a UAV compared to the traditional arrival of the EUMC team not so much in urban areas as in suburban and especially remote rural areas [41, 42]. According to their data, more than 420,000 Americans experience cardiac arrest annually with a survival rate of approximately 10%. Therefore, a serious problem in the treatment of this acute pathological condition remains rapid access to AEDs, which can increase survival up to 40%. Calculations have shown that if an organized network of UAVs equipped with AEDs operates in a designated area, the time it takes to deliver them to the victim is reduced to 10.6 minutes; and if the takeoff of such a UAV occurred within 1 minute after the phone call, then the practical efficiency of using the AED to restore the viability of the human body increases from 4.3 to 80% of cases. That is why many authors recommend a wider development of the network system for equipping populated areas in the suburban zone, including in the territory of summer cottage villages [43–45]. The authors also believe that if the same number of UAVs with AEDs cover only 70% of the territory, then it would be possible to deliver the AED to the patient in less than 5 minutes; and if, with the same number of UAVs with AEDs, the coverage area were increased to 98%, then the AED would be delivered to the patient in less than 10 minutes. In that case, at least 95% of the population would be covered by the ideal placement of UAVs within the given territorial area, and the response time of drones would be 5 times higher than that of the ground-based EMS service.

Fischer P. et al. (2023) showed in a simulation study that the delivery of an AED using a drone in mountainous areas in 22 scenarios took an average of 5.2 minutes; however, paramedics who arrived by car began providing first aid only after 12.15 minutes, and the time it took to “disconnect” their hands from the “patient” was 50 seconds, while for non-professionals these figures were 14.04 minutes and 2.11 minutes, respectively [46]. Assuming that at least 46% of out-of-hospital cardiac arrests were attended by experienced bystanders skilled in AED use, then a network of 500 drones would reduce the average defibrillator delivery time from 7.7 to 2.7 minutes [39]. In this case, the expected survival rates would double (from 12.3 to 24.5%), resulting in an additional efficiency criterion of 30,267 life years (or $858 per patient saved per year). Thus, the development of a network of drones with AEDs is cost-effective under a wide range of assumptions.

Homier V. et al. (2020) compared the possibility of delivering simulated blood products (erythrocyte and platelet mass, and plasma) to an urban trauma center using UAVs and ground transport, including taking into account the maintenance of the required temperature of the simulated blood products within a given range [47]. It was found that the transportation of hematological preparations using UAVs did not exceed 17.06 minutes, while when transported by ground vehicles this time was more than 21.6 minutes. Moreover, in the main series of experiments, the temperature of the simulated blood products remained within the relevant permissible ranges throughout the entire transportation period, while in the control series, these indicators mostly went beyond the acceptable values.

Based on statistical data, Scalea J.R. et al. (2018) claim, that in the USA the average percentage of kidneys unsuitable for transplantation after their air transportation and cold ischemia is approximately 20%. In an experiment on a kidney model, they studied the possibility of using a helicopter-type UAV in comparison with a turboprop aircraft to deliver these internal organs for the purpose of their immediate transplantation [48]. The flight lasted on average 28 minutes, during which the organs were exposed to the corresponding vibration effects of transport vehicles and high-altitude barometric overloads. At the end of the flight, the kidneys were subjected to pathomorphological examination in all the cases. It was established that no pathomorphological changes in the tissue structure were detected during the transportation of kidneys by UAVs. However, in the case of airborne delivery of organs to the airport, histological sections in 12% of cases showed signs of glomerular sclerosis of varying intensity, as well as cortical scarring and hyalinosis. These pathological changes were caused not only by the on-board vibration of the transport vessel and barometric loads, but also by prolonged cold ischemia of the kidneys. Therefore, with the development of faster and larger drones, the delivery of organs over long distances can lead to a significant reduction in cold ischemia time, subsequent improvement in organ quality, and saving thousands of patient lives.

Along with the delivery of various vital medical and humanitarian supplies in time using UAVs [29, 39, 49], some authors assessed the possibilities of using UAVs during the COVID-19 pandemic in real conditions [19, 27, 50–52]. Their research demonstrated not only successful transportation of emergency medical equipment by UAVs in the form of AEDs, but also medicines and even food, especially in remote and rural areas. Thus, in Australia, China, India, the USA and some other countries during the COVID-19 pandemic, drone monitoring flights, in particular over overcrowded cities, made it possible to remotely determine the “questionable” nature of breathing among the population at a distance of up to 55-60 meters. At the same time, mass screening using drone-mounted video cameras and sensors, as well as computer vision technologies, helped continuously monitor crowds of people, recording their body temperature, heart rate, breathing, and sneezing, coughing, and other abnormalities. And in Ghana and Rwanda, small drones have delivered both medicine and coronavirus tests from more than 1,000 health facilities to labs in Accra and Kumasi. In addition to tests, drones transported up to 25% of the country's national blood supply outside the capital during the same period, amounting to more than 7,000 bags of blood products in more than 4,000 drone flights.

UAVs were used to provide sound notification to the population regarding compliance with the anti-epidemic regime, as well as for preventive sanitization of the population and disinfection of objects and territories by spraying appropriate antiseptic and disinfectant agents. Over 2,600 UAVs were used for disinfection over an area of 902 million m2 in 20 provinces in China. Moreover, in the early days of the coronavirus outbreak in Wuhan, UAVs served as night lighting for construction sites, which helped extremely quickly build Huoshenshan and Leishenshan hospitals, intended exclusively for the reception of patients with coronavirus, and subsequently carry out dynamic scanning of patients inside the hospitals of temporarily deployed infectious disease hospitals based on sports facilities. In some cases, UAVs were used in remote areas as wireless communication repeaters to enable rapid response by emergency services [19].

From the above it follows that UAVs and UAS, including those equipped with an artificial intelligence system, have a wide range for their implementation in practical healthcare, which is especially valuable when there is a mass emergence of patients with one or another pathology, or those who are in difficult conditions of their stay.

Currently, developments are actively underway on fundamentally new types of UAVs capable of performing the functions of an “air taxi” or “aeromobile” with vertical takeoff and landing for the air transportation of passengers and cargo over short distances, samples of which were developed back in the late 90s of the last century. Today, some European countries are preparing to deploy an advanced air mobility system to provide unmanned air taxis, cargo flights, medical and passenger flights, as well as continuous automatic surveillance flights, etc. [53]. Such devices are currently being developed in some other countries of the world with the aim of introducing them as urban and suburban air transport. Many medical scientists also focus on these and other similar developments [6, 19, 28, 29]. For example, back in 2006, a robotic medical evacuation drone with vertical takeoff and landing called Cormorant was developed and supplied to the Israeli army, capable of autonomously evacuating one wounded or injured person from the battlefield to the rear to provide qualified medical care. Also, for the evacuation of the wounded from the battlefield in the USA, a device called DP-14 Hawk was created, which fits in the cabin of a car like a traditional ambulance, and many others.

Similar developments are also underway in Russia. However, despite the fact that drones are a promising technology for improving the survival, outcomes and quality of life of patients, especially for those living in remote areas or where there is a lack of funds or appropriate infrastructure; and their speed, convenience and cost-effectiveness, compared to ground transport, make them particularly applicable in the field of emergency and urgent medicine; unfortunately, the process has not progressed beyond individual experimental UAS and UAV samples, which is due to a number of serious problems and unresolved issues [19, 54], including:

1. There is no clear legislative support for the use of UAVs and UAS in emergency rescue operations in the Russian Federation. The relevant laws provide only a very general description, without specific rules regarding the legal status of search and rescue units using UAVs, as well as standards for conducting rescue operations using UAS. UAV rescue operations are related to public safety, meteorology, transportation and other areas, but the existing laws are also unclear in this regard.
2. Russia has strict control over low-altitude airspace. Flights in this airspace segment are generally restricted or prohibited, and the process of opening it is slow. Low-altitude airspace is the primary airspace for UAV participation in emergency rescue operations.
3. The Russian Emergency Response Law establishes the principle of unified leadership and hierarchical responsibility, but administrative control over UAVs is unclear, as it is divided between numerous authorities that do not exchange information. Due to the complexity of applying for the use of airspace, critical rescue opportunities are likely to be missed; and the effectiveness of rescue will be reduced; because UAV technology must be integrated into unified aviation systems, since the aircraft will use the same airspace.
4. Due to the high risk of UAV operation, it is necessary to develop operational standards, airworthiness standards and personnel standards, as well as a flight safety management system.
5. Technical support for long-term continuous active operation of UAVs is also imperfect (low-capacity and heavy batteries, imperfect obstacle avoidance in flight, limited operation in adverse weather conditions, etc.).
6. Lack of professional personnel for the operation and maintenance of UAS and UAVs, there are no appropriate educational institutions for training such specialists, which leads to non-standard operation of unmanned equipment and incompetence in solving complex problems, etc.

One issue that also needs to be addressed is the existence of no-fly zones where drones cannot be used. The development of drone routes within no-fly zones is a major area of research. In addition, in order to facilitate and ensure the safety of the delivery of humanitarian aid using UAVs, there is a need to conclude a corresponding international agreement between countries that operates on a permanent basis.

Nevertheless, the studies conducted show that the use of unmanned drones in the field of emergency and urgent medicine is feasible, and will be received well by the public, as it is economically effective and has wide possibilities for its practical application.

According to A. Lopota (2019), a detailed analysis of the technical and functional characteristics of many UAS developments allows us to identify general trends in the development of devices of this type, including:

1) combining the functionality of various medical and non-medical equipment (patient monitor, ventilator, infusion syringe dispenser, automatic defibrillator, ultrasound scanner, oxygen concentrator, anesthesia machine, video and audio equipment, communication equipment) in one device by implementing the modular design principle;

2) full or partial automation of cardiopulmonary resuscitation (CPR) and intensive care in accordance with CPR algorithms;

3) increasing the level of autonomy of the complexes by using support systems and decision-making to determine the symptoms of pathological conditions, to diagnose and/or assess the severity of the victim's condition, as well as the use of expert systems built on Bayesian belief network technologies, neural networks and artificial intelligence. This allows for a probabilistic diagnosis based on the presence or absence of certain symptoms, as well as determining the types and volumes of patient treatment;

4) reduction of the weight and size characteristics of the developed complexes;

5) integration of technologies for isolating patients suspected of being infected with particularly dangerous infections.

When talking about the prospects for using UAVs in this context, we cannot help but mention service transport in the form of ambulances. The prospects for using such flying machines are truly inspiring, since such transport will arrive precisely on time, following an optimally planned route and informing the subscriber in advance of the approximate time of arrival [55]. It is possible that the call of such a tool will be completely automated, which will eliminate the human factor and all the ensuing features.

To implement 24/7 monitoring in search and rescue operations, the service life of drones must be extended by high-performance batteries [19, 56]. In addition, the endurance of UAVs in harsh conditions, such as strong winds or extreme temperature changes, needs to be improved. Drones can also be made more intelligent by using artificial intelligence, 5G technology and satellite positioning so that they can perceive their environment, avoid obstacles and even return automatically when high-risk conditions arise.

Technological advancement from remote-controlled UAVs to fully autonomous UAVs will be another breakthrough that is likely to occur in the near future. Moreover, the integrated communication platform created by connecting the UAV network to the cellular network or 5G network can facilitate multi-directional communication between UAVs, ground rescue teams and other rescue units.

Smart materials are constantly gaining importance in many industries, including aerospace [57]. This is due to the unique properties of these materials, such as self-awareness, self-adaptability, memory capabilities and various other functions. Such materials will certainly find their rightful place in the development of new UAS technologies.

The undoubted advantages of introducing new UAV models into practical healthcare are as follows: low production cost; wide range of applications; reliability in eliminating human errors; long period of active operation in the air; ability to take off and land vertically in any conditions, and many others [32].

Prospects of the UAV market. According to Fattahov M.R. et al. (2022), 3,789 applications for patents for UAVs were submitted to Rospatent for the period 2000–2020 [58]. The majority of customers (66.8%) are involved in the fields of defense, security, law enforcement, emergency prevention and response (30.3%), science and education (26.4%), and public and municipal administration (10.1%). The growth of patents and government procurements indicate interest in this technology from both manufacturing companies and consumers of services provided using UAS. The development of the Russian UAS market is to a certain extent limited by the insufficient level of provision and development of neurotechnologies and artificial intelligence technologies; technologies for working with large volumes of data; manufacturing technologies, robotics and sensor technologies, distributed ledger technologies, wireless communication technologies, virtual and augmented reality technologies, industrial Internet technologies (Internet of Things), as well as industry digital technologies.

Currently, the potential for drone use in the Russian Federation is more than $1 billion per year. The development of the Russian UAS market is hampered by aviation regulation and the lack of infrastructure (traffic management systems, remote identification, charging and unloading stations, etc.). According to Rosaviatsia, currently 95% of UAVs purchased in the Russian Federation remain unregistered.

The global market for medical drones will gain momentum, reaching USD 1,410.9 million only by 2028, and by 2035, it will amount to USD 2–3 billion. According to Huawei research, the Russian drone market accounts for only 4% of the global market.

Thus, the use of UAVs at the pre-hospital stage, especially in emergency situations, has the following advantages: UAVs help reduce the time required to search for and provide assistance to the wounded, sick and injured located at a great territorial distance and in hard-to-reach places. Using computer "vision" and such sensors as noise probing, binary probing, vibration and thermal probing, drones are capable of searching for living patients not only at sea, high in the mountains and in mines, but also buried under rubble of buildings and structures. UAVs demonstrate advantages in emergency and urgent delivery of medical resuscitation and other medical equipment, medicines, blood products and organs for transplantation to patients, especially those located in remote locations. With the help of UAVs it is possible to effectively sort patients in case of mass sanitary losses, carry out disinfection and remotely monitor the health of patients with highly contagious infectious diseases and other pathological conditions, and also reduce the time for providing other medical and humanitarian services to the population. It is obvious that the use of UAVs requires further study of their promising capabilities, especially in the real conditions of the activities of EUMC services.

CONCLUSION

Over the past 5 years, there has been a significant increase in the number of publications devoted to the capabilities and importance of unmanned aircraft systems and unmanned aerial vehicles at the pre-hospital stage, which implies a significant increase in knowledge, awareness and popularity of the use of unmanned aerial vehicles in emergency and urgent situations, including emergency situations. However, most of the existing literature is experimental in nature, introducing some errors in certain characteristics of unmanned aerial vehicles due to the lack of their use in real emergency and disaster situations.

Most studies have shown that the technical capabilities of drones, or similar innovative approaches, are due to the introduction of radio technologies and computer informatics into the construction of unmanned aerial vehicles, which improve the operational characteristics of drones. However, little attention has been paid to the direct use of unmanned aerial vehicles in emergency and urgent medical care procedures, as most studies have focused on search and rescue tasks, as well as the transportation of medical supplies, equipment or essential goods using drones.

There is not a single report devoted to sufficient practical experience in the use of unmanned aerial vehicles for medical evacuation of patients from the pre-hospital stage to the stage of inpatient qualified and specialized medical care. As a result, additional research is needed to solve this problem. Despite the fact that unmanned aerial vehicle systems, if sufficiently developed, can be used in various other areas of their application, it is still necessary to carry out a number of significant organizational and technical measures to eliminate existing problems and unresolved issues in the widespread use of unmanned aircraft systems and unmanned aerial vehicles at the pre-hospital and inter-hospital stages, especially in emergency situations, natural disasters and catastrophes with mass sanitary losses.

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